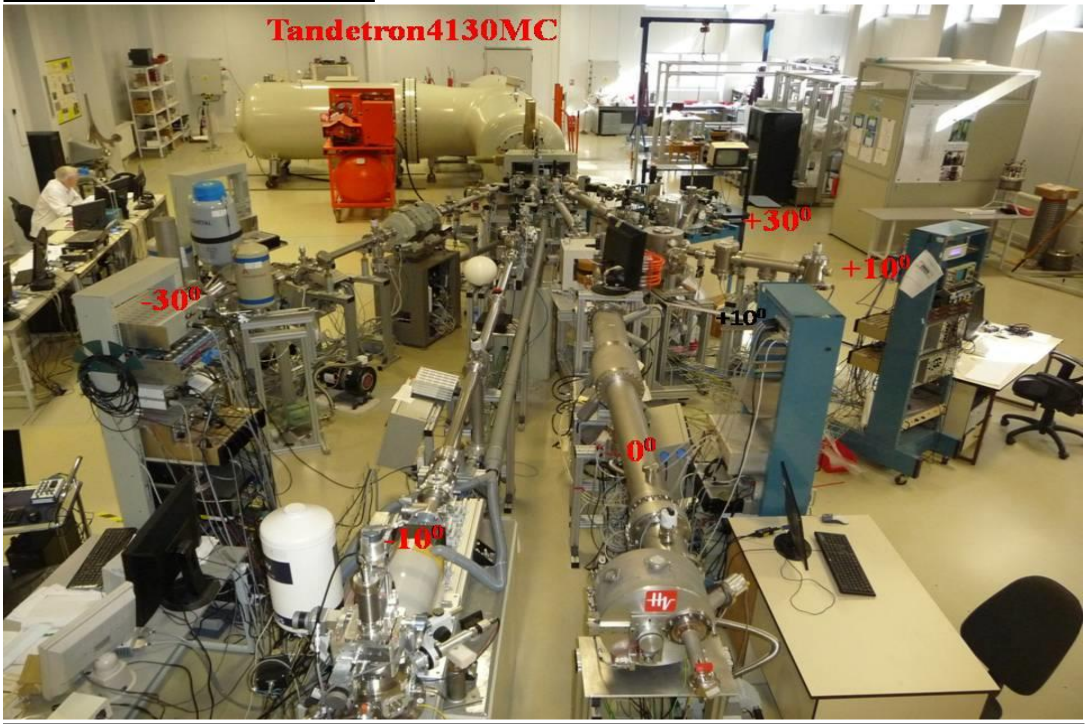
The research activities realized at Department of Physics and Tandetron Laboratory (Nuclear Physics Institute of the Czech Academy of Sciences)

Tandetron Laboratory NPI CAS

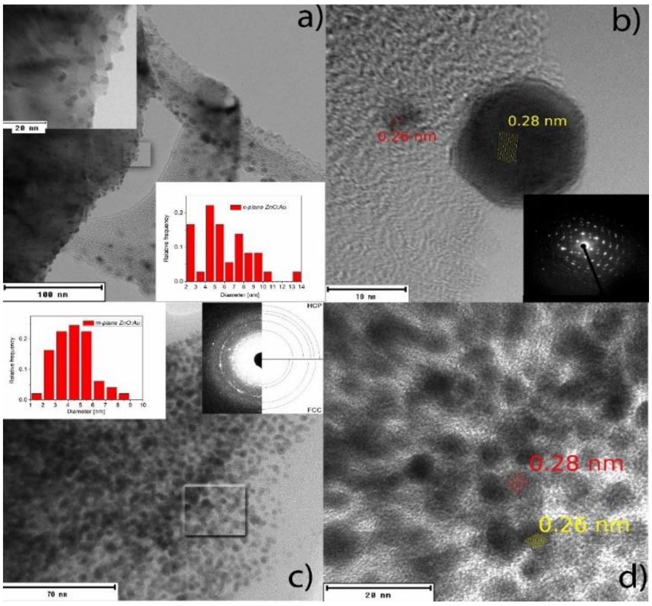


1. Ion synthesis of nano and microstructure and their characterization using ion beam analyses

Nanostructures for optics and photonics will be produced in crystalline and amorphous materials using ion implantation and various deposition techniques. More attention is paid to the study of single-crystal materials, glasses and synthetic polymers implanted. The combination of an appropriate substrate and implanted ion makes it possible to create materials with the desired properties (optical, electrical, magnetic etc.).

Activities

- The nanostructures will be deposited in crystals materials using the ion beam implantation of laser active ions (rare earth), transition metal ions and/or light ion species. The main field of interest is the connection of the structural and elemental changes after the ion implantation in crystals to the optical, electric and magnetic properties of the deposited nanostructures. The characterization of nanostructures in crystals will be accomplished by innovative nuclear analytical methods (RBS channeling, ERDA Time of flight spectrometry) and other nuclear analytical methods (PIXE, PIGE, ERDA, etc.) complementary methods will be used for structural studies (Raman spectroscopy, micro luminescent analysis, XRD) in collaboration with the external partners to shed more light into the structural changes after ion beam implantation which are closely connected to the optical, ferromagnetic and electrical response of such nanostructures applicable in spintronics, optics and photonics.
- The nanostructures will be deposited in amorphous materials (glass, polymers). Silver and gold nanoparticles will be deposited by ion beam implantation in silica glasses and polymers. The prepared nanoparticles are characterized by nuclear analytical methods RBS, ERDA, ERDA TOF (elemental depth profiling, the elemental changes in connection to the implantation irradiation) and the morphology of the nanostructures will be followed with the external partners (XPS, TEM, AFM). The evaluation of the interior morphology nanostructure parameters will be analysed and the simulation of the induced radiation damage, defect etc. will be provided simultaneously with the simulation of electrical properties.



- The nanostructures are potentially perspective in photonics due to their extraordinary optical properties. Importance is attached also to secondary processes, such as the migration and agglomeration of implanted atoms, leading to the creation of nanoparticles during the post-deposition annealing procedure used for the stabilization. Metal nanoparticles can e.g. exhibit a nonlinear optical response several orders of magnitude larger than bulk metals due to surface plasmon resonance. Nanoparticles formed in amorphous or crystalline optical materials can also significantly affect other optical properties such as luminescence. The optical properties will be analysed to get the desired information.

2. Heavy ion energy losses and straggling study and computer modelling of ion and matter interaction

- Material modification by ion beams is advantageous since various approaches can be applied to achieve the required physico-chemical properties in a well controllable way. Accurate knowledge of the interaction of energetic ions with matter is crucial for the effective use of ion beams for both material modification and characterization. The assembly of well-organised nanostructures into prospective architectures as well as the characterisation and subsequent knowledge of the crystal field around the implanted nanoparticles offer a real opportunity for the fabrication of highly functional devices. The measurement of the energy stopping power and energy straggling of ions in different materials is a difficult task, and the already published results are quite varied. The expected aims of the research will be mainly in the basic research, as it offers a thorough systematic modelling of the penetration of implanted particles into amorphous and crystalline materials and also a systematic study of the changes that the implanted particles cause in the structure.

Activities

- Energy losses and energy straggling of swift heavy ions in polymers and related amorphous materials will be studied to get the original experimental values for the further use in dosimetry, detector development and to validate the present semi-empirical models, which will be tested and compared to find out the best theoretical model for the energy loss prediction.
- The simulation and prediction of the energy losses and straggling will be accomplished using different semi-empirical approaches Core and Bond model, Braggs rule and charge exchange model implemented in SRIM, MSTAR and other simulation codes, which will be modified for the testing of the various interaction phenomena between ion and matter and their influencing of the energy losses in the different materials.

3. Ion beam analysis and ion beam synthesis of defect and nanostructures in graphene and carbon based structures

Graphene, a two-dimensional (2D) sheet of carbon atoms arranged in a honeycomb lattice, attracted recently a huge scientific interest, due to its outstanding transport properties, chemical and mechanical stability and to the scalability of graphene devices to nanodimensions. Graphene is a remarkable material with excellent electronic, mechanical, and thermal properties. Its unique low-energy electronic properties stem from the massless and chiral behaviour of electrons never manifested before in condensed-matter physics. However, similar to conventional nanostructures, graphene is not immune to disorder and its electronic properties are expected to be strongly influenced by the presence of defects. The use of graphene devices in space applications, in particular graphene based solar cells which have been already demonstrated, and the stability of these devices in the harsh space environment is best studied by the interaction of MeV ions with graphene. Since graphene is a zero band gap semiconductor its application are limited by this factor. However this limitation can be easily overcome by its combining with other 2D materials. Combination of graphene with layered transition metal dichalcogenides (TMDCH) gives us a great opportunity to develop new micro- and opto-electronic devices and novel energy conversion materials for fuel cell, green hydrogen energy and other electrochemical devices with outstanding application potential.

Activities

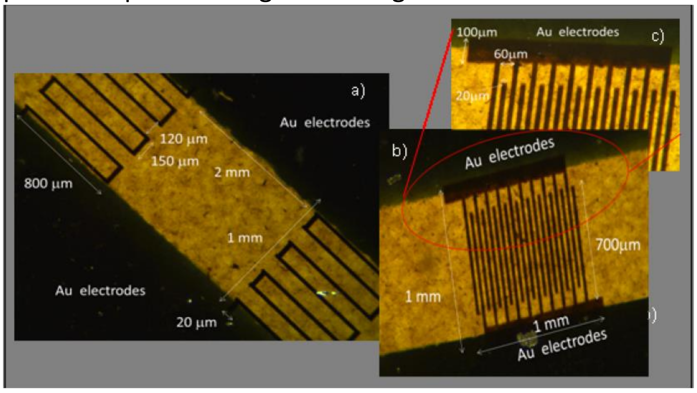
- Only few works have been reported on energetic ion irradiation in graphene. Ion bombardment can be combined with post-irradiation treatment to achieve a desired functionality, e.g. by depositing metal atoms on irradiation-induced defects. All these results indicate that understanding defect production in graphene under ion bombardment is mandatory for successful treatment of graphene by ion beams. At the same time, in the context of fundamental aspects of ion-solid interaction, graphene is a very unusual target. Creation of defects in graphene under ion bombardment will be provided in the context of quantitative assessment of the amount of irradiation-induced damage in graphene samples.
  Light ions will be used in MeV ranges to investigate the energy losses, intentional defect introduction and the modification in the graphene based structures. The implantation of various metal ions with various energies will induce the structural changes and/or intentional implantation to get new structures in graphene.
- EHigh ion fluence irradiation with a focused ion microbeam can be used for cutting and patterning graphene with a high spatial resolution. Ion microprobe represents the best and widely used way to introduce controlled amount of defects in solids and can be used to locally (by focused ion beams or masking) induce modifications in graphene. Microbeam device at Tandetron laboratory will be used for such micropatterning using heavy ion beams from Tandetron accelerator. Elemental composition, elemental-depth profiling and structural properties: Rutherford Back-Scattering spectrometry (RBS) and Elastic Recoil Detection Analysis (ERDA) and ERDA-TOF spectrometer.

4. Ion microprobe application and development

Great technological progress was made after the **ion microbeam** development in our laboratory. The ion beam from the accelerator passes through the combination of several magnetic quadrupole lenses with alternating polarities focusing high-energy ions. The samples are irradiated with an ion beam focused on a spot of about 1 μm in diameter and standard IBA techniques are used for the characterization of the irradiated object. The beam scanning over the sample surface makes it possible to determine the 2D or 3D distribution of elements with nm depth resolution and lateral resolution limited by the size of the beam spot. Ion microprobe is very powerful tool for the investigation of the elemental composition in biological, environmental and geological samples.
The microbeam will be used for the study of the trace elements in the aerosols deposited in nucleopore filters collected from the different public places to follow the air pollution. Microbeam study of the geological samples (granitic rocks and others) will provide 2D elemental mapping in the rock inclusions. The microbeam study of different biological samples will be realized follow the trace element and discover either the information about the trace elements, nanoparticle distribution in living cells and tissues or in the archaeological artefacts to follow the provenance of the archaeological finds.
New microbeam vacuum chamber is planned including movable sample holder, X ray detectors, to enable us the progressive and sophisticated studies of elemental tomography (recording the elemental map from different lateral cuts of the sample which can be reconstructed to 3D precise maps and visualization of the nano and microstructures), which is rare in the world wide context.

Activities

- **Ion beam writing (IWB)**
  The direct writing capability makes this technique suited for a great variety of applications such as microfluidics and optotronic metamaterials, bioscience, miniaturized sensors integrated in micro/nano electro mechanical systems. Proton beam writing technique was recently introduced at Tandetron accelerator. It has been used, to produce three-dimensional (3D) micro-structures in poly(methylmethacrylate) by 2.0 MeV and 2.6 MeV protons micro-beam. A high precision promising technology to produce micro-nano cavities inside materials without the use of cutting or opening and recovering of the sample was established and will be further used.
  Ion microprobe will be applied on the microstructure deposition in polymers and glasses using heavy ion focused beams for optics and electronics, which is unique experiments also in the European context. Various crystalline and glass samples will be irradiated to produce optical waveguides using focused microbeam.



- **Scanning Transmission Ion Microscopy (STIM)**
  Scanning transmission ion microscopy (**STIM**) is a technique in which transmitted ions (e.g., protons or helium ions—alpha particle) are detected; the way the particles loose energy in the sample is exploited to provide information on the structure and density variations within the sample. STIM is useful for correlating the trace element data with structural features and will be used in the microstructure study to facilitate positioning of the elemental maps. STIM is highly applicable in biological materials and patterned microstrucres where the very thin samples for transmission experiments are used. The ion beam has minimal spreading when it passes through the very thin sections of the sample and this makes imaging of fine details possible. Fine details of microstructures are highly desirable in great variety of applications such as microfluidics and optotronic metamaterials, bioscience, miniaturized sensors integrated in micro/nano electro mechanical systems.