CONDENSED MATTER RESEARCH AT THE EG-5 ACCELERATOR

A.S. Doroshkevich[1,2], T.Yu Zelenyak[1], A.I. Madadzada[1,4], A.N. Lihachev[1], M.A. Balasoui[5], E.V.Lychagin[1], P. Badica[6], M. Stef[7], B. Jasinska[3], I.M. Chepurchenko[1], K.Ye. Studnev[1], T.V.Phuc[1,8,9], L.H.Khiem[8,9], P.L.Tuan[1,10], Vesna Teofilović[11], Ivan Ristić[11], Roman Balvanović[12,13,14], Zoran Jovanović[12,13,14], A. Stanculescu[15], C. Mita[16], D Mardare[16], J. Żuk[3], D. Luca[17]

[1] Joint Institute for Nuclear Research, Dubna, Russia;
[2] Donetsk Institute for Physics and Engineering named after O.O. Galkin, Kiev, Ukraine;
[3] Institute of Physics, Maria Curie-Skłodowska University, Lublin, Poland;
[4] National Center for Nuclear Research, Baku, Azerbaijan;
[5] Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH), Bucharest Romania;
[6] National institute of materials physics, Măgurele, Romania;
[7] West University of Timisoara, Timisoara, Romania;
[8] Graduate University of Science and Technology, Vietnam Academy of Science and Technology, 18 Hoang Quoc Viet, CauGiay, Ha Noi10000, Vietnam;
[9] Institute of Physics, Vietnam Academy of Science and Technology, 10 Dao Tan, Ba Dinh, Ha Noi10000, Vietnam;
[10] Vietnam Atomic Energy Institute, 59 Ly ThuongKiet, HoanKiem, Hanoi, Vietnam;
[11] University of Belgrade, INN Vinča, Laboratory of Physics;
[12] National Museum Belgrade, Serbia;
[13] University of Belgrade- Archaeology Department, Serbia;
[14] National Museum Požarevac, Serbia;
[15] National Institute of Materials Physics, Magurele, Romania;
[16] "Alexandru Ioan Cuza" University of Iasi, Faculty of Physics, Iasi, Romania;
[17] "Gheorghe Asachi" Technical University of Iasi (TUIASI), Iasi Romania

E-mail: doroh@jinr.ru

The purpose of the electrostatic accelerator (ESA) EG-5. Along with the experimental nuclear reactor and the IREN electron accelerator, the EG-5 ESA occupies its unique niche as part of the complex of nuclear physics facilities of the FLNP. The beams of high-energy particles produced using EG-5 have extremely high energy stability (± 15 keV per 2 MeV), which makes it possible to conduct unique studies of the elemental composition of solids, including deep profiling, conducting studies of nuclear reactions on fast neutrons, etc. ESA EG-5 is a universal research device that allows to conduct both elemental composition studies and physical, chemical and biological modification of objects of inanimate and living nature, respectively. In particular, there is a unique possibility of irradiating materials with hydrogen ions, helium and fast neutrons, the ability to create structures with layer-by-layer variation of phase and chemical composition through ion implantation in the surface layers of materials, and to cause mutagenesis in biological objects.

The range of ESA energies allows simulating the radiation conditions of near space and nuclear reactors. The absence of slow neutrons in the spectrum produced by the neutron installation allows to conduct irradiation without induced radioactivity, which is extremely important when studying unique samples, in particular, objects of cultural heritage.

Condensed matter physics At the moment, using the EG-5 accelerator, studies are being conducted on the resistance to neutron and proton radiation of Al_2O_3 - ZrO_2 - Y_2O_3 - ceramics, NiTi - alloys promising for the radiation-resistant superconducting solenoids; high-entropy alloys promising for the manufacture of thermonuclear reactor shell; unique studies of degradation of semiconductor heterojunctions of solar cells (SiO_2/TiO_2) under the action of cosmogenic radiation [1]. ESA is used to perform physical modification of materials by a beam of high-energy ions to interface materials with significantly different temperature expansion coefficients by creating helium or hydrogen porosity (Poland - JINR Cooperation Project PPPB/120-26/1128/2022). Using the EG-5 installation on helium ion beams, unique non-destructive experimental studies of elemental depth profiles (RBS method) [2] of metal oxide ceramics based on ZrO_2, Al_2O_3, CuO, ZnO, SnO_2 [3-4], high-entropy metal alloys, borides, nitrides, semiconductors based on Si, SiO_2, ZnO_2, GaAs [5-7], are carried out. The sensitivity limit of the method is 10^{15} at. см cm^{-2} [8], which allows, for example, to determine the impurity content of heavy elements in the amount of 0.001 at.% [9] or to recognize the substance as a layer up to 1 nm thick. There is a unique opportunity to study layered structures. Within the framework of the JINR – Participating countries cooperation program, a study of multilayer semiconductor architectures such as $TiO_2/SiO_2/Si$, $SiO_2/TiO_2/Si$, GaAs; metallic (Fe, Cu) and (ZrO_2) solid solutions, nanopowder and micropowder systems of the composition Al_2O_3 + x% Y_2O_3, where x = 0, 0.5 and 1, nanoscale diamonds, sphalerites, perovskites, ferrites, etc. [10] was carried out.

Radiation biology. On the example of the sorts "Sur sului", "AiKerim" and "Leader" in cooperation with the Kazakh Rice Research Institute named after Jakhaev the possibility of obtaining a drought-resistant rice sort through radiation mutagenesis using neutron irradiation is in investigating.

The study was funded by the Plenipotentiary Representative of the Government of the Poland Republic in JINR within the framework of the Poland – JINR Cooperation Projects PPPB/120-25/1128/2022, PPPB/120-26/1128/2022 and within the framework of the JINR-Romania cooperation program in 2022 (topic 03-4-1128-2017/2022 and 04-4-1143-2021/2025)..

[1] T.V. Phuc, and all. (2022). Variation of TiO2/SiO2 mixed layers induced by Xe+ ion irradiation with energies from 100 to 250 keV. Materials Science and Engineering: B, Volume 277, 115566. https://doi.org/10.1016/j.mseb.2021.115566.

[2] Oura K. et al . Introduction to Surface Physics / M.: Nauka, 2006— - 490 p.

[3] Maletsky A.V. and all. (2021). Structure formation and properties of ceramics based on θ-Aluminium oxide doped with stabilized Zirconium dioxide. Ceramics International https://doi.org/10.1016/j.ceramint.2021.03.286.

[4] D.R.Belichko, and all. (2020) Influence of hafnium oxide on the structure and properties of powders and ceramics of the YSZ–HfO2 composition. Ceramics International 10.1016/j.ceramint.2020.09.151.

[5] P.L. Tuan, and all. Investigations of chemical and atomic composition of native oxide layers covering SI GaAs implanted with Xe ions, Surface and Coatings Technology, Volume 394, 25 July (2020), 12587. http://dx.doi.org/10.1016/j.surfcoat.2020.125871

[6] P. Horodek, and all. (2015) Positron beam and RBS studies of thermally grown oxide films on stainless steel grade 304, Applied Surface Science, 333 96–103

[7] M. Kulik, and all. (2015) Effect of N+2 ion implantation and thermal annealing on near-surface layers of implanted GaAs", Acta Physica Polonica A 128 (5), 918-922.

[8] Komarov and all. Non-destructive analysis of the surface of solids by ion beams. Mn.:-University.1986, - 256p.

[9] Tashlykova-Bushkevich I.I. The Rutherford backscattering method in the analysis of solids. Educational and methodical manual. Mn.: BSUIR, 2003. – 52p.

[10] Tatarinova Alisa and all. (2021) Application of the Rutherford Backscattering Method in Powder Nanotechnology / Spring Meeting of the European Materials Research Society (E-MRS) VIRTUAL Conference from May 31st to June 3rd, 2021. ALTECH 2021 - Analytical techniques for precise characterization of nano materials.