13th European Conference on Accelerators in Applied Research and Technology

ABSTRACT BOOK AND SCIENTIFIC PROGRAMME

5 – 10 May, 2019
Split, Croatia

Abstract book:
13th European Conference on Accelerators in Applied Research and Technology
May 5 - 10, 2019, Split, Croatia
Editors: Zdravko Siketić, Andreo Crnjac, Marko Brajković, Marko Barac, Marin Vukšić
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Welcome Address

On behalf of the local organizing committee, it is our pleasure to welcome you to the 13th European Conference on Accelerators in Applied Research and Technology (ECAART13). This year's conference coincidence with 30th anniversary of the organization of the first ECAART conference that was held in Frankfurt in 1989. In all these years, ECAART has shown to be a high level conference, reporting the constant progress in the development of the accelerator technology and applications in many different scientific and industrial fields such as, material science, art, archaeology, life science, environment, etc.

ECAART13 conference is organized by Ruđer Bošković Institute, the largest research institute in Croatia, covering a broad spectrum of basic and applied research areas. Organization would not be possible without generous support from the Centre of Excellence for Advanced Materials and Sensing Devices, International Atomic Energy Agency and many sponsors and exhibitors.

This year we have accepted more than 150 abstracts, which will be presented in 14 oral and 2 poster sessions. We are grateful to welcome 13 invited speakers as well. Scientific sessions will cover all important aspects of the development of accelerators and their applications in the variety of research and industrial areas. Peer reviewed papers of the presentations given at the conference will be published in a special volume of Nuclear Instruments and Methods in Physics Research B.

ECAART13 will be held in Split, second largest city in Croatia, situated in the very heart of the Adriatic eastern coast. The tourist, industrial, university, and business centre of the region nourishes its "green soul" on the hill Marjan situated in the most western part of the peninsula. The Historic Complex of Split together with the enticing Palace of Diocletian, spanning across 38,500 square meters, is recognized as UNESCO World Cultural Heritage Site. ECAART13 will take place at the Radisson Blu Resort situated on a peaceful pebble beach about 3 km from the Split city centre, allowing guests to easily explore the city. A half day trip to the Krka waterfalls National park will be an excellent opportunity to spend enjoyable moments with colleagues and friends. Some of them we have met already on previous ECAART conferences, some of them we will meet for the first time here in Split.

Finally, we hope that you will enjoy the conference and all that Split can offer.

Zdravko Siketić, Iva Bogdanović Radović, Milko Jakšić, Stjepko Fazinić, RBI

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Locations – map

The conference venue is **Radisson Blu Resort**, Put Trstenika 19, Split, Croatia.
All sessions will be held in the Ballroom hall. For more details please see the Scientific Program. The poster sessions will be held in Oleandar hall. Coffee breaks will be held in the front of the Ballroom hall together with industrial exhibition. The conference registration will be located near the hotel reception.

Exhibitors and Sponsors

The exhibitors and sponsors are very important part of every scientific conference. Not only that through the exhibition scientist get acquainted with the latest achievements in the equipment and instrumentation, this support enables also the cost of the registration to be kept to a minimum and provides additional support for the conference events, students and other activities. We are truly grateful to our sponsors and exhibitors.

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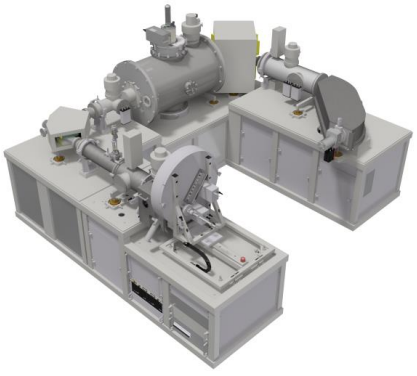

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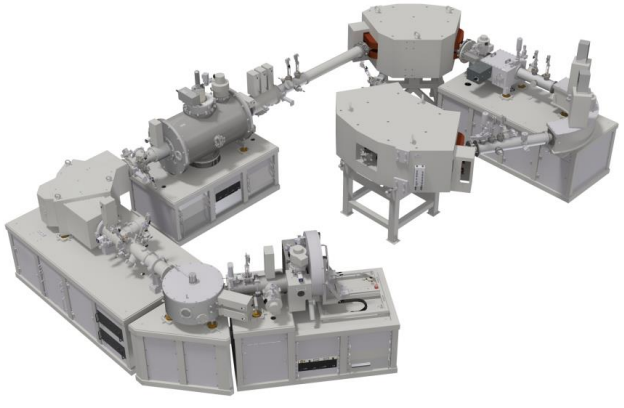

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- Particle Induced X-ray Emission (PIXE)
- Nuclear Reaction Analysis (NRA)
- Elastic Recoil Detection (ERD)
- Medium Energy Ionscattering Spectroscopy (MEIS)

Accelerator Mass Spectrometers

3H, 7Be, 10Be, 14C, 26Al, 32Si, 36Cl, 41Ca, 53Mn, 79Se, 129I, 236U etc. analysis for use in
- Archeology
- Oceanography
- Geosciences
- Material sciences
- Biomedicine
- Etc.

Systems for Micro-beam applications
- Tandetron and Singletron based systems

Neutron Generator Systems
- DC and Pulsed Beam Systems

Electron Accelerator Systems
- Singletron electron accelerators up to 6.0 MV/TV

Components

Ion and electron accelerator tubes, ion and electron sources, beam handling & monitoring equipment, etc.

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General Information

Oral Presentations

Invited talks are 30 minutes long (25 minutes presentation and 5 minutes discussion). Contributed talks are 20 minutes long (15-17 minutes presentation and 3-5 minutes discussion). All the talks should be accompanied by PowerPoint or PDF slides. We will transfer the talk to the conference computer.

Projection Capability

Lecture hall will be equipped with a PC and LCD projection system. The PC will accept USB drives and will have Microsoft PowerPoint and Adobe Reader. You must have your presentation loaded before the start of your session.

Poster Displays

The size allocated for posters is A0 90 cm (width) by 110 cm (length). There will be two poster sessions, the first one will be held on Monday from 16:00 to 18:00 and the second one on Tuesday from 16:00 to 18:00. Poster presenters should be available at their display during this time. Posters should be set up in the morning of the presenting day and taken down at 20:00 the same day. Please display your poster in the slot assigned with your number. Please contact the conference registration desk if you need assistance. Awards for the best student poster will be presented during the conference banquet. Representatives of CEMS and ECAART International Committee will review student posters during the poster sessions.

Conference Proceedings

The ECAART13 conference proceedings will be published as a special volume of the journal "Nuclear Instruments and Methods B: Beam Interactions with Materials and Atoms". All submitted papers must be clearly written in excellent English and contain only original work, which has not been published by or is currently under review for any other journal or conference. All manuscripts and any supplementary material should be submitted through the Elsevier Editorial System (EES). Papers will be reviewed to the same standards as for the regular NIMB papers. Please contact Zdravko Siketić (*zsiketic@irb.hr*) for other publication related questions.

Internet Access

Free internet access is available in the entire hotel and lecture hall.

Registration and Welcome Reception

Registration will be open on Sunday from 17:00 to 19:00 and at 8:00 for other conference days. The welcome reception will be held at the conference hotel on Sunday, May 5, from 19:00 to 21:00. We would like to thank High Voltage Engineering Europa B.V. for sponsoring this great event.

Morning and Afternoon Breaks

Morning and afternoon breaks with refreshments will be held in front of the Ballroom hall within the exhibition area.

Lunches

Lunches will be provided on Monday, Tuesday, Wednesday and Thursday at the conference hotel. Lunches are included in the conference fee.

International Committee Meeting

A meeting of the ECAART International Committee will be held on Tuesday, May 7, after the poster session. The meeting will be held at the conference hotel.

Conference Outing

The Conference outing will be held on Wednesday, starting from 13:15. A half day trip will be organized which will provide the participants with the opportunity to enjoy the KRKA Waterfalls National park. Thanks to travertine barriers and the constant process of calcification, Krka river, with its 7 travertine falls, represents a natural karst phenomenon and in 1985 it was proclaimed National Park. The most impressive waterfalls are Skradinski Buk and Roški Slap.
Equipment: sports shoes required.
Outing is included in the conference fee.

Conference Banquet

The conference banquet will be held in the Radman's mills (Restaurant Kastil Slanica), on Thursday, May 9 with the start at 19:30 (starting at 18:30 from the conference hotel). Banquet is included in the conference fee.

Other Details

We kindly ask participants to stick closely to the allocated duration of oral presentation and to the scheduling for posters. This is particularly important as we have a relatively high attendance and a densely packed program. Please wear your conference badge at all times. We have made special arrangements regarding lunches and refreshments, and your badge needs to be visible at these venues. The Local organizing committee will be pleased to help and advice on travel, touring and other arrangements, or on any problem.

Meeting Questions

If you have any questions, please contact Ana Vidoš or anyone from the local organizing committee. Here are some cell phone numbers that may be useful:

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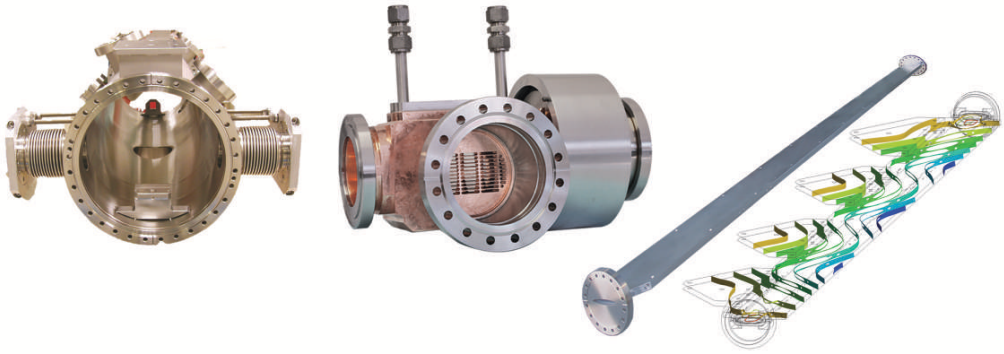

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Scientific programme

Monday (May 6, 2019)

8.30-9.00	Opening	
	Accelerator technology and development 1 **Chair: Tianjue Zhang**	
9.00-9.30	**Peyman Yousefi** *University of Erlangen, Germany* Applications for an Electron Accelerator on a Chip	I-1
9.30-9.50	**Stephanie Stodola** *National Electrostatics Corporation, USA* Expansion of Researcher Need and Applications Drives Manufacturer Innovation	O-1
9.50-10.10	**Sotirios Charisopoulos** *International Atomic Energy Agency (IAEA), Austria* IAEA activities in support of the accelerator-based research and applications	O-2
10.10-10.30	**M. M. Sezer** *ASELSAN A.S., Yenimahalle-Ankara, Turkey* Design of a Low Emittance High Power Thermionic DC Electron Gun	O-3
10.30-11.00	Coffee break	
	Application of novel technologies 1 **Chair: Milko Jakšić**	
11.00-11.30	**Dan Gabriel Ghita** *Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering, Romania* ELI-NP – implementation status and start of the scientific program	I-2
11.30-11.50	**Long K. Vo** *Kansas State University, USA* Time dependent signatures: Moisture content interpretation in well logging applications with a D-T pulsed neutron generator	O-4
11.50-12.10	**Marcos V. Moro** *Uppsala University, Sweden* In-situ study of the chemical composition of photochromic yttrium oxy-hydrides	O-5
12.10-12.30	**Paul Constantin** *Extreme Light Infrastructure - Nuclear Physics (ELI-NP), Romania* The IGISOL radioactive ion beam facility at ELI-NP	O-6
12.30-14.00	Lunch	
	Ion beam analysis and applications 1 **Chair: Alexander F. Gurbich**	
14.00-14.30	**Frank Watt** *National University of Singapore, Singapore* Recent advances in MV particle accelerator applications: a review of low current nanobeam techniques	I-3
14.30-14.50	**M. Kokkoris** *National Technical University of Athens, Greece* MottCalc: A new tool for calculating Mott scattering differential cross sections for analytical purposes	O-7
14.50-15.10	**Christof Vockenhuber** *ETH Zürich* A new accelerator for Material Sciences at the Laboratory of Ion Beam Physics at ETH Zurich	O-8
15.10-15.30	**T. Kobayashi** *Photonics Control Technology Team, RIKEN, Japan* In-situ depth profiling of lithium in solid-electrolyte using ion and neutron beams	O-9
15.30-16.00	Coffee break	
16.00-18.00	**Poster session A**	

Tuesday (May 7, 2019)

	Accelerator Mass Spectrometry **Chair: Lucile Beck**	
9.00-9.30	**Arnold Milenko Müller** *Ionplus AG, Switzerland* MILEA - a new 300 kV multi-isotope AMS facility	I-4
9.30-9.50	**Eric C. Alderson** *National Electrostatics Corp., USA* Progress and Development of Positive Ion Mass Spectroscopy for Multiple Radiocarbon Dating Applications	O-10
9.50-10.10	**Johannes Lachner** *University of Vienna, Austria* Low-level ^{26}Al AMS analysis by Ion-Laser InterAction Mass Spectrometry	O-11
10.10-10.30	**Susan Herb** *University of Cologne, Germany* First AMS measurements of (60Fe/Fe) isotopic ratios at the Cologne 10 MV Tandem Accelerator	O-12
10.30-11.00	Coffee break	
	Application to life science **Chair: Frank Watt**	
11.00-11.30	**Alessandra Gianoncelli** *Elettra Sincrotrone Trieste, Italy* Life Science applications of X-ray microscopy combined with XRF and other synchrotron imaging techniques	I-5
11.30-11.50	**M.V. Zheltonozhskaya** *Lomonosov Moscow State University, Russia* Production of Zirconium-89 in photonuclear reactions	O-13
11.50-12.10	**Tokihiro Ikeda** *RIKEN Nishina Center for Accelerator-Based Science, Japan* Profile measurement of MeV ion microbeam in atmosphere extracted from single tapered glass capillary with an end window	O-14
12.10-12.30	**Esther Punzón-Quijorna** *Jožef Stefan Institute (JSI), Slovenia* Particle Induced X-ray Emission (PIXE) for elemental tissue imaging in prosthesis rejection cases	O-16
12.30-14.00	Lunch	
	Ion beam analysis and applications 2 **Chair: Anna Macková**	
14.00-14.30	**Katarina Vogel-Mikuš** *Jožef Stefan Institute, Slovenia* & University of Ljubljana, Slovenia The use of X-ray and MS based imaging techniques in plant biology for improved food quality and safety	I-6
14.30-14.50	**Darko Mekterović** *University of Rijeka, Croatia* Elemental analysis of particulate matter and biological samples of workers exposed to the dust in a metal workshop	O-16
14.50-15.10	**Michael F. Vineyard** *Union College, USA* Research and Training in Ion-Beam Analysis of Environmental Materials	O-17
15.10-15.30	**Alexander F. Gurbich** *Institute for Physics and Power Engineering, Russia* Calibration of 3 MV Tandetron Accelerator over Nominal Energy Range	O-18
15.30-16.00	Coffee break	
16.00-18.00	**Poster session B**	
19.00-22.00	ECAART International Committee Meeting	

Wednesday (May 8, 2019)

	Medical applications **Chair: Stjepko Fazinić**	
9.00-9.30	**Tony Lomax** *Paul Scherrer Institute (PSI), Switzerland* Proton beam therapy: Current status and future trends	I-7
9.30-9.50	**Vladimir Zverv** *Dukhov Research Institute of Automatics, Russia* Novel Generators for Nuclear Medicine: Technical and Antitumor Characteristics	O-19
9.50-10.10	**Oxana Actis** *Paul Scherrer Institute (PSI), Switzerland* Commissioning of a bi-directional energy sequence for efficient treatment with protons	O-20
10.10-10.40	Coffee break	
	Simulation and fundamentals **Chair: Iva Bogdanović Radović**	
10.40-11.00	**Marko Barac** *Ruđer Bošković Institute, Croatia* Overview of computational methods for processing MeV TOF SIMS spectra and 2D images at RBI	O-21
11.00-11.20	**S. Petrović** *Vinča Institute of nuclear sciences, Serbia* Proton-crystal rainbow interaction potential	O-22
11.20-11.40	**E. Ntemou** *National Technical University of Athens, Greece* Measurement of deuteron differential elastic scattering cross sections on light elements, at energies and angles suitable for EBS (Elastic Backscattering Spectroscopy)	O-23
11.40-12.00	**A. Guesmia** *Faculté des Sciences Université Saad Dahleb, Algeria* Readjustment of the Bohr stopping power for energies between 0.05 keV/u and 10 MeV/u	O-24
12.00-13.00	Lunch	
13.15-19.00	**Excursion**	

Thursday (May 9, 2019)

	Accelerator technology and development 2 **Chair: Timo Sajavaara**	
9.00-9.30	**A. Ibarra** *Centre for Energy, Environment and Technology, Spain* EU approach to the fusion-like neutron source: The DONES Project, present status and other applications	I-8
9.30-9.50	**Jean-Michel Lagniel** *Grand Accélérateur National d'Ions Lourd (GANIL), France* Status of the SPIRAL2 facility	O-25
9.50-10.10	**Sergey V. Kutsaev** *RadiaBeam Technologies, LLC, USA* Ultra-Compact Accelerator for Radioactive Isotope Sources Replacement in Security, NDT and Medical Applications	O-26
10.10-10.30	**Tianjue Zhang** *China Institute of Atomic Energy, China* 52 kW CW Proton Beam Production by CYCIAE-100 and General Design of High Average Power Circular Accelerator	O-27
10.30-11.00	Coffee break	
	Applications to art and archaeology **Chair: T. Calligaro**	
11.00-11.30	**Lorenzo Giuntini** *INFN, Italy & University of Florence, Italy* Status of the MACHINA project, the Movable Accelerator for Cultural Heritage In-situ Non-destructive Analysis	I-9
11.30-11.50	**S. Mathot** *European Organization for Nuclear Research (CERN), Switzerland* The CERN PIXE-RFQ, a transportable proton accelerator for the MACHINA project	O-28
11.50-12.10	**Serena Barone** *National Institute for Nuclear Physics (INFN), Italy* Towards micro-samples radiocarbon dating at INFN-LABEC, Florence	O-29
12.10-12.30	**Lucile Beck** *Laboratoire de Mesure du Carbone 14 (LMC14), France* First radiocarbon dating of lead carbonates by AMS - Application to ancient cosmetics and paintings	O-30
12.30-14.00	Lunch	
	Application of novel technologies 2 **Chair: Arnold Milenko Müller**	
14.00-14.30	**Serguei Molodtsov** *European XFEL, Germany* European XFEL: Unique possibilities for X-ray research	I-10
14.30-14.50	**M. De Cesare** *CIRA Italian Aerospace Research Center, Italy* Ion Beam Analysis and IR-Thermography for innovative Aerospace TPS material characterizations and qualifications at CIRA	O-31
14.50-15.10	**Timo Sajavaara** *University of Jyvaskyla, Finland* A new external beam PIXE setup with transition edge sensor array and polycapillary optics	O-32
15.10-15.30	**Markus Schiffer** *University of Cologne, Germany* Ion Beam Techniques for Nuclear Waste Management	O-33
15.30-16.00	Coffee break	

Thursday (May 9, 2019) - Continued

Ion beam modification of materials	**Chair: Eduardo Alves**	
16.00-16.30	**Jonathan England** *University of Surrey, UK* Investigating the Formation of Isotopically Pure Layers for Quantum Computers using Ion Implantation and Layer Exchange	I-11
16.30-16.50	**O. Toader** *University of Michigan, USA* Transporting Ion Beams into a TEM for In-Situ Irradiation Observation	O-34
16.50-17.10	**G. Gawlik** *Institute of Electronic Materials Technology, Poland* Modification of the graphene adhesion to the substrate by ion beam bombardment	O-35
17.10-17.30	**E. Aradi** *University of Huddersfield, UK* Effects of He ion irradiation on microstructure of 4H-SiC nanowhiskers	O-36
18.30-22.00	**Conference dinner**	

Friday (May 10, 2019)

	Quantum and nano technology applications **Chair: Jonathan England**	
9.00-9.30	**Jan Meijer** *Felix-Bloch Institute for Solid state physics, Germany* Application of ion beam accelerators for Quantum technology	I-12
9.30-9.50	**E. Alves** *Instituto Superior Técnico, Portugal* Structural and optical studies of aluminosilicate films doped with (Tb^{3+}, Er^{3+}) / Yb^{3+} by ion implantation	O-37
9.50-10.10	**Tobias Herzig** *Felix Bloch Institute for Solid State Physics, Germany* Creation of quantum and classical light emitters in silicon using spatial selective, high-resolution ion implantation	O-38
10.10-10.40	Coffee break	
	Nuclear and particle physics applications **Chair: M. Kokkoris**	
10.40-11.00	**Eva Montbarbon** *CERN EN-EA, Switzerland* Studies of the Conventional Beams Working Group within the Physics Beyond Colliders framework at CERN	O-40
11.00-11.20	**Maxim D. Karetnikov** *Dukhov Research Institute of Automatics, Russia* Generators of tagged neutrons and their applications	O-39
11.20-11.50	**Andrey Starodumov** *Ruđer Bošković Institute, Croatia* Single event upsets in CMS pixelated detector	I-13
11.50-12.30	**Final Remarks & Closing**	

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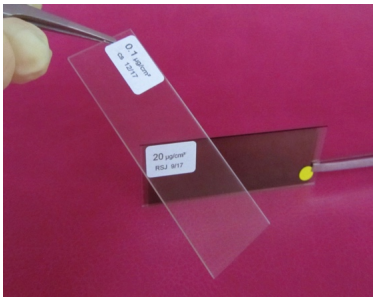

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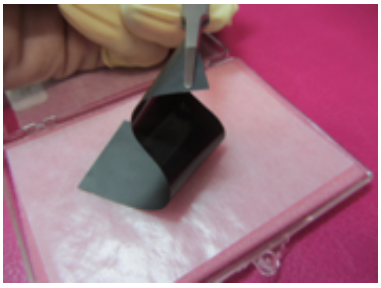

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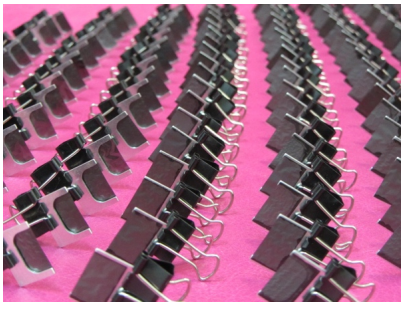

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OCEM Power Electronics has supplied a component to a joint project between CERN and the European Spallation Source seeking to develop a more efficient high-power RF tube amplifier for particle acceleration.
The company's capacitor charger is a high-voltage power supply that feeds an energy storage bank that powers the radio-frequency tube amplifier, which is being tested at CERN. The tube — called the MB-IOT, or Multi Beam Inductive Output Tube — could also be adopted as part of a future upgrade to the CERN injector in Geneva. For the capacitor charger, OCEM had to design a solution that could support a large output voltage of 50 kV together with a large power level of 160 kW.

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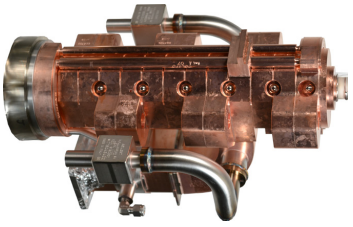

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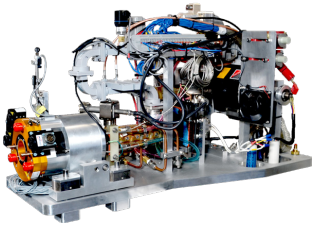

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Invited talks

Applications for an Electron Accelerator on a Chip

R. J. England
Dielectric Laser Acceleration Group, Accelerator Research Division, SLAC National Accelerator Laboratory, 2575 Sand Hill Rd, Menlo Park, CA 94025, USA

Acceleration of particles in laser-driven dielectric structures fabricated using semiconductor manufacturing techniques is a new and promising approach to developing future generations of ultra-compact particle accelerators. There has been substantial progress in this area in recent years, fueled by a growing international collaboration of universities, national laboratories, and companies. We present a conceptual layout for a wafer-scale device based on this approach and discuss potential near-term and longer-term uses for such accelerators in medical, industrial, and scientific fields.

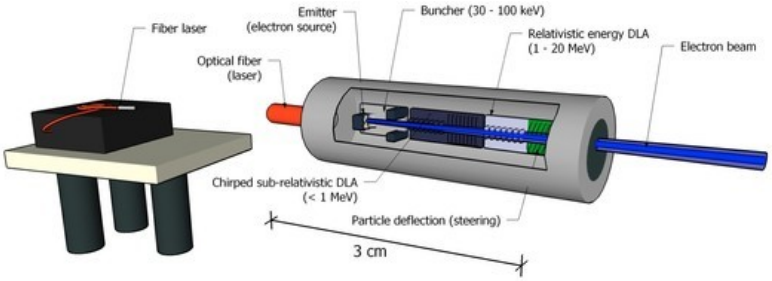

Figure 1: Conceptual illustration of a portable chip-based electron accelerator driven by a high repetition rate solid state fiber laser. Such a system could provide a compact source of MeV-scale electrons for medical, industrial, and security applications.

[1] R. J. England, et al., Reviews of Modern Physics 86 (2014) 1337.
[2] R. J. England, IEEE Journal of Selected Topics in Quantum Electronics 22 (2016) 4401007.

This research was supported by the U.S. Dept. of Energy under Grant DE-AC02-76SF00515 and by the Gordon and Betty Moore Foundation (GBMF4744).

ELI-NP – implementation status and start of the scientific program

D. G. Ghita

Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering, Strada Reactorului 30, Bucharest - Magurele, Romania

The most powerful laser in the world is already under testing and commissioning at Extreme Light Infrastructure – Nuclear Physics. The beyond state-of-the-art experimental set-ups under construction at the moment will soon start to perform photonuclear physics experiments. At the end of the project, ELI-NP will comprise of two major instruments: 2x10 PW laser system (HPLS) and a high intensity gamma beam system. More than 20 experimental set-ups will be placed around these two major systems, covering a very wide range of nuclear physics research and applications using the unique characteristics of the primary and secondary beams.

Recent advances in MV particle accelerator applications: a review of low current nanobeam techniques

F. Watt

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Oxford MIcrobeams Ltd, Science Park, Oxon, UK

The analytical techniques of PIXE (Proton Induced X-ray Emission), RBS (Rutherford Backscattering Spectrometry), and NRA (Nuclear Reaction Analysis) are well known, and in the past these techniques have been the workhorses of low energy accelerators, providing quantitative analytical information on a wide range of samples. More recently however, the low current techniques of Proton Beam Writing, MeV proton (ion) microscopy and single cell radiobiology have made significant advances. This review will outline the uniqueness and therefore high potential of these techniques in the biomedical field, particularly when sub 100nm spot sizes are now attainable.

MILEA - a new 300 kV multi-isotope AMS facility

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[2]Laboratory of Ion Beam Physics, ETH Zurich, Otto-Stern-Weg 5, 8093 Zurich, Switzerland

In 2018 a prototype version of a new compact multi-isotope AMS instrument, the so-called MILEA (Multi Isotope Low Energy AMS), was taken into operation at the Laboratory of Ion Beam Physics at ETH Zurich in collaboration with Ionplus. The system is based on tandem accelerator with 300 kV terminal voltage and is dedicated to the measurement of ^{10}Be, ^{14}C, ^{26}Al, ^{41}Ca (biomedical applications), ^{129}I and actinides (Pu, U, Th and others). In the course of developing MILEA, various technological and ion optical concepts of the well-established MICADAS and Tandy spectrometers were combined and refined for the application with this new multi-isotope system. Moreover, new approaches and developments have been implemented in order to optimize the performance for all mentioned nuclides. Consequently, a very small system footprint could be realized (3.5 x 7 m^2). The machine layout is illustrated in Figure 2. A MICADAS type Cs-sputter ion source is used for the extraction of all elements, followed by an 90° electrostatic deflector and a 90° magnet, which constitute the low energy spectrometer. The accelerator consists of a vacuum insulated terminal supplied by a 300 kV cascade [1]. In order to optimize the measurement performance, ion beam transmission and background for all nuclides, the design of the stripper is crucial [2]. Since the focusing properties of the high energy accelerator stage depends on the charge state of the ions and the molecular fragmentation after the stripper, a quadrupole triplet lens was installed to achieve optimal beam coupling to the HE spectrometer, which consists of a 90° magnet, 120° ESA and 110° magnet. Finally, ions are detected in a high resolution ΔE-E$_{res}$ gas ionization chamber equipped with a removable absorber cell. During the last year, extensive tests and experiments have been performed in order to determine the measurement performance of the system in terms of transmission, background and stability for the above-mentioned radionuclides. The obtained results demonstrated the potential of the instrument and based on the experiences gained with the prototype Ionplus was able to commercialize MILEA successfully. An overview of the most important system features will be given and the latest achievements for the different isotopes will be presented and discussed.

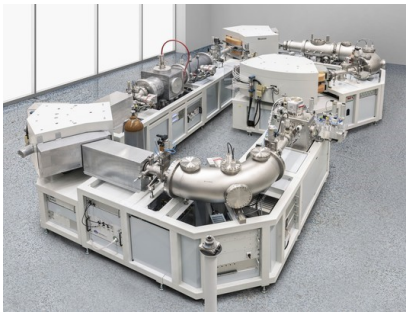

Figure 2: Perspective picture of the prototype version of the new 300 kV multi-isotope AMS (MILEA) facility. With a footprint 3.5 x 7 m^2, the system could be realized in a very compact way.

[1] Sascha Maxeiner et al., NIM B 439 (2019) 84-89
[2] Sascha Maxeiner et al., NIM B 361 (2015) 237-244

Life Science applications of X-ray microscopy combined with XRF and other synchrotron imaging techniques

A. Gianoncelli
Elettra Sincrotrone Trieste, Strada Statale 14 - km 163.5, 34149 Basovizza, Trieste, Italy

Soft X-ray Microscopy has rapidly developed into an important tool for several application fields, life science among the others. This technique is mostly deployed in synchrotron facilities taking advantage of their tunability and high brilliance characteristics. Thanks to the possibility to combine Soft X-ray Microscopy with spectroscopy, insightful morphological and chemical information can be provided simultaneously, helping in the understanding of biochemical processes taking place at sub-micron scales. In the last decade the TwinMic soft X-ray microscopy station [1] (400-2200 eV) installed at the Elettra synchrotron has been attracting the interests of the Life Science community thanks to its complementary imaging capabilities (brightfield and phase contrast) combined with low energy X-ray Fluorescence and X-ray absorption spectroscopy. Indeed the developed low energy XRF system [2] enables to correlate the specimen morphology with the elemental distribution of light elements (from B till P) and of transition metals for which the characteristic emission lines fall in the 180-2100 eV energy range. The most recent outcomes in research fields such as rare diseases, nanotoxicology, clinical and reproductive medicine [3] and food science will be presented through selected results, part of them complemented through other synchrotron techniques.

[1] A. Gianoncelli et al., Journal of Synchrotron Radiation, 22 (2016).
[2] A. Gianoncelli et al., Nuclear Instruments and Method A, 608(1), 195 (2009).
[3] L. Pascolo et al., Reproductive Biomedicine Online, 37, Issue 2, August 2018, 153 (2018).

The use of X-ray and MS based imaging techniques in plant biology for improved food quality and safety

K. Vogel-Mikuš[1,2], P. Pongrac[1], A. Kavčič[2], J. T. van Elteren[3], I. Arčon[4], B. Jenčič[1], P. Vavpetič[1], M. Kelemen[1], M. Regvar[2], P. Pelicon[4, 1]

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[4]University of Nova Gorica, Vipavska 13, SI-6000 Nova Gorica, Jozef Stefan Institute, Jamova 39, SI-1000 Ljubljana, Slovenia

Plants are world's primary producers representing the basis for animal and human diet. Therefore, it is of extreme importance that they contain sufficient amounts of mineral nutrients and essential organic compounds, and low amounts of antinutrients and noxious elements. In addition, plants synthesise a plethora of secondary metabolites that are beneficial for human health, or can be used to treat different diseases. To maintain homeostasis with optimal cell functioning and integrity and/or to avoid toxicity, proper allocation of elements and biomolecules at organ, tissue, cellular and sub-cellular levels is necessary, with proper element/metal speciation and ligand environment presenting a key to bioavailability and homeostasis in organisms. Studies of element and biomolecular spatial distribution, as well as element speciation and ligand environment, are therefore crucial to reveal the mechanisms of element homeostasis, transport and also tolerance and toxicity [1]. Moreover, element and biomolecular localization studies in grains of staple food crops, are of high applicative value, allowing to determine element/biomolecular concentrations in particular tissues and different milling fractions without potential contamination due to mechanical mixing of tissues [2,3]. In the last two decades, a remarkable progress has been made in the development and the application of different 2D imaging techniques (Figure 3) in complex biological systems, especially with regard to improved lateral resolution and sensitivity as well as sample preparation. The latest development and applications of focused beam techniques like μ-PIXE, μ-XRF, LA-ICPMS and SIMS in imaging the distributions of elements and biomolecules in plants will be presented.

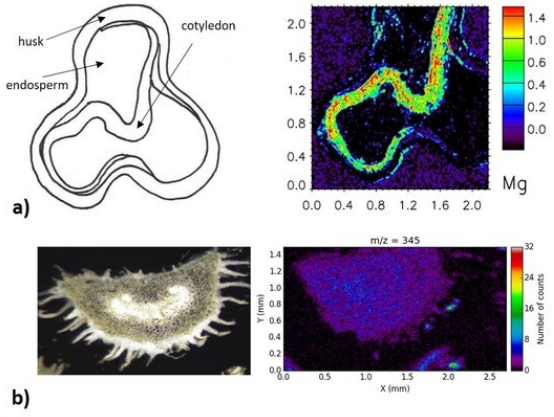

Figure 3: a) Mg distribution in Tartary buckwheat grain with micro-PIXE (Pongrac et al. 2016), b) Localization of THC in cannabis with MeV-SIMS (Jenčič et al. 2016)

[1] K. Vogel-Mikuš et.al, Int. J. PIXE (2014).
[2] P. Pongrac, et al., J. Cereal Sci. 69, 9 (2016).
[3] P. Pongrac, et al. J. Agric. Food Chem. 59, 1275 (2011).

Proton beam therapy: Current status and future trends

T. Lomax
Paul Scherrer Institute (PSI), Forschungsstrasse 111, 5232 Villigen, Switzerland

Radiotherapy is a deceptively simple approach to cancer treatment. Briefly put, by depositing energy in the form of ionizing radiation (dose) into tumour cells, DNA is damaged and the cell 'encouraged' to sterilize itself in a process called apoptosis. Thus, if enough energy is deposited in the tumour, all its cells can be sterilized in a controlled way and its uncontrolled growth arrested. With their advantageous physical characteristics, protons have been recognized for many years as a potentially effective particle for radiotherapy, due to a spatially limited high dose region around the so-called Bragg peak. By depositing many spatially and fluence modulated Bragg peaks through the tumour, highly conformal and homogenous distributions of dose can be delivered to the tumour, whilst minimizing dose to surrounding normal tissues, thus potentially reducing undesirable treatment related side effects. In this lecture, we will summarise the current state-of-the-art of proton therapy and identify some future developments that aim to make proton therapy even more effective and accessible.

EU approach to the fusion-like neutron source: The DONES Project, present status and other applications

A. Ibarra[1], F. Arbeiter[2], D. Bernardi[3], J. Castellanos[1], W. Krolas[4], M. Cappelli[5], U. Fischer[2], F. Martin-Fuertes[1], R. Heidinger[6], G. Micciche[3], A. Muñoz[7], F. S. Nitti[3], T. Pinna[5], J. Quiñones[1]

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[2]Karlsruhe Institute of Technology, Hermann von Helmholtz Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

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[4]Institute of Nuclear Physics PAN, Waleregо Eljasza Radzikowskiego 152, Kraków, Poland

[5]Frascati Research Center, Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Via Enrico Fermi, 45, 00044 Frascati RM, Italy

[6]Fusion for Energy (F4E) Joint Undertaking, Garching, Germany

[7]Empresarios Agrupados, Calle Magallanes, 3, 28015 Madrid, Spain

The International Fusion Materials Irradiation Facility - Demo Oriented NEutron Source (IFMIF-DONES) is a European research infrastructure (recently entered into the ESFRI roadmap) for testing, validation and qualification of the materials to be used in a fusion reactor. It is based on a unique neutron source with energy spectrum and flux tuned to those expected for the first wall in future fusion reactors. Materials irradiation data under such conditions are of fundamental interest for the fusion community as those will feed and validate the modelling tools for materials radiation damage phenomena. IFMIF-DONES will develop unique high-current high-duty cycle accelerator technology, liquid metal target technology and advanced control systems. Since 2007, IFMIF has been pursued by Japan and the European Union through the IFMIF/EVEDA (IFMIF Engineering Validation and Engineering Design Activities) project under the Broader Approach Agreement in the field of fusion energy research. It comprised the engineering design of IFMIF, Validation Activities of the Lithium Loop System, the Irradiation Area System, and the Accelerator System. The latter activities are still on-going with the design of the LIPAc prototype for the low energy section (9 MeV) of the IFMIF deuteron accelerator. IFMIF-DONES is based on a 40 MeV, 125 mA in continuous wave mode (CW) deuteron accelerator (5 MW beam average power) hitting with a rectangular beam size (approx. 20 cm x 5 cm) a liquid Li screen target flowing at 15 m/s – to dissipate the beam power – and generating a flux of neutrons of $\sim 10^{18}$ m^{-2} s^{-1} through nuclear stripping reactions, reproducing the expected conditions of fusion power plants. Materials are irradiated by the neutron beam as close as possible to the Li target to obtain damage rates up to 15 atomic displacements per year (dpa/year) under temperature controlled conditions. After a long irradiation period, irradiated modules will be partially dismantled and the irradiated samples will be characterized. The unique characteristics of the particles produced in the facility also allow the use of the facility in other scientific and technological fields. Possible applications in areas related to nuclear and basic physics, isotopes production, materials characterization etc has been identified and presently are under more detailed analysis. In this work it will be described the main characteristics of IFMIF-DONES making special emphasis on those related to other possible applications outside the fusion ones.

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission, Fusion for Energy, or of the authors' home institutions or research funder.

Status of the MACHINA project, the Movable Accelerator for Cultural Heritage In-situ Non-destructive Analysis

F. Taccetti[1], L. Giuntini[1,2], L. Castelli[1], M. Chiari[1], C. Czelusniak[1], L. Palla[1], M. Fedi[1], P. A. Mandò[1,2], G. Calzolai[1], F. P. C. Benetti[3] S. Mathot[4], G. Anelli[4], A. Lombardi[4], E. Montesinos[5], M. Vretenar[4]

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[4]CERN - European Organization for Nuclear Research, CH-1211 Geneva 23, Switzerland

In recent times, there has been a constantly increasing demand for in-situ compositional analyses in many fields and in particular in Cultural Heritage (CH), as shown for example by the noticeable increment of studies employing mobile XRF scanners. However, XRF systems have some limitations that do not affect the Ion Beam Analysis (IBA) techniques. Thus, an accelerator-based IBA system can provide an insight into the structure of artworks, impossible to obtain with other techniques, of great help to restores and art historians. Unfortunately, at present, IBA analysis are possible only in laboratory, as no transportable accelerator has been developed yet. To make it possible the use of IBA techniques also for in-situ measurements, the European Organization for Nuclear Research (CERN) and the Italian National Institute for Nuclear Physics (INFN), both with a long-lasting and significant experience in the development, use and application of particle accelerators, have jointly started the MACHINA project for the development of a transportable accelerator system. The pillars of such a project are the competencies developed both at INFN-Labec, for external beam IBA studies in C.H. field, and at CERN, concerning beam dynamics for a high frequency radiofrequency quadrupole cavity (HF-RFQ).In this presentation, the current status of the MACHINA project after about one year from the beginning of the project will be presented, together with the activity forecasted for the current year and for the next one.

European XFEL: Unique possibilities for X-ray research

S. Molodtsov
European XFEL, Holzkoppel 4, 22869 Schenefeld, Germany

The European X-ray Free Electron Laser (XFEL) is a new international research installation that is currently under construction and in part in operation in the Hamburg area in Germany. The facility will generate new knowledge in almost all the technical and scientific disciplines that are shaping our daily life - including nanotechnology, medicine, pharmaceutics, chemistry, materials science, power engineering and electronics. The ultra-high brilliance femtosecond X-ray flashes of coherent radiation are produced in a 3.4-kilometre long European XFEL facility. Most of it is housed in tunnels deep below ground. In its start-up configuration, the European XFEL will comprise 3 self-amplified spontaneous emission (SASE) light sources – undulators operating in energy ranges 3 - 25 keV (SASE 1 and SASE 2) and 0.2 - 3 keV (SASE 3), respectively. The world-unique feature of this XFEL is the possibility to provide up to 27.000 ultra-short flashes (10 - 100 fs) that makes the facility particular suitable for wide range of experiments in the range of moderate and hard X-ray photons. In this talk an overview of the European XFEL project will be provided and a review of different applications including spectrometry studies will be given.

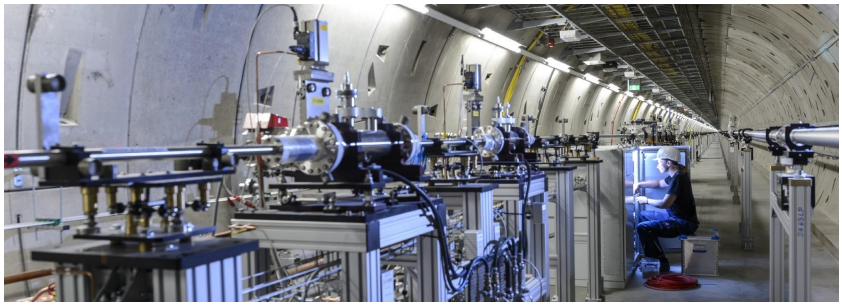

Figure 4: European XFEL beamline

Investigating the Formation of Isotopically Pure Layers for Quantum Computers using Ion Implantation and Layer Exchange

J. England[1], D. Cox[1], N. Cassidy[1], B. Mirkhaydarov[1], A. Perez-Fadon[2]

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[2]Kings College London Mathematics School, 80 Kennington Rd, Lambeth, London SE11 6NJ, UK

In 1998 Bruce Kane proposed that quantum computation could be achieved using Qubits that exploit entangled quantum states formed by locating in close proximity two spinning atoms of, for example, P or Bi. The atoms are isolated from environmental perturbations by incorporating them in a low temperature, "solid state vacuum" which can be formed by cryogenically cooling an isotopically pure, defect free crystalline layer consisting of atoms that have no intrinsic electronic or nuclear spin. Such layers composed of pure ^{28}Si, or ^{74}Ge, would be particularly useful as they could be integrated straightforwardly into conventional CMOS for the industrial manufacture of quantum computers systems. Naturally occurring Si is predominantly (92.2%) ^{28}Si, but significantly contains 4.7% ^{29}Si which, possessing nuclear spin, can interfere with the entangled spins. It might be thought that an ion implanter could be used as an isotope separator to selectively deposit low energy ^{29}Si onto a natural Si substrate. However, our group has previously shown that self-sputtering limits the enrichment possible to ~99.5%, and isobaric ions such as $^{14}N_2$ (and even $^{56}Fe_{2+}$) can contaminate the layer. Surface oxidation, if the implanter end-station is not at ultra-high vacuum, could also be problematic. Similar considerations exist for Ge. This talk describes the results of preliminary investigations to exploit a layer exchange technique to overcome these issues.

The University of Surrey hosts two advanced implanters that are being developed with the aim of reproducibly and deterministically placing single ions to form such Qubits. The SIMPLE (Single Ion Multispecies Positioning at Low Energy) implanters are modified focussed ion beam tools that can deliver pulsed beams in which there is an average of less than one ion per pulse. A SIMPLE tool fitted with a AuGe liquid metal ion source was used in a non-pulsed mode to implant isotopically pure Ge ion beams to fluences of $\sim 10^{17}$ ions/cm^2 into an Al metal layer that had been deposited onto a native-oxide free Si wafer. Implants into $5\mu\mathrm{m}$ x $5\mu\mathrm{m}$ square regions could be completed within a few minutes, enabling experiments over a range of fluences to be undertaken. The implanted regions were annealed under various conditions so that the Ge exchanged places with the Al and grew onto the underlying Si substrate. After Al removal, the exposed Ge layers were analysed for crystal quality and Al content by various means, including TEM. Whilst this approach potentially solved some problems, it introduced others, most notably Al incorporation in the Ge layer. This talk will discuss approaches to minimise Al retention and leverage chemical means for its subsequent removal.

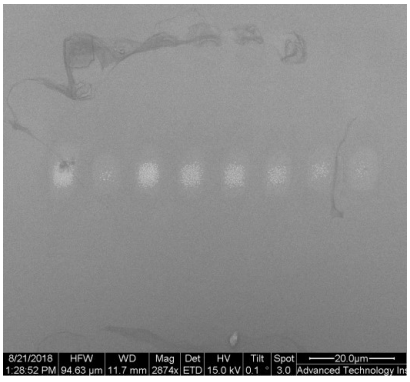

Figure 5: SEM image of eight regions implanted with Ge/25keV over a range of fluences between 1x10^{17}/cm^2 to 4x10^{16}/cm^2 after anneal and Al removal.

Application of ion beam accelerators for Quantum technology

J. Meijer
Felix-Bloch Institute for Solid state physics, University of Leipzig, Linnéstraße 5, 04103 Leipzig, Germany

The key technology to fabricate and operate quantum systems in solids is the positioning and addressing of single atoms with high lateral resolution. Whereas the manipulation of single atoms at the surface is possible since several years, the three dimensional addressing inside solids needs more effort. Especially counting of a single ion (so called deterministic implantation) is difficult. Several attempts are underway to meet this challenge. An image charge detection method is under development in Leipzig to achieve a fast and reliable signal. However, the technology to implant a single ion in a solid is only the first step. The activation of the implanted atom and the annealing of the surrounded defects is of similar importance. Indeed the quantum systems themselves can help to understand these processes and optimize the defect engineering process.

The paper discusses the hints and possible solutions for a road map of single ion implantation and production of quantum systems in solids.

Single event upsets in CMS pixelated detector

A. Starodumov
Institute Ruđer Bošković, Bijenička cesta 54, 10000 Zagreb, Croatia

Single Event Effect (SEE) is caused by heavy ions passing through an integrated circuit (IC). Such events disturb the normal operation of the circuit. The disturbance can be reversible and not reversible. In this talk the, so-called, Single Event Upset (SEU) - a reversible, non-destructive error, will be discussed. Even being non-destructive SEU could prevent a proper functionality of the IC. One has to perform a power cycle to make the circuit been functional again. Such a procedure may course a dead time in the data taking. A brief description of such issue will be given. An ion beam produced by the accelerator of RBI is an excellent instrument to study such effects. The description of the ion beam, test procedures to observe SEU and results of such beam test will be presented in this talk.

Contributed talks

Expansion of Researcher Need and Applications Drives Manufacturer Innovation

S. Stodola, M. Sundquist, R. Kitchen, E. C. Alderson, M. Stodola
National Electrostatics Corporation, 7540 Graber Rd, Middleton, WI 53562, USA

Applications for electrostatic accelerators performing Accelerator Mass Spectrometry (AMS) and Ion Beam Analysis (IBA) techniques continue to expand. With this comes the need to innovate new instruments to accommodate researchers with limited accelerator experience, access to adequate facilities, and limited time, while maintaining or exceeding existing performance. This paper will discuss new compact designs for systems capable of performing radiocarbon and IBA measurements with improved usability and newly developed upgrades and accessories designed to increase efficiency and capability.

IAEA activities in support of the accelerator-based research and applications

S. Charisopoulos[1], N. Skukan[2], I. Swainson[1], D. Ridikas[1]

[1]Physics Section, International Atomic Energy Agency (IAEA), Vienna, Austria
[2]NSIL, Physics Section, International Atomic Energy Agency (IAEA), Vienna, Austria

Promotion of nuclear applications for peaceful purposes and related capacity building is among the missions of the IAEA. In this context, accelerator applications and nuclear instrumentation is one of the thematic areas, where the IAEA supports its Member States in strengthening their capabilities to adopt and benefit from the usage of accelerators. A number of activities are being implemented focusing on accelerator-based applications in multiple disciplines, such as ion beam analysis of materials relevant to fusion or future applications of radioactive beams. This presentation aims at disseminating some of the currently running activities of the Physics Section of IAEA implemented through Coordinated Research Projects and Technical Cooperation projects, especially those aiming at facilitating access to accelerator facilities for the countries without such capabilities. In particular, the outcomes from two recent Technical Meetings on Ion Beam Analysis of materials relevant to energy production via fusion and on future applications of Radioactive Ion Beams will be reported. Plans for the establishment of an accelerator facility at Seibersdorf laboratories will also be presented.

Design of a Low Emittance High Power Thermionic DC Electron Gun

M. M. Sezer, M. G. Sanal, E. Durna
ASELSAN A.S., Yenimahalle-Ankara, Turkey

In this work, a thermionic DC electron gun generating low emittance and high power electron beam is designed. The thermionic cathode made of a LaB_6 single crystal is chosen as a thermionic emitter because of its properties ensuring high electron beam current in lower temperatures which provides lower emittance. Up to 10 kW beam power is achieved by accelerating electrons with a high voltage DC power source. The gun is modelled and simulated in Computer Simulation Technology (CST). To achieve high DC beam current and low emittance, optimization of electrode shapes and corresponding fields is done via this program by using parametrized geometrical properties. In addition, control and regulation of electron beam current is carried out by the control electrode in electron gun. From no current to full current, this current control is provided in every voltage step while minimizing beam's emittance value. Optimization methods and simulation results are presented.

Time dependent signatures: Moisture content interpretation in well logging applications with a D-T pulsed neutron generator

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Measurements were collected at Kansas State University Material Interrogation (KSUMI) facilities to investigate whether a machine source can effectively replace chemical sources or be a feasible alternative to chemical sources in well logging applications. A large test chamber was constructed and filled in respective tests, with 2200 gallons of the following: water, sand, limestone, saline, or a known mixture of those. The filled test chamber acted as an underground environment and the water acted as a surrogate for hydrocarbons. The KSUMI data acquisition system features options for spectroscopic and time dependent studies of neutron-induced photons. The ability to correlate energies to their time of detection opened an avenue for interpretation of the test chamber characteristics by the isotopic time signatures. The results showed that a hydrogen time signature has a strong relationship with the moisture content. The results also indicated that the material density and absorber content have effects on the Hydrogen time signatures, which consequently affect the moisture content interpretation of the test chamber.

In-situ study of the chemical composition of photochromic yttrium oxy-hydrides

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Yttrium oxy-hydride (YH_xO_y) thin films have recently drawn the attention of the scientific community due to their photochromic response, i.e. strong and reversible photodarkening under light illumination at ambient conditions [1]. This optical property makes them attractive for applications in e.g., smart windows and sensors. Although recent works have investigated the photochromic response as a function of chemical composition [2], and correlated their photochromic properties to structural changes [3], a complete understanding of the effect is still missing. In this contribution, we report an in-situ investigation of the chemical composition of reactively sputtered photochromic YH_xO_y thin films during light illumination in a high-vacuum setup. Time-of-Flight-Energy Elastic Recoil Detection Analysis (ToF-E ERDA) provides depth-profiles of all constituents in the film, whereas Elastic Backscattering Spectrometry (EBS) is suited for isotope-specific detection (in this work, we depth-profiled oxygen by making use of the $YH^{16}O(\alpha,\alpha_0)^{16}O$ nuclear reaction) and commonly better depth resolution. First depth-profiles obtained from in-situ recorded ToF-E ERDA spectra revealed that, for these samples, induced photochromism is not linked to any detectable chemical composition change (≥ 2 at.%) in the bulk of the film, with photodarkening being possible even in a high-vacuum environment. As a follow-up, and to focus on the near-surface region, results from oxygen depth-profiling using EBS combined with in-situ illumination will be presented. In these experiments, also the dynamics of relaxation or bleaching (i.e., reversible photochromism) in a high-vacuum environment has been investigated.

[1] T. Mongstad, C. Platzer-Bjorkman, J. P. Maehlen, L. P. A. Mooij, Y. Pivak, B. Dam, E. S. Marstein, B. C. Hauback, S. Zh. Karazhanov, A new thin film photochromic material: Oxygen-containing yttrium hydride, Sol. Energy Mater. Sol. Cells 95 (2011) 3596–3599.

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[3] M. P. Plokker, S. W. H. Eijt, F. Naziris, H. Schut, F. Nafezarefi, H. Schreuders, S. Cornelius and B. Dam, Electronic Structure and vacancy formation in photochromic yttrium oxy-hydride thin films studied by positron annihilation, Sol. Energy Mater. Sol. Cells 177 (2018) 97-105.

The IGISOL radioactive ion beam facility at ELI-NP

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The IGISOL facility at the Extreme Light Infrastructure – Nuclear Physics (ELI-NP), Bucharest, Romania, will study exotic neutron-rich ion beams produced via photo-fission in actinide targets placed at the center of a cryogenic gas cell. Using a complex radio frequency quadrupole for radioactive ion beam formation, a powerful multiple-reflection time-of-flight mass spectrometer for selection of rare refractory isotopes, and several measurement stations, this facility will be an exciting new tool for nuclear scientists. We will present benchmark simulations of the production rates and design studies for the components facilities, especially the gas cell. The expected ion extraction and transport efficiency of the IGISOL beam line will also be discussed.

MottCalc: A new tool for calculating Mott scattering differential cross sections for analytical purposes

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ERDA (Elastic Recoil Detection Analysis), especially due to the recent evolution of ToF (Time of Flight) capabilities, has emerged as one of the most prominent IBA (Ion Beam Analysis) techniques for the accurate quantitative determination of elemental depth profile concentrations in near surface layers of various matrices. However, the occurrence of Mott scattering in all practical ERDA implementations, e.g. traditional (with an absorber foil in front of the detector), transmission, or ToF, requires a careful treatment in the subsequent spectral analysis, since the corresponding cross sections may present very strong deviations from the Rutherford ones, which in certain cases allow their use for the detection of light elements [1]. Mott scattering occurs only during the interaction of identical nuclei (beam – target) and, according to the indistinguishability principle, the elastic scattering in such case can only be calculated quantum mechanically, leading to an interference term contributing to the reaction's cross section. This contribution strongly depends on the J^{π} of the ground state of the interacting nuclei and the phenomenon is described by a well-known analytical formula in literature. Nevertheless, it is important to note here that widely used analytical codes (e.g. SIMNRA, DF) do not presently provide theoretical differential cross-section calculations for Mott scattering. In order to address this problem, a new software support tool has been developed, MottCalc, able to calculate both angular and energy distributions in the case of pure Mott elastic scattering (i.e. excluding nuclear perturbations) and create the appropriate R33 files, suitable for direct implementation in all analytical codes. 314 isotopes are available for the user as both target and incident nuclei, while the screening effect is taken into account by implementing the Andersen model. The tool is available in two different versions, namely as Excel spreadsheet (which provides detailed information about the screening factor and the cross sections in both the lab and center of mass reference frames, as well as comparisons with the Rutherford values if the interference term is ignored) and as stand-alone application (which can produce R33 files for energy or angular distributions for analytical purposes). Both versions will soon be freely available to the scientific community for download and testing via the web page of the Nuclear Physics group at NTUA.

[1] I. Bogdanović-Radović, M. Jakšić and F. Schiettekatte, J. Anal. At. Spectrom., 24, 194-198 (2009).

A new accelerator for Material Sciences at the Laboratory of Ion Beam Physics at ETH Zurich

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At the Laboratory of Ion Beam Physics (LIP) at ETH Zurich a 1.7 MV Tandetron accelerator from High Voltage Engineering Europe (HVEE) is now operational for material sciences. The Tandetron facility had been situated for 10 years at Haute Ecole Arc in La Chaux-de-Fonds, Switzerland, and we moved it to LIP in 2017, after HE-Arc decided to discontinue the activities in that direction. The facility was rebuilt at LIP and installed next to the ion sources of the 6 MV EN Tandem accelerator which had served the material sciences at LIP in the past decades. Two ion sources are available, a HVEE 860 Cs sputter source to provide a wide range of beams from a solid target and a HVEE 358 Duoplasmatron ion source with a Li charge exchange canal for generation of a He^- beam. A long transfer line with XY steerers and an electrostatic quadrupole doublet had to be added to bring the beam in parallel to the big Tandem to a large 90° analyzing magnet. The analyzed beam can be sent either straight to the RBS chamber or bent to the 30° line with the ERDA TOF spectrometer. The existing target chambers and spectrometers developed at the 6 MV Tandem were modified for the new beamlines. Later, an Oxford microbeam will be installed in the 0° line behind the RBS chamber and a high-resolution magnetic RBS spectrometer in the ERDA line. Additionally the RBS target chamber serves as an irradiation station with rastering capabilities. End of 2018 the material science activities at LIP moved from the 6 MV Tandem to the Tandetron facility except for the MeV-SIMS setup and irradiations that require higher energies. An overview of the accelerator facilities with the focus on the performance for material science applications will be presented.

In-situ depth profiling of lithium in solid-electrolyte using ion and neutron beams

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In a path to a sustainable low-carbon society, conversion to renewable energy is steadily proceeding. However, the renewable energy from wind or photovoltaics fluctuates greatly, which makes it difficult to integrate it into the existing transfer grid. If an efficient electricity storage device (that would play a role of a buffer to compensate fluctuations of the energy) would exist, the speed of energy production conversion towards renewable energy would significantly accelerate. As a next generation key device for the electricity storage, a concept of all-solid-state lithium ion battery is promoted. Since the lithium ions move between the positive and negative electrodes in the active lithium ion battery, it is important for further development of the all-solid-state battery system to know how the lithium ions are distributed. It is especially important to understand how the lithium ions are behaving during the charging or discharging processes. Additionally, the issue of the interface resistance of a thin all-solid-state lithium ion battery is considered to be significant, as the resistance of the battery can be strongly affected by a lithium ion transfer. We have recently investigated what happens in a separate solid electrolyte (of a thickness 150 micrometer) when a high voltage (< 15 V) is applied. The measurements were performed using the ^{7}Li(p, ^{4}He)^{4}He and ^{6}Li(n, ^{4}He)^{3}H nuclear reactions. As a result, a lithium depletion layer (a considerable transfer of lithium ions between the sides of the biased thin electrolyte) has been observed (see Fig. 6). Evidently, the depletion of lithium concentration at the surface (and in a near-surface layer) is due to a delithiation process initiated by the biasing of the solid electrolyte.

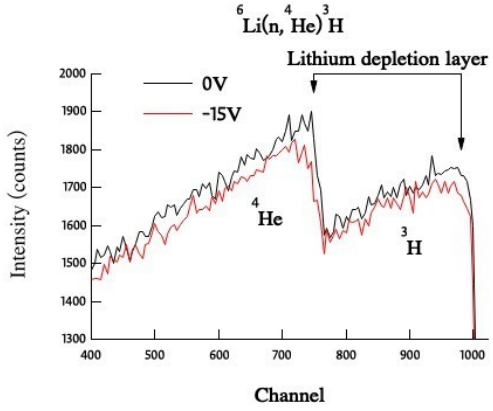

Figure 6: 4He and 3H energy spectra from 6Li(n, 4He)3H reaction obtained from a solid electrolyte with a thickness of 150 micrometer

[1] J. Haruyama, K. Sodeyama, L. Han, K. Takada, and Y. Tateyama, Chem. Mater. 26, 4248-4255 (2014).

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Progress and Development of Positive Ion Mass Spectroscopy for Multiple Radiocarbon Dating Applications

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In 2017 we announced a collaboration between National Electrostatic Corp. (NEC), the Scottish Universities Environmental Research Center (SUERC), and Pantechnik that had developed and operated a prototype Positive Ion Mass Spectroscopy (PIMS) system for radiocarbon dating. We are excited to present our progress on PIMS, currently installed and under testing at SUERC. We will review the principles of PIMS operation, and its various advantages over traditional carbon AMS. We will also present the latest performance results. Finally, we will discuss supporting technology currently in development and opportunities for customization to meet a range of demands, tailored to application.

Low-level ^{26}Al AMS analysis by Ion-Laser InterAction Mass Spectrometry

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Ion Laser InterAction Mass Spectrometry (ILIAMS, [1]) is a new method for the analysis of isotopes with extremely low abundance (typically long-lived radioisotopes) as it features high element selectivity (= selectivity of proton number Z) and thereby strongly suppresses isobaric interferences. The method takes advantage of the selective photodetachment of an ion beam that is decelerated electrostatically and cooled via collisions with a buffer gas (typically He) in a radio-frequency quadrupole. ILIAMS serves as an additional Z filter that is successfully exploited for the separation of $^{36}Cl^-$ from $^{36}S^-$ in routine AMS measurements [2]. AMS measurements of ^{26}Al ($T_{1/2}$=0.7Myr) usually make use of the total suppression of the interfering isobar ^{26}Mg when extracting a negative atomic beam, i.e. Al^-, from the Cs sputter ion source. A higher yield from Al_2O_3 material can be gained by the extraction of AlO^-. However, the formation of MgO^- so far limits the use of AlO^- to large AMS facilities that are able to separate the isobars at high beam energies in the detection process. Using ILIAMS, $^{26}MgO^-$ is suppressed already on the low-energy side of the spectrometer by approximately 13 orders of magnitude. This happens in a combination of collisional destruction or transformation of the MgO^- molecules and their photodetachment using an 18W laser (type VERDI) delivering 532nm photons (E_{ph}=2.3eV). In the process, MgO^- with an electron affinity of 1.6eV is neutralized but AlO^- with an electron affinity of 2.6eV is not affected by the photons. During the measurements the full suppression of the interfering isobar ^{26}Mg is checked in Al_2O_3 samples with a deliberate admixture of ca. 10% MgO that are analyzed along with the unknown samples. After the stripping process on the high voltage terminal either the charge state 2+ or 3+ was used in the measurements and the rare species was detected in a compact dual anode gas ionization chamber. The higher transmission of the Al beam through the accelerator is achieved in the 2+. However, the selection of the Al^{2+} beam brings along interference from $^{13}C^{1+}$ or molecules of $^{13}C_2{}^{2+}$. This interference is reduced but not fully suppressed via ILIAMS. It finally can be separated in the detector due to the different energy loss of the C and Al ions. In a comparison using different unknown samples the same materials of pure Al_2O_3 were analyzed both in a conventional Al^- and in an ILIAMS assisted AlO^- AMS measurement. The ILIAMS assisted AlO^- measurement produced an overall 5-fold increase in efficiency. The increased efficiency using AlO^- ions turns the advance of low-level measurements of $^{26}Al/^{27}Al$ into a main objective of ILIAMS assisted Al measurements. Presently, a ratio 8×10^{-16} is measured in a regular industrial Al_2O_3, which is used as a blank sample in the measurements. Measurements of single cathodes with $^{26}Al/^{27}Al$ ratios of the order of 10^{-14} to uncertainties <10% are completed within 120 minutes.

[1] M. Martschini et al., Int.J. Mass Spect. 415 (2017) 9-17.
[2] J. Lachner et al., Nucl. Instrum. Meth. B, in review.

First AMS measurements of (60Fe/Fe) isotopic ratios at the Cologne 10 MV Tandem Accelerator

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The Accelerator Mass Spectrometer at the Cologne 10 MV Tandem Accelerator is dedicated to medium mass isotopes. The measurement of the long-lived isotope 60Fe, with a half-life of 2.6 Ma, is of special interest in astrophysical applications. As part of arriving supernova remnants on earth and nearly no abundance apart of that, it can be used as an indicator for past supernova events. AMS measurements are a powerful tool to detect these small isotopic (60Fe/Fe) ratios in the range between 10^{-15} and 10^{-16}. With the newly installed setup with a 135° gas-filled magnet combined with a 5 anode gas ionization chamber, AMS measurements of (60Fe/Fe) standard samples, obtained from the Paul Scherrer institute, with isotopic ratios in the range of 10^{-8} and 10^{-10} were performed successfully for the first time. By use of the gas-filled magnet a high separation between 60Fe and its isobar 60Ni was achieved. This contribution will report on these first measurements and discuss the results and future perspectives.

We thank D. Schumann, from Paul Scherrer Institut, for providing 60Fe standard material.

Production of Zirconium-89 in photonuclear reactions

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The positron emission tomography (PET) with radiolabeled monoclonal antibodies (mAbs), sometimes termed as "immunoPET", has shown great potential in cancer imaging since this strategy combines the high sensitivity of PET with the high antigen specificity of mAbs. The ImmunoPET with the radiolabeled mAb can be used for tumor detection as well as treatment planning. ^{89}Zr has appropriate decay characteristics for high resolution Immuno-PET imaging. ^{89}Zr is a neutron deficient isotope of zirconium, and it decays with a half-life of 3.27 days to ^{89}Y. The decay proceeds via electron capture (77%), and positron emission (23%). Usually ^{89}Zr can be produced by proton irradiation of a natural yttrium target through the (p,n)-reaction. However, cyclotron accelerators are complex and power-consuming installations. They require a large number of specialists for their maintenance. At the same time, electron accelerators, such as microtron, are more compact equipment and have undeniable advantages in ease of maintenance and energy costs. Therefore, obtaining ^{89}Zr in photonuclear reactions using electron accelerators will significantly reduce the production cost this radiotracer and increase the availability of PET diagnostics. One of the perspective direction is the use of natural molybdenum and niobium as targets for these purposes. Natural niobium consists of a single stable isotope ^{93}Nb. Natural molybdenum consists of seven stable isotopes: ^{92}Mo (15.86%), ^{94}Mo (9.12%), ^{95}Mo (15.70%), ^{96}Mo (16.50%), ^{97}Mo (9.45%), ^{98}Mo (23.75%) and ^{100}Mo (9.62%). We irradiated molybdenum and niobium targets with bremsstrahlung gamma quantum on the pulsed microtron of the Scobeltsyn Nuclear Physics Institute of Lomonosov Moscow State University with an electron energy of 55 MeV. Targets with 50 mg masses was irradiated during 80 minutes. The average current was 40-45 nA. The subsequent spectrometric measurements were carried out by a semiconductor spectrometer with a detector of high-purity germanium of large volume with an energy resolution of 1.8 keV γ 1332 keV ^{60}Co. As can be seen, after molybdenum and niobium irradiation we observed in both targets the gamma yield accompanying the decay of ^{89}Zr (Figure 7). ^{89}Zr was obtained from ^{93}Nb in (γ,4n)+(γ,p3n)-reactions. In molybdenum targets ^{89}Zr was obtained from ^{92}Mo in (γ,3n)+(γ,p2n)-reactions. To calculate the ^{89}Zr yields, we used data about (γ,n)-reactions yields, because their cross sections were well studied early (for example, [1]). Thus, we obtained the integral yield of ^{89}Zr after irradiation of natural niobium equal 1 mb/MeV, and the integral yield of ^{89}Zr after irradiation of natural molybdenum equal 16 mb/MeV. The studies show new possibilities for zirconium-89 production by electron accelerators. It should be noted that it is possible to produce also technetium-99 from molybdenum-99 simultaneously with zirconium-89 from natural molybdenum using a 55 MeV electron accelerator.

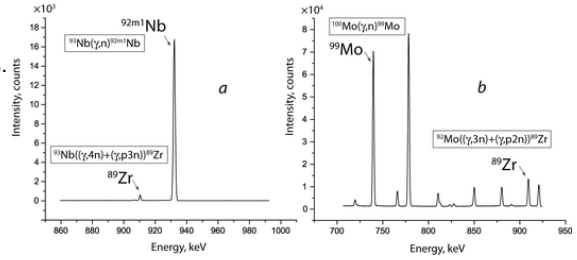

Figure 7: Fragments of measured spectra of irradiated targets: (a) - natural niobium, (b) - natural molybdenum

[1] Varlamov A. V., Varlamov V. V., Rudenko D. S., et al. Atlas of Giant Dipole Resonances// IAEA Nuclear Data Section.Vienna: Wagramerstrasse 5, A-1400: 321, 1999

Profile measurement of MeV ion microbeam in atmosphere extracted from single tapered glass capillary with an end window

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Ion microbeam irradiation to biological target, e.g., a part of an outer organ of an insect, the nucleus of a mammalian cell (Fig.8 (a)) has been developed, employing tapered glass capillary optics to produce microbeams of MeV ions. The beam profiles should be estimated to obtain the narrowest beam spot, especially for the insect irradiation which needs a spot size less than 100 μmϕ for 1 mm-irradiation distance. A 2.8 MeV H^+ beam from the RIKEN Pelletron accelerator was transmitted through a capillary with an end-window, whose outlet size was 9.9 μm (Fig.8 (b)), and then created a spot on a CR-39 piece at the irradiation distance of 1 mm (Fig.8 (c)). The structure of the spot center was measured by another setup as shown in Fig.8 (d) and was found to have an energy-dependence. The FWHM of the peak is larger for lower energy ions (Fig.8 (e)). The results of the profile measurements and a method to obtain smaller spots, as well as ion track observation in a cell nucleus [1], will be presented.

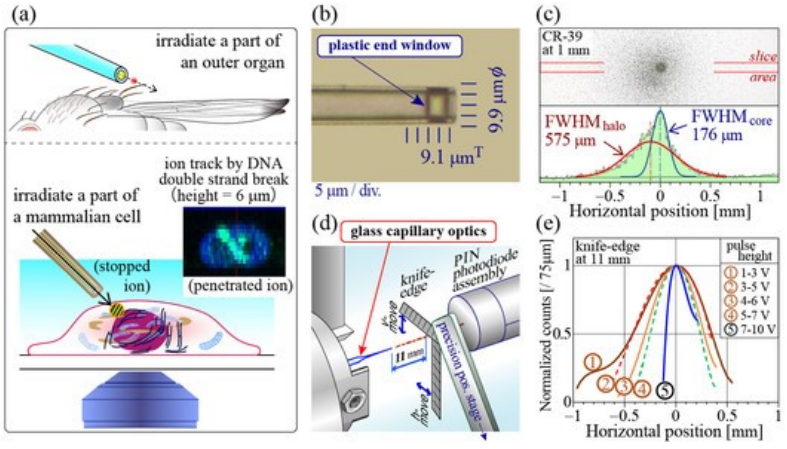

Figure 8: (a) Microbeam irradiation to a fruit fly and a living cell, (b) The outlet of the capillary, (c) Microbeam spot on CR-39 and the histogram along with slice area, (d) Setup of knife-edge method, (e) The profiles according to the ion energy.

[1] Tokihiro Ikeda et al., RIKEN Accel. Prog. Rep. 48 (2015) 315.

Particle Induced X-ray Emission (PIXE) for elemental tissue imaging in prosthesis rejection cases

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Massive reports on failures of prosthesis revealed insufficient understanding of physiological processes that may lead to prosthesis failure [1]. Studies of prosthesis failures revealed complex processes leading to chemical degradation of implants, resulting in release of debris and leached metallic ions into the peri-prosthetic tissue and synovial fluid, causing inflammation and loosening of the hip prosthesis. In this context, techniques currently applied in hospitals, such as X-ray scans and optical tissue microscopies, do not fully explain the effects of implants on the body physiology. Modern tissue microscopy techniques are promising providing elemental and chemical distribution of a tissue, with high sensitivities and lateral resolution. Among these techniques, energy dispersive X-ray analysis (EDX) and electron energy-loss spectroscopy (EELS) provide high lateral resolution (<10 nm), however, they are unable to detect elements present at low concentrations. Proton-Induced X-ray Emission with focused primary proton beam (micro-PIXE) technique combines both high elemental sensitivity with detection limit of 0.1 ppm, as well as lateral resolution of 600 nanometers, and it is particularly suited to screen the tissue for the effects of prosthesis degradation. In particular, micro-PIXE allows determining the quantitative elemental mapping of a tissue and has been proved to suit well for element localization studies in biological tissues, combining high elemental sensitivity and high lateral resolution with the quantification ability [2]. This project is focused on investigating reasons of failures and rejections of hip replacements by application of advanced elemental microscopies to human tissue surrounding hip failures. We study the distribution and concentration of biologically active wear particles (Ti, Al, V, Cr, etc.) in the peri-prosthetic tissue, obtained by biopsy during the hip-replacement surgery. Tissue samples are sliced (from 10 to 40-μm thickness) for analysis. Samples are placed in a special sample holder and scanned with a 3 MeV focused proton beam. The associated proton microprobe of the 2 MV tandem accelerator available at JSI can feature the highest beam brightness at any tandem accelerator worldwide, that makes it especially suited for this type of experiments. First elemental tissue maps have been obtained showing the distribution and quantification of elements from F to Ni. Fig. 9 corresponds to a tissue sample obtained from a patient who suffered a prosthesis failure due to a fracture in the prosthesis neck, which connects the head and the stem. The Ti map (b), obtained with GEOPIXE software, shows the Ti distribution and quantification in the tissue, allowing the univocal identification of the different features observed with the optical microscopy. Results are expected to have an impact on everyday life of patients using or in need of hip replacements.

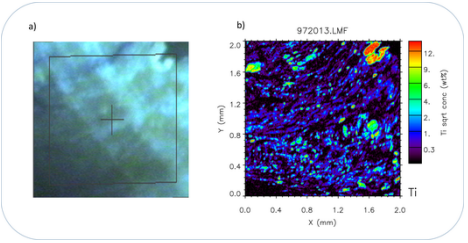

Figure 9: a) Optical microscope image from the pre-prosthetic tissue analyzed. b) PIXE elemental map distribution of Ti in the same area.

[1] Fokter SK, et al., Acta Orthopaedica, 87(2), p.197-202, 2016.
[2] P. Vavpetič et al., NIM-B, vol. 306, pp. 140-143, 2013.
[3] Primoz Pelicon et al., NIM-B, vol. 332, pp. 229-233, 2014.

Elemental analysis of particulate matter and biological samples of workers exposed to the dust in a metal workshop

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Particulate matter is one of the most important air pollutants. It is well known that due to the small particle size fine particulate matter ($PM_{2.5}$) can be harmful for human health because it can enter human respiratory system. Metal processing such as welding, cutting, grinding and turning can produce significant and potentially harmful amounts of heavy metals in fine particulate matter at specific workplaces such as metal workshops. In the present work we present results obtained from the $PM_{2.5}$ samples collected during two sampling campaigns in the metal workshop. In June 2016 12-h samples were collected during two weeks, with sampler positioned at about 30 m from the closest welder. In November 2016 40 hourly samples and four 12-h samples were collected at about 5 m distance from the closest welder. After the second sampling campaign, samples of blood, hair and nails were taken from nine volunteers working in the workshop. Additionally, biological samples were taken from a control group formed of 9 unexposed volunteers. Proton Induced X-Ray Emission (PIXE) was used for elemental analysis of the collected $PM_{2.5}$ samples. Measurements were done using 1.8 MeV protons and concentrations of 20 elements from Na to Pb were determined. Concentrations of metals during working hours were 2 to 3 orders of magnitude higher than typical concentrations at nearby outdoor urban collecting site. Biological samples were analysed with ICP-MS technique. Blood samples did not show significantly elevated concentrations of metals comparing to the blood samples of control group. Contrary to that in hair samples of exposed workers significantly higher concentrations of Al, Cr, Mn and Fe compared to control group were measured. Similarly, nail samples of workers exposed to metal dust had significantly higher concentrations of Cr, Mn, Fe, Ni and Ti if compared with hair samples of unexposed volunteers.

Research and Training in Ion-Beam Analysis of Environmental Materials

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We have an active research program at the Union College Ion-Beam Analysis Laboratory (UCIBAL) focused on the study of environmental materials. Accelerator-based ion-beam analysis (IBA) is a powerful tool for the study of environmental materials because it can provide information on a broad range of elements with high sensitivity and low detection limits, is non-destructive, and often requires little or no sample preparation. It also provides excellent training for students. Beams of protons and alpha particles with energies of a few MeV from the 1.1-MV tandem Pelletron accelerator (NEC Model 3SDH) in UCIBAL are used to characterize environmental samples using IBA techniques such as proton-induced X-ray emission, Rutherford back-scattering, and proton-induced gamma-ray emission. Recent and current projects include the characterization of atmospheric aerosols in the Adirondack Mountains, the search for heavy metals in synthetic turf, depth profiling of diffusion in geological samples, the study of heavy metal pollutants in soil along the East River, the investigation of possible mercury emissions from crematoria, and the screening of a variety of environmental samples for per- and polyfluoroalkyl substances (PFAS). We will describe our research program and discuss a few of the recent and current projects.

Calibration of 3 MV Tandetron Accelerator over Nominal Energy Range

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There are many cases when a precise knowledge of the beam energy is important. For example, a poor knowledge of the beam energy can result in very large errors for non-Rutherford backscattering spectrometry and nuclear reaction analysis for which the utilized cross-sections are often of a strong resonance structure. In its basic configuration the Tandetron^{TM} accelerator is not equipped with a magnetic analyzer for measuring the beam energy. Instead, the energy stabilization is provided by means of accurate measurements of terminal voltage (TV) with a generating voltmeter (GVM). The early models of GVM were reported to be highly sensitive to the temperature, the deviation of TV due to the thermal drift in the GVM being about 1 kV/$^{\circ}$C. The advanced model of GVM used in the new 3 MV Tandetron^{TM} 4130 MC+ accelerator installed at IPPE has a pressure sensor, measuring the pressure of the insulating gas for compensating the deviation of the TV readout due to pressure changes during operation of the accelerator. The aim of the present work was to study to what extent this compensation provides linearity of GVM over the whole TV diapason. The method based on the measurement of proton beam energies using the non-resonant direct-capture reaction ^{16}O(p,γ)^{17}F* [1] was employed. At TV=3 MV the tandem accelerator produces a proton beam of about 6 MeV. This energy is too high for the calibration method used both because of a large background in the γ-ray spectra and due to the lack of γ-ray sources for the spectrometer calibration. In order to get around this problem the measurements were made at two different beam lines. At low TV values a regular proton beam was used whereas at higher TV the measurements were made with neutrals at the 0° port of the switching magnet, the charged fraction of the beam being deflected by the magnet. Thus the particles accelerated by TV only once were obtained. The neutrals flow estimated through the count rate was equivalent to $\sim$10 μA of a proton current. The γ-spectra were measured with a HPGe detector at 8 points from TV=500 kV to TV=2800 kV. The measurements were made twice with the interval of 3 months. The results of the calibration are presented and discussed.

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Novel Generators for Nuclear Medicine: Technical and Antitumor Characteristics

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The antitumor radiotherapy involves a variety of modern modalities. Among these gamma-irradiation of tumors remains the most important. Nevertheless, this treatment may induce tumor cell resistance; furthermore, escalation of the site dose can be problematic due to damage of normal tissues. The hadron particle therapy that includes protons, carbon atoms and neutrons emerged as a promising strategy. The advantages of this treatment are a high linear energy transfer in the tumor, a bigger value of biological efficacy and a low oxygen enhancement ratio. The neutron therapy gained momentum in treatment of radioresistant and/or deeply located tumors. However, the use of this modality presumes powerful sources that are environmentally safe, compact and affordable. A unique portable generator of fast neutrons NG-24 has been engineered at Dukhov Research Institute of Automatics. In this device a compact ion accelerator is placed inside a hermetically sealed case. Unlike vacuum accelerators, in NG-24 the atmospheric pollution by the exhausted tritium is completely prevented; this important invention seriously improves safety for patients and personnel. The device 40×110 cm in size can generate up to 10^{11} neutrons/sec, the intensity acceptable for radiotherapy. The NG-24 generator currently undergoes testing with a perspective to become a widely applicable medical device for neutron therapy. The biological characterization of the neutron beam generated by NG-24 was performed on a panel of human tumor cell lines such as MCF7 breast carcinoma and HCT116 colon cancer as well as HCT116p53KO subline with non-functional p53. We determined a range of single irradiation doses that cause a sublethal or lethal effect as determined by colony formation assays. The density of cell monolayer is a critical parameter to be considered in the design of radiosensitizing agents, in particular those that disrupt cell-cell cooperation. Irradiation of cells with the neutron beam (up to 6 Gy single dose) led to activation of signaling events both dependent and independent of p53. Apoptosis was not a major mode of cell death; alterations of cell cycle distribution were associated with p21 activation and emergence of a senescence phenotype by irradiated cells. This phenomenon can be regarded as an opportunity for the cell to escape death, at least temporarily. Thus, we designed and engineered a prototypic device for generating therapeutically relevant flow of fast neutrons. Our further strategy is aimed at the production and marketing of clinical instruments with a reliable safety and efficacy. These instruments will also be used for basic studies in cancer radiobiology.

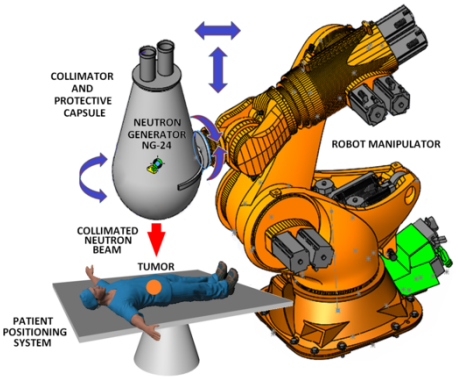

Figure 10: A therapeutic unit employing neutron generator

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Commissioning of a bi-directional energy sequence for efficient treatment with protons

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The 250 MeV COMET cyclotron [1] at PSI provides proton beam for three treatment areas: Gantry 2, Gantry 3 and OPTIS2. Gantry 2 employs Pencil Beam Scanning (PBS) technology where the proton beam is delivered spot-wise sequentially in various location of the tumor. The degrader and all beam-line elements of Gantry 2 were designed to enable a fast energy switching time below 100 ms allowing for a fast and precise patient irradiation. However, for moving targets (e.g. lung or breast cancer) the tumor movement is interfering with the beam delivery requiring an additional motion mitigation. The technique currently used at Gantry 2 is a volumetric rescanning (VR) where the whole tumor volume is scanned multiple times with a fraction of a total dose. Each scan is performed at a different movement phase allowing to average the errors over the volume. Current implementation of VR uses only down-going energies and creates a substantial dead time due to ramping of the beam line before setting the first (highest) energy of the field. Therefore, we introduced an energy meandering strategy that allows us to avoid beam line ramping between energy series. The technical commissioning of beam line parameters for inverse energy direction has been completed last year [2]. However, in a clinical workflow we rely on several types of dosimetric quality assurance (QA) measurements: a direct measurement of the delivered dose in water and an independent dose calculation (IDC) [3] based on machine log-files produced during the patient treatment. The log-file contains dose monitors and beam position information measured by the on-line monitoring system. The IDC use the Gantry 2 proton beam model that consist of depth-dose curves, multiple Coulomb scattering in a patient and a characterization of the beam width in air. To compare new beam parameters to the ones used for the model we measured the dose depth curves and the 2D transverse beam profiles for both down-going and inverse energy sequence. The measured range for both energy directions showed a very good agreement with the model data. Maximal deviation in range we obtained to be better than 0.2 mm. The gamma analysis performed on a full depth dose profiles was evaluated based on 1%/1mm global gamma criteria. For all energies the gamma pass rate was 100%. The beam width deviation measured in air for both energy directions was less than 1%. In addition, to validate the new energy meander strategy we performed corresponding patient QA tests. Both, direct dose measurement and IDC performed using new method were compared to a standard beam application with down-going energies only and large ramping pauses. The point-to-point dose difference between standard and new application for IDC was less than 2%. We obtained a similar deviation below 2% for a direct measurement with the water phantom. These results are well within clinical limits and allow us to proceed with the clinical implementation of a new method.

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Overview of computational methods for processing MeV TOF SIMS spectra and 2D images at RBI

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Complex, multivariate nature of MeV time-of-flight secondary ion mass spectroscopy (TOF SIMS) datasets requires the use of advanced statistical and machine learning methods for proper data interpretation (identification, classification or prediction). Such fast and efficient methods minimize subjectivity during analysis and use all the information available in the dataset. They improve signal to noise ratio and are able to remove potential bias. On the other hand, there are numerous different procedures to choose from, and some can be difficult to understand and interpret. Appropriate selection of data pre-processing and analysis method are critical for accurate interpretation of MeV TOF SIMS data. MeV TOF SIMS is a fairly new technique in use at heavy ion microprobe installed at the 45° beam line of the 6 MV Tandem Van de Graaff accelerator at RBI. So far it has been used in the analysis of forensic samples (mapping intersections of inks and toners, spectra of signatures and stamps, mapping of cocaine traces in fingerprints etc.) and biological samples (mouse serum and urine, liver tissue, biological cells etc.). This talk will cover the use and comparison of various computational methods, such as principal component analysis (PCA), non-negative matrix factorization (NMF), k-means clustering, multivariate empirical Bayes statistics (MEBA) in time series analysis and random forest, used in analysis of spectra and 2D images of mentioned samples.

Proton-crystal rainbow interaction potential

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This work is devoted to the construction of the proton-crystal rainbow interaction potential for very thin crystals with the cubic crystallographic structure, in the (001) orientation with respect to 2 MeV proton beams. It has been done by modifying the Moliere's interaction potential. We show that it is possible to obtain a universal proton-crystal interaction potential from the morphological analysis of the rainbows in the proton transmission angular plane.

Measurement of deuteron differential elastic scattering cross sections on light elements, at energies and angles suitable for EBS (Elastic Backscattering Spectroscopy)

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Light elements find numerous technological applications in the industry. They are crucial in the field of material analysis due to their presence in ceramics, glasses, and polymers, while they are also frequently added in metallic alloys in order to improve their corresponding properties, such as, hardness, wear and heat resistance, or rigidity. Nitrogen and silicon are heavily used in the semiconductor- and insulator technology, since the former is a common dopant for the creation of n-type semiconductors and the latter is the key component in wafers on which integrated circuits are built. Beryllium has also recently emerged as an important material in plasma facing components of controlled fusion devices, while Lithium, due to the high neutron cross section ($\sim$940 barn) of ^{6}Li, that readily fissions, is the main source of tritium which is used in biochemical research, thermonuclear weapons and future controlled fission. Consequently, the accurate quantitative determination of light-element depth profile concentrations in a variety of matrices is of paramount importance in contemporary science and technology. This determination can best be accomplished via the implementation of IBA (Ion Beam Analysis) techniques and more specifically via ERDA (Elastic Recoil Detection Analysis), for ultra-thin surficial layers and NRA (Nuclear Reaction Analysis) due to the production of isolated peaks (high Q-values involved) with negligible background. At the same time, the use of a deuteron beam provides high depth resolution, deep layer analysis and allows for the simultaneous study of practically all the main light isotopes/elements coexisting in a target. The implementation of d-NRA could be further greatly enhanced if one could also coherently analyze the elastic scattering spectra which are simultaneously acquired using the same experimental and electronics setup. However, the general applicability of d-EBS is still limited nowadays, mostly because of the lack of reliable and coherent datasets of differential cross-sections in literature for energies and angles suitable for IBA. Hence in the present work a comprehensive review is presented concerning results obtained over the last 3 years for deuteron elastic scattering on many important stable light elements and isotopes, such as ^{6}Li, ^{7}Li, ^{9}Be, ^{nat}N, ^{19}F, ^{23}Na, ^{nat}Si and ^{31}P at energies and angles suitable for analytical purposes. In several cases the obtained differential cross-section datasets were also benchmarked using thick targets of accurate stoichiometry. All measurements were carried out at the 5.5 MV Tandem Accelerator of N.C.S.R. "Demokritos", Athens, Greece. The experimental setup consisted of a high-precision goniometer, along with six silicon surface barrier (SSB) detectors (500μm in thickness). Most of the obtained differential cross-section datasets are already available to the scientific community via IBANDL (Ion Beam Analysis Nuclear Data Library).

This work has been supported by the Greek Scholarship Foundation and has been funded by the "Doctoral Research Financial Support" Act from resources of the OP "Development of Human Resources, Education and Lifelong Learning" 2014-2020, which is co-funded by the European Social Fund–ESF and the Greek Government.

Readjustment of the Bohr stopping power for energies between 0.05 keV/u and 10 MeV/u

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In basis of the presence of different processes participating in the slowing down of ions in matter according to their probability to occur, the stopping power Bohr model has been readjusted. The new modified Bohr stopping power model was applied to heavier (Intermediate) ions ($3<Z1<18$) for energy range 0.1-10^4keV/n in various target materials. Depending on the energies range, the obtained values of the stopping powers were presented and compared with predictions of the widely used SRIM-2013, the Bohr stopping power for distant and close collision, Bethe-Bloch model, the Firsov model and the Lindhard-Scharff-Schiott formula. The aim of such comparison is to check the reliability and accuracy of the existing stopping power formulations. The electronic stopping power generate by the readjusted Bohr model was found surprisingly to reproduce the experimental data for various ions and simple targets with a discrepancy less than 4%.

Status of the SPIRAL2 facility

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The SPIRAL2 facility at GANIL will use a high-power superconducting linac driver for nuclear physics, astrophysics and interdisciplinary research. This linac is designed to accelerate p, d and heavy-ion up to A/Q = 3, at energies from 0.73 MeV/u up to 20 MeV/u (33 MeV p), intensities up to 5 mA in CW or pulsed mode including a "bunch selector mode" isolating single 88 MHz bunches for time of flight measurements. The first phase of the SPIRAL2 project deals with the high-power superconducting linac and two experimental areas called "Neutron for Science" (NFS) and "Super Separator Spectrometer" (S3). The low energy experimental hall DESIR, under construction, will complete the facility with a connection to the existing cyclotron facility. All the linac and beam line components are installed and ready for operation. The first beams were produced in 2014 and the injector commissioning (two ion sources and the A/Q = 3 RFQ) was successfully done up to end 2018 reaching all nominal parameters for ions with A/Q from 1 to 3. The linac commissioning is in progress. After having briefly recalled the project scope and parameters, the constraints linked to the safety rules, the accelerator status, NFS, S3 and DESIR and overall planning will be presented.

Ultra-Compact Accelerator for Radioactive Isotope Sources Replacement in Security, NDT and Medical Applications

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Approximately 5,000 devices containing 55,000 high-activity radionuclide sources are in use in the United States alone, in applications ranging from cancer therapy to oil exploration. US and IAEA authorities have identified as a priority the replacement of radioactive sources with alternative technologies, due to the risk of accidents and diversion by terrorists for use in Radiological Dispersal Devices. Many of these sources can be replaced with the X-rays produced by electron beams accelerated to energies of around 1 MeV. One particular applications of radioactive materials is in safeguard tools at nuclear facilities. Enrichment plants represent one of the most sensitive parts of the nuclear fuel cycle, and the Co-57 (122 keV) based Cascade Header Enrichment Monitor (CHEM) is used to detect the presence of UF_6 gas at low pressures within a closed piping and to determine whether this UF_6 is highly enriched. Although, X-ray tubes can produce the required energies (200 keV), they are too heavy and bulky to be attached to a hand-held device. Also, X-ray tubes are not practical for the energies beyond 500 keV and not practically scalable after 1 MeV. RadiaBeam Systems, LLC has developed an inexpensive, hand-portable 180 keV electron accelerator to replace Co-57 radionuclide source in CHEM detectors. We used two innovative technologies in our design: Ku-band magnetrons, and a split accelerating structure design to fabricate the linac in two halves and to avoid labor-intensive tuning steps. In this paper, we will discuss the accelerator, including X-ray convertor and accelerating structure design. The results of RF measurements of a Ku-band split structure will also be reviewed. Other applications of Ku-band linacs include compact both backscatter- and transmission- X-ray inspection systems, as well as computed tomography (CT) for luggage and parcel screening with or without modulated energy pulses. The main requirement for systems for luggage inspection is that the X-ray source must be extremely compact. The required energies should cover the range from 180 keV to 1 MeV. In this paper, we will discuss the linac's energy scalability and other modifications that will enable our technology to address these applications.

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52 kW CW Proton Beam Production by CYCIAE-100 and General Design of High Average Power Circular Accelerator

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The 100 MeV compact cyclotron, CYCIAE-100 was approved to start the construction in 2011, and the first proton beam was extracted from the cyclotron on July 4, 2014. After that, the extracted beam was maintained at about 25 μA for 9 hours on July 25, 2014 for the test acceptance of machine stable operation. In 2017, the 200 μA proton beam development was conducted, and in 2018, the production of high power proton beam from 20 kW to 52 kW had been delivered successfully to the beam dump, which was installed at the end of the beam line. The commissioning of proton beam line system had been finished as well, and the proton beam was provided for about 20 users domestic and oversea.

Due to the successful construction of 435 tons large-scale precision magnet for CYCIAE-100, it has been proved that the gradient adjustment of magnetic field along radius can effectively enhance the vertical focusing during the isochronous acceleration. This key technology is applied to the general design of a 2 GeV CW proton accelerator, the energy limitation of the isochronous machine is increased from 800 MeV ($\sim$1 GeV) to 2 GeV, by our contribution of the beam dynamics study for high energy isochronous FFAG.

This paper will introduce CIAE's extensive engineering experience of precision magnet, high power RF systems, and the advantages of beam dynamics simulation based on large-scale parallel computing. The cost-effective solution for such a 2 GeV high power circular accelerator complex will be also presented after the brief introduction about the high power proton beam production by the CYCIAE-100.

The CERN PIXE-RFQ, a transportable proton accelerator for the MACHINA project

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Following the first high frequency Radio Frequency Quadrupole (HF-RFQ) accelerator developed for a compact injector for proton therapy, CERN has been building a new transportable RFQ for use in the examination of art masterpieces based mainly on the PIXE (Proton Induced X-ray Emission) technique with an extracted beam. This new PIXE-RFQ accelerator is more compact, only one meter in length with a power consumption of less than 6 kVA for a beam energy of 2 MeV and an average current of 5 nA. The PIXE-RFQ will be used for the MACHINA (Movable Accelerator for Cultural Heritage In-situ Non-destructive Analysis) project developed jointly by CERN and INFN. This paper will present the detailed design and performances of the PIXE-RFQ as well as the fabrication technologies used and the current status of the project. The technologies where initially required for the CERN Linac4 RFQ, the first accelerating structure of the new injector for the LHC and then successfully applied for the first HF-RFQ, resulting in the world's smallest RFQ. In a next step, for the PIXE-RFQ, the beam dynamics have been further improved to reduce the power consumption in addition to the compactness and the minimisation of beam losses above 1 MeV. The beam size and the peak current / duty cycle of the RFQ have been optimised for the Ion Beam Analysis (IBA) of artwork objects.

Towards micro-samples radiocarbon dating at INFN-LABEC, Florence

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In the field of radiocarbon applied research, both in Cultural Heritage and environmental contexts, minimising the invasiveness of the analysis is of fundamental importance. For this reason, at INFN-LABEC laboratory in Florence, the CHNet_Lilliput experiment aimed at reducing the graphite sample masses down to a few tens of μg of carbon, while the typical masses collected at the end of the preparation process is about 700 μg. New graphitization reactors were installed: their volume is reduced to improve the collected pressure to favour the graphitization reaction even with low mass samples. In each of the reactors, a short quartz tube is used as the "hot" part of the reaction chamber (a new small oven was designed and home-assembled); a new silver cold finger, cooled down by a Peltier-based device, is directly soldered to the body of the chamber; a new pressure gauge with a small internal volume is installed and pressure data are acquired through an Arduino board. As far as the AMS measurements in the Tandem accelerator are concerned, new beam run conditions have been set-up, especially considering the sputtering ion source and the injection timings of the three carbon isotope masses into the accelerator tube. Here we discuss the results of the first test runs, when samples of about 50 μg were measured. Reproducibility of radiocarbon concentrations in NIST Oxalic Acid II samples has been satisfying, as well as the comparison of ^{14}C ratios of unknown samples already measured in the "standard" conditions. Blank values have been resulted to be slightly worse than the typical values measured for 700 μg samples. This is somehow expected, since the possible contaminations from the environment, such as dust, can become more critical when lowering the sample masses. Next strategies to improve background will be proposed.

First radiocarbon dating of lead carbonates by AMS - Application to ancient cosmetics and paintings

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Lead white was the major white pigment used in European paintings from the Antiquity to the beginning of the 20th century. This pigment is mainly composed of two lead carbonates, cerussite ($PbCO_3$) and hydrocerussite ($2PbCO_3.Pb(OH)_2$). Greek and Egyptian cosmetics were also manufactured with lead carbonates such as cerussite and phosgenite ($Pb_2Cl_2CO_3$). As we recently demonstrated that organic carbon dioxide was incorporated in its production up to the 18th century [1], we propose here to date lead white in cosmetics and paintings by the AMS radiocarbon method. We developed an innovative protocol for the carbon extraction based on a selective thermal decomposition of the carbonates [2]. Radiocarbon and the other carbon isotopes were measured by accelerator mass spectrometry using the ARTEMIS facility (LMC14-LSCE, Saclay, France) [3]. We successfully dated Greek and Egyptian ancient lead-based cosmetics as well as mural paintings of castles and church. These results demonstrate the capacity of the AMS radiocarbon method to date lead white. Direct pigment dating provides a more reliable age and a stronger evidence for painting authentication than the dating of the canvas or support which may have been reused. We provide a new tool for the detection of forgery and the authentication of paintings.

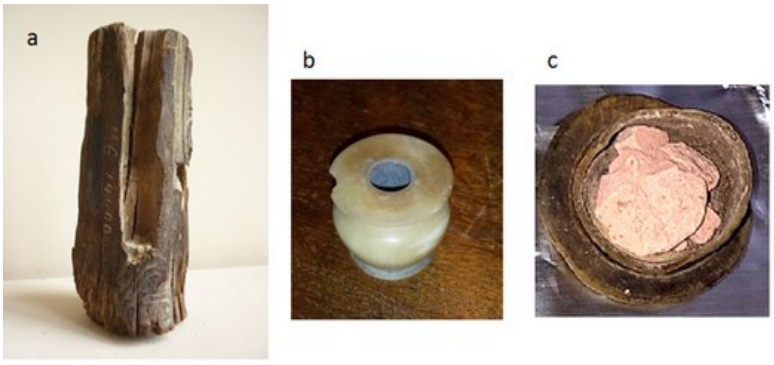

Figure 11: Kohl-pots from the Louvre museum containing cosmetics dated by AMS 14C

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Ion Beam Analysis and IR-Thermography for innovative Aerospace TPS material characterizations and qualifications at CIRA

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The conditions reached by a vehicle during Earth's atmosphere or from interplanetary trajectories re-entry are characterized by very high speed and high temperatures (2000 °C) due to high heat fluxes. The reproduction of these flow conditions during the on-ground experimental tests is one of the crucial points in the qualification and verification of the Thermal Protection Systems (TPS) representing the space vehicle subcomponents. As a matter of fact one of the most complex issues during a CIRA hypersonic Plasma Wind Tunnel (PWT) test campaign is to measure and monitor, besides the high heat fluxes, the correlated wear rate (mostly due to oxidation processes) at a certain surface temperatures affecting the behavior of TPS materials. Novel Ion Beam Analysis (IBA) as well as IR-thermographic methodology applications are under study in a research collaboration framework between respectively CIRA and UNICAMPANIA. The Surface Layer Implantation (SLI) method by means of ^{7}Be radioactive beam implantation technique generated by the 3 MV Tandem Accelerator at CIRCE laboratory University, might set the bases to develop a novel Remote, On-Line and Non-Intrusive methodology to measure the wear rate of the TPS materials [1], overcoming the invasive and the offline techniques used in the aerospace field today. Furthermore the IBA method (ex., Rutherford Back Scattering) could be applied to conduct a quantitative analysis both on the TPS multi-elemental stoichiometry change as well as on the thickness of the layers before and after the PWT tests to better interpret and understand the wear phenomena. Moreover, thermography is a non-intrusive and non-destructive method based on the measurement of the InfraRed thermal radiation emitted by the object surfaces through a thermal camera. Anyway, the temperature determination can be extremely inaccurate since the TPS material undergoes progressive emissivity change due to the chemical transformation making the measurement very difficult and inaccurate with standard thermographic techniques. A Dual Color free emissivity IR thermography technique is on the help on this topic [2,3]. In this work the state of art, the preliminary and feasibility studies on these novel physics methodologies still in development by the collaboration are discussed.

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A new external beam PIXE setup with transition edge sensor array and polycapillary optics

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A new external beam setup for high energy resolution PIXE measurements is presented. For the 160-pixel transition-edge sensor (TES) array, a helium filled polycapillary lens is used between the sample and the detector to increase the effective solid angle and to prevent scattered protons reaching the detector. By means of this setup, the detection of low-energy X-rays down to 0.5 keV has been demonstrated and the usable energy range extends to more than 10 keV. A single pixel in TES array can reach an energy resolution of 3 eV for 5.9 keV X-rays [1] and total resolution of $>$100 pixels is better than 10 eV. The benefits in terms of detection levels and element identification will be demonstrated with several examples.

[1] M. R. J. Palosaari et al. Journal of Low Temperature Physics 176.3-4 (2013) 285–290.

Ion Beam Techniques for Nuclear Waste Management

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In the field of nuclear waste management, the determination of difficult to measure isotopes are important for the isotopic nuclide inventory in disposal material. Accelerator mass spectrometry can propose a new precise and reliable way for the quantification of the radioactive material by the means of direct atom counting. One example is the measurement of ^{14}C, which is normally measured with the liquid scintillation technique (LS). The AMS technique offers a much higher sensitivity which becomes crucial for future German clearance levels of 0.1 Bq/g. In addition no pre-treatment of the samples are needed. Especially in the case of reactor concrete originated e.g. from the bio-shield of a nuclear power plant, the sample material can be directly burned in an Elemental Analyzer (EA) and the extracted CO_2 gas can be delivered to the AMS system. For the radiological characterization of radioactive material, the reference nuclides ^{60}Co or ^{152}Eu are normally used, because they are relatively easy to measure by gamma ray spectroscopy. The disadvantages are the relatively short half-lives and in the case of reactor concrete they are produced at trace elements. Therefore, we investigated the suitability of ^{41}Ca as a reference isotope for reactor concrete. Over one hundred defined neutron irradiated heavy concrete samples, with isotopic ratios in the range of 1.0e-12 to 1.0e-9, were measured at the Cologne AMS system. The results confirm that AMS is very well suited for decommissioning purposes. In addition, the technique of Projectile X-ray AMS (PXAMS) offers the opportunity to measure medium mass isotopes like ^{90}Sr, by the measurement of characteristic X-rays. We investigated the X-ray production yields for different target materials in an ion energy range of 0.35 MeV/u to 1.80 MeV/u for the determination of attainable sensitivity.

Transporting Ion Beams into a TEM for In-Situ Irradiation Observation

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The Michigan Ion Beam Laboratory (MIBL) at the University of Michigan in Ann Arbor Michigan, USA, is equipped with a 3 MV Tandem, a 1.7 MV Tandem and a 400 kV Ion Implanter for conducting single or simultaneous dual and triple ion beam experiments employing a combination of two and three accelerators. The installation of a 300 kV FEI Tecnai TEM provides the capability to conduct in-situ observation of radiation damage. The goal is to observe and characterize the microstructure evolution during single or dual beam irradiation experiments. Direct in-situ observation will provide data on the evolution of defect clusters and will be instrumental in developing models for the early stages of damage development. The newly built beamline 6 (BL6) is now interfaced with the TEM and is used to deliver up to 1.2 MeV Kr^{+++} ions from the 400 kV ion implanter into the microscope. An RF ion source connected through a short vertical beamline (BL8) to an ion mixer, brings lower energy He^{+} ions into a collinear beam with Kr^{+++} to provide for He injection during irradiation. The presentation will focus on the process of designing and building of the beamlines and on detailing the ion transport process from the ion implanter to the TEM, as well as the transport of light ions through BL8 to the TEM.

Modification of the graphene adhesion to the substrate by ion beam bombardment

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The main aim of the work was investigation of the possibility of modification of graphene adhesion to the substrate by ion beam bombardment. The CVD graphene grown on Cu foil transferred onto glass substrate was used. The graphene membrane of one atom thickness is attached to the new substrate by weak van der Waals bond. Chemical bonds may increase graphene adhesion to the substrate however, any chemical bond to the graphene surface is assumed as a graphene defect because of local change of its electronic structure. Bombardment of graphene on glass by beams of helium ions and nitrogen ions of energy 100keV was applied for creation of point defects in the graphene. Density and size of created defects were evaluated with using Raman spectroscopy utilizing the concept presented by Lucchese in [1] based on G to D Raman lines ratio. Various defect density were applied by varying of ion fluency accordingly to relations of defect density on the ion fluency presented in [2]. Adhesion of the graphene to the substrate was evaluated with laboratory made scratch wear test using polymer pin with hemispherical tip as a normal force required for exfoliation of the graphene from the substrate. Creation of wear defects in form of cohesive cracks and exfoliation of the graphene from the substrate under test conditions depending on applied normal force and ion fluency were observed. It was found that normal force required for graphene exfoliation i.e. adhesion strongly increases up to about ten times after bombardment of the graphene by ions at fluency specific for each of applied ion. Graphene adhesion increases proportionally to ion fluency however, the range of required fluencies is higher in case of helium ions than for nitrogen ions bombardment. However, it was found from Raman measurements that the adhesion increases with increasing of density of ion induced defects similarly in case of both helium and nitrogen ions. It supports the idea that graphene adhesion may be modified by creation of defects which may support creation of chemical bonds between graphene and substrate. The micrograph of scanning electron microscope (SEM) of the wear track on the pristine graphene and on the graphene bombarded with nitrogen ions up to the fluency $4x10^{13}$/ cm^2 at the same force load is presented in the Figure 12.

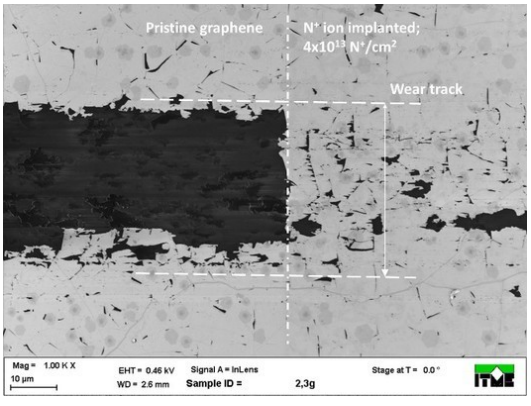

Figure 12: The micrograph of scanning electron microscope (SEM) of the wear track on the pristine graphene (left side) and on the graphene bombarded with nitrogen ions up to the fluency $4x10^{13}$/ cm^2 (right side) at the constant load 2.3 g.

[1] M.M. Lucchese, at al, CARBON 48 (2010) 1592–1597
[2] G. Gawlik, at al, Nucl. Instr. Meth. B 408 (2017) 228–234

Effects of He ion irradiation on microstructure of 4H-SiC nanowhiskers

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Silicon carbide (SiC) is currently intended to be used as structural confinement material in some nuclear fusion and Generation IV fission reactor projects. This because it possesses remarkable high temperature strength, chemical inertness and small neutron capture cross section that make it promising for applications in advanced nuclear systems such as DEMO fusion reactor. In these applications SiC will be exposed to high level of irradiation, high temperatures and accumulation of helium gas bubbles from radioactive decay. Various studies have been conducted focusing on the irradiation-induced defect and helium diffusion in single crystalline silicon carbide. Nanoporous materials have been shown to possess high radiation tolerance due to their large free surface that acts as a non-saturable sink for radiation induced damage. Using in-situ transmission electron microscopy studies, we investigate the response of SiC nanowhiskers (NWs) as a model system for nanoporous SiC to radiation damage with an aim of revealing its radiation tolerance in nuclear environment. The SiC samples were irradiated with 10 keV He at temperatures between 100 and 1273 K and doses up to 50 dpa. At temperatures above 250 K, the nanowhiskers remains crystalline and no He bubble nucleation occurs up to the doses studied. Between 773 and 1273 K, He bubble nucleation occurs with the bubble density increasing with increasing dose. In contrast to single crystalline samples at 1273 K, no He platelets or bubble discs were observed in the NWs with increasing dose indicating a high radiation tolerance. Radiation induced segregation and precipitation was also observed to occur in the NW samples for high temperature irradiation.

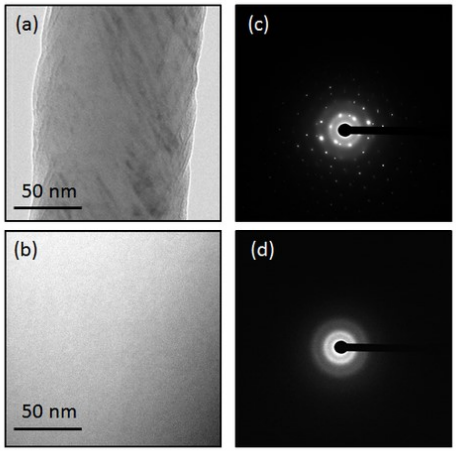

Figure 13: (a) and (b) represent the BF-TEM images for SiC nanowhisker and thin film respectively irradiated with 10 keV He at room temperature to a total dose of 10 dpa. (c) and (d) are the corresponding selected area diffraction patterns showing complete anorphization of the thin film and the crystalline NW after irradiation.

[1] T. Taguchi et al., Acta Mater., 154, (2018)90–99.
[2] E. Friedland et al., Nucl. Inst. Methods Phys. Res. B, 391, (2017)10–13.
[3] R. . Harrison et al., J. Eur. Ceram. Soc., 38 (2018) 3719-3726.

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Structural and optical studies of aluminosilicate films doped with (Tb^{3+}, Er^{3+}) / Yb^{3+} by ion implantation

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Harvesting solar energy demands efficient solar cells working over the larger region of the solar spectrum possible. The extension of the wavelength region is viable through the use of frequency converting phosphors. Rare earth (RE) elements fulfil this criteria and in particular the Erbium/Ytterbium pair allows a good coverage from the near-infrared (NIR) to visible up conversion (UC) luminescence at room temperature. In this study we report the structural and optical properties of aluminosilicate films grown by sol-gel (SG) spin-coating deposition technique and co-doped with (Tb^{3+}, Er^{3+}) / Yb^{3+} pairs by ion implantation with different fluences and energies. After implantation the films were annealed at 1000 °C for 20 min and characterized by Rutherford Backscattering spectrometry (RBS), Secondary electron microscopy (SEM), X-ray diffraction and Photoluminescence. For the samples implanted with fluences below 1×10^{16} cm^{-2} the annealing produces a redistribution of the RE ions over the entire implanted region with some segregation to the surface. For higher fluences the RE profiles remain unchanged and XRD results indicate some crystallization suggesting the possibility to form $YbAl_3$. SEM reveals the formation of nanostructures dispersed on the surface of the films. These structures display a square shape with a silicon rich round structures at the center. The photoluminescence shows the presence of bright spots and the correlation of the luminescence properties with the nanostructures is being investigated and will be discussed and presented. Also the results will be compared with in-situ doped samples during the spin coating deposition.

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Creation of quantum and classical light emitters in silicon using spatial selective, high-resolution ion implantation

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For many years, the high demand for more efficient electronics has been satisfied by decreasing structure sizes of electrical components on integrated circuits (IC) and by adaption of new designs (e.g. 3D stacking, FinFET, etc.) based on these components. This allowed a steady increase of transistor counts on ICs and therefore an improvement of clock rates, resulting in better performing electronics. But prospectively, this progress will slowly cease since with decreasing structure sizes, the signal delay is no longer dictated by the gate switching time but by the wiring delay ("interconnect bottleneck"). As this physical limitation is inevitable, new concepts for next generation computers must be developed. Since silicon has always been the main material in semiconductor fabrication, new designs based on this element would simplify the widespread transition to new technologies. A promising concept to achieve this is the combination of quantum computing and silicon-based photonics. Usually, natural silicon is highly improbable to emit photons, but by modifying the crystal structure, the probability of radiative recombination can be enhanced. This is achievable by e.g. the creation of a defect in silicon called G-center [1]. Such defect consists of one interstitial and one substitutional carbon atom in the silicon lattice and is excitable to emit photons with a sharp zero-phonon line at 1280 nm, matching the near infrared O-band of telecommunication. Therefore, G-centers are promising candidates for the realization of photonic-based microchips. Additionally, single-photon emitting G-centers could be used for long-distance entanglement of solid state qubits and therefore promoting the realization of a silicon-based quantum computer as predicted by e.g. [2]. Thus, light extraction in silicon might be the key for next generation computers. But to achieve this, well-defined placement of single defects is required. Within our project we will develop an easy method to generate G-centers only by well-established methods from semiconductor production. A solid source ion implanter with mica-foil aperture system is used to implant carbon isotopes into various silicon photonic structures like waveguides, pillars and microcavities. After rapid thermal annealing to incorporate the carbon atoms into the lattice, a Singletron high-energy accelerator with focusing setup and microbeam scanning system is used to irradiate samples with protons of up to 3 MeV to create carbon interstitials. The generated luminescence is measured with confocal photoluminescence microscopy to investigate optical properties of the created defects. Our research provides new insights on the characteristics of this defect, with the aim to develop LEDs, lasers, and single-photon sources directly within silicon and therefore paving the path to the realization of silicon-based high-intensity optical devices and the capability for quantum computing.

[1] C. Beaufils et al., Phys. Rev. B 97 (2018) 035303
[2] G. Tosi et al., Nature Communications 8 (2017) Article number: 450

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Generators of tagged neutrons and their applications

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Each 14 MeV neutron in T(d,n)He4 fusion reaction is accompanied (tagged) by 3.5 MeV alpha-particle emitted in the opposite direction. The nanosecond tagged neutron technology (NTNT) is based on the spatial-time analysis of the products (prompt gammas or neutrons) of nuclear reactions initiated by 14 MeV fast neutrons which escape time, energy, and direction of flight are known by the detection of the alpha particles associated with these neutrons. Figure 14 shows block diagram of typical NTNT device for neutron activation analysis. While inelastic scattering of fast neutrons by nuclei the energy spectrum of gamma rays is unique for different chemical elements, and can be used for their identification. Distance L from the target of the neutron generator to the point of emission of a gamma-quantum can be defined by measuring a time interval between recording of the gamma quantum and alpha particle associated with the neutron. Knowing the distance L and vector of neutron motion, one can calculate the location of gamma-ray emission and, from the cumulative data, determine the 3D distribution of chemical elements in the interrogated object. A key component of NTNT is a CW D-T neutron generator with a built-in position-sensitive alpha-detector. To provide a stable neutron emission, a 100-120 keV gas-filled sealed accelerating tube with a DC Penning-type ion source is used. The alpha-detector shall possess the following features to be capable of working in a sealed neutron tube: High efficiency of 3 MeV alpha-particles recording; Low degassing to support the background pressure at about 10^{-5} Pa; Protection from backscattered ions, products of ion sputtering, and ion-stimulated optical emission generated by the deutron beam at the target; Thermal stability at a heating up to 400 °C during accelerating tube manufacturing; Radiation resistance more than 100 – 1000 Gy; Time resolution of alpha-particle recording close to 1ns; Low sensitivity to the electromagnetic noise from the neutron generator power supply and ion source. Currently, VNIIA produces specialized gas-filled sealed accelerating tubes with a variety of built-in semiconductor multipixel detectors that do not deteriorate vacuum and electrical stability of accelerating tube, endure high temperature and high radiation during the manufacturing and operation of the neutron generator. Along with neutron generators VNIIA produces a complete set of equipment for handheld, robotic and stationary NTNT systems. They have great potentialities in various fields of research, industry, and homeland security such as the study of neutron scattering, revision of neutron differential cross-sections, calibration of fast neutron detectors, separation of ores in mining industry, detection of explosives, drugs and chemical warfare, measuring the chemical composition of soil in the Earth, and explore the planetary subsurface at the future space missions.

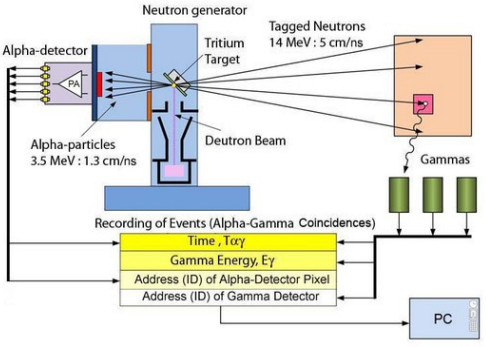

Figure 14: Block diagram of typical NTNT device for neutron activation analysis

Studies of the Conventional Beams Working Group within the Physics Beyond Colliders framework at CERN

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CERN Management has launched in 2016 an exploratory study aiming at exploiting the full scientific potential of CERN's accelerator complex and its scientific infrastructure through projects complementary to the LHC, HL-LHC and other possible future colliders. These projects will span the period from 2022 to about 2040. The role of the Conventional Beams Working Group (CBWG) is to study the technical feasibility of a multitude of proposals, particularly in the North Area of CERN, and finally to estimate the cost caused to beam lines changes. The three experimental halls of the North Area EHN1, EHN2 and ECN3 are served by the H2, H4, H6 and H8, M2, and K12 beamlines respectively. In EHN1, NA61++ aims at running a similar set-up compared to NA61/SHINE at higher intensities and with better protection of sensitive equipment. NA64++ would require an increased electron flux and an optimised hadron beam in the H4 line. Within the ECN3 cavern, the NA62++ experiment could run in a beam dump mode to allow for Hidden Sector searches. For this, simulations have been performed to minimise the muon background. KLEVER is a proposal of a new experiment aiming at studying the rare decay $\mathrm{K_L} \to \pi^0\nu\nu$. A new neutral beamline in ECN3 has thus been designed and is currently being optimised through simulations. NA60++ and DIRAC++ are as well interested to run in ECN3. Finally, EHN2 could host a modified COMPASS set-up (COMPASS++/AMBER) with the existing M2 beam configurations but with different physics aims. Furthermore, the proponents are interested in the exploitation of a new RF-separated antiproton and kaon beam, which needs a new design of the M2 beamline. CBWG has also studied the possibility to run in parallel NA64++ (mu) and MuonE, both requiring a muon beam, with COMPASS++. The results of all these studies driven by CBWG are listed in [1]. We will give an overview of these studies with a particular emphasis of the design of the RF-separated beam in EHN2.

[1] Lau Gatignon et al., CERN-PBC-REPORT-2018-002

Poster session A

Monday (May 6, 2019)

AMS of ^{90}Sr at the sub-fg-level using ILIAMS – a new means for isobar suppression by laser photodetachment

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The big challenge in accelerator mass spectrometry of long lived fission products ($m \approx 100$ u) is the generally strong interference from abundant stable isobars. The new Ion Laser InterAction Mass Spectrometry (ILIAMS) technique at the Vienna Environmental Research Accelerator (VERA) overcomes this problem. It achieves near-complete suppression of isobar contaminants in negative ion beams via selective laser photodetachment in a gas-filled radio frequency quadrupole (RFQ) [1]. The technique exploits differences in electron affinities (EA) within elemental or molecular isobaric systems neutralizing anions with EAs smaller than the photon energy. In addition, collisional detachment or chemical reactions with the buffer gas can further enhance anion separation. We report on the successful application of this technique for AMS of ^{90}Sr ($T_{1/2} = 28.64$ a), a fission product of high environmental interest both for its radiotoxicity and its potential as a tracer. Up to now, ^{90}Sr detection limits of mass spectrometric techniques like RIMS, ICP-MS or AMS have been similar to the radiometric limit of 3 mBq due to peak tailing of stable isotopes and, in the case of AMS, interference from the stable isobar ^{90}Zr [1,2]. ILIAMS provides a suppression of ZrF_3^- and YF_3^- vs SrF_3^- of $> 10^7$ with 12 W of laser power from a 532 nm cw-laser and He-O_2 mixtures as buffer gas. Extraction of SrF_3^- from the ion source and elemental separation in the ionization chamber provide additional suppression of Zr of $> 10^5$. First measurements on a dilution series from IAEA-TEL-2016-03 reference solution and Zr- and Y-spiked targets were successfully conducted. The overall Sr-detection efficiency is 8×10^{-4} and the blank value ^{90}Sr/Sr $= (5 \pm 3) \times 10^{-15}$. This corresponds to an improved detection limit of (0.08 ± 0.05) mBq or (0.015 ± 0.009) fg. In this contribution, we will detail this new means for isobar suppression and discuss which other long lived fission products could become accessible.

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[2] W. Bu et al., Spectrochim. Acta B 119 (2016) 65-75.
[3] S.J. Tumey et al., J. Radioanal. Nucl.Chem. 282 (2009) 821-824.

^{14}C dating of sea shells for geomorphology studies at the 1 MV Tandetron

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This paper gives an overview of the Accelerator Mass Spectrometry at the 1 MV Tandetron and of the ^{14}C dating of sea shells for geomorphology studies. Accelerator Mass Spectrometry (AMS) is today the most sensitive isotopic analysis method known. The AMS sensitivity can reach 10^{-15} scarce isotope (^{14}C)/ abundant isotope (^{12}C). Due to its exceptional sensitivity, this method has opened a very wide range of applications in various fields: geomorphology, medicine, archaeology, atmospheric physics, paleoclimatology, astrophysics, nuclear physics, nuclear pollution tracking, etc. The isotope with mass 14 known as radiocarbon is one of the unstable isotopes of carbon with widespread applications in the scientific world. The use of ^{14}C as a „clock" for estimating the age of various historical and pre-historical samples is one of its most important applications. Sampling, sample preparation and measurement of the ^{14}C content are important steps in obtaining reliable radiocarbon ages. In the ^{14}C AMS technique, the element of interest (sample carbon) is chemically separated from the original sample, converted to graphite, pressed into a cathode (sample target holder) where it forms a solid graphite layer and is then placed into a sputter ion source of an accelerator. Calibration of radiocarbon ages is the final step in establishing chronologies. The main purpose of this study on the Black Sea samples is: to calculate the deposition rates of sediments in different underwater environments from the Black Sea, to date underwater geological events as: turbidite flows, landslides, etc., to date the main incisions of the canyons on the continental platform and flexure zone. Black Sea is a very pelicular basin, due to its character of a semi-enclosed sea and its episodic connectivity with the Mediterranean Sea and further with the world ocean during Quaternary. This pecularity produced a complex pattern of paleo-shorelines and paleo-hydrography, imprinted in the sedimentary structures deposited and/or eroded, on the actual continental platform and in the shelf break area. The sea level variations have been convoluted with other local, regional active tectonics and glacial isostatic adjustment; as a result the morphology of the seabed and the shallow sub-structure of the sea bottom, that are the main geological and geomorphological features we can measure and depict in order to decipher the evolution of the paleo-shorelines and paleo-hydrography in general, are very complex in the NW Black Sea.

Figure 15: The AMS system

A systematic study of charge exchange in a terminal stripper for optimisation of ^{10}Be Accelerator Mass Spectrometry

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Accelerator Mass Spectrometry (AMS) at University of Helsinki is based on a 5 MV tandem accelerator that routinely performs radiocarbon measurements. Due to increasing interest in processes of a time scale wider than the limit of radiocarbon dating, for example geological applications, the development of measurement techniques for other isotopes is underway. One such isotope ^{10}Be with a long half-life ($t_{1/2} = 1.5 \times 10^6$ years) is suitable for geosciences studies. To adapt the existing AMS setup for ^{10}Be analysis, transmission of the ^{9}Be ion beam through the accelerator is studied. The charge state distributions of ions after passage through the gaseous (CO_2 and Ar) terminal stripper were measured to optimise Be beam transmission. The charge-exchange process of Be at energies of 1 - 5 MeV has so far not been investigated adequately in the literature. It is important from a practical point of view to ascertain which charge state gives the highest beam intensity for ^{10}Be AMS measurements. The measured yields of ^{9}Be charge states (q= +1, +2, +3, and +4) are at energies of 0.5 to 2 MeV. The $^{9}Be^{+q}$ ions were produced from injected BeO^- molecular beam in the terminal stripper with terminal voltages from 1 to 5 MV, and the yields were determined from the energy and mass analysed beam currents measured by Faraday cups, after the 90° injector and analysing magnets. Measurements of currents were also made with beam profilometers. Correlation of total transmission efficiency and stripper gas pressure was compared with the results of SRIM simulations. To investigate charge exchange processes further injection of atomic Be^- was also tested. In this way we could also test various theories to see if they differ for atomic and molecular beams. Also, the effect of stripping medium was studied using both Ar and CO_2 stripper gases. The presented results were compared against experimental values found from literature, semi empirical parametrisation models and charge-exchange theories. The optimum parameters for Be AMS with a 5 MV tandem and BeO^- injection were found to be 4.17 MV terminal voltage and a charge state of +2. A second stripper might be required for the charge state of +2, if there is a high molecular background, as it would be necessary to break up the molecules. With the 5 MV tandem accelerator, despite a lower beam current than for the measured +2 charge state, with a second stripper, a charge state of +3 might be of interest.

A new graphite preparation line in the INFN Bari laboratory for radiocarbon dating

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Many versatile applications in the life/earth science are based on the measurement of the radiocarbon. These applications are often limited by the minimum amount of carbon that can be measured in the sample: minimum size radiocarbon samples can be affected by contamination introduced during the sample preparation. Comprehensive systematic investigations to reduce the sample size limit down to a few micro-grams carbon are currently in progress in the INFN CHNet_Lilliput experiment. For such goal, a new original graphite preparation facility is being constructed at the INFN laboratory of Bari (Italy). The CO_2 from the combusted sample is cryogenically purified using a simple vacuum line set-up. The produced graphite targets will be measured using the Accelerator Mass Spectrometry (AMS) at the INFN-LABEC laboratory of Florence (Italy) where since 2004, sample measurements for radiocarbon dating are performed. In this contribution, the status of the sample preparation and the graphitization line will be described. Also results from preliminary tests will be given.

Assessment of anthropogenic radionuclides from GNPP environmental contaminations around the Domitia coast (Southern Italy)

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The work aims to investigate the in-depth distribution of anthropogenic radionuclides (^{239}Pu, ^{240}Pu) along the Domitian coastal zone (Campania Region, Southern Italy) downstream of the Garigliano and Volturno rivers. These coastal beach sediments, rarely investigated during the years, are the ideal samples to carry out and check for the influence of the decommissioned Garigliano Nuclear Power Plant releases, located near a bend of the Garigliano river. Despite the coastal sands are difficult to deal, both because in continuous evolution and for the limited scientific investigation presence of the environmental radioactivity of the sands vs. depth, the present work attempted to fill this gap and try to evaluate the presence of radionuclide contamination in the study area. The analytical methods to extract ^{239,240}Pu actinides by coastal sands, detected by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) at Riso National Laboratory, Denmark, and, for the first time, with Accelerator Mass Spectrometry (AMS) technique at CIRCE laboratory, Italy, proved to be reliable and reproducible, offering some avenues for future applications.

A new position-sensitive silicon solid state detector for ^{14}C-AMS beam line

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At INFN-LABEC laboratory in Florence, where ^{14}C-AMS analyses have been performed on the 3 MV Tandem accelerator dedicated beam line since 2004, a new silicon solid state detector has been installed to improve ^{14}C measurements, especially when dealing with small graphite samples (mass of about tens of μg). Actually, when the expected counting rate is very low, the optimization of the beam tuning to maximize the number of the acquired ^{14}C counts is even more so crucial. The new detector is a silicon state detector (300 μm thickness) with the 50×50 mm^2 active area divided into four sectors. Signals from each of the four sectors are independently acquired: sum of the counts in the four spectra gives us the total amount of acquired ^{14}C ions, while their subtraction allows us to check the beam transversal position with respect to the optical axis of the accelerator beam line. Here we discuss the first tests of this detector after installing it at the end of the AMS beam line. Tests were carried out using both an α-emitting source (^{241}Am), placed directly upon the sensitive side of the detector, and the ^{14}C ion beam during a "normal" AMS beam run. Measurements have shown that the trajectory of the rare isotope beam is pretty fixed and its transport can be easily achieved thanks to the existing tuning electrostatic and magnetic elements.

Development of a dedicated, linear electron-accelerator (LINAC) for a compact neutron source at AIST

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Neutrons are a powerful probe of large sized material samples due to their high penetration. As part of the Innovative Structural Materials R&D project funded by the New Energy and Industrial Technology Development Organization (NEDO), the Innovative Structural Materials Association (ISMA) has developed a dedicated, linear electron-accelerator (LINAC) based neutron source at the National Institute of Advanced Industrial Science and Technology (AIST) in Tsukuba, Japan, for the characterization of structural materials. The LINAC has a maximum design electron beam power of 10 kW ($\sim$36 MeV and $\sim$275 mA), with neutrons generated via photonuclear reactions after the electron beam is irradiated on a water-cooled Ta target. The electron beam has a maximum pulse length of around 10 μs at a maximum repetition rate of 100 Hz. A neutron beamline designed for Bragg-edge imaging spectroscopy has been installed in combination with a decoupled solid methane moderator cooled to 20 K. In the future, it is possible to add an additional beamline with a coupled moderator. In this contribution we will describe the preliminary operation and commissioning dedicated neutron source, with particular emphasis on the electron accelerator.

The CERN East Area renovation

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The East Area is among the oldest and longest-operating CERN's facilities, which operates beam tests, experiments and irradiations since the 1960's. The primary beam of 24 GeV/c protons is extracted from the Proton Synchrotron (PS), from which it is directed either towards the IRRAD and CHARM irradiation facilities or towards a primary target, from where three secondary beam lines are derived. These beams of up to 12 GeV/c (T9) and 6 GeV/c (T10) serve test beam areas, while the 3.6 GeV/c T11 beam serves the CLOUD experiment, which studies cloud formation under the influence of cosmic rays. More than 20 user teams are using the East Area for around 200 days of running each year. In order to continue delivering reliable beams in the future, the CERN Management has approved the East Area Renovation Project in 2016. Its implementation has already started and is mainly scheduled during the current two-year stop of all beams at CERN. Future beam optics will ensure an enhanced flexibility for the test beams users, as well as a better purity of the secondary beams, allowing for pure electron, hadron or muon beams. The new beam lines will provide higher energies (15 GeV/c T9 and 12 GeV/c T10) and thus give a useful energy overlap to the CERN North Area beam lines. Furthermore, the new layout will further limit radiation to equipment and personnel and will include new power supplies and laminated magnets that will allow for a cycled powering scheme. Together with infrastructure renovation, significant energy savings will be achieved. An overview of the project scope will be given and future beamlines and technological upgrades will be detailed.

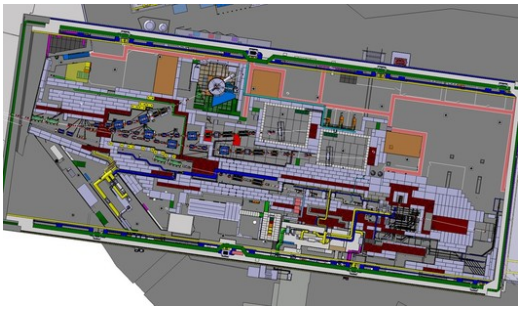

Figure 16: Future East Area layout. The primary beam comes from the left. It feeds either the T8 primary beam to the IRRAD and CHARM facilities, or T9 and T10 test beams, as well as the T11 beam, which serves the CLOUD experiment (from bottom to top).

A new 3D positioner for the analytical mapping of non-flat objects under accelerator beams

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Imaging strategies implemented by particle accelerators or synchrotrons which rely on raster scanning of micro beams at the surface of a sample can efficiently provide the multi-scale mapping of elements and compounds over large areas. This approach is however most often restricted to flat samples, because the employed analytical methods require that the analysed surface to be placed at a specific working distance and oriented with respect with the detection system for each measurement point. It is limitation in cultural heritage applications where three dimensional objects are common. Within a joint research activity of the IPERION-CH European program[1] untitled "Innovative instruments and methods for integrated approaches to CH analysis and diagnostics", we report here the implementation of a 3D positioner at external beam of the AGLAE accelerator of the C2RMF in Paris[2] that allow carrying out mapping non-flat surfaces. Designed upon a robot-vision scheme, the positioner operates in two steps: 1) the surface of the target is directly digitized using a 3D scanner integrated in the analytical end-station with its visual texture. The absolute coordinates of the recorded unevenly spaced cloud points are interpolated onto a rectangular grid suitable for scanning 2) The sample is moved under the beam using three linear stages in X/Y/Z directions (Z along the beam) holding an hexapod robot for the rotations around the corresponding axes. In this mechanical stack, the raster scanning of the areas is carried out with the X/Y linear stages while the target surface is kept in focus with the Z stage and oriented perpendicular to the analytical beam by means of off-axis rotations around the beam impact point executed by the hexapod. The scanned area is logically divided in small square tiles (e.g. 0.5 × 0.5 mm) that are eventually stitched together to cover the entire area. Areas of up to 100 mm × 100 mm with a spatial resolution of 50 μm and maximum curvature of 30° can be mapped on targets measuring up to 200 × 200 × 200 mm and weighting up to 5 kg. The positioner design can be adapted to other large scale facility end-stations offering access within the of IPERION-CH project, such as for example the PUMA X-ray beam line at the SOLEIL synchrotron or the neutron beam lines of the Budapest Neutron Centre.

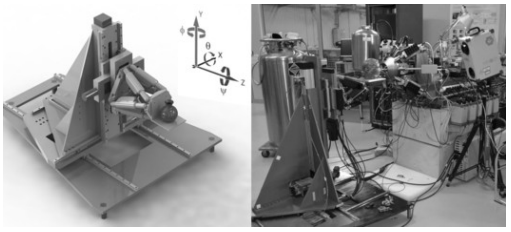

Figure 17: Positioner layout combining X/Y/Z linear stages with an hexapod (left) and its implementation in the AGLAE external beamline (right).

[1] IPERION : www.iperion-ch.eu

[2] L. Pichon, B. Moignard, Q. Lemasson, C. Pacheco, P. Walter, NIM-B 318 (2014) 27-31

Using the Multirhodotron as an Advanced Rhodotron

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In this report was assessed the use of the new type of electron accelerator "Multi-rhodotron" to energize FEL at the megawatt level of power in the continuous wave (CW) mode. Possibilities to use this accelerator for "electron cooling" in proton accelerators and colliders or for manufacture medical isotopes instead of nuclear reactors were suggested too.

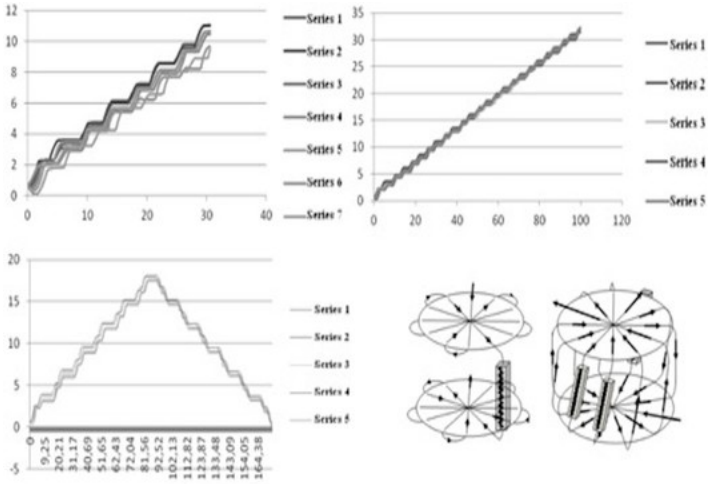

Figure 18: Results of simulating and types of radiators

Coherent THz Transition Radiation from Short Electron Bunches at the PBP-CMU Electron Linac Laboratory

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Coherent terahertz (THz) transition radiation is produced from short electron bunches at the Plasma and Beam Physics Research Facility, Chiang Mai University, Thailand. At our facility, short electron bunches are generated from a thermionic RF electron gun with a maximum kinetic energy of about 2 - 2.5 MeV and a bunch length of around 100 ps. The electron bunches are compressed to have shorter bunch length by using an alpha magnet. Then, they are accelerated by a travelling-wave linac to reach a kinetic energy in a range of 10 - 20 MeV. Together with the bunch compression in the alpha magnet and the velocity bunching in the linac, the electron bunches with a length in order of femtosecond can be obtained at the experimental station. These electron short bunches are used to generate the THz transition radiation by placing an Al-foil with 45° orientation facing the electron beam direction. The emitted backward radiation is collimated by an off-axis parabolic mirror and transmitted through a high density polyethylene (HDPE) window before the radiation entering the measuring system where its properties are investigated. Transportation of the THz radiation from the radiator to the detector in the experimental setup is simulated by using the ZEMAX program. The radiation properties including spatial distribution, polarization and collective efficiency are calculated. The measuring system is then developed based on the ZEMAX calculation results. The electron bunch length and the radiation spectrum are measured with the Michelson interferometer using autocorrelation technique. The property characterization of THz transition radiation produced from the electron bunches with energy in a range of 10 - 20 MeV will be conducted. The measurement results will then be compared with the calculation values.

Design of a 500 MHz RFQ linear accelerator for compact neutron source RANS3

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A compact neutron source using a particle accelerator is a promising tool for material analysis, infrastructural diagnostics, fissile material detection and medical applications. At RIKEN, the accelerator-driven compact neutron source (RANS[1]) which consists of a 7 MeV proton LINAC system (RFQ linac and DTL linac) and a beryllium target has been operated for more 6 years for measurements of materials used in industry and infrastructure. In addition, the prototype of transportable neutron source (RANS2) utilizing a 200 MHz RFQ linac and lithium target is being developed[2]. In non-destructive inspection of degradation of aged concrete and reinforcing steel on site, it is essential to make the neutron source system lighters and maller. In order to make a lighter RFQ linac for a transportable compact neutron source, we have developed a 500 MHz RFQ linac which mainly consists of three components (a measure vane and two minor vanes). Since the resonance frequency of the cavity is chosen as 500 MHz, the cavity diameter and the weight are lower than in a conventional four-vane type RFQ linac. As part of development, we have designed a 500MHz RFQ linac for a compact neutron source. First, by beam tracking simulation software, we designed the cell parameters of the 500 MHz RFQ linac which can accelerate a proton beam from 30 keV to 2.49 MeV. Using three-dimensional electromagnetic simulation software and multiphysics simulation software, we optimized the cavity design of the 500 MHz RFQ linac, and investigated the thermal properties of the cavity with the cooling channel. In the presentation we will discuss the design and simulation results.

[1] Y. OTAKE, In: Applications of Laser-driven Particle Acceleration. CRC Press, (2018), 291-314.
[2] T. KOBAYASHI, et al., In: 2017 IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC). IEEE, (2017), p. 1-2.

Development of a four-beam IH-RFQ linear accelerator

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Because the upper limit of the beam current in an RFQ linac depends on the applied voltage at the RFQ electrode and the strength of the space charge effect, it is difficult to accelerate a high intensity heavy ion beam. In order to achieve a higher beam current, such as 100 mA or more, a multi-beam RFQ linac system can be used. A multi-beam RFQ linac has multiple beam-channels accelerating several beams in parallel in one cavity, and utilizes multiple beams to decrease the space charge effect [1]. At Tokyo Institute of Technology, a two beam IH-RFQ linear accelerator was developed, and accelerated a carbon ion beam with a current of 108 mA (54 mA/channel $\times$ 2) from 5 up to 60 keV/u using a two beam laser ion source with a direct plasma injection scheme [2]. However, since the relationship between electric field property and beam channel layout are not clarified, a four-beam type RFQ linac has not been demonstrated yet. In order to demonstrate that a four-beam IH-RFQ linear accelerator is suitable for high-intensity heavy ion beam acceleration, we have been developing a four-beam prototype. We have investigated the electric field property for the beam channel layout, and designed a four-beam IH-RFQ cavity using three-dimensional electromagnetic simulation software and beam tracking simulation software [3]. A four-beam IH-RFQ cavity was fabricated according to the designed cavity parameters. Low-level RF property measurements of the fabricated four-beam IH-RFQ cavity were carried out with a network-analyzer, and the electric field strength in the RFQ electrode was measured by means of the bead perturbation method. After the low-level RF property measurements, we performed a high-power test and an acceleration test. In the presentation we will discuss the fabrication and experimental results of this four-beam IH-RFQ cavity.

[1] U. Ratzinger, et al., Nuclear Instruments and Methods in Physics Research Section A, 415, (1998) 281-286.
[2] T. Ishibashi, N. Hayashizaki, and T. Hattori, PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 14, 060101, (2011).
[3] S. Ikeda, A. Murata, and N. Hayashizaki, Nuclear Instruments and Methods in Physics Research Section B, 406 (2017), 239-243.

Emittance evaluation of electron beams produced by photoemission

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In this work we investigate the geometric and electromagnetic characteristics of electron beams generated by three photocathodes (PCs) based on one pure Cu sample and two nanodiamond (ND) layers [1,2]. Specifically, the active layers of the ND-based PCs consisted of untreated and hydrogenated ND particles, 250 nm in size, sprayed on p-doped silicon substrates. The photoemission measurements were carried out by a KrF nanosecond excimer laser (wavelength, $\lambda = 248$ nm; photon energy, $E_{\mathrm{Ph}} = 5$ eV) in a vacuum chamber at 10^{-6} mbar. The photo-generated electron beams were accelerated at different voltage values, by means of an electrostatic system mounted in the vacuum chamber. The emittance evaluation was performed by the pepper pot method utilizing radio-chromic films, HD-810 Gafchromic, as sensible targets. The study was performed by varying the laser spot onto the PC surface and the accelerating voltage (5, 10 and 15 kV). The obtained results have shown very low values of emittance and normalized emittance, about 2 mm mrad and 0.2π mm mrad, respectively.

[1] L. Velardi, A. Valentini, G. Cicala, Appl. Phys. Lett. 108 (2016) 083503
[2] A. Valentini, D. Melisi, G. De Pascali, G. Cicala, L. Velardi, A. Massaro, 2017, International Patent n. WO/2017/051318.

Design and development of dielectric assist accelerating structure

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A dielectric assist accelerating (DAA) structure [1], a type of dielectric loaded accelerating structures, is greatly superior in power efficiency compared with the conventional disk-loaded copper structures. The DAA structure is a higher-order TM mode standing-wave accelerating structure, which consists of low-loss dielectric cylinders and disks with irises which are periodically arranged in a metallic enclosure. The advantage of DAA structure is that it has an extremely high quality (Q_0) factor and a high shunt impedance (Z_{sh}) at room temperature since the electromagnetic field distribution of the accelerating mode can be controlled by the geometry of its structure to reduce the wall loss on metallic surface [1,2]. A prototype of the multi-cell C-band (5.712 GHz) DAA structure was designed by three-dimensional electromagnetic simulation. Radio-frequency (RF) properties such as Q_0 and Z_{sh} were measured and high-power test is currently in progress. Based on these results, we are considering an application of DAA structure to a compact X-ray source driven by RF linear accelerator. In this presentation, the latest results of simulation studies and experiments of DAA structure are reported.

[1] D. Satoh, M. Yoshida, and N. Hayashizaki, "Dielectric assist accelerating structure" Phys. Rev. Accel. Beams 19, 011302 (2016).
[2] D. Satoh, M. Yoshida, and N. Hayashizaki, "Fabrication and cold test of dielectric assist accelerating structure" Phys. Rev. Accel. Beams 20, 091302 (2017).

Development of a transportable accelerator-driven neutron source prototype

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RANS-II (RIKEN Accelerator-driven compact Neutron Source II) is a prototype of a transportable compact accelerator neutron source, which will be used for diagnostics of aged infrastructures and for a portable analysis station of materials. RANS-II aims to confirm the performance of accelerator, target, shielding, chiller and instrumentation for measurement. The design of the system started in 2016 and it is in the last stage of the construction. Lithium was chosen as a target material for neutron production via the ^{7}Li(p,n)^{7}Be reaction, and the incident proton energy was determined to be 2.49 MeV. Angular dependent neutron spectra at the Li target was calculated by the PHITS[1] Monte Carlo particle transport code with ENDF/B-VII.0, which exhibits a neutron flux peak in the energy from 500 keV to 700 keV with a maximum energy of about 800 keV. The total neutron flux (100 μA of incident proton) at 1 m distance from the target is estimated to be $1.65{\cdot}10^{5}$ cm^{-2}s^{-1}. This number suggests that the neutron transmission or reflection imaging technique could be applicable for up to 300 mm thickness in concrete. The pulsed 2.45 GHz microwave ECR ion source and the 2.49 MeV RFQ-LINAC are in operation tests for confirmation of design parameters. So far, proton current of 3 mA at a pulse peak was measured at the end of the RFQ with a low duty (0.09 %) operation. If it is operated at the designed value (3 % duty), a time averaged current will be 90 μA. The lithium target with a cooling system, the target station with shielding, and HEBT are very close to complete. High-duty ($\sim$3 %) operation with neutron emission will start after all the systems are relocated to the dedicated laboratory.

[1] T. Sato et al., J. Nucl. Sci. Technol. 55, 684-690 (2017)

Coherent THz Transition Radiation for Polarization Imaging Experiments

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THz radiation have been produced by the accelerator-based radiation source at the Plasma and Beam Physics Research Facility, Chiang Mai University, Thailand. The high intensity and coherent THz transition radiation was generated from short electron bunches of hundred micrometers or less. THz radiation is reflected by conducting materials and has the capability to penetrate a wide variety of non-conducting materials. With such abilities, THz radiation has great potential for imaging applications, for example, security screening and quality inspection for packaged electronics chips and electronics circuit boards. Coherent transition radiation was generated from electron beams of 8 MeV average energy by using an Al-foil tilted by 45° facing the electron beam direction. Characterization of the backward transition radiation properties was conducted, including spatial distribution, polarization and radiation spectrum. The radiation spectrum was measured by a Michelson interferometer and the radiation polarization was measured by using a wire-grid polarizer. The THz radiation was then used to create images of a print circuit board by reflective THz imaging setup. THz imaging with polarized transition radiation is demonstrated. With selected radiation polarization, reflective THz imaging can be improved.

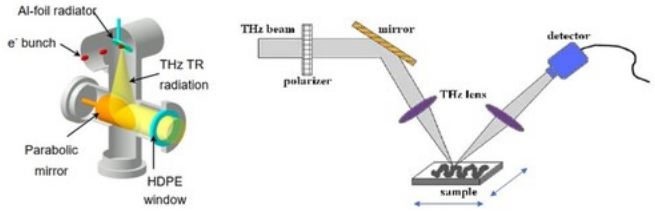

Figure 19: Generation of THz transition radiation and THz imaging experimental setup.

Development of high charge electron source using cerium-iridium alloy cathode

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Electron sources are becoming a significant part of modern scientific research instrumentation, with uses ranging from scanning electron microscope to the front end of X-ray free-electron lasers. In our group, high charge electron source using cerium-iridium (Ce-Ir) alloy cathode have been under development for an electron accelerator driven compact X-ray source. Ce-Ir alloys, owing to their good thermionic emission properties and resistance to electron and ion bombardment [1], are excellent as thermionic cathode. Moreover, they are also suitable as photoemitters for electron accelerators since they have reasonably high quantum efficiency (QE $> 10^{-4}$) and long lifetime [2]. In our study, we tried to optimize the composition ratio of cerium and iridium for Ce-Ir alloys in order to improve electron emission properties and investigated the availability of them as electron source. The design and performance analysis of an electron gun has been worked out using electromagnetic simulation of a finite element method and a beam tracking code. In this presentation, the latest results of design and development of Ce-Ir alloy electron source are reported.

[1] G.I.Kuznetsov, Journal of Physics: Conference Series 2 (2004) 35–41.
[2] D. Satoh, T. Shibuya, N. Hayashizaki, R. Zhang, X. Zhou, T. Natsui, and M. Yoshida, Energy Procedia 131, (2017) 326-333.

Proton beams obtained by hydrogenated Al targets

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Ion sources and in particular proton beams of high quality represent the key component in many scientific and medical applications. Nowadays, the transport and acceleration of the beams is performed by conventional accelerators, but in the last decade the scientific community's efforts go into studying the laser-driven ion acceleration that offers a potentially more compact and cost-effective means of delivering ions/protons. To this purpose, the choice of the target is crucial for the final quality of the beam. The starting point to obtain protons is the use of materials rich in hydrogen (adsorbed as contaminants, i.e. hydrocarbons and H_2O) or hydrogenated chemical compound (Hydrates, polymers and so on). In this paper, we show preliminary results about a new method for the hydrogen enrichment of Al targets to enhance the proton yield. This method consists in the treatment of the Al target surface with a laser beam in H_2 atmosphere. In particular,at first, the samples are treated by a laser cleaning procedure (via KrF excimer laser); successively, the samples are exposed to a constant flow of pure H_2 and finally they are exposed to laser irradiation (maintaining the H_2 flow) in order to promote the absorption of hydrogen. Different measurements performed on the treated targets of aluminum have showed an increase of proton yield with respect to reference targets not enriched in hydrogen.

A system of power supplies and quench detector units for a novel neutron decay experiment: the proton electron radiation channel

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The Proton Electron Radiation Channel (PERC) is a novel experiment in the field of low energy particle physics to be installed at the Forschungs-Neutronquelle Heinz Meier-Leibnitz (FRM II) in Garching (Germany). The project aims to investigate the angular correlations in the b-decay of free cold neutrons by measuring the decay products (protons and electrons) emitted from the "active decay volume", namely the neutron guide inside the PERC long solenoid. PERC incorporates a magnet system consisting of 10 superconducting solenoids made out of NbTi and cooled with liquid helium via a thermosiphon principle, operating at 4.5 K. The superconducting solenoids are grouped in four independent circuits; each circuit has its own power supply system, equipped with a quench detection and protection unit implemented by quench heater units (together with cold diodes integrated in the cold mass). This paper describes the design and the manufacturing process of the novel power supplies specifically developed for this project.

Development of a downsized proton accelerator system for compact neutron sources

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An accelerator-driven compact neutron source utilizing a downsized proton accelerator is developed as an entry level model for industrial use and materials development, which consists of a proton source, a four-vane radio frequency quadrupole linear accelerator (RFQ linac) and a lithium target for neutrons production by the Li(p,n)Be reaction. An RFQ linac is suitable to accelerate protons in low energy region because it accepts DC beams extracted from the proton source and effectively accelerates them up to design energy with bunching and focusing using the RFQ electric fields. The four-vane RFQ linac, which accelerates beams with the electric field excited by the TE211 mode, is considered appropriate for proton acceleration driven by high operating frequency. Furthermore, it is possible to design the RFQ cavity having higher frequency than conventional one owing to technological advance of high power solid-state RF amplifiers. Therefore, we investigated its specifications for 500 MHz and 650 MHz through beam trajectory and electromagnetic simulations and fabricated a 2.5 MeV prototype of the former frequency.

Refit of a single ended 3 MV accelerator with an ECR source – a status report

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The single ended 3 MV accelerator LIPSION at the University Leipzig is currently undergoing the final phase of a refit with an ECR source. For this, the terminal area of the machine has to be completely replaced with a new terminal that houses the source and accompanying equipment. Therefore, our project partners at Dreebit had to design an ECR-source that fits not only the narrow spatial constraints in the terminal, but also meets the requirements and limitations given by the nature of an SF_6 insulated machine running at up to 3 MV. We will give a status report on the current progress of the project and first testing results. We will discuss the performance, advantages and disadvantages of the source compared to our current RF source, especially with respect to our microprobe application.

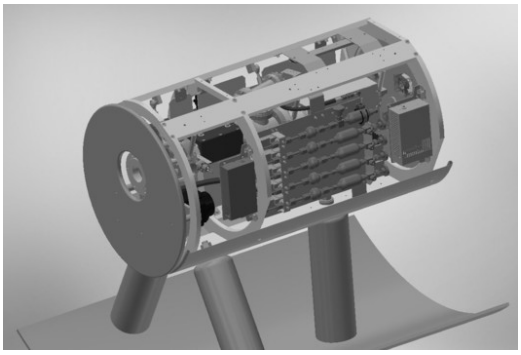

Figure 20: Drawing of the newly designed replacement terminal including the ECR-source

The REX irradiation facility and its applications

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Radiations are more and more frequently applied for scientiflc investigations in the field of material science, geology and biology, either in the world of cultural heritage for restoration and conservation purposes. The REX facility is a versatile irradiation machine thought to be used for experimental campaigns in different research fields thanks to its customizable beam. It is based on a linear electron accelerator and a removable head containing an electron to X-ray converter with its collimator. Its equipment has a compact design in which are assembled the main subsystems each one comprised of the several components. Changing its performance parameters REX allows treatment with the two-radiation quality: electrons and X-rays: i) sterilization of bio-degradated material surfaces, modification of polymer rheology, controlled damage of materials for nuclear fusion interest, by the direct use of the electron beam; ii) treatments for biodeteriogens removal in the cultural heritage field, irradiations of insects in the biological Sterile Insect Technique (SIT) and macro-organisms removal, research in medical applications, with the employment of the electron-X-Ray converter; iii) technical development in compact accelerators building field e.g. electron and photon beam diagnostics. The research campaigns are carried out with a high control degree of beams and dose rate in a fixed geometry for the series of test enclosures (on the contrary of the radioactive sources that need to change geometrical setups for all the trials) and for volume treatments. The machine and the irradiation chamber were manufactured and commissioned at ENEA Frascati Research Center. An overview of the REX facility in its present status and its future development, and the performed activities, are given in this work and specific attention is devoted to the application on the cultural heritage for the preservation and conservation of artefacts.

Control system of MACHINA: Movable Accelerator for Cultural Heritage In-situ Non-destructive Analysis

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In cultural heritage studies, ion beams applied as a tool for elemental analysis of paintings, frescoes, sculptures and archaeological fragments provide a fundamental scientific support for art restoration and conservation professionals. While these techniques – PIXE (particle-induced x-ray emission), PIGE (particle-induce gamma emission), RBS (Rutherford Backscattering), among others – are well-consolidated and more powerful than other methods such as x-ray fluorescence (XRF), a major drawback is the need to transport the sample to an accelerator facility in order to perform the analysis. However, the development of more compact accelerators, especially for biomedical purposes, has opened up the way for the construction of a transportable ion beam analysis machine. This is the scope of the project MACHINA, a collaboration between the Cultural Heritage Network (CHNet) at INFN and CERN: to build a compact high-frequency radio-frequency quadrupole specifically for the analysis of cultural heritage artworks. Its limited size permits it to be transported to sites where previously the application of ion beam analysis techniques was limited or impossible, such as frescoes or archaeological sites, as well as museums, which house works of art that can be costly and risky to transport. The innovative, compact machine requires a customized configuration of its components and control systems. Here we present the control system developed specifically for MACHINA, using open source hardware and software to link the accelerator components (such as vacuum pumps and power supplies) to the computers which support the graphical user interface (GUI), fully developed in Qt/C++ by our group. From these interfaces the user will have full control of MACHINA, from monitoring component status to managing vacuum pumps, the ion source, power supplies and beam diagnostics. The customized system is flexible, allowing for future adaptation to new developments in both the accelerator equipment as well as in the analysis tools.

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The CHNet multipurpose X-ray fluorescence scanner developed for in situ analysis

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Instrument transportability has become more and more important in Cultural Heritage studies. Often artworks cannot be moved from their site, either because of their size or due to problems with permission issues, or simply because moving them to a laboratory is physically impossible, as e.g. in the case of mural paintings. That is why the INFN network for Cultural Heritage (INFN-CHNet) has developed an X-ray fluorescence scanner for in situ analysis. The instrument is the result of a wide collaboration, where different units of the network have been developing the diverse parts, merged in a single system. Here we present the latest version of the XRF scanner (Figure 21), that has been designed to be a four-season and green instrument. The control/acquisition/analysis software has been fully developed by our group, using only open-source software. Other strong points of the system are ease of use, high portability, good performance and ultra-low radiation dispersion, which allows us to use it even when the public is present. It can run both with mains or on batteries, in the latter case with a maximum runtime longer than 10 hours. It has a very low cost, when compared to commercial systems with equivalent performances, and easily replaceable components, which makes it accessible for a much wider portion of the interested community. The system has been thought and designed as an open system, suitable for further development/improvements, that can be of interest for non-conventional XRF analysis. The CHNet XRF scanner has proved to be very well suited for applications in the Cultural Heritage field, as testified by the many recent applications. Here we also report on the tests performed to characterize its main features, such as spatial and energy resolution and scanning speed.

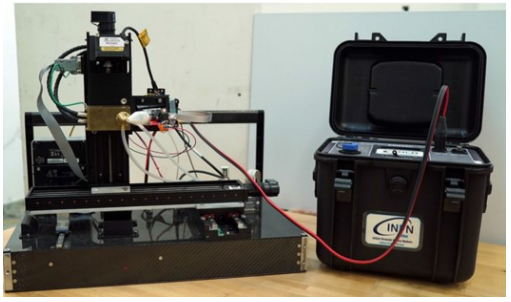

Figure 21: The most recent version of the CHNet-INFN scanner connected to the batteries. The brass piece is the case of the X-ray tube, 4 mm thick, which cuts down to background level the radiation emitted backwards, equipped with a brass cone holding the collimator. Also visible are the pipes for helium, both along the primary and secondary X-ray paths, the detector assembly (in the white plastic cone), the telemeter unit (above the brass box) and the three motorized axes.

[1] C. Ruberto et al., Imaging study of Raffaello's 'La Muta' by a portable XRF spectrometer. Microchem J 126 (2016) 63–69.

A study of uncertainty estimation of the annual radiation dose received from dating samples by ThermoLuminescence technique using the HPGe detector

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The thermoluminescence (TL) dating has many versatile applications in life/earth science, in particular for dating of anthropological and archeological samples. The age of the sample is proportional to the natural dose (paleodose) received by the sample and inverse proportional to the annual dose. The gamma spectrometry allows the estimation of the absorbed annual dose. For a precise assessment of the gamma contribution to the annual dose to be made, the sample should be in a uniform surround of soil. In our study, we focus the attention in those cases where the knowledge of the surroundings of the sample is not precisely known and the dose from gamma measurements could be severely affected from this uncertainty. For such work, the precise measurement of the absolute full-energy-peak efficiency of the HPGe detector and the comparison with Monte-Carlo simulation (Geant4) will be shown. Results from MC simulations and from dedicated software for gamma spectrometry (Angle) on the variation of gamma dose as a function at different density/composition soils will be presented. Since 2008, the laboratory for dating archeological finds and historical objects by means of thermoluminescence is active in the Physics Department of the University of Bari in collaboration with the Italian Institute for Nuclear Physics (INFN). The laboratory is equipped with a Riso TL reader and an Ortec n-type coaxial high purity germanium (HPGe) detector.

PIXE spectroscopy for the ADAMO project

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Within the Excellence's Center of the Regione Lazio Cultural Technological District, the ADAMO (tecnologie di Analisi, DiAgnostica e MOnitoraggio per la conservazione ed il restuaro dei beni culturali) project proposes applied researches aimed at analysis, diagnostics and environmental monitoring for the conservation and restoration of the local artistic heritage. This scope also includes the use of large scale facilities. For this purpose, a new set-up of the protons extraction vertical line for PIXE analysis with the pulsed accelerator TOP-IMPLART (Oncological Therapy with Protons – Intensity Modulated Proton Linear Accelerator for RadioTherapy) was carried out. The pulsed accelerator has already been used successfully in demonstration campaigns for PIXE and differential PIXE measurements [1, 2]. The elemental analysis of cultural heritage objects from the rich regional geographic area will be performed in collaboration between the APAM laboratory of ENEA-Frascati and the LABEC laboratory of INFN in Florence. The results of the preliminary characterization of this new system for PIXE measurements and some of the experimental campaigns are presented in this work.

[1]: M. Vadrucci, G. Bazzano, F. Borgognoni, M. Chiari, A. Mazzinghi, L. Picardi, C. Ronsivalle, C. Ruberto, F. Taccetti; 2017, A new small-footprint external-beam PIXE facility for cultural heritage applications using pulsed proton beams, Nucl. Instr. Meth. Phys. Res. B, 10.1016/j.nimb.2017.02.045;
[2]: M. Vadrucci, A. Mazzinghi, A. Gorghinian, L. Picardi, C. Ronsivalle, C. Ruberto, M. Chiari; 2018 Analysis of Roman Imperial coins by combined PIXE, HE-PIXE and μ-XRF, Appl. Rad. .Isot., 10.1016/j.apradiso.2018.10.016

IBA and complementary spectroscopic methods for corrosion phenomena in binary bronze alloys

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For efficient preservation of cultural heritage objects, a thorough understanding of corrosion of indoor bronze pieces of art, especially clarification of corrosion phenomena occurring on bronze exposed to different corrosive media, is of high importance [1,2]. In this work, two binary bronze alloys prepared by magnetron sputtering deposition were investigated using several analytical methods in order to clarify the growth of corrosion products on bronze. Bronzes were exposed to two corrosive media simulating marine and urban corrosion environment for 15 days. The main goal was to monitor corrosion phenomena in the first and the most pronounced period of corrosion layer formation in duration of two weeks. For this purpose two ion beam techniques (PIXE and RBS) were used to define the general stoichiometry and thickness of the sample layers. Furthermore, the X-ray absorption near edge structure (XANES) measurements were performed at the XAFS beam-line of the Elettra synchrotron. The position and intensity shift of the XANES spectra components during the corrosion buildup clearly discriminate Cu(0), Cu (I) and Cu (II), thus providing the copper oxidation states in the corrosion layers as a function of the exposure duration of bronze to corrosion media. Additionally, FT-IR and Raman measurements were employed to find out if beside copper I and II, other oxides were present in the corrosion layer as well.

[1] D. Šatović, L. Valek Žulj, V. Desnica, S. Fazinić, S. Martinez, Corrosion Science 51, 2009, 1596.
[2] D. Šatović, V. Desnica, S. Fazinić, Spectrochimica acta Part B 89, 2013, 7.

IBA and complementary spectroscopic methods for identification of Zagreb mummy's pigments

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Identification of pigments on archaeological objects is crucial for understanding the ancient graphical technology and applied raw materials. This paper presents a thorough study of the artifacts from the Zagreb mummy's inventory, including the pertaining cartonnage, jewelry, papyrus, and marked textile strips left from the mummification preparation. The investigations were also carried out on one of the most important exhibits from the Archaeological museum in Zagreb, the Liber linteus Zagrabiensis (The linen book of Zagreb), and the results were compared. For this purpose, black and red pigments of the linen book, black pigments of papyrus and marked strips, and pigments palette of the cartonnage and jewelry were investigated using several analytical methods, such as X-ray fluorescence analysis, Raman and Fourier transform infrared spectroscopy, colorimetry, and an ion beam microprobe. The goal was to explain elemental and molecular composition of original pigments, define stoichiometry and thickness of pigment layers, identify layers of cartonnage preparation, layers of pigments sedimentation and deterioration, as well as the growth of impurities over the original layers.

14 MeV High Intensity Cyclotrons: Two Projects in Progress

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A 14 MeV high intensity compact cyclotron, CYCIAE-14, was built at China Institute of Atomic Energy (CIAE). In order to provide high quality proton beams for instant radiopharmaceutical distribution, and to produce a variety of radioactive ion beams taking use of the solid target, CYCIAE-14 adopts an injection system based on the external H- ion source, axial injection, and spiral inflector with a designed high beam intensity, while most PET cyclotrons adopt internal ion source. With the different using for the cyclotron, there are two projects. One is a beam intensity of 200 μA/14 MeV was extracted from the cyclotron with a small multi-cusp H- ion source (CIAE-CH-I type) and a short injection line, which can produced the usual isotope for PET of ^{11}C, ^{15}O, ^{13}N and ^{18}F. Another is a beam intensity of more than 400 μA/14 MeV was extracted from the cyclotron with a bigger multi-cusp H- ion source (CIAE-CH-II type) and a longer injection line, which can produced not only the usual isotope for PET of ^{11}C, ^{15}O, ^{13}N and ^{18}F, but also the isotopes such as ^{64}Cu, ^{124}I, ^{99m}Tc. The iostope of ^{99m}Tc has wide usage in the field of nulear medicine, produced by the reaction of ^{100}Mo(p, 2n)^{99m}Tc. This paper will introduce the cyclotron of CYCIAE-14 with the two projects, and some experiments finished on the cyclotron will also be given in the paper, for example the ^{18}F and ^{89}Zr production, BNCT test. Some special experiments using in IGBT will be introduced, too.

Low-Energy N Ion Beam Irradiation Produced New Fragrant Sangyod Phatthalung Rice Lines for Increasing Production Yield of Fermented Rice Vermicelli

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Fermented rice vermicelli is considered as a main staple food in Southeast Asia, especially in Thailand, Laos, Vietnam and Myanmar. However, the current production of fermented rice vermicelli is a long and tedious process as it requires the use of grains of mixed varieties which have to be stored for at least eight months. It consequently leads to increased production cost and unstable product quality. To tackle this problem, we developed the low energy N ion beam irradiation method to induce mutations in red, low-amylose and non-aromatic Sangyod Phatthalung rice seeds (*Oryza sativa* L. cv. Sangyod Phatthalung) for new rice lines, specifically suited to fermented rice vermicelli production. Seven thousands of the rice seeds were bombarded with 50 kV accelerated mixed nitrogen ions (N^++N_2^+) to a fluence of 4×10^{16} ions/ cm^2. Primarily, we obtained and isolated seven photoperiod-insensitive and semi-dwarf mutants named MSY-1-1, MSY-1-2, MSY-1-3, MSY-2-1, MSY-2-2, MSY-3 and MSY-4 (Fig. 22a). These mutants were shorter and produced a higher number of panicles, accounting for 23-74% higher crop yield. In terms of the grain quality, the mutants produced fragrant brown rice with white pericarp. The mutants also had a high amylose content and significantly lower protein and fat contents ($p \leq 0.05$).To assess the suitability for the fermented rice vermicelli production after four months storage, we compared the flour obtained from the mutant rice with those of the wild type background and other conventional non-aromatic rice varieties for this production. The rice flours of all mutants (except only one) exhibited similar whiteness index, starch morphology, water absorption index and pasting properties, which resulted in a 59% higher yield as compared to standard varieties (Fig. 22b).Finally, to ensure that the high-amylose mutants are derived from low-amylose background, we assessed the mutants' genetic background using 25 Asian rice microsatellite markers. As a result, the high-amylose mutants did not displayed marked different allelic profiles when compared to the low-amylose wild-type, demonstrating that low energy N beam irradiation can introduce mutations that significantly enhance rice productivity.

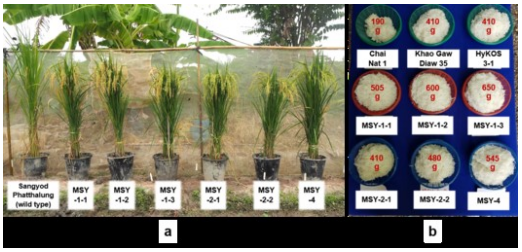

Figure 22: Evidences of rice lines for increasing the vermicelli production. (a) Phenotypes of the rice lines and (b) fermented rice vermicelli produced by using 350 grams of the rice lines compared with using conventional rice varieties.

Characterization of a new transparent charged particle beam profiler based on secondary electrons emission

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A new type of profiler is under development and will equip the beam line of the ARRONAX Cyclotron [1]. The aim is to monitor the beam continuously and hence introduce the smallest possible perturbation and be highly tolerant to radiations. The profiler must measure the beam lateral shape in a broad range of energy 15 - 70 MeV and a wide range of intensity 100fA - 100nA, for alpha, proton and deuteron particles. The beam lateral profile is measured through segmented electrodes consisting of nanometric thick gold strips deposited on a thin polymer membrane. When crossed by the beam, the strips emit the secondary electrons. The total thickness of the profiler is below 15 μm water-equivalent. This small thickness disturbs very little the incident beam, which can then be delivered to the end user while keeping the profiler in the line, ensuring continuous monitoring. The thinness of the monitor makes the energy loss very small and consequently the associated heating. Besides, the absence of mechanical efforts on the membranes makes radiation damages of less consequence than with classical systems like ionisation chambers allowing to extend the operation duration of the system. A prototype has been successfully operated with a proton beam in a wide range of currents and for several energies [2]. Experimental data on secondary electron emission yields from proton beam energy greater than 10 MeV are scarce but are necessary to determine the detector sensibility and to compare with the simulation code based on the electron emission theory. Thus, experiments were done to measure these yields vs the proton beam energy and intensity. In parallel, several irradiation campaigns with proton beams, electron beams and gamma sources have been conducted to evaluate the irradiation damages with the deposited dose (up to 10^9 Gy) and to identify the physicochemical parameters involved in the damage processes. Optical spectroscopy and surface microscopy tools have been used to characterize the damages induced in the polymer. We will present the detector performance, secondary electron yields measurements and damage studies, as well as the assets of this detector in the perspective of its use in hadrontherapy.

[1] www.cyclotron-nantes.fr/
[2] Boyer et al, https://doi.org/10.1016/j.nima.2018.09.134

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Slow beam extraction form a synchrotron using a radio frequency knockout system with a broadband

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A synchrotron has been used for a cancer therapy with proton or carbon beams. A spot scanning irradiation requires a fast beam-on/off control in a slow beam extraction from a synchrotron to give the best flux distribution [1]. A radio frequency (RF) knockout method (RF-knockout method) based on the transverse beam heating at a constant separatrix is used in several facilities for the slow beam extraction [2], for example at the Heavy Ion Medical Accelerator in Chiba. The beam-on or -off times are reported as the order of 1ms. The present authors have developed a new extraction method which has a shorter beam-on/off time and a smaller variation of spill intensity. The simulation result shows that frequency bands solely around the resonances (n+1/3 and n+2/3) contribute to the diffusion and the uniform spill requires to include many bands around the resonances (Colored Noise). The required frequency band is 1-14 MHz for the WERC synchrotron a beam experiment was performed. In order to realize this method, the authors have developed an APN (All Pass Network) to apply constant voltage in the required frequency band and a broadband IT (Impedance Transformer) for impedance matching between a radio frequency source and the APN. Moreover, a method of generating the colored noise has been proposed using a digital-to-analog (D/A) converter. Data for the colored noise are calculated in advance to be saved in the memory of a D/A converter, and are output synchronized with external clocks [3]. A prototype RFKO system is constructed using an RFKO electrode similar to the WERC's one, two 40 W wideband amplifiers, the APN, and the IT. A measured frequency characteristic shows that the electrode voltage increases by 9% between 1 and 3 MHz and decreases by 11% at 14 MHz, which is a not significant problem. Using this RFKO system, a beam experiment is performed with the WERC synchrotron that the RFKO system is connected to an RFKO electrode in the synchrotron. The extracted particles are carbon ions with an energy of 55 MeV/u and the extraction time is 250 ms with a period of 2s. The numbers of bunds for the colored noise data are 1, 2, 4, 6, 8, and 10. The experimental result shows a spill with the colored noise including 10 bands is clearly more uniform than that with the colored noise by a band. The extraction is also performed when the circulating beam is bunched with a longitudinal RF field. The result shows that the spills with 1 and 10 bands have almost the same uniformity.

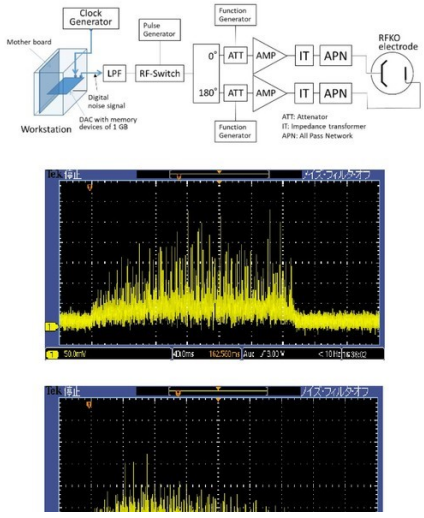

Figure 23: (a) A broadband RFKO System, (b) beam experimental result with 10 bands, (c) beam experimental result with 1 band.

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Intensity and distribution of antioxidant rutin in common and Tartary buckwheat grain tissue

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Secondary ion mass spectrometry (SIMS), based on primary ions within the MeV energy domain, also known as MeV SIMS [1], is a subject of increasing scientific interest. The main drive for the interest in the development of MeV SIMS is the ability to desorb high yields of large non-fragmented organic molecular ions from the sample surface. This makes MeV SIMS particulary useful in imaging metabolite distribution in biological tissues. Molecular investigation of common and Tartary buckwheat grain was employed through pulsed 6 MeV $^{35}Cl^{6+}$ primary ion beam, focused to 5 micrometres. The use of secondary ion optics improved the performance of commonly used pulsed MeV SIMS mode [2]. Analysis of samples was also carried out through lower primary ion currents, enabling significantly higher lateral and mass resolution. We also tested the novel frozen-hydrated tissue preparation protocol, which enables complete preservation of organic tissue. Advantages and shortcomings of such approach are discussed. We measured spectra and lateral distribution of molecules in both common and Tartary buckwheat grain tissue. Presence of glycoside rutin was found in both species, however, its contentration in Tartary buckwheat was one to two orders of magnitude higher. Key differences in peak intensity and spatial distribution were observed and interpreted.

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[2] B. Jenčič, L. Jeromel, N. Ogrinc - Potočnik, K. Vogel - Mikuš, E. Kovačec, M. Regvar, Z. Siketić, P. Vavpetič, Z. Rupnik, K. Bučar, M. Kelemen, J. Kovač and P. Pelicon, "Molecular imaging of cannabis leaf tissue with MeV-SIMS method," Nucl. Instru. Methods Phys. Res. B, vol. 371, pp. 205-210, 2016.

Experimental verification of small field with low energy carbon-ion scanning in NIRS-HIMAC

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To make the best use of the characteristics of a carbon-ion beam and provide flexible dose delivery, three-dimensional (3D) pencil-beam scanning is an ideal irradiation technique. To suppress beam spread due to multiple scattering and nuclear reactions, we then developed a full energy scanning method [1]. In some case such as eye treatment, the irradiation fields are very small and short range. Thus, we prepared a minimum low energy carbon-ion beam corresponding to the water-equivalent residual ranges less than 2 mm. In our presentation, we introduce the experimental verification for low energy carbon-ion beam.

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Experimental verification of beam switching operation for multiple-ion therapy application at the HIMAC synchrotron

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National Institute of Radiological Sciences (NIRS) has performed carbon-ion radiotherapy since 1994 using the Heavy Ion Medical Accelerator in Chiba (HIMAC) [1] which is the world's flrst heavy-ion accelerator facility dedicated to medical use. The treatments with the carbon-ion beams have been successfully carried out for more than 10000 patients in the NIRS. Now, the NIRS has investigated multiple-ion therapy [2] with the energetic beams of more than two ion species to improve outcomes of the refractory cancer treatment. By appling the multiple-ion beams for treatment irradiation, we become controllable not only the dose but also the linear energy transfer (LET), which concerns with the biological effect, in the target volume. To realize multiple-ion therapy, it is required that the accelerator control system can switch the ion species, energy and intensity of the output beams quickly in the treatment session. For this purpose, we have studied the switching method of the multiple-ion beams using multiple-energy operation at the HIMAC [3]. Since this method accelerates the multiple-ion beams with the charge-to-mass ratio Q/A of 1/2 without changing the magnetic operation pattern of the synchrotron, the irradiation ion species can be changed only by switching the ion sources and the injector parameters. Therefore, this method can perform the fast switching of the irradiation ion species. In addition, because of the use of the same magnetic operation pattern, we can reduce the time for the commissioning and daily adjustments of the multiple-ion beams. In this paper, we describe our accelerator control method for multi-ion therapy operation and the results of the beam experiments at the HIMAC.

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The effect of general ion recombination on dose measurement for high-dose rate carbon ion scanning beam

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Cancer treatment using heavy ions, e.g. carbon ions, has been popularized. National Institute of Radiological Sciences (NIRS) in Japan is treating patient using 3D scanning method [1]. In order to shorten the irradiation time, irradiation using a high intensity beam has recently been required. However, the dose monitor is a parallel plate ionization chamber (PPIC), and the conventional design has a problem that the dose cannot be accurately measured due to the ion recombination when the beam intensity is high. In this work, we confirmed the effect of ion recombination used by the PPIC. We used two types of PPIC: the dose monitor for clinical use and the Advanced Markus® Chamber developed by PTW which is generally used for dosimetry. The 290 MeV/u carbon-ion beam was irradiated at 5 cm $\times$ 5 cm, with 2 mm spacing in both x and y directions, in continuous spot-scanning method. We tested three dose rates: 90 nA (typical dose rate), 1.79 μA and 2.68 μA, at two LETs: 5 keV/μm and 200 keV/μm. The charge (Q) was measured by changing the voltage of the chamber (40 V to 300 V) and the dose monitor (400 V to 2500 V) (Figure 24). Then, Boag, Jaffé, and empirical methods were used to calculate the saturated charge (Q_{sat}) [2,3]. For the chamber, Q_{sat}/Q at 300 V was within 0.2% for 5 keV/μm and within 0.4% for 200 keV/μm were calculated, for different dose rates, which indicate that the 300 V is the sufficient potential to collect charge. For the dose monitor, Q_{sat}/Q at 2500 V was 0.3% for the 90 nA, but 2.5% for 2.68 μA, indicating that the recombination correction can not be ignored when high dose rate treatment is performed using carbon ions.

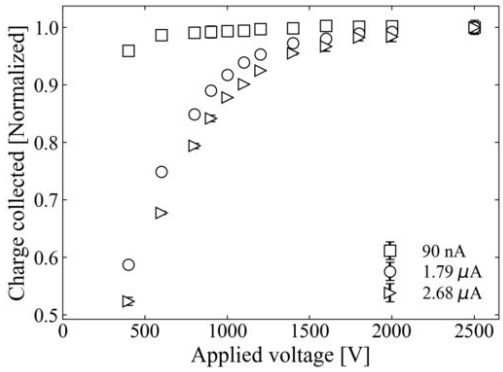

Figure 24: The charge corrected by the dose monitor for the different dose rates of carbon ions.

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A facile and chip computer-milled microfluidic chip for colorimetric and biochemical aged-related macular degeneration bioassays

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We introduce a facile and eco-friendly 3D microfluidic chemical sensing chips capable of colorimetric and biochemical analyses at the same time. The sensing chip was prototyped by injecting 10% cellulose microfiber mixtures on computer-controlled milling substrates, and a 3-fold faster flow rate than conventional microfluidic paper-based analytical devices as well as a recyclable platform. The colorimetric assays of our chips can successfully detect clinically relevant concentrations of albumin (R2=0.9994) and glucose (R2=0.9464). The gold nanoparticle (GNP)-induced surface-enhanced Raman scattering (SERS) label-free bioassay of our chips can enhance the Raman signal by 5.15 $\times$ 108 and a sensitivity of 0.94 (10 pM–1 mM for CV molecules) with an excellent stability of <5%. Furthermore, we can measure trace amounts of human aqueous humors of patients with age-related macular degeneration (AMD) using the SERS-functionalized chip in combination with a linear threshold value or principal component linear discriminant analysis (PC-LDA) model. We can detect the presence of exudative AMD from human aqueous humors with >96% clinical sensitivity and >78% clinical specificity with an accuracy of >87% from PC-LDA model-based multivariate statistical analysis methods.

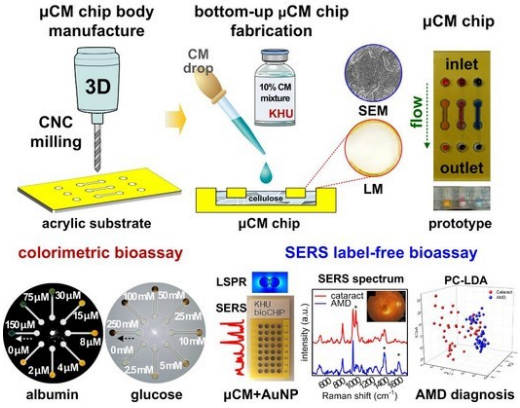

Figure 25: Colorimteric & SERS label-free bioassay.

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The Zero-degrees irradiation facilities at INFN-LNS

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At the Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali del Sud (INFN-LNS) in Catania a proton/ion multidisciplinary beam-line is active and is called zero-degree (ZD) irradiation room.The ZD hall is dedicated to the in-air and in-vacuum irradiation both with protons and heavy ions accelerated by the LNS Superconducting Cyclotron with kinetic energies up to 80 AMeV. Lower energy beams, accelerated by the electrostatic Tandem accelerator can be delivered, as well.The ZD beam line is also entirely simulated with the Monte Carlo Geant4 toolkit, so that all the information on the main beam parameters (energy, fluence, spatial distribution, dose, linear energy transfer (LET) at different points can be provided to the Users (upon request) to better plan the experiment or to perform the following data analysis.[1,2] This room was recently implemented (thanks to the ASIF support and to meet the ESA specifications) whit the goal to develop new single-event dosimetric approaches for the cellular and materials irradiation with heavy ions for space applications. In order to allow both, in-air and in-vacuum Single Event Effect (SEE) test irradiation different ions provided by the Cyclotron can be delivered according to the LNS available beam list, as reported in LNS website [3]. In particular it is planned to use noble gas beams (^{20}Ne,^{40}Ar,^{84}Kr,^{129}Xe) and flux can be easily provided from 10 ions/cm^2/s to 10^5 ions/cm^2/s. A beam flux with an uniformity of +- 10% over the area of the device under test (DTU), is obtained by a system of magnets and suitable collimators (figure 26). A Collimation system placed on the actual beam axis coordinates chosen by the users, in order to guarantee the radiation field with required uniformity over the area of the Device Under Test (DUT), Plastic Scintillator + PMT in order to perform an on-line flux and fluence measurements, mirror and CCD camera, to measure the beam profile and define the actual beam axis coordinates, and a Test board mechanically supporting the sample under test. A remotely controlled positioning system has been designed and built in order to ensure repeatability and accuracy for the irradiation process. By the motion control software and video surveillance system is possible the remote monitoring in real time of the DUT position with respect to the beam spot, highlighted by a laser point. In case of in-air irradiation LET values can be also changed using air as a degrader. The LNS group supporting external Users during irradiation is responsible to guarantee a beam with the required characteristics in terms of dimensions and homogeneity . This is done through the use of a beam profiler system, directly connected with the accelerators operators. A dedicated software was developed for real-time data acquisition and processing

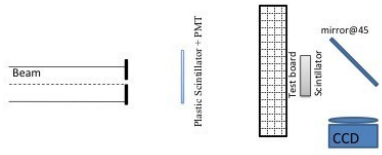

Figure 26: Sketch of the apparatus used in the facility

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Enhancement of critical current density in He ion irradiated $BaFe_{1.84}Co_{0.16}$ As_2 superconductor thin films

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The effect of 600 keV He^+ ion irradiation on the temperature and magnetic field dependent critical current density J_C of high quality $BaFe_{1.84}Co_{1.84}As_2$ thin films prepared by pulsed laser deposition on GaF_2 substrates is investigated. Upon He^+ ion irradiation with varied dosages between $1x10^{13}$ ions/cm^2 and $1x10^{16}$ ions/cm^2, the critical transition temperature TC drops slightly from 23 K for the as deposited virgin sample to about 18.5 K for the sample with the highest irradiation level. However, the critical current density J_C, derived from the magnetic hysteresis data using the Bean model, is increased significantly for samples with low level irradiation, while it is reduced upon further increase in irradiation dosages. The analysis of the dependence of pinning force on magnetic field shows that the pinning behaviour remains unchanged in all as deposited and He^+ ion irradiated samples, suggesting that He^+ ion irradiation process introduces more pinning centres of similar characteristics as those already presented in the as deposited thin film samples. This work demonstrates that the irradiation of light ions such as He^+ with relatively low energy could also increase the critical current density in iron based superconductors.

Dynamics of the radiation induced defects in semiconductors studied by pulsed ion beams and micro RBS channeling

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Irradiation with pulsed ion beams is used to induce defects in semiconductor materials. Point defects are created around ion tracks in the crystal lattice. Pulsed pause time allows for defects recombinations before new radiation sequence. Defect dynamics are studied by varying pulsed pause times and controlling sample temperature. Relative number of defects in irradiated areas is quantified by means of RBS channeling technique, which was performed ex-situ. During channeling, beam spot size is focused to less than 10 micrometer dimension, and beam scanning allows to locate irradiated areas with RBSc used as the microscopic position sensitive technique. Experiment results are used to interpret the effect of beam pulsing time and sample temperature on the relative number of radiation induced defects in investigated semiconductor materials.

Investigation and Numerical Simulation of Beam Physics for 230 MeV SC Cyclotron under Construction at CIAE

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In China, there are strong demand for the mid-energy proton accelerators in two separate fields, cancer therapy and space science. The proton therapy based on proton cyclotron is undoubtedly beneficial for more than 4 million new cancer patients each year in China. For the rapid development of Space Science, the laboratory simulation of space radiation based on proton cyclotron is also very useful and cost effective. For the applications of proton therapy and proton irradiation, the energy range of proton beam usually is from 200 MeV to 250 MeV, or even higher for astronavigation study. In this paper, the investigation and numerical simulation of beam physics for a 230 MeV superconducting cyclotron under construction at CIAE will be presented in detail. The paper will focus on: 1. The beam dynamics behavior in very narrow central region of the SC cyclotron and the design challenges including the micro PIG ion source, the tips of magnetic poles and RF cavities; 2. the numerical simulation and optimization of the phase shift and tune diagram in acceleration region, and the magnetic field mapping and shimming; 3. The orbit simulation in the extraction region, measures for increasing the turn separation and resonance study; 4. the fast intensity modulation, closed-loop feedback of phase of extracted beam, and the basic algorithm for controlling the beam intensity, adjusting the phase and their implementation. The construction progress of the 230 MeV superconducting cyclotron will also be briefly introduced.

Stopping powers of polypropylene for ^{16}O, ^{19}F, ^{28}Si from 40 to 115 MeV

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[4]Universite de Batna, Batna, Algérie

The stopping powers of ^{16}O, ^{19}F, ^{28}Si heavy ions crossing thin polymeric foil (polypropylene) have been determined over a wide energy range from 40 to 115 MeV, using the direct transmission experimental set up. The deduced experimental stopping values have been compared to those generated by SRIM-2010 computer code, MSTAR calculations and ICRU-73 tables. Excellent agreement has been obtained between our experimental stopping powers values and those determined by SRIM-2010 computer code and ICRU-73 tables, however a large discrepancy is observed with MSTAR calculations especially with ^{19}F and ^{28}Si heavy ions. In this work we have also deduced the experimental effective charge of these heavy ions. A good agreement between the experimental effective charge and the Northcliffe and Schilling expression was obtained.

Nuclear data relevant to reaction dynamics modelling and reactor technology: Application of ion beam accelerators

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In view of the recent advances in Accelerator Driven Energy Systems (ADES), there is a great need of precise data on reaction cross-sections induced by light as well as heavy ions (HIs). The HI-induced reaction data is also needed for environmental and medical applications. With the development of heavy ion accelerator technology and advancement in detector systems, it has become possible to obtain precise data for nuclear reactions. Such data has also been used to test various theoretical models as well. It may be remarked that, the reaction mechanism for HI interaction at energies near and just above the Coulomb barrier (CB) is not well understood. Both complete and incomplete fusion (ICF) reaction mechanisms are likely to compete at these energies [1]. Keeping all this in view, the excitation functions (EFs) for a large number of incident ion beam-target interactions have been measured over a broad energy range from close to Coulomb barrier to well above it for ^{19}F+^{1}Tb and ^{16}O+^{159}Tb systems. The experiments have been carried out using pelletron accelerator ion beam facility at the Inter University Accelerator Centre (IUAC), New Delhi, India. The experimental data has been analysed within the framework of statistical models. The analysis of data for alpha emitting channels indicates a significant contribution due to incomplete fusion process. Interesting systematics for these ICF reactions has been obtained. Further, since last two decades, various techniques like gravimetric, thermal microbalance, loss of reflectivity, interference colour, metallographic examination and electrical resistance for measuring corrosion, erosion and wear rates of materials have been developed [2]. However, these conventional techniques are not enough and efficient to measure surface loss of materials in the range of nanometres to micrometer. As such, the measured cross-section data for ^{19}F+^{159}Tb and ^{16}O+^{159}Tb systems, has also been used to develop thin layer activation (TLA) technique which is established as a sensitive tool to measure the surface loss of materials by populating radioisotopes within a thin layer from the surface of material by charged particle induced nuclear reactions. Generally, light ion beams of suitable energy are used to populate a thin layer of activities up to a few hundred micrometer. However, with the availability of variety of ion beams from particle accelerators it is now possible to measure low level loss in samples of interest by generating extremely thin layer of activities [3]. The calibration curves for various radio-isotopes, relevant to reactor technology, produced as a result of different reaction processes have been obtained to get the percentage of remaining activity against the depth of the material removed from the surface. Details of the experiments, analysis and results will be presented.

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Features of formation and application of accelerated correlated wave packet

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The traditional method of analysis of the processes of interaction of accelerated particles with different objects and material media is based on their presentation in the form of unbounded in space plane waves. Such a simplified approximation is convenient for calculation and quick estimates. On the other hand, it is obvious that this method of presenting particles is rather artificial and is not quite adequate to real phenomena since it is rather difficult to compare the motion of a particle confined in space with its model description in the form of a plane wave. An alternative and more adequate method for describing and modeling of such accelerated particles with mass M is their representation in the form of moving limited Gaussian normalized wave packets with an initial longitudinal width L=1...10 nm and averaged kinetic energy $\langle \mathrm{T} \rangle$. Such packets correspond to uncorrelated states of a moving particle. Such states have many significant drawbacks.The main disadvantage of such a description is the limiting instability of such packets for the case of their small initial size: they spread very quickly in the space and decrease sharply in amplitude. For example, to focus such packets at a given distance (as well as to focus beams of "ordinary" particles), it is necessary to use special very complex focusing systems. It is much more efficient to use correlated wave packets, in which the individual wave components are in certain (optimal) phase relations [1-3]. The report describes the possible method of creation and the main advantages of such wave packets. There are two fundamentally features of correlated packets. a) The process of packet self-compression to the state of space collapse at a controlled distance. The area of collapse can be remote from the area of packet formation for a long distance and it is possible to influence this distance. In this region, very sharp (by many orders of magnitude) self-similar spatial compression of a packet occurs with a simultaneous increase of its amplitude, after which the accelerated "spreading" takes place. b) Space and time evolution of the correlated packet leads to "giant" increase of the fluctuations of the momentum and kinetic energy T (in the collapse area) up to quantities, which are many orders of magnitude greater than the average momentum $\langle \mathrm{p} \rangle$ and average kinetic energy $\langle \mathrm{T} \rangle$ of the packet.These features are presented in a symbolic form in the figure. The methods of formation of such correlated wave packet by special modulation of "usual" accelerated particles or beams of particles are also discussed. The paper also considers the possible application of a correlated packet for actual problems of applied physics and other sciences (e.g. for proton therapy or for local hyperthermia in a medical application, for a realization of controlled nuclear fusion with the participation of low energy particles in a distant target, for high-tech nanofabrication in modern technologies etc.).

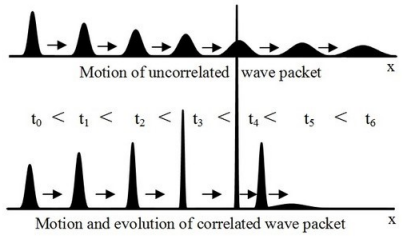

Figure 27: Wave packet evolution

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Nanostructured graphene: structure, properties and potential applications in electronics

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Few-layer graphene shows incredible properties, that are of significance both for fundamental investigations and technology. When nanostructured graphene is prepared with a massive amount of nano-domain boundaries and ripples it becomes to be the most favorable material for graphene-based electronic and spintronic applications. Indeed, the nano-domain edges can completely reflect electrons over a great range of energies and hold spin-polarized electronic states. Moreover, transport gap opening and spin-orbit coupling can be created by ripples at the graphene domain edges. Here we report the structure, transport and magnetic properties of continuous and uniform nanostructured few-layer graphene with self-aligned nano-domain boundaries synthesized on the standard SiC/Si(001) wafers. Our low temperature transport experiments clearly proof that nano-domain systems can induce a charge transport gap greater than 1.3 eV, while the current on-off ratio can reach 10^4 [1]. Moreover, the magneto-resistance measurements disclose an exceptional big positive magneto-resistance in parallel magnetic fieldwith a strong temperature dependence [2]. Theoretical calculations confirm, that observed the transport and magnetic properties of graphene/SiC(001) are interrelated to the localized states at the nano-domain boundaries. Our results show that using purely graphene it is possible to engineer new tunable electronic and magnetic nanostructures [3].

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Astigmatism Correction with an Adaptive Quadrupole and an Expander Lens for Electron Accelerators

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Astigmatism is a type of aberration in electron beam aperture which causes asymmetry in transverse coordinates. This asymmetric beam often shows an elliptical aperture instead of circular, which may cause various major and minor ellipse axes diameters and ellipse azimuth angle. In this research work, a novel astigmatism correction system is proposed for electron accelerators with minimum number of electromagnetic lenses. In this way, an adaptive quadrupole lens is designed by coaxially locating two quadrupoles having 45 degrees apart from each other. Focusing and defocusing axes and the azimuth angle of the resultant adaptive quadrupole are determined adaptively by the vector sum of created magnetic fields of two coaxially located quadrupoles. The adaptive quadrupole lens is eventually placed on the common focal point of two solenoids as part of the expander lens. By this way, focal points of major and minor axes of elliptical aperture are slightly changed from common focal point of expander. This act helps increasing the minor axis diameter of electron beam while decreasing the major one, resulting in a circular aperture. Both 2D beam trajectory model in MATLAB and a 3D Particle Accelerator simulation with Computer Simulation Technology (CST) tool show that the proposed method successfully corrects the astigmatic apertures having any elliptical parameters for a sample electron beam.

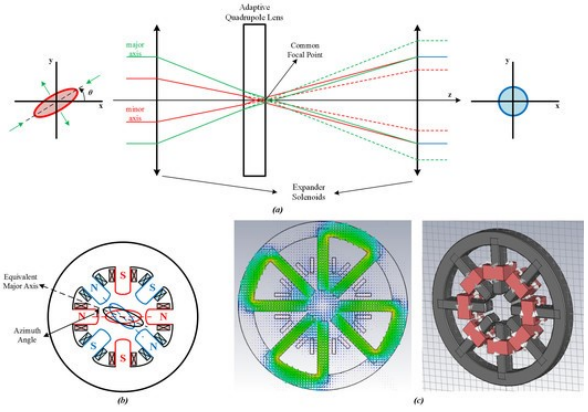

Figure 28: a) Astigmatism Correction Method, b) Adaptive Quadrupole Lens Structure and c) FEM analysis of designed adaptive quadrupole

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Competition between Atomic and Molecular Auger Decay in $CHCl_3$

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The Auger electron spectra after the chlorine 2p excitation and ionization in the gas phase CHCl3 molecule were investigated both theoretically and experimentally. A series of high-level ab initio quantum mechanical calculations have been performed at multiconfigurational self-consistent field (MCSCF) and multireference configuration interaction (MRCI) levels of theory to compute the Cl L2,3VV Auger lines. Calculations were compared with the corresponding experimental photoexcited and photoionized spectra.

Accelerator production routes of ^{67}Cu

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The ^{67}Cu is a good candidate radionuclide for theranostic investigations due to its emitted medium energy beta particles, its half-life and the associated gamma emissions. Its decay mode is 100% β^-, its half life is 2.58 d, the mean beta energy is 141keV, E_γ=185keV, I_γ=48.7%. Its accelerator production routes on nickel, zinc and gallium may provide the ^{67}Cu isotope potentially in high specific activity form. However, there are additional reaction channels open for each of the production routes by proton, deuteron, and alpha-particle irradiations of gallium, zinc or nickel targets, in which additional copper isotopes are produced. We have investigated the ^{64}Ni(α,p)^{67}Cu reaction experimentally. Only a few earlier works were published regarding the cross sections of this reaction. The main trend of the published data sets corresponds to each other, but the data points are scattered and the maximum of the excitation function is determined with large uncertainty. In the experiments stacked target technique and activation method followed by high resolution gamma spectrometry of the activated target foils were used. The irradiations using different target foils and irradiation parameters were performed at the AVF cyclotron of RIKEN RI Beam Factory. In three independent irradiations we have determined the cross sections of the ^{64}Ni(α,p)^{67}Cu reaction from threshold up to 50 MeV alpha particle energy. The ^{64}Ni(α,p)^{67}Cu reaction can provide moderate yield of ^{67}Cu in high specific activity form and low radio-contamination level, which is enough for local use in hospitals. Due to the high stopping power of the alpha particles this reaction requires the less amount of target material. Since the ^{67}Cu has the longest half life among the radioactive Cu isotopes by applying long cooling time the radio isotopic contamination level of the ^{67}Cu product can be improved. Additionally, we have studied each production route theoretically to estimate the expected activity and radionuclidic contamination for enriched target material, which was supposed to reach et least 98% enrichment level for the main target isotope. Production yields of ^{67}Cu were compared for seven reactions supposing 72h irradiation time and 1μA beam current then applying 62h cooling time. This cooling time is about one half life of ^{67}Cu. More detailed analysis can be done regarding the number of produced contaminating atoms and their corresponding activities for every possible isotope, co-produced on the used target material.

A Comparative Study of Stopping Power Calculations Implemented in Monte Carlo Codes and Compilations

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The stopping power calculations, inherently implemented in all widely used, general purpose Monte Carlo codes, play a critical role in the determination of any expected reaction yield, when charged particles are present either as beam particles or reaction products. Small changes in the stopping power values, and therefore in the corresponding particle energies, can lead to significant changes in the cross sections involved. This effect may be critical in a variety of problems, ranging from detector physics to dose calculations and – to the authors' best knowledge – it has never been thoroughly investigated in the past. Thus, the aim of the present work is to examine the differences in the stopping power calculations between GEANT4, FLUKA, MCNP/MCNPX and PHITS and to compare the results (whenever possible) against the widely used and partially benchmarked stopping power compilations, as implemented in the SRIM2013, PSTAR and ASTAR (ICRU) codes. In the particular case of GEANT4, all the available models for the electromagnetic interactions were independently tested. More specifically, in all Monte Carlo codes, protons, alpha particles, ^{12}C, ^{16}O and ^{56}Fe ions were generated as beam particles in the energy range between 1 and 1000 MeV/u and were subsequently transported, impinging on a variety of infinitely thick, pure, single–element targets, such as aluminum, iron, copper and silicon, which are typically used as shielding materials or components in complex devices. Water was also examined, being a close substitute for biological tissue. In all the simulations the process of multiple scattering was disabled, while in certain cases tables with stopping power values were generated for comparison. The obtained results show large discrepancies for specific beam particle – target combinations in certain energy ranges. They also deviate, especially at low energies, from the SRIM2013, PSTAR and ASTAR predictions. The final values are presented in graphical form and the observed similarities and discrepancies are discussed and analyzed. Since stopping power calculations have not yet been fully benchmarked against experimental data over a broad energy range, the final assessment of the obtained results relies on the user.

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Electron Beam Dynamic Study and Monte Carlo Simulation of Accelerator-based Irradiation System for Natural Rubber Vulcanization

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The electron accelerator in this research can produce and accelerate electron beam to reach the maximum average kinetic energy of 4 MeV. The electrons are generated from a DC gun that has an accelerating voltage of 17 kV. Then, the electron beam transfers to an RF linac which has a resonant frequency of 2996.395 MHz and an RF macro-pulse duration of 4 μs. The effective length of the linac is 0.2215 m. A thin titanium foil with a thickness of 50 μm and a diameter of 12.7 mm is connected at the position 6 mm downstream the linac accelerating field exit. The purpose of this research is to develop the electron beam vulcanization system for the natural rubber latex to reduce the chemical usage and the processing time. The goal of the project is to produce the electron beam with an irradiation dose of at least 50 to 150 kGy that is required for the rubber vulcanization. The simulation of the whole system is performed to estimate its performance before performing the real experiment. The simulation is divided into two parts, the first part is done by using A Space Charge Tracking Algorithm (ASTRA) program and the second part is done by using Geometry and Tracking (Geant4) program. The ASTRA simulation is used to study electron beam dynamics in the linac before the beam collides with the titanium window. This part of simulation, the accelerating gradient of the linac is varied to investigate the average kinetic energy of the beam at the titanium window exit in a range of 1 to 4 MeV. Then, the particle distributions obtained from ASTRA simulation results are utilized to study the interaction between electrons and matters by using the Monte Carlo simulation technique with Geant4 program. The electron beam with various energies collide the 50 μm titanium window, then travel through the air and penetrate in the natural rubber latex. The electron dose distributions for both transverse and longitudinal axes are investigated in the different media along the beam path. The natural rubber latex: placed 18 cm downstream the titanium window; gets different dose deposition and has different transverse radius depending on the average kinetic energy of electron beam. The dose of electron beam which absorbed by the natural rubber latex is then estimated. Finally, the simulation results are compared with the results from the experiment.

On the influence of uncertainties in scattering potentials on quantitative analysis using keV ions

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In this contribution we analyse how modifying the screened Coulomb potential affects simulation of spectra obtained from low energies up to the medium energy regime (15-150 keV). As materials of interest we choose transition metal nitrides. This specific choice is made due to their high technological relevance [1] and the presence of light and heavy constituents with different impact on energy loss and multiple scattering. Experimental reference spectra were obtained with the Uppsala Time-of-Flight Medium energy ion scattering set-up [2]. Simulations were performed using the TRBS (TRim for BackScattering) Monte-Carlo package [3]. We use different scaling factors for the electronic stopping power and for the screening length in either the Thomas-Fermi-Molière (Firsov screening) or the Universal potential in the calculations. The resulting energy dependence of the yield N(E) with characteristic features such as the width of obtained spectra are studied. As an example, the attached figure shows experimental data (open symbols) and simulations obtained for 25 keV He scattered from a 15.6 nm film of HfN on carbon for a detection angle of 155 degrees with respect to the primary beam. The simulations shown exhibit a significantly different energy dependence of N(E) visible mainly in a different intensity of the low-energy signal and the rise of the plateau, both features associated with dual and multiple scattering. In contrast, the spectral width for the present choice of parameters is found less affected. We discuss the relevance of the expected uncertainties in the input parameters for the simulation on information that can be extracted from experimental spectra, such as thickness and composition of an analysed film or information on inelastic energy loss in fundamental studies. Additionally, complementary simulations for transmission experiments are performed.

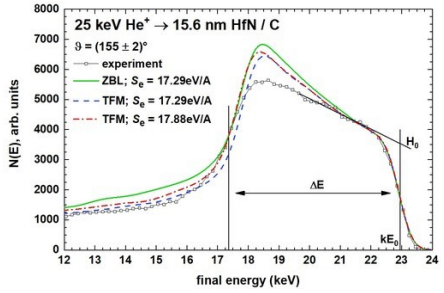

Figure 29: Experimental data (open symbols) and simulations obtained for 25 keV He scattered from a 15.6 nm film of HfN on carbon for a detection angle of 155 degrees with respect to the primary beam.

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Poster session B

Tuesday (May 7, 2019)

The ACOLISSA time-of-flight low energy ion scattering setup – a status report

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Low energy ion scattering (LEIS) is a non-destructive method commonly employed to analyze composition and structure of surfaces as well as thickness of ultra-thin films. Additionally, it permits to study electronic processes as charge exchange and energy transfer between projectile and surface atoms. The UHV time-of-flight LEIS system ACOLISSA (Analysis of the Charge Of Light Ions Scattered from Surface Atoms) constructed at the Johannes Kepler University Linz is a powerful setup to study ion-surface interactions. The gas ion source is capable of providing atomic as well as molecular ion beams of H, D, ^{3}He, ^{4}He, Ne and Ar with primary energies between 0.5 keV and 10 keV. Particles backscattered in an angle of $\theta = 129^\circ$ are detected by a set of MCP's. A post-acceleration system in the detector beam line allows to separate scattered positive ions and neutrals in their time-of-flight. More details on the setup can be found in Ref. [1]. The setup has been extended to feature an integrated UHV target preparation chamber [2] joined with the main system via a transfer valve. In the preparation chamber a triple source e-beam evaporator permits in-situ deposition of thin films. Additionally, different gases (e.g. oxygen) can be introduced during evaporation. Auger electron spectroscopy can be performed in-situ to identify chemical composition of the surface of the targets of interest. A load-lock system allows for a quick insertion or removal of targets without breaking the vacuum. The chamber also features a sputter gun and an annealing stage for cleaning of target surfaces. The crystallinity of the targets can be checked by a low energy electron diffraction system. Recently, the whole setup was relocated to Uppsala University. The vacuum control system, and the cooling of the ion source have been refurbished. Following this commissioning process the system was thoroughly tested. In this contribution we intend to present our first results obtained from measurements on a single crystalline target material. Currently the mapping of shadowing/blocking patterns has to be done indirectly by recording polar or azimuthal scans. To overcome this limitation, we plan to install an additional position sensitive detector in the ToF-LEIS chamber allowing for 3D-analysis (two spatial and one temporal dimension). This modification will facilitate data acquisition for surface structure analysis and simplify studies of ion-solid interaction with respect to interaction potentials and electronic excitations.

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Automating the setup and control of the pre-sample charge measurement system at LIBAF

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In IBA applications, normalisation of the number of probe particles incident on the target is vital to obtaining quantitive figures characterising the sample. In previous work at the LIBAF, a pre-sample charge measurement system was developed to avoid the drawbacks associated with conventional on-sample and post-sample charge measurement systems [1]. In this work, a further upgrade to this system is presented.

The existing system uses a pair of electro-static deflection plates powered by a HV pulse generator module to periodically direct the beam into a pre-sample Faraday cup. For a fixed beam energy, the system can be manually adjusted to ensure the beam is incident in the Faraday cup when deflected, but when performing measurements where the energy of the beam must be stepped, manual adjustment becomes impractical. When using a deuterium beam, manual setup is impossible due the the risk of irradiation to the user. This means the deflector must be setup using a proton beam and the ion source then changed with the assumption that the deflection setting will remain adequate.

The upgrade involves the modification of the PVM-4210 Pulse Generator Module for remote operation using a Teensy 3.2 micro-controller operated from a custom-built GUI. The Teensy's ADC channels are also used to read in the voltage on the plates and charge measured in the pre-sample Faraday cup, as well as charge measurements from the sample and other positions in the beam-line if necessary. The upgrade will allow for rechecking of the charge collection efficiency at any time to identify drift and apply corrections where necessary. All monitoring and adjustment can be performed remotely (from the control room) meaning that deflection for deuterated beams can be set directly.

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Design and Development of a Beam Chopper for Ion Beam Current Measurements

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The Ion Beam Analysis (IBA) has been a powerful analytical technique to study the composition and structure of a sample based on using accelerated MeV ions [1]. Measuring the scattering or nuclear cross section is another application of IBA. The most applications aim to obtain quantitative information. To this end, the knowledge of the number of incident ions in the sample is necessary [2]. There are various methods to determine beam current such as, current measurement by using of a Faraday cup, a using of beam chopper and directly from the sample. Selection each of these methods depends on the accuracy needed and the possibility that the system and sample are prepared. In the thick sample or insulator a Faraday cup is unusable. Direct measurement from the sample does not work in the case of insulator sample as well as in semiconductors with a wide band gap [3]. So, an alternative method should be applied. Employing beam chopper seems to be a proper supplement. In this paper, design and development of the beam chopper is presented as an alternative beam current measurements method in the RBS-C analysis chamber. Fig. 30a shows the beam chopper mounted at the entrance of ion beam transport–tube to the chamber. This system consists of a holder, a stepper motor, a chopper plate made of stainless steel and four transmission-type photosensors. The holder is 98 mm in diameter with a hole in its center of 10 mm in diameter. The center of the holder is along the axis of ion beam transport–tube, so that ion beam can enter the chamber through the hole. The chopper plate is a circle of 54 mm in diameter with two empty arcs in the opposite its quarters. The arcs are 4 mm in width and its inner radius is 16 mm from the center of the plate. Time-sharing between the beam current measurement and ions pass through the arcs is equal. There is a hole of 1 mm in diameter in the chopper plate through which the light of emitter device of photosensor can reach to the receiver one. Four photosensors are used to detect the position of the chopper respect to the beam. The electronic controller box of chopper is shown in Fig. 30b. There are three BNC terminals, one allows direct ion beam current measurement from the chopper, the second and third one supply logic pulse with width equal to time of current measurement and one of ions pass to the target. These pulses are used as a gate pulse of current digitizer and ADC respectively. There are also four bottoms working according to the photosensors signals to start and stop the chopper besides, controlling the position of the chopper. So that the chopper can be used just in the condition that the ion current cannot be measured from the sample. Since the initial system of current measurement employed in the RBS-C chamber is not precise due to secondary electron emission, we are not concerned about the accuracy of the current measured by the chopper. We just normalized the current measured by chopper with the one measured by the sample.

Figure 30: a) the beam chopper mounted in the RBS-C chamber, b) the electronic controller box of chopper.

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An IBA and CO-SS study of sputtering yield amplification of C, Si and Ge, with the addition of W, and of Al with the addition of Ti

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Thin films of C, Si and Ge were co-deposited with W, as well as Al films with co-deposition of Ti, to study the change in the sputtering yield. The spatial distribution of deposits was experimental measured; both the total deposit and that of each element, and the same were simulated using the Co-Sputtering Simulation (CO-SS) software. The elementary spatial distribution was measured by RBS analysis and Profilometry was used to study the total deposit spatial distribution (film thickness). The simulation of the spatial distributions using CO-SS used the form of the angular emission of atoms from the target, and the sputtering yields, as fitting parameters. The analysis of the experimental results using CO-SS showed that the addition of one, two and three W pieces to the C target resulted in a sputtering yield amplification, SYA, of 1.87, 1.78 and 1.66, respectively. For the Si target the SYA was 1.16, 1.44 and 1.75 for one, two and three pieces of W. However, there was no change in the sputtering yield of Ge with the addition of pieces of W. The SYA for the Al target with one piece of Ti was small, 1.06, but for two and three pieces of Ti the SYA was more notable at 1.25 and 1.09. The angular emission of the atoms from the target was also affected by the presence of W or Ti inserts on the surface of each target. The elemental analysis of probe samples of Si placed at two places on the racetrack of the Si target, far from the position of the W inserts, showed that increasing the number W inserts increased the surface concentration of W on the probe samples. Based on this dispersion of W on the surface of the Si target, it is reasonable to assume that C, Si and Ge would be dispersed on to the corresponding pieces of W and, similarly, the piece of Ti would have Al on the surface. However, the results showed no evidence of SYA for the pieces of W, or Ti, with the addition of these elements.

L-shell X-ray production cross sections of Ag and Au induced by carbon ions between 2 MeV and 5 MeV

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In this work we experimentally determined Ag and Au L-Shell X-ray production cross sections by 2 to 5 MeV carbon ions. The measurements were performed using the standard measurement setup already used to measure M-Shell X-ray production cross sections [1]. Ag and Au thin targets were used and related X-ray spectra were measured with Si(Li) and SDD X-ray detectors simultaneously with the carbon backscattering spectra. The present new data are compared to the data available in the literature [2-3] as well as to theoretical predictions of ECPSSR [4] and ECUSAR [5] models. The analysis of data shows that the ECUSAR predictions are good at low carbon ion energies while the ECPSSR predictions agree at the higher incident energies.

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PIXE and Thermoluminescence Analysis of Rice Samples of Iran

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Rice, a staple food for many countries, is one of the important agricultural products in the world [1]. Although the rice has some essential elements for the human body, in some sample of rice toxic elements such as Arsenic have been observed. So, investigation of elements in different samples of rice has been performed by different authors [2]. In this paper, in order to determine the concentration of essential and toxic elements of Iranian rice samples, PIXE analysis have been done for three different samples. Also, according to the observed elemental composition from PIXE, an investigation has been done on the thermoluminescence (TL) glow curve of samples in order to evaluate the feasibility of using rice as a dosimeter in radiation processing of this product. Three rice samples were collected for north zone of Iran (Gilan province). The samples were washed, dried and ground into fine powder with size less than 200 μm. The samples were analyzed using PIXE technique. This analysis was performed at the 3 MV Van De Graff accelerator at the Nuclear Science and Technology Research Institute. All measurements were carried out using a 2 MeV proton beam with average current of 2.5 nA. The pressure of the chamber was 10^{-5} Torr during the measurements. The characteristic X-ray induced by the proton beam were detected by a Canberra Si(Li) detector positioned at an angle of 135 with respect to the direction of the incident beam. The energy resolution of the detector was 165 eV at 6.4 keV. The quantitative analysis was performed using GUPIX software [3]. The emitted X-ray spectrum of the rice samples is depicted in Fig 31a. As shown in this figure, the concentration of Potassium, Calcium, Sulfur and Chlorine in Iranian rice samples analyzed using PIXE method is significant. These elements are essential for human body. Furthermore, the element of Iron was observed in samples 1 and 3. Also, the elements of Manganese and Zinc were detected in sample 1b. Due to observation of elements such as calcium and sulfur in the rice samples, the thermoluminescence properties of them was also investigated. Thus, the powder samples were irradiated by gamma rays of ^{60}Co in the Gammacell-220 irradiator with absorbed doses of 200 and 1000 Gy. The thermoluminescence glow curve of irradiated samples was readout using a Harshaw-4500 TLD reader. The glow curve of samples was recorded at temperature intervals of 230 to 600 Kelvin with a heating rate of 5° C/s. The thermoluminescence glow curve of one of the samples is shown in Fig 31b. The thermoluminescence property of rice samples can be caused by mineral compounds such as calcium sulfate or calcium carbonate. As shown in Fig 31b, the thermoluminescence glow curve increases by increasing the absorbed dose delivered to the sample. The results of this study can be used for feasibility studies of using rice as a dosimeter in radiation processing on accident dosimetry.

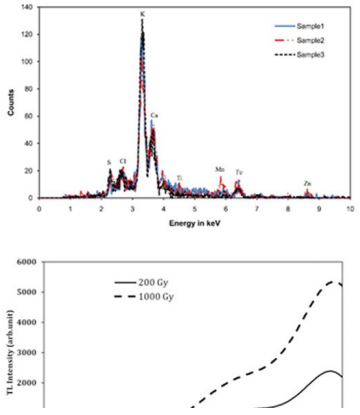

Figure 31: PIXE analysis of rice samples of Iran, The thermoluminescence glow curve of rice samples

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PIXE analysis applications recently developed at Chiang Mai University

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Since the particle induced X-ray emission (PIXE) analysis technique was established based on our 1.7-MV Tandetron tandem accelerator at Chiang Mai University (CMU) more than a decade ago, various applications of the technique have recently been rigorously developed to serve local research and society. The applications included analysis of collected local aerosols for air pollution monitoring, analysis of mineral composition and concentrations of ion-beam-induced local rice mutants, analysis of gemstones for the origin identification and chemical compositions, analysis of various local archeological articles for composition studies and age dating, detection of forensic materials such as gun powder, development of MeV heavy-ion PIXE, and development of capillary microbeam and mapping of local plant leaves for investigation of element transportation and storage in leaf vein and lamina parts, etc. The PIXE technical characters are described and results in the various applications are presented or summarized. These successful applications demonstrated that the accelerator-based nuclear technology such as PIXE could act as an effective tool playing active role in assisting various researches for developing countries.

Measurement of differential cross sections of deuteron elastic scattering on ^{31}P for EBS purposes

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Phosphorus (with ^{31}P being the only stable isotope) is a light chemical element, essential for life, and highly reactive. Phosphorus is an important component in steel production (namely it is used as an alloying element in copper with oxygen in order to increase the hydrogen embrittlement resistance compared to normal copper), in glass manufacturing and it is also used as a dopant for n-type semiconductors. Thus, the accurate quantitative determination of phosphorus depth profile concentrations, especially in light element matrices, is important in many technological, medical, archaeological and environmental studies. Several IBA (Ion Beam Analysis) techniques can be applied to achieve this goal, namely ERDA (Elastic Recoil Detection Analysis) for thin, surficial layers, p-EBS (Elastic Backscattering Spectroscopy) due to the existence of evaluated and benchmarked differential cross-section datasets in literature and NRA (Nuclear Reaction Analysis). The latter, especially d-NRA (via the simultaneous implementation of ^{31}P(d,p$_x$) and ^{31}P(d,α_x) reactions), seems to be the most promising technique for phosphorus depth profiling in complex matrices, since it yields isolated high-energy peaks with practically no background. However, d-NRA's full implementation is usually impeded by the significant lack of the associated d-EBS differential cross-section datasets in literature. In order to address this problem, the differential cross sections of deuteron elastic scattering on ^{31}P were determined in the present work for the first time, in the projectile energy range E$_{d,lab}$= 900-2400 keV (in energy steps of $\sim$10-30 keV), suitable for analytical purposes. The experimental setup consisted of five silicon surface barrier (SSB) detectors, placed at the angles between 130° and 170° (in steps of 10°) in a high-precision goniometer. The implemented target was a thin GaP layer, which was created by evaporating high-purity GaP powder on top of a thin C stripping foil, with the Ga presence needed for normalization purposes. The measurements were performed at the 5.5 MV TN11 HV Tandem Accelerator of N.C.S.R. "Demokritos", Athens, Greece. The obtained differential cross-section datasets were benchmarked against a polished GaP crystal and the deviations from the corresponding ones using Rutherford's formula will be discussed and analyzed. The results of the present work will soon be available to the scientific community via IBANDL (www-nds.iaea.org/ibandl/) in both graphical and tabular forms.

Differential elastic scattering cross sections for deuterons on ^{9}Be, at energies and angles suitable for EBS (Elastic Backscattering Spectroscopy)

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Although beryllium (100% ^{9}Be, with traces of ^{7}Be and ^{10}Be) is a relatively rare element in the universe, it has various applications in the industry. It is added as an alloying element to iron, copper (beryllium copper), aluminum and nickel as it improves many physical properties and it is extensively used in consumer electronics and telecommunications. Due to its high thermal conductivity, thermal stability, metal flexural rigidity and low density, it is used in mechanical and defense applications, namely as aerospace material for guided missiles, aircraft components, satellite structures and spacecrafts. Moreover, beryllium is the most crucial material in plasma-facing components due to its low Z, its reasonably high melting point and due to its capability as an oxygen getter. Hence, the accurate quantitative determination of beryllium depth profiles is critical, especially for the assessment of beryllium deposition and erosion processes, by analyzing samples from fusion devices, via the implementation of Ion Beam Analysis (IBA) techniques. Among all IBA techniques, d-EBS (Elastic Backscattering Spectroscopy), usually employed along with d-NRA, is a widely used technique that can provide accurate quantitative depth profiling data for the majority of light elements that coexist in a complex matrix along with other low- and/or medium-Z elements. However, by examining the literature for the particular case of beryllium, only scarce datasets can be found, presenting many discrepancies among them. Therefore, the aim of the present work is to provide coherent differential cross-section datasets concerning the deuteron elastic scattering on ^{9}Be, in the energy range 1600-2200 keV, in steps of 20 keV and for the laboratory scattering angles of 120°, 140°, 150°, 160° and 170°. The experiment was conducted at the 5.5 MV Tandem Accelerator at NCSR "Demokritos", Athens, Greece and the target used was a thin Si_3N_4 self-supporting foil produced by Silson Ltd., with a thin beryllium layer placed on top by means of reactive magnetron sputtering. The detection apparatus consisted of five, 500 μm thick, silicon surface barrier (SSB) detectors mounted on a high precision goniometer inside a cylindrical chamber (R$\sim$40cm). he acquired differential cross sections are compared to already existing ones in literature and the resulting differences and similarities are discussed.

This work has been supported by the Greek Scholarship Foundation and has been funded by the "Doctoral Research Financial Support" Act from resources of the OP "Development of Human Resources, Education and Lifelong Learning" 2014-2020, which is co-funded by the European Social Fund–ESF and the Greek Government.

Thin films of light elements were produced with deposits of heavy elements to study the effects SAY using Co-Sputtering Simulation software (CO-SS) and ion beam techniques (IBA)

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Since the introduction of the planar magnetron by J.S. Chapin in 1974 magnetron sputtering has become the most important technology for the deposition of thin films. Today it has conquered all industrial branches needing high-quality coatings for realization of new or improvement of existing products. Sputter yield amplification (SYA) is an effect where the sputtering yield of a given material is significantly increased by the introduction of a small concentration of a heavy impurity at the surface. To illustrate the physical mechanisms behind this sputtering yield amplification (SYA) effect. In this study, thin films of AlTi, CW and SiW were produced to measure the change of the sputtering yield. Thin films of C, Si and Ge were co-deposited with W, as well as Al films with co-deposition of Ti, to study the change in the sputtering yield. The spatial distribution of deposits was experimental measured, both the total deposit and that of each element, and the same were simulated using the Co-Sputtering Simulation (CO-SS) software. The simulation of the spatial distributions using CO-SS used the form of the angular emission of atoms from the target, and the sputtering yields, as fitting parameters. The effect his sputtering yield amplification SYA was studied with software (CO-SS) and ion beam techniques (IBA). The elementary spatial distribution was measured by RBS analysis and Profilometry was used to study the total deposit spatial distribution (film thickness). The angular emission of the atoms from the target was also affected by the presence of W or Ti inserts on the surface of each target. The elemental analysis of probe samples of Si placed at two places on the racetrack of the Si target, far from the position of the W inserts, showed that increasing the number W inserts increased the surface concentration of W on the probe samples. Based on this dispersion of W on the surface of the Si target, it is reasonable to assume that C, Si and Ge would be dispersed on to the corresponding pieces of W and, similarly, the piece of Ti would have Al on the surface. However, the results showed no evidence of SYA for the pieces of W, or Ti, with the addition of these elements.

Electron emission induced by pulsed ion-beams: A time-of-flight approach

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When ions with energies of several ten keV interact with matter, a multitude of effects can be observed. Apart from scattering from target nuclei and electrons, these ions can induce luminescence, electron emission and sputtering of atoms and ions. In a traditional medium energy ion scattering (MEIS) approach, scattering in a backward geometry is used for elemental depth profiling of thin film samples in a fashion similar to Rutherford backscattering spectrometry (RBS). Detecting secondary particles, however, allows for a more comprehensive characterisation of a sample and for gaining a more complete understanding of the underlying ion-solid interactions. The Uppsala MEIS set-up combines a time-of-flight (ToF) detection system using pulsed beams with a large, position-sensitive microchannel-plate detector [1]. This approach allows to study scattered primary as well secondary particles in the same set-up often even within one single measurement. In this contribution, we explore the possibility to measure energies of secondary electrons emitted from thin film materials upon the impact of pulsed ion beams both in backscattering and in transmission geometry. The latter allows to study free-standing foils and two-dimensional materials such as single-layer graphene. The electronic properties of graphene have previously been studied by measuring the charge-exchange processes of ions [2]. Measuring the energy of secondary electrons improves our understanding of these interaction processes further. We present the current status of the Uppsala ToF-MEIS set-up, where transmission experiments now can be performed. To allow for the detection of electrons with small initial kinetic energies (few eV), appropriate measures such as an accelerating field and shielding from other sources had to be implemented. We present our first results from measurements both in backscattering and transmission geometry employing thin carbon and gold films as well as single-layer graphene as samples.

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Ion channelling effect and damage accumulation in yttria-stabilized zirconia implanted with Ag ions

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Yttria stabilized zirconia (YSZ) is well known as a radiation resistant material. In this study, we present results from 400 keV Ag^+ implantations of the (100) YSZ single crystals to fluences ranging from 5×10^{15} to 5×10^{16} cm^{-2}. The damage depth profiling and accumulation were followed using Rutherford backscattering spectrometry in channelling mode (RBS-C) and X-ray diffraction (XRD). The axial channelling effect of 2 MeV He^+ ions at energies in the implanted YSZ was studied. RBS-C provides us the detailed information about the displaced atoms density depth profiles which is evident at fluence higher than 1.0×10^{16} cm^{-2}. YSZ implanted with Ag^+ ions exhibits some step of damage accumulation with the increased ion fluence, where each step is characterized by radiation-defect reorganization. Transmission electron microscopy (TEM) was utilized to characterize the microstructure evolution after the implantation. At low fluence 5×10^{15} cm^{-2}, Ag precipitation is no evidenced on electron diffraction patterns. Above 1×10^{16} cm^{-2}, TEM micrographs exhibit Ag precipitation in the depth of 30-130 nm with a roughly damaged implanted layer. The experimental damage peaks are consistent with those calculated using stopping and range of ions in matter (SRIM), where the damage maximum is in $\sim$98 nm.

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Determination of deposition order of toners, inkjet ink and blue ballpoint pen using MeV Secondary Ion Mass Spectrometry

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One of the problems in forensic science which still doesn't have an established analysis method is the determination of deposition order of different overlapping writing tools. Time-of-flight Secondary Ion Mass Spectrometry using MeV ions for the excitation (TOF MeV SIMS) is a surface sensitive technique that can give information about molecular composition of the first few monolayers of a sample and therefore has potential within this forensic field. In the present work the TOF-SIMS instrument at the RBI microprobe facility in Zagreb was used with 8 MeV Si^{4+} ions to look at intersecting lines of blue ballpoint pens, laser printer toners and inkjet printer ink. Combination of these writing tools were investigated as they are often used in different official documents. Samples with different combinations and deposition orders of the writing tools on standard paper were prepared and imaging of the intersection lines was performed. Matlabs RGB software and PCA analysis were both used on the data acquired to produce molecular maps of the intersections by taking specific molecular peaks for each writing tool. The line was believed to be deposited first if a break was observed in the mapped image or second if the line was continuous. Both analysis methods had the same results. Using this instrumentation, the deposition order of intersections involving the ballpoint pen and the laser printer toner were successfully determined. However, incorrect results were observed when the inkjet printer ink was on the top of all intersections. Not only did the inkjet printer line always show a break in the mapped image but the corresponding laser or ballpoint pen line was always continuous. This was suspected to be due to the penetration properties of the different inks used for these three writing instruments.

Development of MeV TOF-SIMS capillary microprobe

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Time-of-Flight Secondary Ion Mass Spectrometry (TOF-SIMS) is a mass spectrometry technique used for identification of atomic and molecular species by measuring time-of-flight of the secondary ions sputtered from the sample surface. Instead of the conventionally used keV primary beam, one can use MeV primary ions to reduce fragmentation and increase secondary molecular ion yield. In order to avoid limitations due to the focusing power of the magnetic optical elements, borosilicate glass micro-capillary is used for primary beam collimation to micrometer dimensions independently of the ion mass and energy. Samples are mounted on a piezo scanning stage which enables 2D imaging of molecular distribution. Dual stage reflectron type TOF analyzer is used for extraction and analysis of secondary ions. So far, the setup has been only used for thin transmission samples , where the start signal for TOF measurements is triggered by a PIN diode placed behind the target. In this work, first measurements performed on a new MeV TOF-SIMS setup based on a micro-capillary will be presented. Results on the current and energy distribution measurements through the micro-capillary for several heavy ions (Cu, Si, I and Au with energies up to 20 MeV) will be shown. Different parameters of the TOF analyzer (reflect, retard and extraction voltages) were varied to obtain optimum mass resolution and sensitivity. First mass spectra of organic samples obtained on a new setup with optimized parameters will be presented, as well as first 2D molecular images.

Upgrade of the ERDA setup at the HZDR 6 MV tandem accelerator

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During 2019 the elastic recoil detection (ERD) beamline attached to the 6 MV tandem accelerator at the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) has been modernized completely. Since many of the vacuum and electrical components of the previous setup had been showing signs of aging or failing, the decision was made to replace these and rebuild the setup. Additionally, during 2018 the construction of a new time-of-flight spectrometer for ERD was also completed, and it was seen that the ERD setup as a whole would benefit from a combination of a new chamber, mechanical supports and a control system.

The new setup incorporates the previously used Z-separating Bragg ionization chamber (BIC), which is typically used with 43 MeV ^{35}Cl beam. It is connected to a port on the chamber giving 30 degree scattering angle. The time-of-flight branch is attached to the other side of the chamber at a 40 degree scattering angle. Various beams up to an energy of 20 MeV for ^{35}Cl or 30 MeV for ^{63}Cu can be used, or even higher if hydrogen depth profiling is not necessary. The detector branches can be operated independently of each other, minimizing downtime due to breakdowns of detectors or maintenance. This is exceedingly important since the ion beam center (IBC) is a user facility and the beam time for the 6 MV accelerator is allocated based on proposals and scheduled long in advance to the actual measurement.

This presentation will give an overview of the new ERD setup, including specifics on the design of the new chamber, control and vacuum systems, detectors and data acquisition as well as some experimental data, performance figures and experiences gained during the construction of the setup.

Using resonant nuclear reaction analysis for studying H site occupancy in ultrathin V layers: a quest for proximity effects

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We investigate the potential of resonant nuclear reaction analysis (NRA) to study proximity effects on the absorption of hydrogen in thin V films and to investigate the phase boundaries of strained metal hydrogen systems. We employ the $^{1}H(^{15}N,\alpha\gamma)^{12}C$ reaction around the resonance energy of 6.385 MeV which allows for high-resolution hydrogen depth profiling [1]. Superlattices of Fe/V or Cr/V, can be grown as single crystals with exceptional quality [2] and offer an ideal platform to study the proximity of a non-absorbing constituent on the hydrogen uptake in vanadium. An accurate analysis of composition and structure of the samples was performed by Rutherford Backscattering Spectrometry (RBS) and x-ray diffraction, respectively. NRA was employed to obtain depth profiles of the hydrogen concentration and to correlate it to complementary optical transmission experiments. By a combination of NRA with channeling experiments, i.e. sample alignment to specific crystal axes, we aim to directly identify the interstitial site occupancy of the hydrogen atoms in the bcc metal lattice. The sample alignment was performed using the signal of scattered primary particles and using X-rays emitted on particle impact respectively. In this contribution we will explain in detail our experimental approach as well as present results obtained from probing samples with different composition, structure, i.e. stacking sequence and hydrogen concentrations.

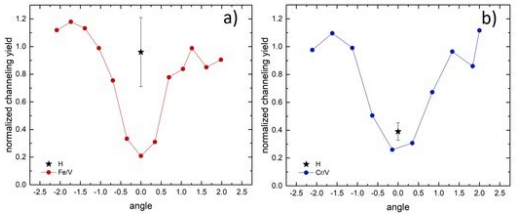

Figure 32: Yield of backscattered ^{15}N-ions (full circles) for a) Fe/V & b) Cr/V superlattices; the minimum corresponds to the (001)-axis. Asterisks represent the yield from the $^{1}H(^{15}N,\alpha\gamma)^{12}C$ reaction in channeling normalized to random incidence.

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Energy calibration of a one megavolt AMS tandem accelerator using EBS cross sections energy resonances from $^{12}C(p,p)^{12}C$ and $^{28}Si(p,p)^{28}Si$

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This work presents an adaptation of a tandem accelerator of 1 MV (HVEE) with the installation of a new line that can be used for multiple applications, such as the modification of materials by means of ion implants, analysis of materials of ion beams, nuclear reactions (NR). The new line takes advantage of the 1 MV tandem accelerators (HVEE) with the multi-cathode ion source (MCIS) and the fine-tuned injection system to deliver low energy beams into a multi-purpose scattering chamber. The MCIS allows for a very quick and smooth change of the ion species to be accelerated, and the ability to tune automatically all the optics in the injection system produce an accelerator laboratory that can change the beam particles, intensities and energies in minutes. The energy calibration of the beams in the NBL using EBS proton spectra from $^{12}C(p, p)^{12}C$ and $^{28}Si(p, p)^{28}Si$ with SIMNRA simulation program proved to be a very sensitive method and served also to compare with the GVM reading from the tandem accelerator. The magnet in the line was calibrated with the SIMNRA simulation using EBS proton spectra from $^{12}C(p, p)^{12}C$ and $^{28}Si(p, p)^{28}Si$ applying know proton cross sections resonances of ^{12}C and ^{28}Si input files from the IBANDL data base. A summary of analysis to EBS spectra from the $^{12}C(p, p)^{12}C$ and $^{28}Si(p, p)^{28}Si$ The comparison of E_b vs E_s linear fit gives a correlation factor 0.9998. Therefore, one can conclude the GVM is well calibrated to provide the beam particle energy given the tandem high voltage The magnetic field Bs vs i obtained from the SIMNRA simulation of the EBS protons from the $^{12}C(p, p)^{12}C$ and $^{28}Si(p, p)$ ^{28}Si spectra.

Accelerators in Applied Physics at Laboratori Nazionali di Legnaro

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Two ion accelerators are in operation at Laboratori Nazionali di Legnaro for Interdisciplinary and Applied Physics: CN and AN2000. Both of them are electrostatic linear accelerators, i.e. Var der Graaf machines, which in the last 30 years have been found not more interesting for experiments of Nuclear Physics, the main activity of the Laboratory. However since 1990 they have been considered useful in the field of Applied Physics and worth to be maintained in operation. So every year they continue to provide about 2500 hours of beam on target for experiments and irradiations in this field. Here a review will be given of the accelerators features, how they may be used, the ion beams that are available in term of ion species, current intensity and type (continuous, pulsed). The different beam lines and experimental facilities which are available in the two experimental halls will be also described. At last, a description will be provided of the fields for applications which may be explored with irradiation at Laboratori Nazionali di Legnaro.

Figure 33: The building where the Van der Graaf CN accelerator is installed and working.

SIGMA – a new set-up used for in-situ growth and ion beam analysis of photochromic YHO films

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SIGMA (Set-up for In-situ Growth, Material modification and Analysis) is a recently developed ultra-high vacuum set-up for high-resolution depth profiling studies using ion beams provided by the 5 MV 15 SDH-2 Tandem accelerator at Uppsala University. The equipment enables film deposition (by e-beam evaporation), sample modification (annealing, oxidation, hydrogenation, argon sputtering for surface cleaning and film removal) and in-situ characterization by Ion Beam Analysis techniques (Rutherford/Elastic Backscattering Spectrometry, Particle Induced X-ray Emission and Nuclear Reaction Analysis). An additional capability is the irradiation of the samples with an ion beam during film deposition and/or oxidation. In this contribution, we present an in-situ study on oxygen containing yttrium hydride films (YH_xO_y) illustrating the capabilities of SIGMA. This material has recently attracted attention as it can exhibit reversible photochromism at ambient conditions. Photochromic YH_xO_y thin films have so far been commonly produced by reactive magnetron sputtering, followed by post-oxidation under exposure to air. The influence of post-oxidation, affecting both the surface and the bulk of the film, is only characterized when the samples are removed from the sputtering chamber. As a result, obtaining a complete understanding of the connection between the photochromic properties and the sample composition is challenging. SIGMA allows for growth of pure yttrium hydrides by reactive e-beam evaporation, followed by controlled in-situ oxidation and in-situ characterization (i.e, compositional analysis) by ion beams. We managed to grow YH_xO_y films that exhibited a reversible photochromic response by e-beam evaporation. As a follow-up, a systematic investigation of the dependence of film composition and photochromic response on different growth conditions was performed. This investigation includes in-situ oxidation and hydrogenation in a controlled manner combined with in-situ (by EBS and NRA) and ex-situ (by ToF-ERDA) characterization, an assessment of the optical properties of the materials and comparison to other photochromic YH_xO_y films produced by reactive magnetron sputtering. Our results show that photochromism strongly depends on the chemical composition of the film (Y, O and H). Further oxidation of the produced samples, due to air exposure, gradually alters their photochromic response. Same growth conditions but different exposure times yielded different O/Y ratios. These differences, when correlated to the photochromic response, are in agreement with photochromic samples produced by magnetron sputtering.

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Analysis of the substrate CO-CR-MO coated with layers of TiAlPtN to determine the biocompatibility of prostheses and surgical implants

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CO-CR-MO alloy is one of the alloys used in the manufacture of surgical prosthesis and implants with "investment casting" techniques, due to their high toughness, high corrosion resistance and excellent biocompatibility. In the as-cast state it has a microstructure formed by a cobalt rich FCC dendritic matrix with presence of second phases, such as M23, C6 carbides, in interdendritic zones and grain boundaries, which form the main hardening mechanism in this type of alloys. Multilayer /TiAlN/TiAl coatings were analyzed by the PVD reactive magnetron on CO-CR-MO substrate in order to improve resistance to biomedical tribocorrosion. Micrographs of the produced tracks were taken to determine the critical loads of the separate coatings of the substrate. Tests were performed to observe the TiAlPtN coatings in TiAlPtN/TiAl multilayer periods, on the CO-CR-MO alloy, to study the resistance behavior to tribocorrosion. Further resistance to tribocorrosion and adhesion of TiAlPtN/TiAlN-TiAl coatings on a CO-CR-MO substrate was observed. The objective of the present work was to provide information about the structures of the present phases and the possible transformations that could occur during the solidification and to compare with the behavior of the CO-CR-MO alloy with TiAlPtN coatings in order to optimize thermal processes later. The elemental composition and the thickness of the coating were evaluated by RBS, using an alpha particle beam of 2.0 MeV and NRA with a 1.30 MeV deuterium beam, before and after the alternative movement in the tribocorrosion test. In order to simulate the elemental profile of the samples, SIMNRA simulation software was used.

Upgraded time-of-flight medium energy ion scattering setup with multiple detectors

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In this contribution we present the most recent upgrade of the time-of-flight-medium energy ion scattering (ToF-MEIS) system in Uppsala. Following the modifications two delay line detectors for composition analysis with high depth resolution and depth-resolved crystallography of thin films can be operated simultaneously. The ToF-MEIS setup in Uppsala [1] is based on a 350 kV ion source, a beam line with an electrostatic chopper system and a drift tube beam buncher. The experimental chamber features a 6 axis goniometer with a sample annealing stage and two MCP detectors with delay line anodes (DLD) from Roentdek [2]. The first detector is a DLD120 with large solid angle and can be moved from 0 to 160°, allowing to detect backscattered or transmitted ions from the sample. Viewed from the typical beam impact position the detector has 24° diameter allowing to obtain stereographic projections for crystalline samples. The second detector was recently installed in our setup with increased flight distance from sample to detector resulting in an enhanced energy resolution due to increasing time separation for different velocities. This enhancement can be exemplified by an improvement in energy resolution from 1.4 to 0.4 keV for 100 keV He scattered from a Au surface for 1 ns time resolution equivalent to a depth resolution of 6 $\AA$. Additionally, in the detector telescope, we installed an electrostatic deflection electrode in order to be able to deflect charged particles. This installation allows us to study the charge state for scattered ions in the medium energy regime, which is an important question with respect for quantification in the more-abundant MEIS-systems based on electrostatic or magnetic spectrometers.

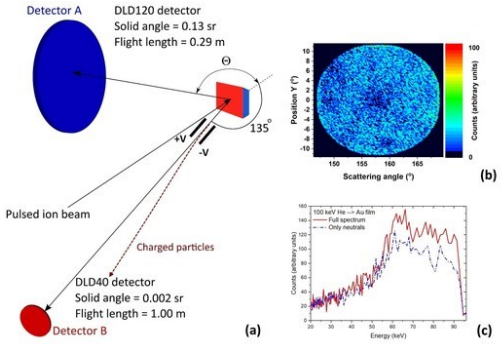

Figure 34: (a) Schematics of the ToF-MEIS setup with 2 DLD detectors, (b) Stereographic projection of a FeV/V superlattice on the large area detector, (c) spectrum of scattered neutral He particles from a 30 nm gold film.

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Data acquisition and control system for medium size laboratories

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A flexible data acquisition and control system was developed for medium size laboratories allowing for a wide variety of experiments to be performed with the same system. A Xilinx Virtex 6 FPGA is used in conjunction with custom made FMC daughter boards allowing one system to connect and control beam modification devices, such as ion beam optics elements, and simultaneously collect data from multiple detectors. The user selects the experimental parameters and the FPGA is automatically reprogrammed for the experiment. This real time reprogrammable nature of the FPGA coupled with a modular design approach allow for the ADCs, processing algorithms and communication protocols to be interchanged and upgraded while keeping a constant user interface through the SPECTOR software package. This work illustrates the design process and difficulties of creating a flexible data acquisition and control system and explores the benefits of such a system compared to other available systems. The benefits of an initial large investment in hardware and development time is observed over the long term by a large fraction of development reusability and easy integration into larger systems by the implementation of TANGO or EPICS supervisory control and data acquisition (SCADA) frameworks.

Differential cross-section measurements of the ^{31}P(p,p'γ)^{31}P reaction for target characterization using the PIGE technique

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Phosphorus (natural abundance: 100% ^{31}P) is a highly reactive light element which is met in natural heritage and in many geological, environmental, medical and technological applications. Many phosphate compounds are commonly used for fertilizers and pesticides, but also for detergents. Moreover, phosphorus is used as a dopant for n-type semiconductors, and it is important in archeology, where the precise bulk quantification with the minimum possible sample damage is desired. Among the most common least destructive techniques used for quick and accurate bulk analysis (if the determination of depth profile concentrations is not required) are the Ion Beam Analysis (IBA) ones, namely Particle Induced X-ray Emission (PIXE) and Particle Induced Gamma-ray Emission (PIGE). In the case of matrices where phosphorus coexists with other light elements (e.g. F, B, Al etc.), PIGE can provide more detailed information allowing for the simultaneous determination of several main light isotopes. However, there is a lack of differential cross-section datasets for the ^{31}P(p,p'γ)^{31}P reaction in literature, with just two measurements [1, 2] at 90° available in the Ion Beam Analysis Nuclear Data Library (IBANDL, https://www-nds.iaea.org/exfor/ibandl.htm). These datasets have an overlap at a limited energy range where the discrepancies are negligible, nevertheless, it is crucial for the applications, but also for theoretical calculations, to have differential cross sections for multiple angles and higher energies. Therefore, an experiment was conducted at the 5.5 MV HV Tandem Accelerator Laboratory of the Institute of Nuclear and Particle Physics (INPP) of the National Center for Scientific Research "Demokritos" (NCSR – "D") in Athens, Greece, using proton beam energies $E_p \sim 2.6 - 4$ MeV and four (4) HPGe detectors placed at 0°, 55°, 90° and 165° with respect to the beam direction. The obtained results have been validated via thick-target measurements and will be presented.

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^{nat}Mg(p,p)^{nat}Mg differential cross-section measurement relevant to the EBS technique

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Magnesium is a widely used metal, implemented mainly as an alloy in electronic devices. Its quantification, when present in high-Z matrices, presents a strong challenge for most of the analytical techniques as it forms complex compounds due to its highly reactive character. Among the commonly used Ion Beam Analysis methods for Magnesium depth profiling, deuteron probed Nuclear Reaction Analysis and proton Elastic Backscattering Spectroscopy are the most promising. Nuclear Reaction Analysis is more suitable in the case where magnesium coexists with other light elements in the under-study sample, as the peaks of the detected products are well separated. On the other hand, regarding radiation safety precautions arising from the neutron producing reactions, proton EBS is preferable. The use of the latter technique for the depth profiling of Magnesium has been enhanced by the existence of evaluated and benchmarked differential cross sections produced via SigmaCalc [1]. However, the existing evaluation stops at 2700 keV and, in conjunction with the absence of experimental data above this energy, restricts the use of the technique and its advantageous probing depth. Towards the goal of extending the evaluation, in the present work we report on the differential cross section measurements of the ^{nat}Mg(p,p)^{nat}Mg reaction, in the proton beam energy range between 2500 to 4200 keV and at six detection angles (120° to 170° with a 10° step). The obtained results are validated through a rigorous benchmarking procedure and compared with the existing ones from the literature.

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X-ray detector setup description with quantification of elements with characteristic K X-ray energies

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To report quantifiable results by analyzing PIXE spectra with various programs for elemental analysis, accurate physical detector description is mandatory. Understanding the detector efficiency transfer function is of essential importance for correct detector description and thus quantification of detected elements. The objective was to determine the efficiency of Si(Li), SDD (silicon drift detector) and iGe (intrinsic germanium) semiconductor X-ray detectors for nuclear microprobe detector setup at Jožef Stefan Institute (JSI). For X-ray energies under the silicon K absorption edge special attention was implied to most accurately describe SDD and Si(Li) detector efficiency in order to achieve better quantification of chemical elements with characteristic K X-ray lines with energy under the silicon absorption edge (1.84 keV). The same applies for iGe detector and chemical elements with characteristic K X-ray lines with energy under the germanium absorption edge (11.115 keV). Measurements were conducted on various standardized monoelemental and multielemental samples with known thickness and composition. Samples were exposed to focused proton beam with distinct energy, beam current and diameter. Measured spectra were analyzed with spectra deconvolution programs (GUPIXWIN [1] and GEOPIXE [2]) and description of all parameters of detection system with accurate physical model used in both programs is presented. The method to achieve accurate physical detector transfer function is described. The determined physical model for each X-ray detector is the same for both programs and gives matching quantification results for any target analyzed, regardless of its thickness and composition, within statistical error (not more than 5%) throughout the entire energy range of each detector. The entire detector setup covers the energy range between 0.7 to 54 keV which is used for most applications on nuclear microprobe setup at JSI [3].

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Low Energy Ar^{4+} Ion Beam Modification of WO_3-PEDOT: PSS hybrid Nanocomposites thin films for Gas Sensing Applications

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In this work, we are presenting the influence of low energy ion beam irradiation on the structural, optical and surface morphological properties of (Glass/WO_3-PEDOT: PSS) hybrid nanocomposites device. The hybrid nanocomposites were synthesized by uniformly dispersion of 1 wt%, 3 wt%, 5 wt%, of WO_3 nano-powder (prepared by co-precipitation method) in PEDOT: PSS conducting polymer solution. Sol-gel spin casting technique was applied for developing nanocomposite films on glass substrate. The nanocomposite thin films of different molecular weight percent were irradiated with low energy Argon ion (700 keV) beam with fluence 1×10^{15} ions·cm^{-2} and 1×10^{16} ions·cm^{-2} at Inter University Accelerator Center, New Delhi, India. The pristine and irradiated nanocomposite thin films were systematically characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR) and Raman spectroscopy to investigate the structural information of materials prepared. UV-Vis spectroscopy and photoluminescence (PL) spectroscopy were used to study the optical properties of pristine and irradiated nanocomposite films. Surface morphology characterized by atomic force microscopy (AFM). The surface roughness (R_a average roughness and R_q root mean square roughness) and grains size variation showed dependence on ion fluence. The modification in the properties of irradiated nanocomposite films were attributed to the crosslinking, scissoring of polymer chains and formation of defects due to ion irradiation. The enhancement in structural, optical and morphological properties of nanocomposite material by ion irradiation may be useful for energy applications. Detailed results will be discussed during the presentation.

Sequential swift heavy ion irradiation of gallium nitride

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Damage introduced by swift heavy ions into radiation hard materials is a concept of large interest which still remains only partially understood. The basic principle by which defects are produced consists of the formation of ion tracks on the surface or in the bulk of the material. It is important to investigate the impact of swift heavy ion irradiation on these materials, with GaN being a prominent example, because there is a possibility of damage build-up in the material which leads to complex behaviour, especially in radiation harsh environments. Furthermore, dynamics of damage formation during doping by ion implantation is also an important issue [1], since the efficacy of implantation can be improved if other processes occurring simultaneously are controlled or suppressed. In our previous study [2], we found no evidence of ion track formation in the bulk after swift heavy ion irradiation using 23 MeV I and 90 MeV Xe beams. However, recently we were able to introduce additional disorder into moderately damaged GaN crystals using the same 23 MeV Iodine and 90 MeV Xe beams in cases where GaN samples have been pre-irradiated with 2 MeV Au or with 900 MeV Xe ion beams. Two different ion beams are expected to introduce damage into GaN via nuclear and electronic stopping, respectively [3]. Moreover, sequential ion irradiation of GaN has not been investigated so far. In this contribution, we report new results of sequential ion irradiation of GaN based on the RBS/c, TEM and AFM measurements.

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Distribution of Hydrogen in Cu Irradiated by Pulsed Ion in Dense Plasma Focus Device

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Irradiation of materials with energetic ions produced various kinds of defectsin their lattice structure such as vacancies, dislocation, extrinsic or intrinsic stacking, twin faults and local distortions which called strain or stress. Plasma focus (PF) device is known as a pulsed energetic ion generator which has been used for thin film deposition, ion implantation and surface modification. The last application makes it a prospective device to study the materials that widely used in large, powerful plasma fusion devices, nuclear reactor and accelerators. Since Cu alloys are one of the proposed materials for making the first wall of ITER, The modification produced under irradiation of pulsed ion in dense plasma focus device have been studied theoretically and experimentally[1]. It is known that many metals become brittle by absorbing hydrogen, so that, in this paper distribution of hydrogen in Cu was investigated. The 2.7 KJ MTPF-2 Mather-type plasma focus device, with a capacitor bank of 13.5 μF, maximum charge voltage of 20 kV, inductance of 158 nH, and discharge current of 49 kA was used as a source of proton ions. In order to study the temperature and ion flux effects on diffusion and distribution of hydrogen, the Cu samples were irradiated by 1 and 10 PF discharge. The changes in the surface morphology were analyzed using scanning electron microscope (Fig.35a,b).

The Hydrogen concentration distributions inside the two samples were investigated by elastic recoil detection analysis (ERD) (Fig.35c,d). It is shown that the surface damage and H concentration in the sample irradiated by 10 PF discharge is significant because ion flux increases by increasing number of times PF discharge. Furthermore, the more H concentration in the surface of the sample irradiated by 1 PF discharge indicates the diffusion of Hydrogen from the sample surface to the bulk. This Hydrogen diffusion is a result of rising temperature in each PF discharge. The H deposition and the collision events in irradiated Cu samples are calculated by the SRIM software with the quick Kinchin–Pease approach using TRIM.DAT file (Fig.35e)[2]. It is illustrated that the maximum of H concentration in the sample calculated by SRIM is at the same depth as one measured by ERD analysis. The vacancy is calculated 5 per ion. The damage energy T_{dam} is 237.5 eV calculated by[3]: $\nu_{\mathrm{NRT}} = 0.8T_{\mathrm{dam}}/2E_{\mathrm{d}}$, where ν_{NRT} is the total number of Frenkel pairs produced by the initial energy of a primary knock-on atom (PKA) and E_{d} is the displacement threshold energy to create a stable Frenkel pair. The damage energy represents the portion of the PKA energy that is dissipated in elastic collisions with atoms in the lattice. E_{d} is 19 eV for Cu. Damage rate is calculated by: Damage Rate $= \nu_{\mathrm{NRT}}\Phi/N$, where Φ is ion flux and N is atomic density. The total damage rate is 5.8 dpa per second. Damage rate along the ion penetration depth in the target calculated by the SRIM is shown in Fig.35f which approves the H concentration calculated by ERD.

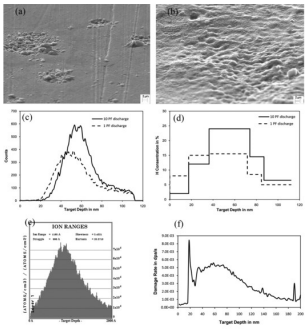

Figure 35: Surface morphologies of irradiated Cu by a) 1 PF discharge, b) 10 PF discharge, c) ERD analysis, d) H concentration in irradiated Cu, e) H ion range in Cu, f) Damage rate.

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Reduction of Graphene Oxide via Hydrogen and Argon Plasma

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Plasma treatment is one of the effective processes to reduce graphene oxide (GO). Interactions between plasma ions and GO lead to removal of oxygen-containing functional groups and/or functionalization of the surface of GO. In this work, hydrogen plasma and argon plasma were produced using radio frequency (13.56 MHz) in an inductively coupled discharge to treat free-standing GO films. The power of the radio frequency was kept at 150 W while the treatment time was varied from 600 s to 3600 s. Optical emission spectroscopy was carried out to observe properties of the plasma. The reduction of GO was deduced from the decrease in sheet resistance. It was found that the plasma treatments could significantly lower the sheet resistance from 28.23 MΩ/sq of pristine GO to $\sim$6 MΩ/sq of reduced GO (rGO). Scanning electron microscopy showed that rGO had smoother surface after plasma treatments. The rms roughness, obtained from atomic force microscopy, decrease from $\sim$141 nm (GO) to $\sim$44 nm (rGO). X-ray photoelectron spectroscopy was used to analyze the composition and functional groups prior to and after the plasma treatments. Raman spectroscopy measurements revealed that defects on rGO were dependent on the treatment times. The correlation between the plasma properties and the GO structure as well as the sheet resistance will be discussed to envisage the potential of plasma treatment in reduction of GO.

Development of the Dual-beam ion irradiation facility for FUsion materials (DiFU) at RBI, Zagreb

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The Dual-beam ion irradiation facility for FUsion materials (DiFU) is under development at the Ruder Boskovic Institute in Zagreb, Croatia, allowing irradiation of fusion-related samples by one or two ion beams. Two ion beams come to the DiFU chamber at an angle of 17° between them, from 6 MV HVEC Tandem VDG and 1 MV HVEE Tandetron accelerator. Ion beam handling and scanning systems enable fast electrostatic scanning of the beams over the sample at frequencies 256 - 3200 Hz in the horizontal and vertical axes, enabling the irradiation of areas from 5×5 to 30×30 mm^2. The sample holder enables XYZ positioning of heated, cooled or room temperature samples. Ion fluxes are measured indirectly by insertion of two large Faraday cups in ion beams. Besides, the ion flux is monitored continuously by two sets of XY slits, which, in turn, define limits of the irradiation area on the sample. Sample temperature and conditions during irradiation are monitored by a set of thermocouples, an IR camera and a high-sensitive video-camera.

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Comparison of GO and polymer micro-capacitors prepared by ion beam writing

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Carbon micro-beam writing was employed as a method for mask-less production of micro-scale capacitors in both insulating graphene oxide (GO) and polymers matrix. The GO, PMMA and PI foils were irradiated using 5 MeV C^{3+} beam with micrometer scale resolution and to different ion fluencies. As follows, the shape of created micro-structures and compositional changes were studied using SEM/EDX method. The thickness variation after ion beam treatment was measured using STIM and the structural progression was characterized by micro-Raman spectroscopy. The improvement of prepared structures electrical properties was also studied and can be concluded that the carbon irradiation leads to the removal of oxygen functionalities and growth of the carbon domains on the surface, which is connected with the increasing of surface conductivity.

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Compositional, morphological and optical modifications in polydimethylsiloxane irradiated by micro ion beam

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Ion micro beam was employed to induce modifications in surface and optical properties of poly(dimethylsiloxane) PDMS. This polymer was produced from commercially available two component addition materials. To induce the chemical modification of the polymer necessary for selective etching, energetic ions at various ion fluences were employed for application in microelectronics. The mechanical and adhesive properties of PDMS were tested by atomic force microscopy for applications as dry adhesives or dry transfer of 2D materials. The wettability, to observe the hydrophilic properties compared to the unirradiated PDMS. The compositional and structural changes in PDMS during the ion irradiation and the changing of its optical properties were monitored by Rutherford backscattering spectroscopy, elastic recoil detection analyses Raman spectroscopy and optical measurements, respectively.

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Relation between optical and mechanical properties of polycarbonate by ion beams

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Ion irradiation of polymers produces changes in their physical and chemical properties associated with the breaking and the rearrangement of original bonds in surface. The modification of the chain structure occurs within well-defined ion fluence ranges that depends on the linear energy transfer (LET) and on the target materials. These modifications result from changes in the chemical bonding when the incident ions cut the polymer chains, break covalent bonds, promote cross-linking and unsaturated bonding, and liberate certain volatile species.[1-2] Polycarbonate(PC) which are increasingly used in automobile and electronic product industry because they offer better lightweight and mechanical properties, need to enhance the surface properties such as surface hardness including anti-scratch property and no color & glossiness changes under UV and visible light for a long term. As well known, the surface hardness enhancement of polymer by ion beam is due to the cross-linking of surface polymer chains depending on ion mass and ion fluence. Fig.36 shows IR data for variation in the absorbance intensity of various functional groups of ion-irradiated PC with ion species. The observed chemical changes of PC are as follows: (i) increase in the concentrations of O-H (3000-3900 cm^{-1}), unsaturated C=C(1600-1650 cm^{-1}) and C=O (1728 cm^{-1}) with decreasing the ion mass, (ii) decrease in the concentrations of keton C=O (1680-1750 cm^{-1}) , aromatic C=C (1500-1700 cm^{-1}) and C-H (2900-3100 cm^{-1}) with decreasing the ion mass. As a result of IR spectra, hydrogen ion irradiation of PC was more efficient for mechanical property comparing with nitrogen irradiation due to the increase of unsaturated bonding of C=C, C=O bond concerning with cross-linkage of polymer chain.[3] Generally, heavy ion irradiation is efficient for surface hardness of polymer due to high LET. As a result of nano-indentation test, the surface hardness of PC enhanced up to 4 GPa after hydrogen ion irradiation. However, heavy ion irradiation of polymer has the disadvantage for color changes of polymer. Therefore, in this study, we aim to improve the surface hardness, weatherability and UV and visible light resistance for a long term without changing color of PC through hydrogen ion implantation.

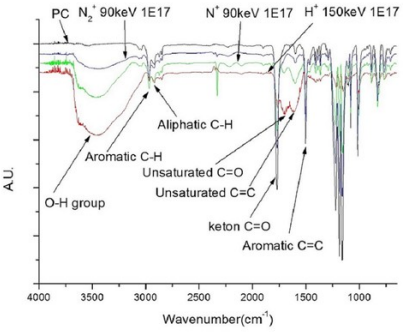

Figure 36: Microstructral changes of PC after ion irradiation

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Structural investigation of RBMK nuclear graphite modified by ion implantation

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Neutron irradiation of graphite-moderated nuclear reactors induces the radiation damage in the graphitic core components, which affects the physical properties of material. The understanding about dynamics of structural changes in nuclear graphite under irradiation conditions would provide insights into the migration of impurities (e.g. ^{14}N) as well as distribution of activation products (e.g. ^{14}C, ^{36}Cl). In order to avoid works with activated materials and quickly generate defects at level similar to induced by neutrons in the RBMK-1500 nuclear reactor, the ion implantation can be used as a substitute for neutron irradiation. The SRIM-2013 code was used to estimate such damage profile inside the surface layer of the graphite samples after irradiation, which would provide similar displacements per atom values for neutrons and ions fluxes. The structural changes at the surface of RBMK graphite samples were investigated by Raman and XPS spectroscopy in order to evaluate the structural disorder level before and after ion implantation as well as after thermal treatment. In this work the irradiation of the RBMK nuclear graphite was performed with different ion fluences creating defects level which are similar to those induced in the RBMK reactor. Ion implantation results in a strong disorder of the graphite samples surface, while the thermal treatment led to recrystallization at the fluencies below some critical level. The observed different annealing behaviors at the different locations of the analyzed area could be explained by the different nature of the defects as well due to presence of randomly distributed defect clusters in the inhomogeneous structure of nuclear graphite.

Effects of concentration quenching on the structural and luminescent properties of TiO_2 nanocrystals doped with Sm^{3+} and $Sm^{3+}Li^{+}$

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The structural and luminescent properties of TiO2 powders doped with Sm^{3+} and Sm^{3+}-Li^{+} ions synthesized by microwave irradiation and annealed at 200°C for two hours were studied. The structural and luminescent characterization was carried out using PL, XRD, TEM, HRTEM, HRSEM, EDS and IBA. The best photoluminescent emissions were obtained with a concentration quenching of 1% Sm and 10.5% Li (mol %). The TiO_2:Sm^{3+} and Li_xTiO_2:Sm^{3+} samples exhibit a strong characteristic emission generated by the excitation of Sm^{3+} ions. In both systems, the emissions correspond to the transitions from the excited $^4G_{5/2}$ level to the $^6H_{11/2}$, $^6H_{9/2}$, $^6H_{7/2}$ and $^6H_{5/2}$ levels. For the TiO_2:Sm^{3+} system, the photoluminescent emissions were originated by the indirect excitation of Sm^{3+} ions through an energy transference process from electron-hole pairs created in TiO_2 matrix. For the Li_xTiO_2:Sm^{3+} powder, the photoluminescent emissions were generated via a direct transfer of energy from the charge transfer band to the lanthanide ions. The Li_xTiO_2:Sm^{3+} powders show a photoluminescent emission that is 2.46 times more intense than that registered in the TiO_2:Sm^{3+} sample. The measure of Li, Sm, Ti and O atomic concentrations as a function of the Li and Sm doping concentrations of the prepared TiO_2:Sm^{3+} and Li_xTiO_2:Sm^{3+} samples was crucial to explain the luminescent mechanism, resulting in a Lithium composition of x= 0.017 for the Li_xTiO_2:Sm^{3+} sample. Nanocrystal size of 6 and 12 nm with anatase phase were observed for the TiO_2:Sm^{3+} and Li_xTiO_2:Sm^{3+}, respectively. Additionally, it was found that the Li_xTiO_2:Sm^{3+} nanocrystals show a remarkable 50% level of exposed $\{001\}$ facets.

Synthesis of the Ti2C MXene by ion beam sputtering and an effect of ion irradiation on its microstructure

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Thin titanium carbide (Ti_2C) films were prepared by the ion beam sputtering method from pure titanium and graphite targets. The deposited films were subsequently annealed at 600 °C for 6 h in vacuum (10^{-4} mbar) to promote intermixing and interaction of phases. After the annealing the samples were irradiated by the Ar+ ion beam with the fluence of 10^{15} ions / cm^2. The stoichiometry of the thin films was analysed by the combination of classical Rutherford back-Scattering (RBS) and Nuclear Resonance Analysis methods using the α-particle ion beam probe with energies: 2.0 MeV, 3.04 MeV (O resonance) and 4.27 MeV (C resonance). The stoichiometry was found close to $Ti_{2.2}C_1$. The synthetized film, however, contained considerable amount of oxygen (ca 30 at. %). The microstructure of the films was analysed, prior and after the irradiation, by the HR-TEM microscope (the analysis was carried out in UIC Chicago). Prior to the irradiation the structure was found to be almost fully amorphous with an irregular array of sub-nm large pores. The thickness of the as-prepared films was ca 67 nm. After the irradiation, an extensive crystallization and formation of a laminar structure of Ti_2C was observed. The thickness of the irradiated film was ca 83 nm, i.e., about 20 % higher than before bombardment. Obviously, the ion irradiation seemed to promote the consecutive processes of the Ti_2C crystallization, self-organization and laminar formation.

Effect of irradiation conditions by swift heavy ions on the microstructure and composition of PMMA

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Hydrogen ions of medium and high energy were extensively used in the past to study effects of irradiation on polymethylmethacrylate (PMMA); this is one reason why nowadays PMMA is a widely used material for micromachining by proton beam writing. This type of ion is characterized by low linear energy transfer (LET) and a dependence of material changing on ion implantation fluence and shows similarities to other forms of irradiation – X-ray, gamma-ray, electrons. At high LET the balance between cross-linking and scission is different from that of low LET. The data on elemental material modification, microstructure morphology quality caused by irradiation of ions with high LET is not thorough and investigation in this direction goes on. Our research is devoted to the compaction and carbonization of PMMA after micro-structuring by focused energetic heavy ions – ion beam lithography. 10 MeV O^{4+} and 6 MeV Si^{4+} ions were used in the experiment. The beam was focused using a compact Oxford triplet system. Parallel lines of 1 mm in length and 10 μm in thickness were created. Ion fluence, number of scan loops and beam blanking time were varied. The influence of the irradiation regime on PMMA elemental composition in microstructured parts and microstructure morphology were studied. The created microstructure was controlled by optical microscope. Scanning Electron Microscopy with Energy Dispersive X-ray spectroscopy (SEM-EDX) and Atomic Force Microscopy were used for the fine detail study as well as for checking the microstructure quality. SEM-EDX provided the elemental map of major elements (C, O). Micro-Raman spectroscopy was realized to follow the PMMA structure modification under the ion beam bombardment. It was shown that the beginning of the carbonization process depends not only on fluence, but also on effective ion flux. Creation of pattern by scanning in several loops allows the carbonization process to be shifted to higher ion fluence. The dependence of the line thickness on the scanning speed was observed, which means that during low-speed scanning, the sample is exposed not only to radiation, but also to heating.

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Erbium ion implantation into single- and nano-crystalline ZnO

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Zinc oxide (ZnO) is a II-VI type wide-bandgap semiconductor ($E_g \approx 3.3$ eV) hexagonal crystal with low phonon energy and very good physical and chemical stability [1]. Nowadays, ZnO crystal material is broadly studied in photonics for many applications, for example the nanostructures such as 1D nanowires as ideal building blocks for nanophotonics. It was demonstrated that such ZnO nanostructures show electroluminescence [2] as well as stimulated light emission [3]. However, for device applications, effective doping of the semiconducting nanostructures – modifying their electrical, optical and magnetic properties – could be required. Doping of materials with lanthanides follows mainly two different motivations: enabling either new optical properties or new magnetic properties of the modified materials. Erbium (+III) ions belong to the rare earth ions with the main emission transition around wavelength of 1.5 μm. Ion doping of nanostructured ZnO with Er ions is enabling to utilize both special properties of nanocrystals as well as light emission of laser-active ions. In this contribution we report on the results of Er^+ ion implantation into various ZnO nanostructures – nanostructured thin films and nanorods. The comparison with the Er^+ ion implantation into standard single crystal c-plane (0001) ZnO wafers was done, as well. Er^+ ions were implanted using 190 keV energy and implantation fluences in a range of 5×10^{14} to 5×10^{15} ions/cm^2. The nanostructured thin films were deposited using reactive magnetron sputtering technique. The thickness of the films ranged between 100–300 nm. Randomly oriented nanorods were grown on fused silica glass substrates by hydrothermal process and were characterized by Scanning Electron Microscopy (SEM). Er concentration depth profiles and a degree of crystal damage were measured using Rutherford Backscattering Spectrometry (RBS) and RBS/Channeling. Additionally, Raman spectroscopy was used to analyse structural modifications of the prepared samples. Luminescence properties of the prepared thin films were investigated by VIS-NIR luminescence spectroscopy.

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Au nanoparticle synthesis and subsequent modification in ZnO using energetic ions

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Metal nanoparticles (NPs) have generated a great interest in recent decades due to their remarkable optical properties, dominated by the localized surface plasmon resonances (LSPR). Applications of the plasmonic NPs are equally diverse and cover a large number of areas, like photonics, surface enhanced spectroscopies, biological imaging, and energy production etc. [1,2]. Noble metal nanoparticle dispersed in semiconductors are intensively investigated and recently Ag nanoparticle formation in lithium niobate and their morphology modification (elongation) by swift heavy ions (SHI) was observed [3], contrary such clear evidence of SHI irradiation influence on noble metal nanoparticle shape was not observed in AlAs containing Au nanoparticles [4]. Implantation damage growth, Au nanoparticle formation and their modification in morphology after energetic ion irradiation was followed in our experiment. Au nanoparticle were synthetized in ZnO various orientations a-plane, m-plane and c-plane ZnO using Au^+ 1 MeV ion implantation with the ion fluence 1×10^{16} cm^{-2} and subsequent annealing at 600°C in ambient atmosphere. Afterwards irradiation using O^{n+} 10 MeV with fluence 5×10^{14} cm^{-2} was used to modify Au nanoparticles morphology as well as to follow the structural modification of ZnO host matrix. Rutherford Backscattering Spectrometry (RBS) in channelling mode (RBS-C) and Raman spectroscopy study was used to follow the ZnO structural modification. Transmission Electron Microscopy (TEM) and UV Vis spectroscopy was employed to investigate Au nanoparticle morphology modification and optical response after oxygen energetic ion irradiation.

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Upgrades and developments on JANNUS Saclay Facility

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Ion accelerators have been used by material scientists for decades to investigate radiation damage formation in nuclear materials and thus to emulate neutron-induced changes. The versatility of conditions in terms of particle energy, dose rate, fluence... is a key asset of ion beams allowing for well-controlled analytical studies. In addition, very short irradiation times and handling of non-radioactive samples dramatically curtail the global cost and duration as compared to in-reactor testing. Coupling of two or more beams and use of heated/cooled sample holders pave the way to observation of microstructural and property evolution in various extreme radiation conditions more closely mimicking the nuclear environments. For these reasons, multiple ion beam facilities have been commissioned worldwide. In France, at CEA Paris-Saclay, the JANNUS Saclay facility for Joint Accelerators for Nanosciences and Nuclear Simulation comprises three electrostatics ion accelerators with complementary performances. The unique triple beam facility in Europe allows the simultaneous irradiation with heavy ions (Fe, W,...) for nuclear recoil damage and implantation of a large array of ions including gasses for well-controlled modelling-oriented experiments. To continue to improve its performances and enlarge its studies, the JANNUS Saclay facility continuously upgrades equipment and develops new experiment set-ups such as a high temperature chamber and a cryogenic chamber with resistivity measurement.

The formation of H_2 molecules in a Fe-12%wt.Cr-ODS steel irradiated with dual and triple ions beams characterized by Raman spectroscopy and SIMS

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Oxide-dispersion strengthened (ODS) ferritic steels are candidates for a use as first-wall materials in future fusion reactors. This application will lead to neutron bombardment and, helium and hydrogen productions by transmutation. In such an environment, ODS steels will undergo modifications with the incorporation of hydrogen and helium. In order to study these effects, we investigated the hydrogen trapping in a Fe–12wt.%Cr–0.4wt.%Y_2O_3 steel using surrogate conditions by triple ion irradiation with $Fe^{8+}/He^{+}/H^{+}$ beams [1]. The synergistic effects of multi-beam irradiations were specifically studied by comparing the triple beam irradiation with single beam of H^{+}, dual beams of 24 MeV Fe^{8+}/ H^{+} and 1.0 MeV He^{+}/ H^{+} irradiations. Irradiated samples were characterized by secondary-ion mass spectrometry for profiling hydrogen and Raman spectroscopy for profiling H_2 molecules [2]. The formation of the H_2 dihydrogen molecule is observed only when the ODS steel is co-irradiated with H and He beams and with $Fe^{8+}/He^{+}/H^{+}$ beams [3]. These results show that irradiation damage and helium play a role in the retention of hydrogen in the specimen.

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Detection enhancement for nitrogen vacancy centres using 2D diamond cavities

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The negative charged nitrogen vacancy (NV) centre in diamond offers a promising variety of properties for quantum technological applications like quantum computing or quantum sensing [1]. Many of this applications would benefit from enhancing the readout process. This could be done by coupling the NV centres with optical cavities. Our approach for this coupling is to embed a thin diamond film, containing NV centres, in between two mirrors to form a two dimensional cavity. To create a mono crystalline diamond film we irradiate a bulk diamond with an ion beam creating damage that is sufficient to amorphise the crystal at a specific depth. Since ion beams create the maximum damage close to their maximum penetration depth, the surface layer of diamond remains sufficiently crystalline to recover in a subsequent annealing step [2]. Thus this process forms a diamond thin film on an amorphous carbon layer on top of a bulk diamond. To unpick the diamond thin film the different chemical bonds of amorphous carbon and diamond can be exploited. The amorphous carbon can be removed by heating the sample in an oxygen atmosphere while the diamond stays stable. After this step the thin film can be transferred to a glass substrate with mirrors to build up the cavity. To tune the cavity to the preferred wavelength it is necessary to create a diamond film having a thickness of about half the wavelength of light in the medium. To enhance the NV centre fluorescence film thicknesses less than 150 nm are needed. Moreover this process could be used to create structures like distributed Bragg reflectors directly in bulk diamond.

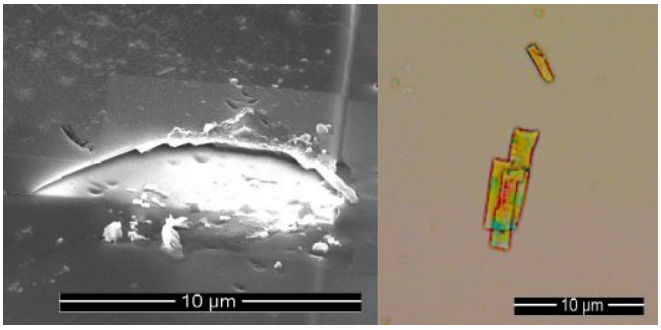

Figure 37: SEM micrograph under an angle of 52 degree with respect to the sample, showing a gap between diamond thin film and bulk diamond (left). Optical micrograph of diamond thin film flakes transferred to a glass substrate (right).

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Nitrogen implantation with a scanning electron microscope

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Established techniques for ion implantation rely on technically advanced and costly machines like particle accelerators that only few research groups possess. We report about a new and surprisingly simple ion implantation method that is based upon a widespread laboratory instrument: The scanning electron microscope (SEM). We show, by the example of nitrogen implantation into diamond, that the SEM can be utilised to ionise atoms and molecules from the residual gas (by collisions with electrons of the beam) and subsequently accelerate and implant them into an insulating sample by the effect of a potential building up at the sample surface. The implanted nitrogen ions are subsequently converted (by thermal annealing) into nitrogen vacancy (NV) centres which are further measured by fluorescence confocal microscopy. To provide evidence that the observed centres are truly generated in the way we describe, we supplied a 98% isotopically enriched ^{15}N gas to the chamber, whose natural abundance is very low. Thus, we were able to verify that the investigated centres are actually created from the ^{15}N isotopes, by employing the method of optically detected magnetic resonance. Here, the nature of the nitrogen isotopes of the NV centres is revealed by the hyperfine coupling between the electron spin of the centre and the nuclear spin of the nucleus. Additionally, we show that this method is compatible with lithography techniques using e-beam resist, as demonstrated by the implantation of lines using PMMA.

Platinum silicide formation on silicon carbide substrates via controlled solid-state diffusion

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Platinum Silicide formation on silicon carbide at relatively low temperatures was been investigated. Multi-layered thin films of Pt and amorphous silicon of different thickness were deposited on SiC substrates. The first set of samples had 30 nm wide Pt layer on 20 nm wide Si layer while the second set had 15 nm wide Pt layer on 20 nm wide Si layer. The samples were annealed in vacuum from 100 °C to 400 °C. The interdiffusion, reaction temperature, silicide phase identification and surface morphology were investigated with Rutherford backscattering spectrometry, grazing incidence X-ray diffraction (GIXRD) and scanning electron microscopy (SEM). The RBS results indicate that interdiffusion starts to occur at Pt/Si interface after annealing at 200 °C for the Pt (30 nm)/Si (20 nm) sample. The solid-state reactions in this sample start at 250 °C with the formation of Pt_2Si which was confirmed by GIXRD analysis. The width of the Pt_2Si phase increased up to 400 °C when the reaction was complete. The solid state reactions in the Pt (15 nm)/Si (20 nm) sample showed the formation of PtSi phase. The reactions in the two samples did not involve the SiC substrate which was still intact. Pt silicides that formed on SiC had good contact with SiC substrate and did no delaminate.

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A Novel High Bandwidth Bipolar corrector Power Supply in Taiwan Photon Source

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From 2012 to 2017, Taiwan government has a most important technology project is Taiwan Photon Source (TPS), the total budget of TPS fund to over US300 million. It set up a synchrotron storage ring (electron energy of 3.3 GeV, circumference of 518 m, and low emittance) that provides one of the world's brightest synchrotron sources of x-rays. This study presents a compensator design for corrector magnet power supply to avoid limitations in stabilizing the frequency when the machine output current load is valid. A lead–lag compensator had been built in a full-bridge converter to improve the system bandwidth. Lead–lag compensators influence various disciplines, such as robotics, satellite control, automobile diagnostics, and laser frequency stabilization. A prototype DC/DC corrector power supply using a MOSFET full bridge circuit with a 200kHz PWM control signal and achieved up of 2kHz bandwidth with less than 3-dB attenuation for a small refer signal of the maximum operation current of 10 amperes. Finally, a 50V output voltage and 10A output current prototype converter is fabricated in the laboratory, the experimental results, the effectiveness of the control loop design can be verified from the gain margin and phase margin.

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Classification of Thai Mutant Jasmine Rice using Synchrotron Radiation-based on FTIR Spectroscopy

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Thai jasmine rice (*Oryza sativa* L. cv. KDML 105) is very popular in the world rice market due to its dominant features, which are unique aroma, pleasant flavor, slender kernel, and soft texture when cooked. Generally, KDML 105 can be cultivated only once a year during July – December because of its photoperiod sensitivity and low disease resistance. Aiming to increasing the product yield, low energy ion beam bombardment was used to bombard on the KDML 105 rice seeds to induce genetic modification at the Plasma and Beam Physics Research Facility, Chiang Mai University. There were several mutant rice traits obtained from this technique. The selected mutant rice traits based on their satisfying quality are HyKOS3, HyKOS3-1, HyKOS16, HyKOS21, and HyKOS22. In this research, we are interested in the chemical contents – amylose, protein, and lipid – of rice grains for the original KDML 105 rice (control rice) and its mutants. There are several kinds of techniques that can be used to investigate the physical and chemical properties of rice. In this project, however, we concentrated on using the synchrotron radiation-based Fourier transform infrared (FTIR) spectroscopy to investigate the chemical contents of the control rice and mutant samples. The results were compared and verified with the standard AOAC official method. The broadband and high brightness mid-infrared radiation was obtained from the synchrotron radiation of the infrared beamline (BL 4.1) at the Synchrotron Light Research Institute (SLRI), Thailand. The radiation has the wavenumber and the photon energy in a range of 2.5 – 100 microns and 0.01 – 0.5 MeV, respectively. The Vertex 70 spectrometer with a 100-micron narrow band MCT detector and the Hyperion 2000 microscope were used in the experiment at the beamline end-station. Then, the FTIR spectroscopy data were analyzed using the principal component analysis (PCA). The experimental results clearly show the difference of the chemical contents in the 4 considered rice cultivars, allowing trait classification. The detailed results and the possibility of using this technique as a tool for effectively rapid identification for mutant rices will be further discussed in this conference.

Experimental and Theoretical Investigations on Mechanism of Natural Rubber Vulcanization Using Accelerator-based Electron Beam Irradiation

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Electron beam irradiation is interesting techniques among others for natural rubber vulcanization. In this process, the accelerated electrons will break the chemical bonds between carbon and hydrogen. This results in the generation of free radicals in several carbon atoms of the rubber molecules. The molecules' cross-link can happen at the free radical positions. Investigation on this process mechanism was conducted. For the experimental study, the synchrotron-based Fourier transform infrared (FTIR) spectroscopy was used to investigate the possible positions of free radicals in the vulcanized rubber. The irradiation doses for the rubber samples was varied in a range of within 200 kGy. For the theoretical study, we focused on the generation of free radicals in different positions in the rubber molecule. Molecular structures and energies in these reactions were calculated using the density functional theory. Moreover, the transition states and reaction pathways were investigated using the linear and the quadratic synchronous transit methods. The activation energies, which are related to the efficiency of each reaction, were calculated. Finally, we compared the experimental results with the theoretical output to conclude the appropriate positions of radical carbon atoms for natural rubber vulcanization.

Synchrotron soft X-Ray microscopy and XRF to monitor biochemical changes induced by carbon nanotubes exposure in Chang liver cells

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A new health risk coming from the release of nanomaterials on the environment calls for detailed qualitative and quantitative examination. The potential risks of the carbon nanotubes (CNTs) and other nanomaterials are currently the subject of hundreds of studies. Carbon nanotubes are promising nanomaterials with outstanding properties and are relevant for many scientific and industrial application fields, including biomedicine and biotechnology. CNTs have also emerged as efficient drug delivery carriers in biomedicine [1]. Numerous investigations have, in recent years, aimed at evaluating the health impact of CNTs in an occupational, environmental and biomedical context. Recent research suggests that they have toxic effects similar to those of asbestos fibers, possibly because they share some of their physico-chemical properties. As-prepared, "raw" CNTs usually contain significant amounts of ultrafine metal particles derived from the original growth catalyst or support. A number of studies have indicated that these metals are particularly relevant when evaluating the biological effects of CNTs since they can induce oxidative stress [2,3]. Our study aimed at investigating and following CNT interaction and internalization in liver Chang cells and possibly reveal early toxicity signs, like morphological changes and altered metabolisms of endogenous elements. Chang liver cells are a non transformed cell line which closely resembles normal human liver in the expression of key proteins of the major hepatic biochemical pathway. This cell line is a conventional model in toxicology, commonly used for testing potential hepatotoxicity of drugs and natural compounds in vitro, since cells tend to respond fast with evident changes. In our study, Chang liver cells were exposed to row SWCNTs or partially purified SWCNTs for 6 hours. Fixed cells were then analyzed by conventional light microscopy and SEM, and subsequently by XRM and LEXRF. Conventional microscopy suggests that all tested CNTs produce cell membrane alterations and intracellular vacuolization. These changes are better confirmed by Phase Contrast images from soft X-ray microscopy revealing the intracellular localization of the nanomaterials in close relation with the numerous intracellular vesicles of the treated cells. Further XRF analyses revealed that the exposure to "raw" CNTs causes the appearance in treated cells of hotspots containing Fe and Cu. Some spots are in relation with the intracellular vesicles. The partially purified CNTs produce important morphological changes in the Chang liver cells, but do not seem to significantly alter the Fe and Cu distribution.

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XRF analyses reveal that capacitation procedures produce changes in magnesium and copper levels in human sperm

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Capacitation is a biochemical step of the maturation of spermatozoa making them competent to fertilize the oocytes. This step can be induced in vitro and this usually happens before Artificial Reproductive Technology (ART) procedures with the aim of isolating as many motile and viable spermatozoa as possible, while eliminating those non-motile or dead. The most frequent protocol is the so called "swim up", consisting in an incubation of spermatozoa with an albumin containing medium and subsequent washes. The quality and motility of the sperm is routinely measured by the operators through light microscopy. In the present study we tested the possibility of adding quality information by evaluating the content of some light elements and metals by X-ray Fluorescence (XRF) imaging, similarly to what we previously performed for female primordial gametes [1]. Total semen (after fluidification) and capacitated sperm from 4 healthy patients were first evaluated by light microscopy for purity and motility: all patients had an initial total motility of 20-70%, progressive motility of 15-60%, while capacitation produced sperm with 80-100% motility. Different aliquots from total and capacitated sperm preparations were washed in physiological solution and deposited onto SiN_4 windows. The air dried samples were raster-scanned under the microXRF set-up of TwinMic at Elettra synchrotron, at an energy of 1.5 keV and with a pixel size of 1 μm. X-Ray Microscopy images at higher resolution where also collected to better correlate elemental distribution to the cellular structures. Using the PymCA software, average spectra were extracted on the heads of hundreds of sperm cells, from samples before and after capacitation, and compared. With this approach we identified some major differences in elemental concentration between the two conditions, indicating that Mg and Cu sperm contents are greatly reduced by capacitation, while there is an apparent Na increase. Since capacitation is a selection of high motile cells, the lower levels of Cu could be considered a sign of good semen quality: this is in agreement whit what previously suggested by others [2]. At the same time, for the first time we suggest that high Mg in semen preparation is associated with poorer semen quality, since inversely correlates with motility. The results may have translational potential proposing elemental imaging to advantage ART procedures.

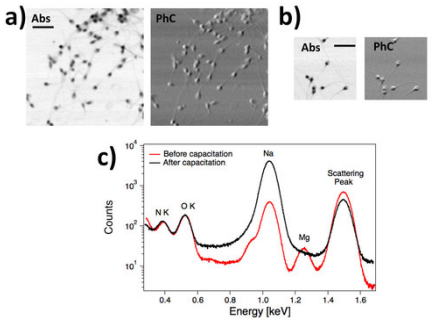

Figure 38: X-ray absorption (Abs) and phase contrast (PhC) images of sperms before (a) and after (b) capacition together with the average spectra acquired on the sperms head for both cases. Scale bar is 10 μm.

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Retrieving Sample Topography from Synchrotron XRF and STXM examination of Diatom Microalgae

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X-ray Fluorescence spectroscopy (XRF) is one of the most widely used techniques for elemental analysis of a wide variety of samples. XRF emission is an isotropic phenomenon, however XRF detection depends on the detector angular position. Despite this known angular dependence, artefacts remain an issue especially when using micro- or nano-X-ray beams and detectors located at small angles with respect to the sample's surface. The sample topography and surface roughness might play an important role and may cause misleading interpretation if not carefully evaluated. This is particularly true for inhomogeneous samples with non-flat surface such as biological specimens However this angular dependence may be also an advantage in some cases: if correctly exploited it can allow retrieving topographical information about the analysed specimens. This work is illustrating an ongoing research project on this topic [1]. The poster will present the results of a synchrotron experiment where diatom microalgae [2] were studied through Scanning Trasnmission X-ray Microscopy (STXM) and XRF (Fig. 39) using 8 silicon drift detectors (SDD) at the TwinMic beamline [3] (Elettra Sincrotrone Trieste) for the purpose of advancing the research on XRF topography.

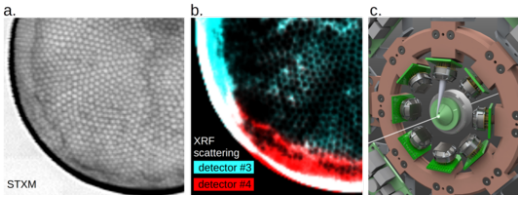

Figure 39: (a) STXM map of a portion of a diatom: 60 μm $\times$ 60 μm with 500 nm step size, 1450 eV incident photon energy. (b) XRF map of Scattering peak highlighting the detection difference from 2 of the 8 SDDs

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