SYSTEM DEVELOPMENT OF A TIME-OF-FLIGHT SPECTROMETER FOR SURFACE ANALYSIS OF MATERIALS

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Abstract

This is original study on design the time-of-flight Rutherford backscattering spectrometry (TOF-RBS) technique for nano-material surface analysis with high resolution. At Fast Neutron Research Facility, FNRF, upgrading of the existing pulsed-beam accelerator from 150-keV of D^+ to 280 keV of He^+ was proposed to use for the most powerful method of a near-surface characterization of materials utilizing TOF-RBS. The beam transport was redesigned based on the new multicusp ion source which was designed the extraction and focusing system for optimization by the computer program KOBRA, and the existing beam pulsing system to provide He^+ ion beam with a few nano-second width and 280-keV acceleration energy. Simulation was done by the computer program Beam Optics, resulting in the beam size at the target position of 1 mm in diameter. The measured beam size was 6 mm in diameter. The optimization of the target position was done by the PARMELA program, to be at 3.14 m from the middle point of the buncher. Components, beam transport characteristics, beam optic simulation, and role of quadrupole magnet were explained with technical data listed. Design and test of the scattering chamber for TOF-RBS were shown with He-ion scattered spectra which were measured by the MCP detector. The quadrupole triplet was designed and constructed at FNRF. Development of TOF-RBS system was implemented in this study. Designing component, fabrication and installation to the accelerator system were completed. Beam extraction and He-scattering tests were done.

INTRODUCTION

The most powerful method in the material science for analyzing the surface of the material is the Rutherford Backscattering Spectroscopy (RBS) technique because of its inbuilt capability of providing not only a non-destructive, fast, sensitive and simple assessment of the total quantity of element, but also their depth distributions in a sample [1]. A near-surface analysis which is a few nm and below, are able to used the RBS incorporate with the time-of-flight (TOF) technique with the incident energy in the MeV range. The TOF-RBS at medium incident energy has gained increasing interest [2, 3]. In 1998, the accelerator used the 140-keV pulsed-deuteron beam to perform surface characterization of material sample by the TOF-RBS technique [4]. The sample was copper and gold coated on a silicon substrate(Cu-Au/Si). The experimental timing resolution of the system was 7.4 ns and the energy resolution was 3.7 keV. Thus the mass resolution of the system was estimated to be a 1/143 relative to Au (197 u). Improvement of the resolution by some modification of this system was then considered. By calculation of He^+-pulsed-beam of the energy 280 keV, the energy resolution of 7.9 keV at the same value of the experimental timing resolution was 7.4 ns. The mass resolution of the system was a 1/40 relative to Au which is a better mass resolution as expected for upgrade the existing accelerator. So that the He^+ beam with energy of 280 keV was chosen for upgrading by the existing pulsing system control still be used. Some beam transport elements, such as ion source, an analyzing magnet and quadrupole magnets were to be designed and constructed. They were used to replace the old components.

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THE ION PULSED BEAM ACCELERATOR

A schematic diagram of a 280-keV He-ion beam accelerator which can produce 2-ns pulses at the target is shown in Fig. 1. Briefly, the continuous He-ion beam, which is extracted from the multicusp ion source (MIS) with energy of 10 keV, enters an accelerating tube and accelerated to 280 keV. The He-ion beam passes through the 45^o-bending magnet, which selects the required He^+ component. The He^+-beam is focused by a triplet quadrupole magnet. The magnet was designed by the MAGNET program and construction was done at the FNRF machine shop. The beam is then chopped by a system that is composed of two orthogonal slits, and an X- and Y-deflector. The first slit limits the beam diameter before entering the X-deflector, which is operated at 2 MHz. The X-deflector sweeps the beam in the y-axis and the Y-deflector connects with a fast switch to kick the beam off the second slit. After that the beam is chopped to a 50-ns pulse width and then goes into the bunching system. The buncher has 2 gaps and the distance between the gaps is 46 cm. It is connected to a 4-MHz radio frequency source and with high voltage of 13 kV. After the pulsed-beam passes through the buncher, it is compressed when travelling along the drift space and reaches the target with a 2-ns pulse width [5]. The target is 3.14 m from the middle of the buncher which has the same result as simulation by PARMELA program code [6]. The result of the PARMELA simulation is shown in Fig. 2, the phase space is 0.69 ns at the target position with the energy spread $\pm 0.01\%$.

After installation the tube was conditioned up to 300 kV

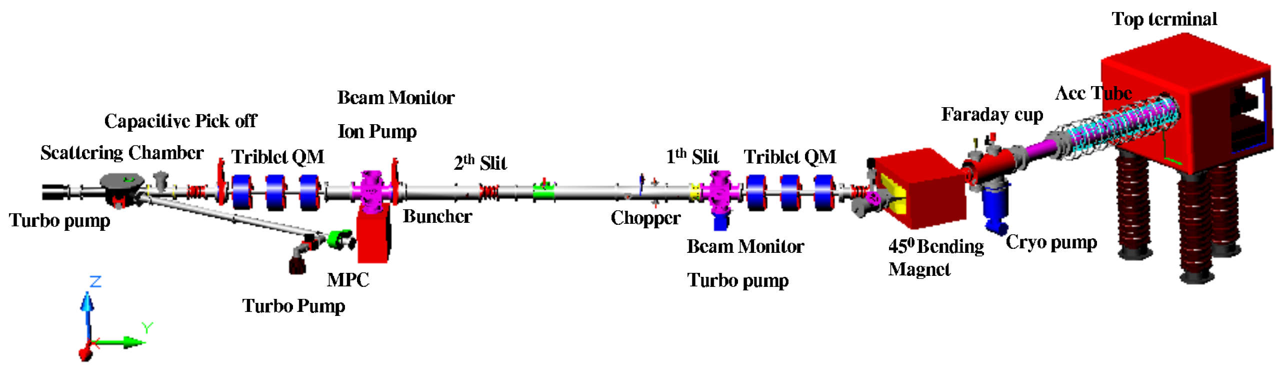

Figure 1: The He^+-pulsed-beam 300-kV accelerator.

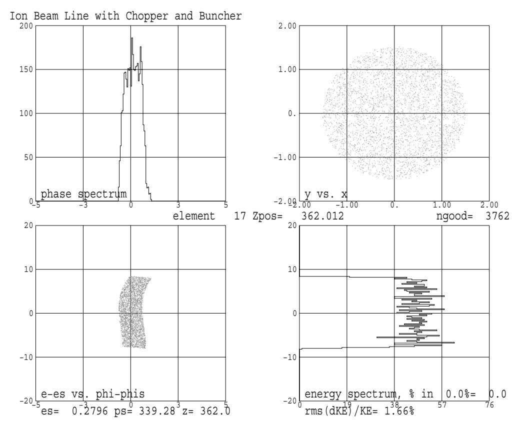

Figure 2: The average energy versus the particle longitudinal position with energy spread $\pm 0.01\%$.

and then tested. The test is done by acceleration of He^+ to an energy of 280 keV and measurements of the beam current by a faraday cup which has 80 cm distance from the exit of the accelerating tube. Results are shown in Fig. 3.

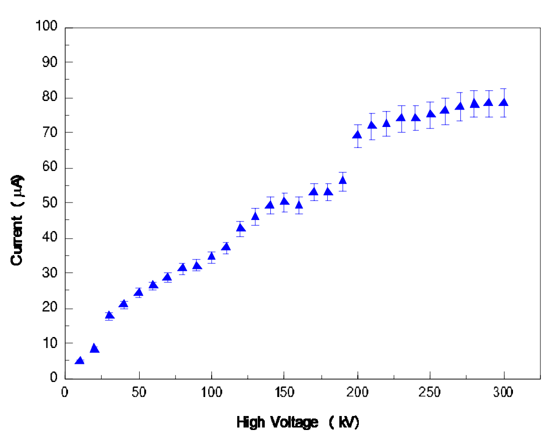

Figure 3: The beam currents at different high voltages.

ION SOURCE AND BEAM EMITTANCE

The MIS was optimized at the filament currents of 15-20 A, while the discharge current was at 2 A. The extraction system and the Einzel lens was designed by the computer code KOBRA3-INP [7]. The maximum helium beam currents measured by the faraday cup were 17.0, 19.4 and 20.4 μA as shown in Fig. 4 at the extraction voltages 5, 10 and 13 kV and the focusing voltage of 3.5, 6.5 and 8.8 kV respectively. The beam-emittance measurement varied between 6-12 mm mrad. The beam size at the exit of the Einzel lens was 1.5 mm in diameter, which was off from the simulation by 20%.

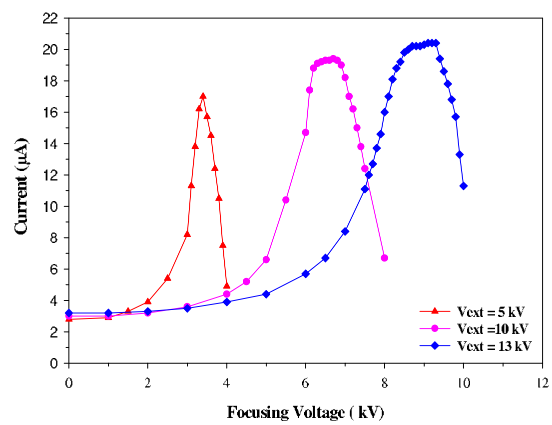

Figure 4: The helium beam currents at extracting voltage.

BEAM TRANSPORT

The behavior of the particle beam along the beam line was used to simulate by the Beam Optics program. The resembled result to get the beam size less than 2 mm diameter at the target position by using 2 triplet quadrupole magnets, one located in front of the first slit and another one located in front of the target chamber as shown in Fig. 1. The quadrupole magnet were designed with the MAGNET PROGRAM [8] and also constructed, specifications are as shown in Table 1.

The results of quadrupole magnet are magnetic field gradient of 283.5 G/cm and magnetic field of 34.5 G at the current of 3 A. The effective length, bore radius and iron length were chosen to be 17.5, 2.5 and 15 cm, respectively. The beam size was measured at the end of the acceleration tube and at the monitor I and II (see Fig. 1). The beam diameters are 1 cm, 1.4 cm and 1.8 cm respectively. The

Table 1: Quadrupole magnet specifications

Parameters	Value Unit
Bore radius	2.5 cm
Focal length	13.3 cm
Length	15 cm
Focussing strength	50 m^{-2}
Field Gradient	1517.16 Gauss/cm
Maximum field at the pole tip	3792.9 Gauss
Maximum current	10 Ampere
Number of turn	400 Turns

beam size at the monitor II shown in Fig. 5.

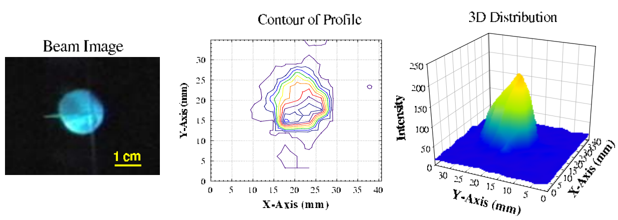

Figure 5: The beam at the beam monitor II.

SCATTERING SPECTRUM

The accelerator was operated at 280 kV, the He-ions were accelerated and transported to a Si-target by the bending magnet and quadrupole lens. The ions hit the target, they were then back-scattered. Measurement of the back-scattered ions was done using electronics as shown in Fig. 6. The backscattered He-ions were detected by the MCP, generating the output signals which were then amplified. Data acquisition was done by a multiparameter analyzer[1]. The signals were analyzed by the ADC and then displayed on a computer monitor through the MPA-Base interface. The spectrum is shown in Fig. 7. The pulsing system will be tested afterward when the chopper is repaired. The TOF-RBS spectra of surface of nano-materials can therefore be obtained.

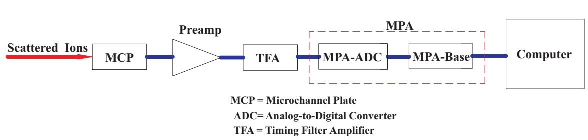

Figure 6: Electronic diagram of the backscattered-He-ions measurement.

CONCLUSIONS

Development of TOF-RBS system was implemented for designing, component studies, accelerator system installation, beam and scattering tests. Some problems are left for future refinement of pulsing components. TOF-RBS analysis of thin-multi-layered surface of nano-materials can be efficiently researched by using the presently developed system. TOF-RBS spectra need to be measured when the chopper and buncher are repaired. Timimg resolution of the system needs to be improved after modification of the buncher and it is strongly suggested.

[1]MCP-3, a product of the FAST ComTach Communication Technology GmbH, Germany

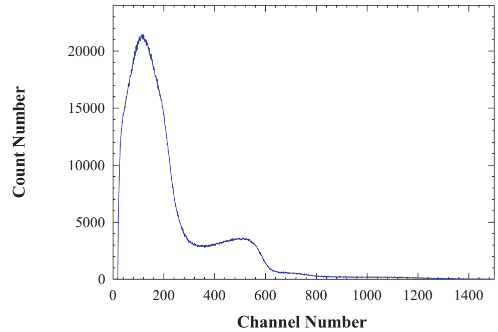

Figure 7: The spectrum of backscattered He-ions from the Si-sample with the 280-keV incident beam.

ACKNOWLEDGEMENTS

The authors would like to thank Prof. Helmut Weidemann for some advice, Prof. Harry J.Whitlow to bring some detector equipments for us. We would like to thank Thai Research Fund (TRF) for financial support under project No. RTA-01-2543, the International Atomic Energy Agency (IAEA) Program No. THA/1/009 for technical assistance and the Royal Golden Jubilee Ph.D. Program (RGJ) for support in this project under scholarship No. PHD/0213/2543.

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