ION BEAM ANALYSIS

Alexander Kobzev, Miroslav Kulik
Frank Laboratory of Neutron Physics

INTRODUCTION

The purpose of this project is studying of nuclear physics analytical methods of investigation of near – surface layers of solids. The analytical methods such as Rutherford Backscattering Spectrometry (RBS), Elastic Recoil Detection (ERD) and Particle Induce X-ray Emission (PIXE) are used for investigation of the depth distribution of different elements in near surface layers of solids [1-3]. The $^4He^+$ ions beam with energy 2-3 MeV is required for such kind of investigations. These methods allow measuring element contents of solid samples without their destructions because the beam intensity does not exceed 1μA. The Van de Graaff accelerator of JINR produces the helium ions beams and protons beams with energy in region 1-3 MeV with energy spread less then 700 eV. The modern spectrometers of charged particles allow to measure the spectra of scattered $^4He^+$ ions with rather high energy resolutions (for 5 MeV helium ions – 15 keV). Because a range of helium ions with energy near 2 MeV in solids does not excide 10 μm, there is a possibility to investigate the layered structure with the thickness layers of some nanometers. The investigations in this field are presented at different international scientific forums such as:

- EIPBN 2015, the 59nd International Conference on Electron, Ion, and Photon Beam Technology and Nanofabrication, May 26 - 29, 2015, San Diego, USA.
- CAARI 2016, 24th International Conference on the Application of Accelerators in Research and Industry, October 30th – November 4th, 2016, Texas, USA.
- IBA 2015, 22nd International Conference on Ion Beam Analysis, June 14-19, 2015, Opatija, Croatia.
- ECASIA - 15 European Conference on Applications of Surface and Interface Analysis. 27 September – 2 October 2015, Granada, Spine.

The students will see the design of the accelerator and will acquaint themselves with its parameters. They will see the opening vacuum chamber in which the investigated samples and charged particle detectors placed in special positions. These positions determine of the experiment conditions such as the scattering angle, the solid angle of the detector and an angle between the beam direction and the surface of target (Fig.1). The students will change some parameters of spectrometer in order to get the most complete information about element depth profiles in the investigated samples. The students will study the mine physical principle what are used for RBS and ERD analytical methods. They will study the computer code SIMNRA [4], with help of which they will to calculate the depth distribution of the different elements using the experimental RBS, ERD and PIXE spectra.

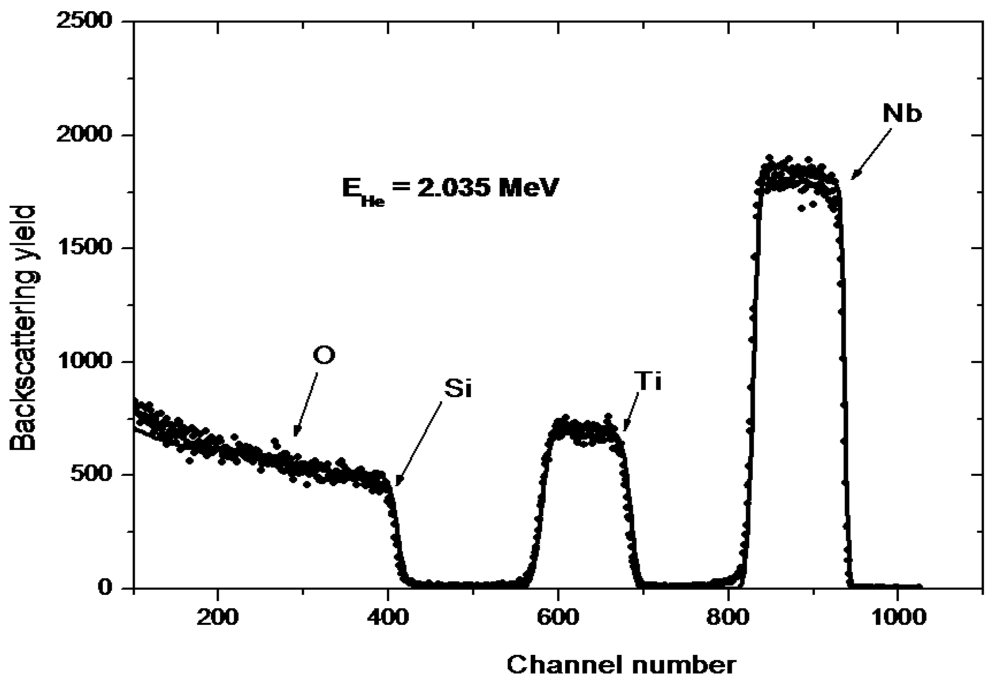

Fig.1. RBS spectra measured at the sample, consisting from 4 elements.

They will store the RBS and ERD spectra in the computer memory and will fulfill the data acquisition of the experimental spectra using SIMNRA computer code in order to get an element depth distribution for the different samples, contenting the difference elements in near surface layers. The students must know the physical lows of interactions of charged particles with solids and the methods of registration of charged particles. They will study the main principles of pointed above ion beam analytical methods RBS, ERD and PIXE, which are complementary one to another. Using three these method one can investigate depth distribution of any element with the atomic mass from hydrogen up to very heavy elements. The students will present their results of calculation spectra of the different investigated samples in form of tables, containing the width of layers in at/cm^2 and atomic concentration of all the elements that make up each layer of the sample.

DESCRIPTION OF THE PROJECT

Van de Graaff accelerator placed in a tank under pressure of 9 atmospheres of dry nitrogen for usual running conditions because a voltage at the top electrode of the accelerating tube reaches more, than 3 millions volts. Fig.2 shows general view of the top part of accelerator without tank. At Fig.2 the high voltage electrode (half-sphere) covers the ion source placed at the top part the accelerated tube. The vertical accelerating tube, consisting from 160 sections, one can see also at Fig.2. Accelerated beam is inclined at ±90 deg. by a magnet and may be directed in any from two the experimental halls. The magnetic analyser there is in each experimental hall. The students will carry out the project at the 3-th beam line of EG-5 accelerator. They will be get the knowledge about the main parameters of Van de Graaff accelerator, about three analytical method and about the spectrometers of charged particles and X-ray radiation.

At the beam line N3 there is an experimental chamber for the all three analytical methods RBS, ERD and PIXE. General view of experimental chamber with a collimator for the charged particles beam, the surface-barrier silicon detector for registration of ions, scattered under angle 120^O, the detector for the registering of recoiled ions and the 4-position target holder is shown in fig.3. In the case of the combined RBS and ERD methods two experimental spectra are registered simultaneously: the spectrum of helium ions, scattered under an angle 120^O and spectrum of the recoiled protons – under an angle 30^0. The helium ions, scattered under 30^0, loss full energy in Al-filter, but the recoiled from target protons loss only a part of their energy. A spectrometer on the base PC has two independent spectrometric tracts under control by the computer program. The maximum analyzed depth in the sample reaches 1-2 μm and the depth resolution – 10 nm. The Si(Li) detector is used for registration of the characteristic X-rays, excited by ion beam in irradiated solids in PIXE method.

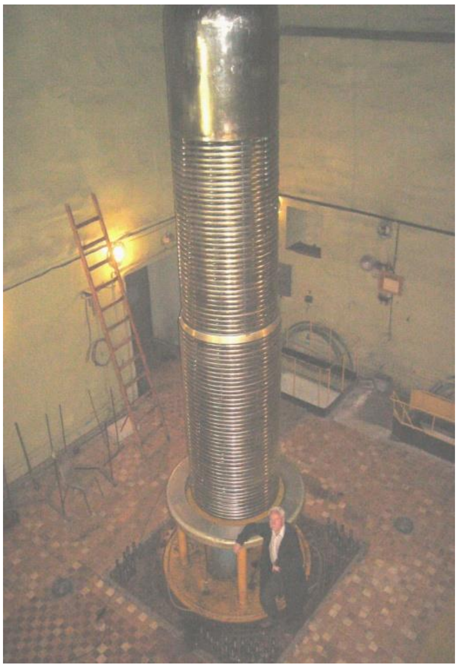

Fig.2. General view of top part of EG-5 accelerator.

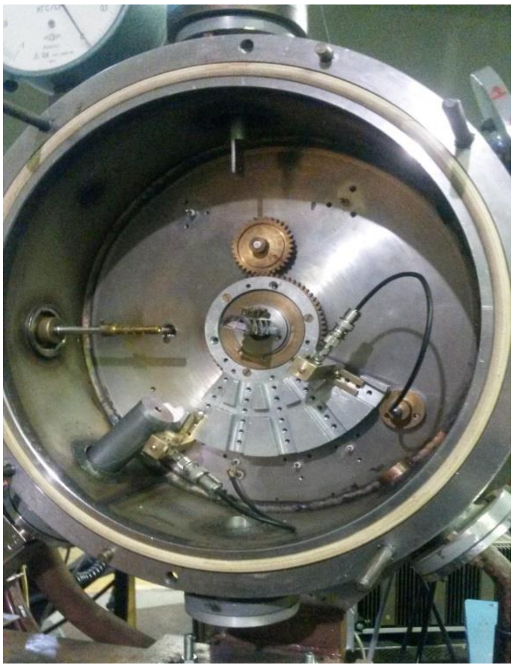

Fig.3. Inside of the experimental chamber for analytical methods.

The students will carry out the calibration procedure for the charged particle detectors and for the X-ray detector in order to measure the energy of scattered ions and the energy of X-ray with the high precision. For this purpose they will use the experimental spectra measured in the same experimental conditions at the samples with known element contents. The students will use the computer for control of the experimental conditions (start of the exposition, observation of the collection of the spectrum, dead time, ending of the exposition and saving a spectrum). Then they will perform the data acquisitions using SIMNRA computer code. In order to get good agreement an experimental spectrum with calculated one (fig.1), the students have to know the lows of elastic scattering of charged particles in the fields of nuclei, calculation of energy losses and struggling for complex materials, and the possibility to calculate the X-rays yield for ionizing process of the solid and the charged particle yield from the nuclear reactions. A report will content a description of experiments with the graphs.

In order to take part in this training – investigation project is required to study nuclear physics and theory of penetrating of charged particles through the solids.

REFERENCES

1. Wei-Kan Chu, James W. Mayer, Marc-A. Nicolet. Backscattering Spectrometry. Academic Press, New York, San Francisco, London 1978.
2. Kulik M., Kobzev A.P., Jaworska D., Źuk J., Filiks J. Investigation of indium diffusion process and optical effects in In^+ implanted GaAs. Vacuum 81, Issue 10, (2007) pp.1124-1128.
3. J.Huran, A.Valovic, A.P.Kobzev, N.I.Balalykin, M.Kucera, S.Haschik, S.Malinovskij, E.Kovacova. Structural and physical characteristics of PECVD nanocrystalline silicon carbide thin films. Physics Procedia 32 (2012) 303 – 307.
4. M. Mayer, SIMNRA User's Guide 6.05, Max-Plank-Institut fur Plasmaphysik, Garching, Germany, 2009

The number of participants in project is 3-4 persons in the same time.

The project is realized under supervision Dr. Kobzev Alexander in Frank Laboratory of Neutron Physics, Nuclear Physics Division. He is a specialist in field of interaction of the charged particles with solids and, in particular, in the Vavilov-Cherenkov radiation. Dr. Kulik Miroslav participates in this project also.