CURRENT STATUS OF RAPID, THE UNIVERSITY OF TOKYO

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Abstract

The 1.7 MV tandem accelerator RAPID (Rutherford Backscattering Spectroscopic Analyzer with Particle Induced X-ray Emission and Ion Implantation Devices), at the University of Tokyo has been dedicated to various scientific and engineering studies in a wide range of fields by the ion beam analysis availability, including RBS (Rutherford Backscattering Spectroscopy), PIXE (Particle induced X-ray emission) and ion implantation. Total accelerator operation time amounted to 9358 hours since its installation with the highest annual operation time recorded in 2007. RAPID-PIXE analysis system has been contributed to many environmental studies by analyzing elemental composition of water and sediments samples. It is also applied to the analysis of several cultural heritages such as a works of gilded frame from Renaissance in Italy. Recently, the low level ion irradiation system was also developed and applied for the study of CR-39 track detector with proton beam.

INTRODUCTION

RAPID (Rutherford Backscattering Spectroscopic Analyzer with Particle Induced X-ray Emission and Ion Implantation Devices) is an elemental analysis and the ion implantation system using ion beams accelerated by an electrostatic accelerator at the University of Tokyo, Japan. The system consists of a 1.7 MV tandem accelerator (Tandetron^{TM}, Model 4117-HC, provided by HVEE: High Voltage Engineering Europe corp., Netherlands), two negative ion sources (a Cs sputter solid ion source and "Duoplasmatron" gas ion source) and three beam lines (Fig. 1 and Table 1).

The 1.7 MV "Tandetron^{TM}" has Cockcroft Walton type charging system. The terminal voltage is monitored and stabilized by a Generating Volt Meter (GVM). Various ion species can be produced by the dual negative ion sources system. Totally 24 ion species, from Hydrogen to Gold, had been generated and accelerated. Especially it is one of specific features of RAPID that He^- ion is available by the "Duoplasmatron" gas ion source. PIXE detector system, RBS&ERDA detector system and Ion implantation chamber are equipped at the end of each beam line. PIXE chamber is mounted with three axis and one translation sample manipulator with Si(Li) detector. RBS chamber is mounted with three axis goniometer and silicon surface barrier detector. Recently ERDA system is also set up in the RBS chamber. The angle of Ion implantation line is fixed at -7° to the central axis of the accelerator. A target holder of ion implantation can be heated up to 800°.

RAPID was installed in 1994 at Research Center for Nuclear Science and Technology, The University of Tokyo at first and since then it has been used for various research fields using ion beams. As the Center was reorganized to be a department of School of Engineering in 2005, the educational utilization became an important mission of RAPID. Besides several application studies with PIXE analysis, environmental analysis (pond sediments and atmospheric SPM - Suspended Particulate Matter) is performed as a student experiment. Heavy metal elements analysis of gilded frames of art works from Florence, Italy is also one of recent topics. Another major topic is that a special beam irradiation system was developed to evaluate the response of CR-39 track detector to low level radiation.

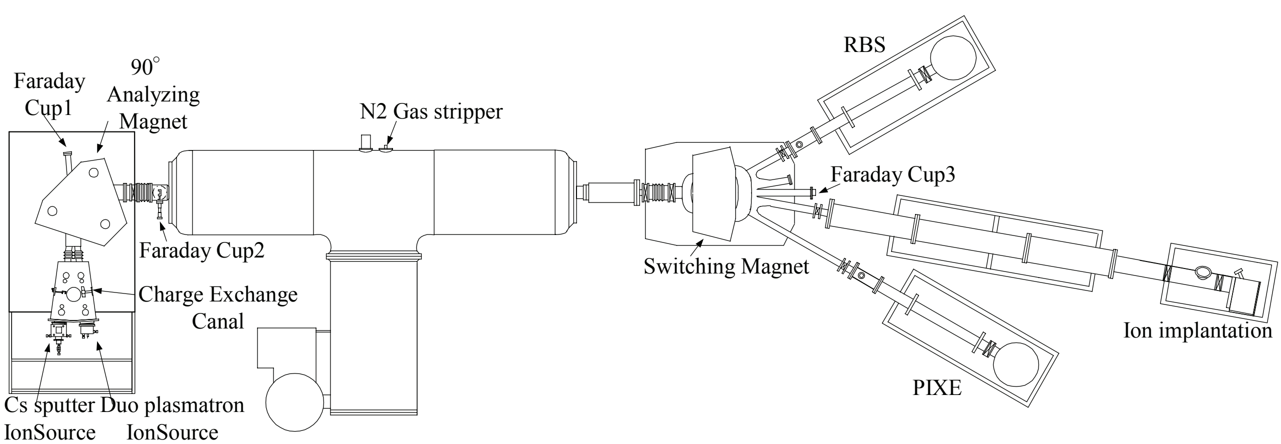

Figure 1: Schematic illustration of the 1.7 MV tandem accelerator system.

Table 1: Specification of RAPID

Negative ion Sources	
Cs sputtering Type	
Extraction Voltage	20kV
Duoplasmatron Type	
Extraction Voltage	20kV
Top Accelerator	
Available voltage range	0.1-1.7MV
Stability	< 80 Vrms
Ripple	< 30 Vrms
Produced beam current	
H^+	25 μA (3.4 MeV)
He^{2+}	2 μA (5.1 MeV)
Si^{2+}	140μA (5.1 MeV)
Au^{2+}	60 μA (5.1 MeV)
Cu^2	20 μA (5.1MeV)
N^{2+}	19μA (5.1 MeV)

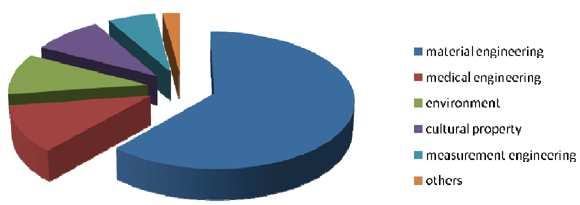

Figure 2: The percentage of various research fields in 2007.

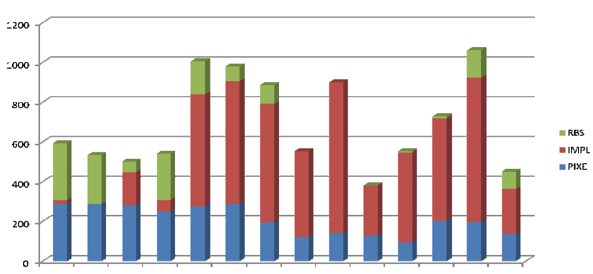

Figure 3: Yearly operation time for each beam line since 1995.

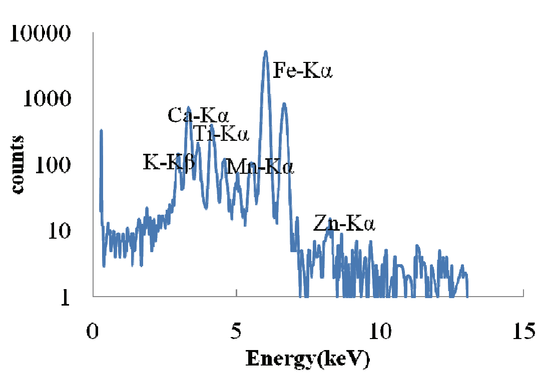

Figure 4: PIXE spectrum of pond sediment. This is that of “Sanshiro-ike” pond in the University of Tokyo.

Fig. 2 shows the percentage by which each application field occupies the RAPID machine time. Fig. 3 shows the yearly accelerator operation time of RAPID. Considerable drop in operation time in 2008 is due to the off-line development for low level irradiation system and new ERDA system. The total operation time has reached 9358 hours. Since RAPID has been operated carefully, it has never experienced a severe sparking nor a fatal discharging. That is why the main accelerator tank has never opened since the construction.

APPLICATIONS

PIXE Analysis of Pond Sediments and Air Dust

PIXE is a good example for understanding the basics of the IBA technique and is easily applied to the environmental study. Hence, a student experimental program was designed with PIXE analysis of environmental samples. Main subject of the program is simply the PIXE analysis of the pond sediments collected from the bottom of a “Sanshiro-ike” in the University of Tokyo, where various plants and creatures are living [1].

However, it contains from the field work, sampling, pre-treatment for the IBA, PIXE analysis itself and detailed analysis of the data. Students are expected to recognize the relationship between human and natural bio system as well as the acquisition of the PIXE technique through this program.

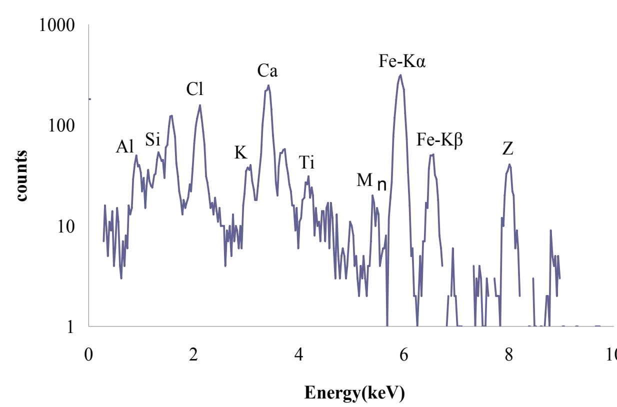

Figure 5: PIXE spectrum of SPM corrected in the campus of University of Tokyo.

Fig. 4 shows an example of the PIXE analysis spectrum of the pond sediments. Fortunately, pollutant metals such as Cd, As, Hg was not observed. In 2009, newly designed student experiment program was started which treats SPM (Suspended Particulate Matter) in the atmosphere. Atmospheric dust particles larger than 0.45 micro-m size were collected by a hand-made dust collector at the rooftop of the accelerator building. The main component of the dust around Tokyo area is 1) natural soil, 2) volcanic ash, 3) artificial origin dust due to such as the exhausted gas from the automobiles or factories, 4) Sea salt and 5) Yellow sand from Chinese continent.

The amount and the portion of these components varies with the seasons and the weather. For example, the

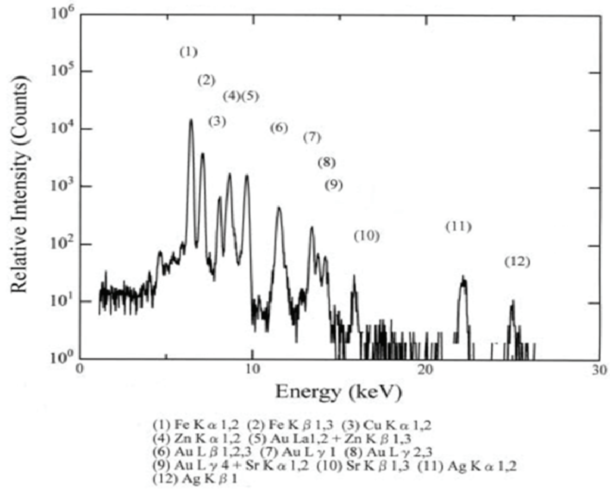

Figure 6: PIXE spectrum of the gilded frame of art works including one from Florence.

amount of the yellow sand arriving in Japan is greatly enhanced during the term from February to May. The PIXE spectrum of SPM collected at April 1st, 2009 is shown in Fig. 5. The main components of the yellow sand, Si, Al, are detected.

Analysis of Cultural Heritage

Cultural heritage is also an interesting target for PIXE analysis concerning the study of the history of "art". Here, the analysis of the gilded frame at Florence, Italy is shown as an example. After the Renaissance era, the frame started to be used with paintings. Dr. Sumiko Hasegawa recognized the historical importance of this fact and considered that people of the Renaissance era began to recognize the importance of the frame. They found that a frame could enhance the fascination of the painting by the frame, i.e., excellent morphological design and coloring of the frame makes the painting more attractive. With such recognition, precious material such as gold came to be used (Figs. 6 and 7) [2].

Development of Low Level Irradiation Chamber

To evaluate the response of CR-39 track detector to low level irradiation, specially designed irradiation chamber system was developed and set at the ion implantation line of RAPID. If we receive accelerated proton beam directly, it is difficult to reduce the flux to less than $1x10^8$ [ions/s·cm^2]. Newly developed system uses the backscatter proton and enables to reduce proton dose significantly.

The backscatter angle is 45° [3]. The proton flux can be reduced to the degree of the backscattering cross section and the actual solid angle of the irradiation area. The geometry of the system is shown in Fig. 8. As a result, the dose was restricted to less than 10^7 [ions/s cm^2]. Initial proton flux is monitored by the faraday cup placed co-axially. The distance between the scattering target and the irradiated sample is 160 mm and the inner diameter of the aperture in front of the irradiated sample is 8 mm. Hence the actual solid angle for the scattered ion particles is as small as 0.063 sr so that the irradiation can be considered uniform. By the Silicon Surface Barrier detector placed behind the irradiated sample the energy spectrum of the back scattered ion particles is measured. The energy distribution of the scattered ion particles can be changed by changing the thickness and the materials of the scattered target film. Using this system the response of CR-39 to low level irradiation was investigated. Fig. 9 (a) is the result of direct irradiation of the initial proton beam to the CR-39 and Fig. 9 (b) is the result of the irradiation by the scattered ion particles. Obviously an appropriate dose rate to identify each ion track is the case of the scattered ion particle irradiation (Fig. 9 (b)). Each spot on the Fig. 9 (b) corresponds to a track. Concentrated spot means the concentrated energy deposit by the ion, a large energy loss near the end of the track. Track Spot A is more concentrated than track Spot B in Fig. 9 (b). Energy deposit for track Spot B is smaller which means that the ion had higher energy and the energy loss was smaller. Fig. 9 (c) shows the energy spectrum of the irradiated ion particles generated by the backscattering which was measured by a solid state detector.

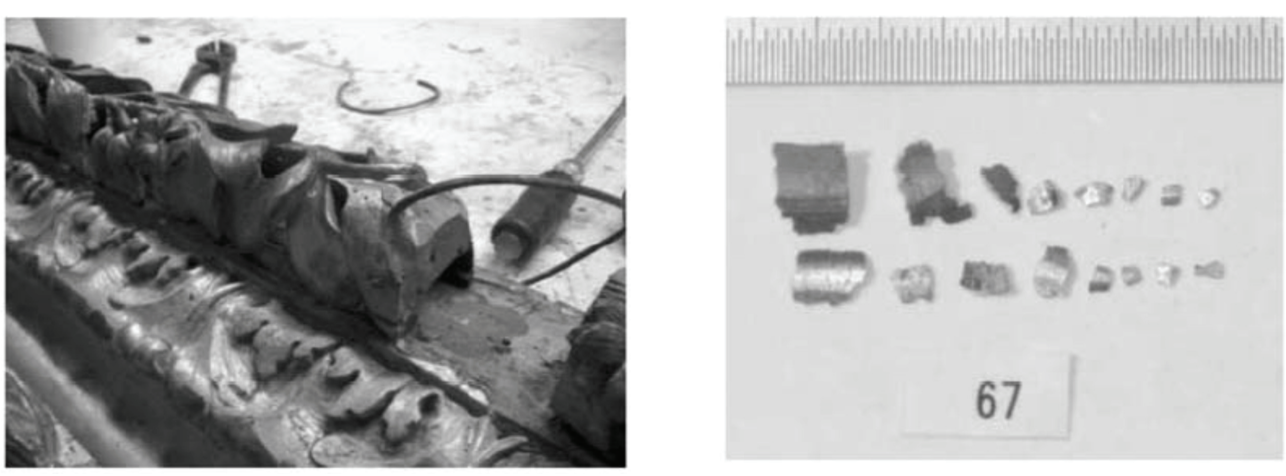

Figure 7: A gilded frame being restored (left) and pieces of impress gold foil on (right).

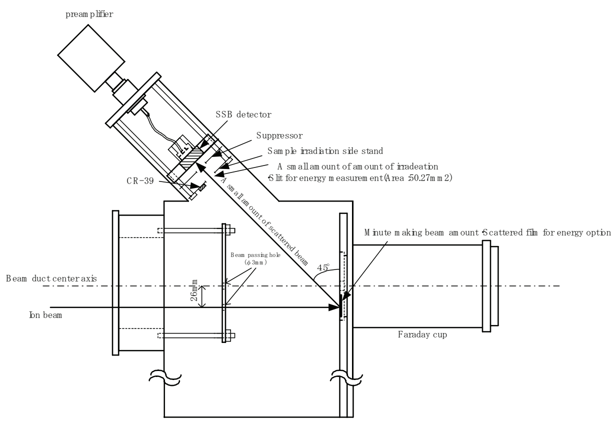

Figure 8: Schematic drawing of new irradiation system.

SUMMARY

RAPID, at the University of Tokyo, is a beam analysis and ion implantation system being used for various application studies. The range of application field extends not only in engineering but also to cultural heritages. Total accelerator operation time of RAPID amounts to 9358 hours since 1995. Recently environmental analysis (pond sediments and atmospheric dust) using PIXE was performed as a student experiment. A special irradiation chamber system was developed which enabled low level irradiation (less than 10^4 ions/s cm^2) by means of back scattering. The energy distribution of the back scattering beam is also variable by changing the thickness and materials of the scattered target. Using this system the response of CR-39 track detector to low level irradiation was investigated.

ACKNOWLEDGEMENT

The authors thank Kosako laboratory, the University of Tokyo, for providing CR-39 photos. The authors also express gratitude to Dr. Yosuke Miyairi, Ms. Yoko Tsuchiya and Mr. Chuichiro Nakano, the University of Tokyo for cooperation of student experiments. Dr. Fumitaka Nishiyama (Hiroshima University) and Mr. Masuchika Kohno (Kyoto University) are kindly provided useful advises about PIXE analysis. Mr. Masaru Yasumoto, the University of Tokyo fully helped the authors in developing the new irradiation chamber system. The authors appreciate all of them.

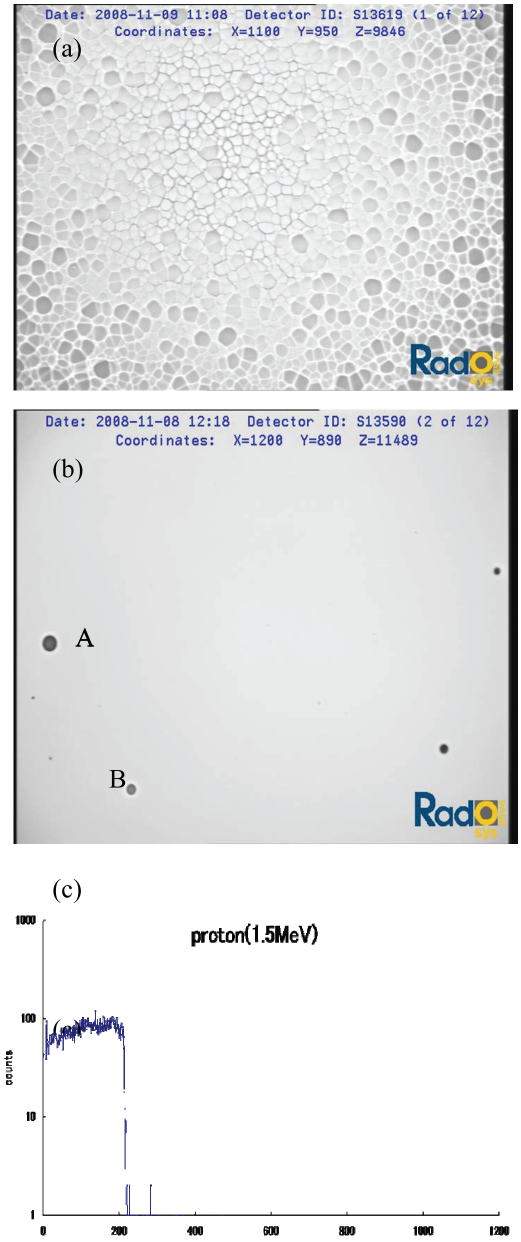

Figure 9: Photograph of the irradiated CR-39 by proton beam; (a) Direct irradiation (b) Backscattered irradiation (c) Energy spectrum of backscattered proton beam transmitting CR-39, which was obtained simultaneously with Fig. 9 (b). (Scatter target = 12.5 mm thick Al foil).

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