Laboratory of Nuclear Analytical Methods of Nuclear Physics Institute ASCR

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Abstract. Basic facilities of the laboratory are new Tandetron 4130 MC , installed in 2005, and old 3.5 MV Van de Graaff accelerators. The latter is mostly used for standard analyses by RBS and PIXE/PIGE techniques with protons and helium ions. The laboratory at Tandetron accelerator is equipped with devices for analyses of materials by RBS, RBS-channelling, ERDA, ERDA-TOF, PIXE/PIGE methods. Ion microprobe is under construction. Also available is equipment for ion implantation and several devices for production of nano- and micro-structured systems. The research program is conducted in close collaboration with specialized research institutions in Czech Republic and abroad. Most notable research topics are nano-and micro- structured systems with special optical, electromagnetic and biological properties and processes proceeding within, radiation degradation of materials and environmental research.

1. Introduction

The Laboratory of Nuclear Analytical Methods of Nuclear Physics Institute (LAM-NPI) at Řež has a long term experience with the utilization of ion beam techniques as Rutherford Backscattering Spectroscopy (RBS), Proton Induced X-Ray Emission (PIXE), Proton Induced Gamma-Ray Emission (PIGE), Energy Recoil Detection Analysis (ERDA) and Proton Elastic Scattering Analysis (PESA). Until recently, only and older Van de Graaff electrostatic accelerator providing 1-3.5 MeV proton and helium beams was available for measurements. The situation has changed in 2005, when a new 3MV electrostatic accelerator Tandetron 4130 MC supplied by HVEE [1] was installed at the NPI. Actually, the Tandetron project, partly financed and coordinated by the IAEA should started already few years earlier. Unfortunately it had to be postponed due to the heavy flood which hit the institute in 2002. The project finally started in 2004 by purchasing the Tandem accelerator and constructing a new experimental hall. The accelerator was delivered to Řež in September 2005 and already in December 2005 was commissioned and fully operable. Since then, we have started the installation of the beam lines. The first finished line (-10 deg.) was equipped with an experimental chamber for the RBS analysis (later extended by TOF-ERDA telescope) and by the installation for the high energy ion implantation. First experiment on this line was performed in the summer 2006. Next the experimental chamber for the RBS and RBS-channelling form NEC company [2] was installed on -30 deg. line. The RBS-channelling is only experimental set-up on Tandetron, which was completely supplied by the commercial company, including the precise goniometer, vacuum system, detectors, acquisition electronics and control software. By now (spring 2009) other two lines proton microbeam and multi-purpose PIXE, PIGE, RBS, NRA (Nuclear Reaction Analysis) line are assembled and prepared for testing with ion beam. The recent view (January 2009) of experimental beam-lines is shown on the *Fig.1*.

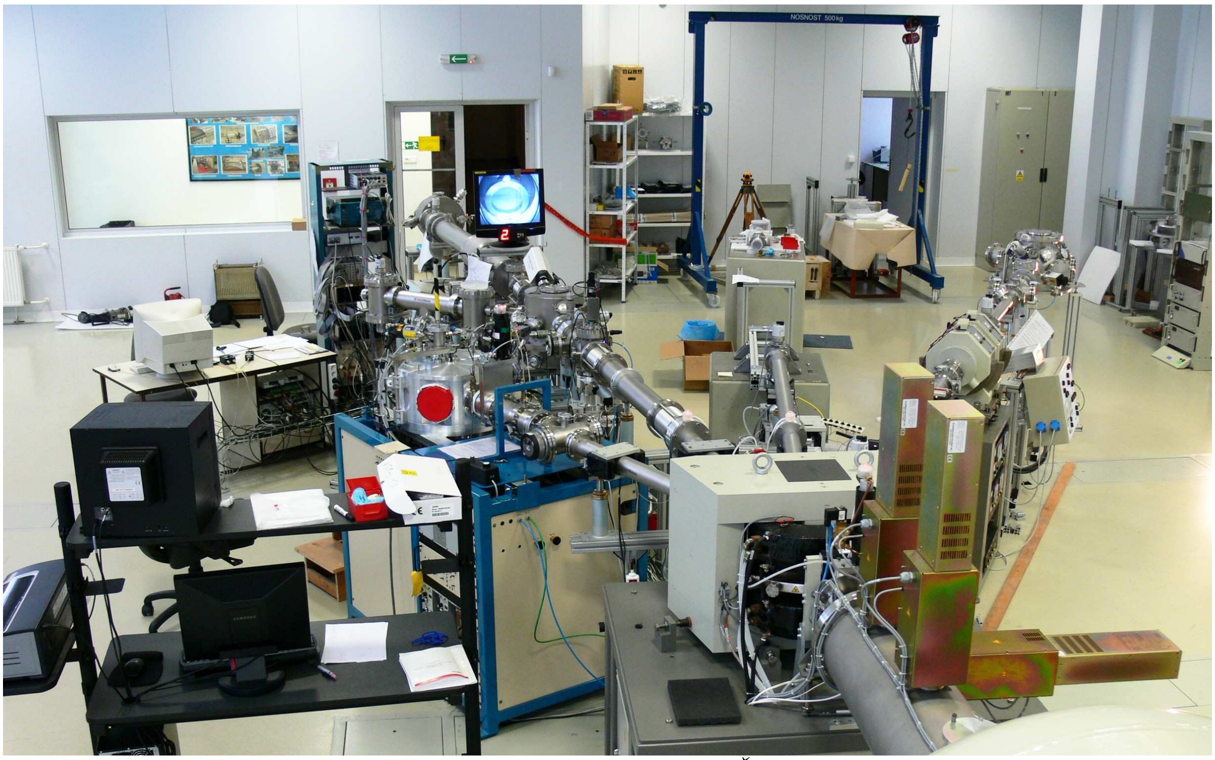

Fig.1. *The view of the beam lines at Tandetron laboratory at Řež - January 2009. From the left: RBS-Channelling, ion implantation line with the RBS and TOF-ERDA scattering chamber in the middle of the line, ion microbeam (under construction) and most to the right the multi-purpose PIXE, PIGE, RBS, NRA line.*

2. Tandetron performance

The Tandetron 4130 MC is equipped with two ion sources (duoplasmatron gas ion source and Cs sputter ion source), which can produced negatively charged ions or radicals needed for the injection into the accelerator,. The used ion sources allow to produce and accelerate almost all ions (elements) of the periodic system. The exception are noble gasses heavier then He, which cannot form negative ions or radicals. The 3MV high voltage generator supply the voltage for the two, tandem arranged, accelerating which can accelerate the ions to energies form aprox. 400keV up to more then 20MeV, depending on the applied voltage and final charge state of ions. For light ions thus the maximum energy is 6MeV for protons and 9MeV for alphas. Until now we have experience with the production of H, He, C, O, Si, Cu, Ag and Au ions and have tested some others as Li, N, F, Al, Ti, Mn, Fe, Co, Ni, Er. The ion currents can be varied from several nA for analysis up to few μA for implantation. The high ion currents (μA range) can be reached only for ions (elements) which can be easy produced in the ion source, as H, C, O, Si or Au.

3. High energy ion implantation

The high energy implantation beam line was the first line completed at the new Tandetron accelerator. It consist of several parts provided by different vendors. The x-y beam scanning unit and the neutral ion trap was bought from the National Electrostatic Corporation USA (NEC) [2], the implantation chamber from HVEE [1] with financial assistance of IAEA. Vacuum beam line components and pumping system was purchased from Vacuum Praha s.r.o. [3] and Pfeiffer Vacuum [4]. The implantation control and operating code, based on the LabVIEW platform [5], was developed in our Laboratory.

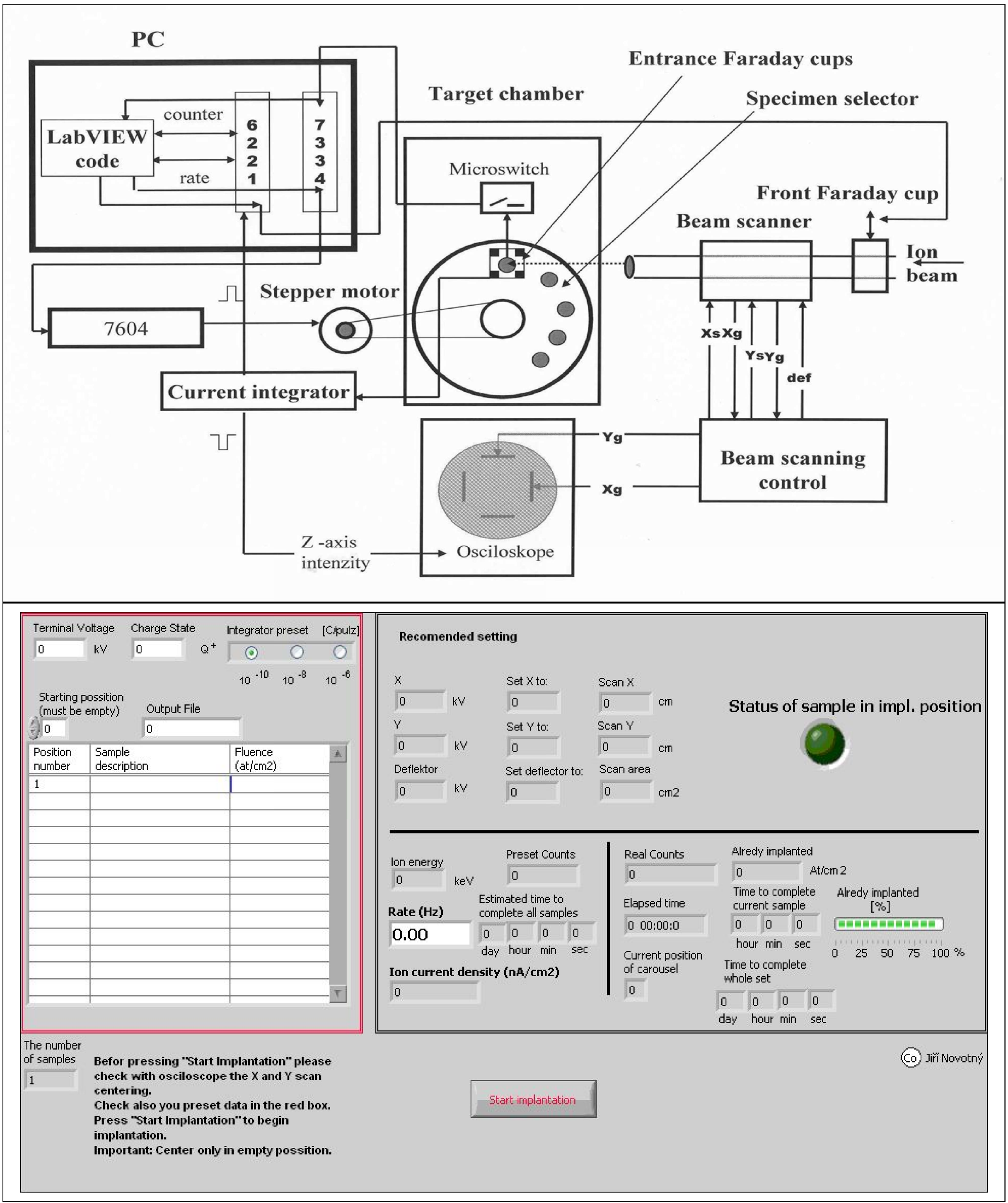

Fig.2. The schema of the high energy ion implantation set-up and the main page of the implantation control code.

The maximum energy of implanted ions is limited to 2.5 MeV per unit ion charge, which is a technical limit of our neutral ion beam trap. This means that for instance Au^{9+} ions can be implanted with energy up to 22.5MeV. The low energy limit is done by the general properties of the accelerator (beam focusing, stripper efficiency and stability of HV generator) and it is about 300-400keV. Also the maximum reachable ion current strongly depends on ion energy, charge state and ion type (different yields from the sputter source). The ion current decreases considerably for higher charge states and lower ion energy (below cca. 1MeV). The doses of the implanted ions can be selected aprox. from 10^8 at./cm^2 up to 10^{16} at./cm^2 . The range limitation of implanted doses is determinate mainly by the dose measurement (using the ORTEC 439 digital current integrator) for the low doses, and reasonable time of the implantation for the high doses. The schema of the implantation line and the main page of the control code are shown on *Fig.2*. Some recent publication with the examples of ion implantations performed at Tandetron 4130 MC at Řež and related research can be found at [6,7].

4. RBS and TOF-ERDA target chamber

The RBS and TOF-ERDA (Time of Flight Energy Recoil Detection Analysis) scattering chamber is installed on -10 deg. beam line prior to the heavy ion implantation set-up. Inside the chamber there are two charge particles detectors installed at 170 deg. and 30 deg. scattering angles. The first is dedicated for the RBS measurement and the second for ordinary ERDA measurement, especially intended for the hydrogen depth profiling. Additionally the TOF-ERDA telescope is positioned at the 45 deg. scattering angle. The telescope consist of two time detectors (start and stop detector with a 100 nm thick carbon foil) and one energy particle detector. The distance between the time detectors is 70 cm. The telescope can also be operated in a simplified configuration with only the start and energy detector. In this case the stop timing signal is provided by the preamplifier timing output of the energy detector. The time and energy resolution using the configuration with one timing and one energy detector was 1.6 ns and 30 keV respectively, as measured with the ^{241}Am alpha source. The picture of the time detector and the spectra of the LiF layer on glassy carbon is depicted on *Fig.3*. Detailed description of the TOF-ERDA set-up can be found in [8].

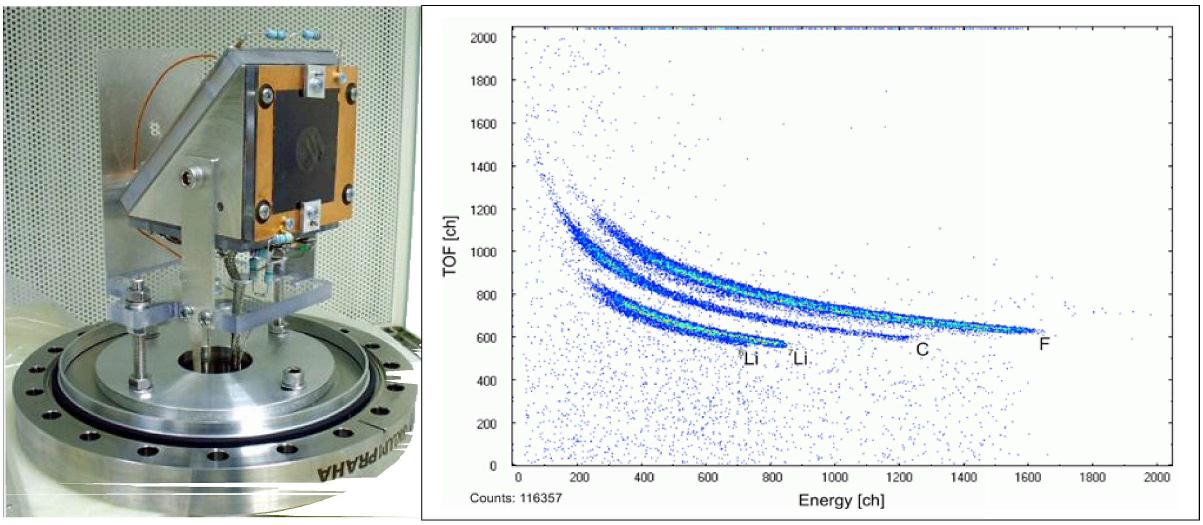

Fig.3*. The TOF-ERDA time detector and the spectrum of the LiF layer on glassy carbon measured width 15.6 MeV Cu^{6+} ions. The TOF scale is aprox. 10 channels per ns.*

5. RBS-Channelling

The RBS-Channelling installation is only equipment which was fully supplied by the external vendor. It was bought from NEC company USA [2] and installed at -30 deg. beam line. The target chamber is equipped with fine goniometer with five degrees of freedom (x,y,z,θ,ϕ) and two charge particle detectors. There is also a possibility to add additional x-ray or γ-ray detector, so the PIXE or PIGE channelling experiments can be performed in the future. The set-up is now used for routine RBS-channelling, RBS and ERDA measurements.

6. Ion Microbeam

The basic components of the ion micro-beam was produce by the Oxford Microbeam Ltd. [9] company including the quadrupole triplet OM150, object and beam defining slits, x-y raster scanner, target vacuum chamber, xyz positioning system, external beam extension station, acquisition electronic and control software. These components was purchased with some financial and technical assistance through the IAEA. However the majority of the investment was covered by our institute and by the ASCR. The microprobe components was delivered with a small delay in December 2008 and from January 2009 we have started the installation of the beamline. The assembly of the microprobe line and vacuum system is now complete. After tests and installation of detectors for the PIXE and RBS analysis into the target chamber we will continue with the beam adjustment and testing of the acquisition and beam control electronic. We plan to perform the first tests of the microprobe in the middle of the 2009 year.

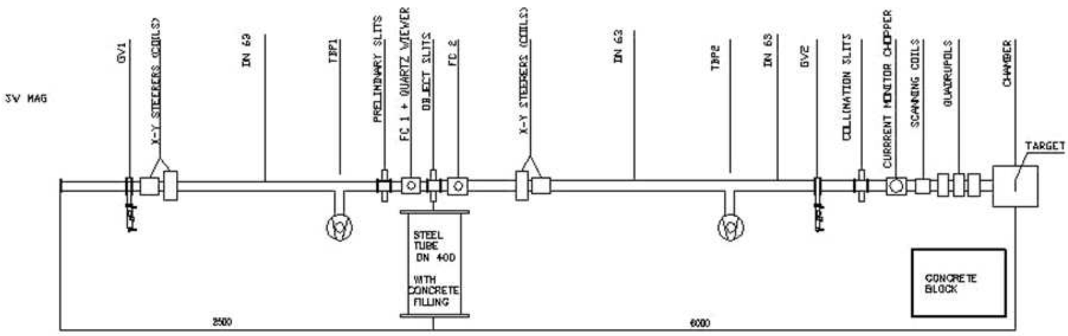

Fig.4. *The schema of the microprobe beam line. The steel tube under the object slit was replaced by the second concrete block in the final design.*

7. Multipurpose PIXE, PIGE, RBS and NRA experimental chamber

The +30 deg. beam line is dedicated for the standard PIXE, PIGE and RBS analysis. The target chamber is designed to be equipped with up to two X-ray detectors, one γ-detector and two or more charge particle detectors at back or forward scattering angles. The scattering angle for particle detectors is adjustable in wide range of angles from 0 to 180 deg. with the step of 2.5 deg. The design concept of the chamber was inspired by the similar chamber [10] installed at our older 3.5MV Van de Graaff. This chamber is successfully used for a routine analysis of environmental, geological and other samples already for several years. The flexible design of the new target chamber allows also other utilization, as the tests of a new kinds of particle detectors, experiments with other NRA, or the resonant cross section measurement for the non-Rutherford elastic scattering analysis or γ-ray producing yields for PIGE analysis. We already have used the chamber for the testing of the charge particle detection properties of advanced positive sensitive Medipix2 detectors [11].

8. Conclusion

The new Tandetron 4130 MC accelerator has significantly improved the analytical capabilities of our Laboratory. After the three years of operation, since its commissioning in December 2005, we have installed three experimental ion chambers including the beamlines which are now in routine operation. Two other lines are just before completing. The accelerator is used in numerous research projects dealing with the preparation and investigation of advanced surface layers with defined mechanical, chemical, optical and magnetic properties. It is used in biological, medical and polymer research, for high energy ion implantation and for many others applications. There are a number of new cooperations between our institute and Czech and foreign universities and research institutions which are based on the utilization of Tandetron accelerator. Number of recently awarded research grants used the accelerator as basic experimental tool. We expect further extension of research projects in the near future.

Acknowledgement

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