DEVELOPMENT OF NRA SYSTEM FOR A 1.7 MV TANDEM ACCELERATOR

- HUMAN RESOURCE DEVELOPMENT PROGRAM FOR NUCLEAR ENGINEERING, THE UNIVERSITY OF TOKYO -

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Abstract

Extremely high sensitivity has been required in the measurement of light elements for the frontier materials science. Ion beam analysis can meet this. We have developed a new NRA system. The system shown successfully its performance by the demonstrative experiment in which fluorine profiles in TiO2 substrate were clearly obtained using 19F (p, αγ)16O reaction.

This system was applied for the student experiment. The newly developed NRA system has great potential for the frontier research.

INTRODUCTION

The 1.7MV tandem accelerator (Rutherford Backscattering Spectroscopic Analyzer with Particle Induced X-ray Emission and Ion Implantation Device, RAPID) at the University of Tokyo has been used for various research projects and educational studies since its installation in 1994. Additively, it has been used for the educational purpose recently. Model experiments with ion beam analysis are very helpful for students to understand ion-material interaction which is the foundation of nuclear engineering and materials processing.

Several developments and modifications have also done for new research including, for example, a low level ion irradiation system [1]. In the fall of 2011, we were newly developed a NRA (Nuclear Reaction Analysis) system in order to respond to the recent demand for the sensitive quantification of light elements (H, N, O, F, etc). The performance of new NRA system were demonstrated using 19F (p, αγ)16O reaction. This demonstration was so simple to understand that this model experiment immediately arranged to a student experiment program. The program was used as a part of "Human resource development program for nuclear engineering" proceeded by our department. The new NRA system has great potential for the frontier research for the materials science and functional material process engineering.

DEVELOPMENT OF NEW NRA SYSTEM

Figure 1 shows the schematic illustration of the 1.7MV tandem accelerator RAPID. RAPID has three beam lines: RBS&ERDA, PIXE and Ion implantation course.

The angle of Ion implantation line is fixed at -7° to the central axis of the accelerator to eliminate neutral particles. NRA detection system was newly developed at the end of the ion implantation line.

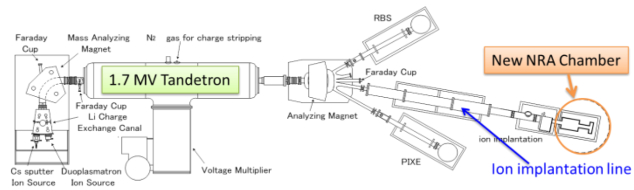

Figure 1: Schematic illustration of the RAPID.

Outline of New NRA System

Figure 2 shows the layout of new NRA system. The new NRA chamber consists of the main chamber, the sample insertion port and a vacuum pump. The Gamma ray induced by proton beam is detected with a 4 inch bismuth germanate scintillation detector. The BGO detector put in perpendicular to the direction of proton beam travel. The NRA system has several features as follows:

1) Chamber design for high counting efficiency.
2) Effective electron suppression.
3) Effective avoidance against charge-up by using fine copper mesh.

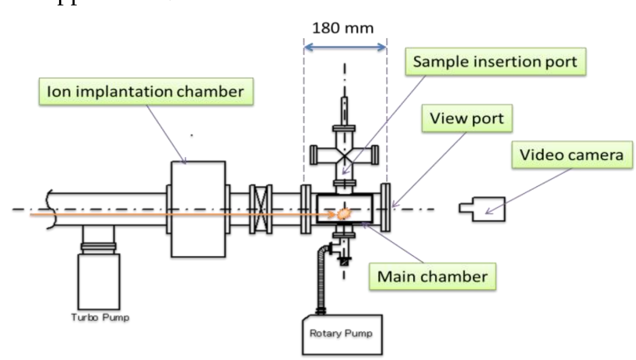

Figure 2: Layout of new NRA system.

Main Chamber

Figure 3 shows the top view of the main chamber. The special feature is a deeply scooped duct to make the BGO detector being close to the reaction position. Electron suppressor electrode is put in front of the target. The shape of the suppressor is specially designed to suppress secondary electrons effectively. By this design, large effective solid angle for the detector is realized.

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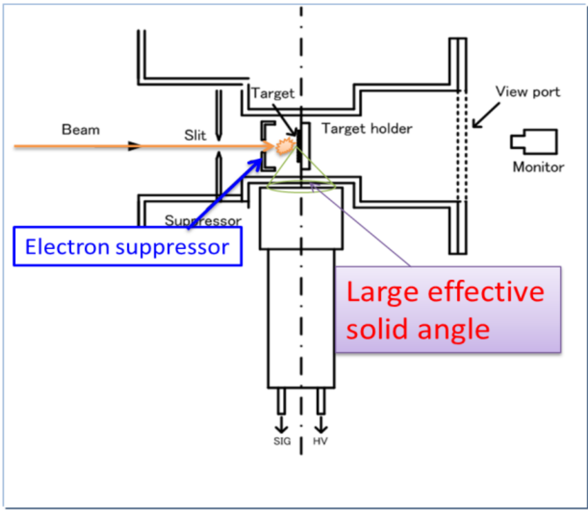

Figure 3: Main chamber.

Effective Electron Suppression and Monitor

Target holder is made of metal stainless (SUS304) plate and samples are just put on the plate. This plate can move up and down to select the sample to be analysed.

Figure 4 illustrates the electron suppressor and beam monitor. The electron suppressor electrode is a circular plate with folding edge so that the cross section is L-shape as shown in Figure 4. By this the equi-potential surface becomes surrounding shape by which the secondary electrons will be effectively forced back.

A glass plate is put at the beam monitor position (a hole on the target holder metal plate) to make the beam monitor. The glass is lit by the beam and this light can be observed by a video camera set at the end of the main port. A fine copper mesh (opening 98%) is set in front of the glass to avoid charge-up.

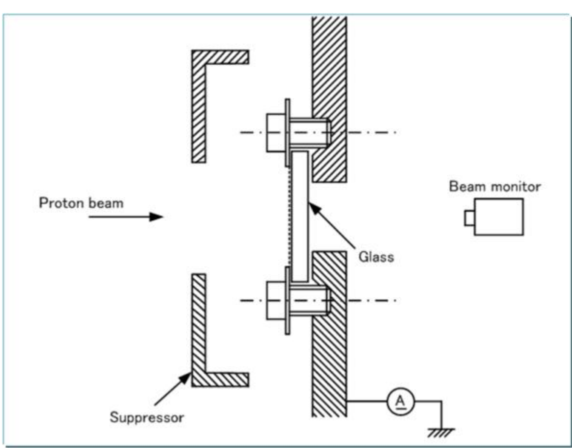

Figure 4: Effective electron suppression and monitor.

The Effect of the Copper Mesh

Figure 5 shows comparison of observed ion current profiles with respect to the suppressor voltage:

(A) Beam is at the position of the metal plate
(B) Beam is at the beam monitor position (glass with mesh).

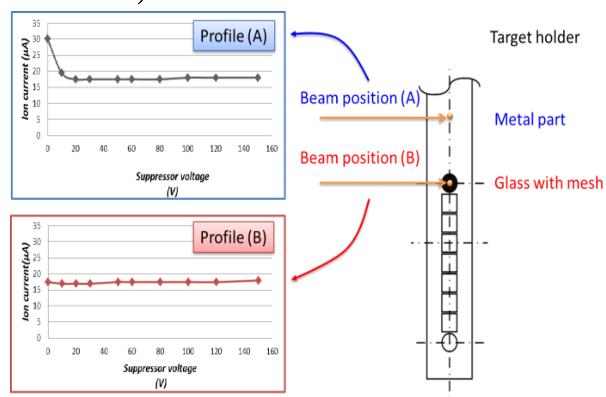

Figure 5: Comparison of observed ion current profiles.

In the profile (B), even at the zero-suppressor voltage, no electron escape was observed. This means that the copper mesh acts not only as charge-up inhibitor but also as an electron suppressor.

DEMONSTRATION OF NEW SYSTEM

The NRA experiments were demonstrated using $^{19}F(p, \alpha\gamma)^{16}O$ reaction. The experiment obtains the Fluorine depth profiles of TiO_2 substrate.

Target Samples Preparation

For the demonstration targets were prepared by the ion implantation of Fluorine ion on the TiO_2 substrates with different dose, i.e., 1.0E16 (ions/cm^2), 5.0E16 (ions/cm2) with 524keV and 1024keV energy at room temperature.

Table-1 summarizes the three conditions of target samples preparation A, B and C.

Table 1: Samples Preparation: 3 Conditions

Sample	Projectile energy (keV)	Total dose (ions/cm^2)
A	524	1.0E16
B	524	5.0E16
C	1024	5.0E16

The ^{19}F (p, αγ) ^{16}O reaction

We used resonance of ^{19}F (p, αγ)^{16}O reaction. The resonance energy of projectile proton is 872 and 935 keV (Table 2) [2].

Table 2: Using Nuclear Resonance of Fluorine

Proton energy (keV)	Reaction	Gamma-ray energy (MeV)	Cross section (mb)
872	^{19}F (p, αγ)^{16}O	7.12,6.93,6.13	540
935	^{19}F (p, αγ)^{16}O	7.12,6.93,6.13	180

Results

Figure 6 shows the results of NRA by using resonance of ^{19}F (p, αγ)^{16}O reaction. Difference of range due to the injection energy and difference of ^{19}F ions abundance due to dose are clearly shown. The spread of the spectra are due to the resonance width of the reaction.

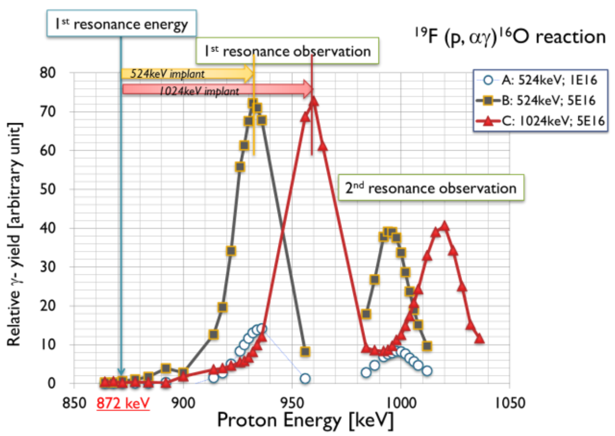

Figure 6: Resonance spectrum of Fluorine

From the observation, positions (depths) of F ion doped were estimated as following (Figure 6, Table 4).The estimations from 1st resonance data and 2nd resonance data are consistent with each other.

The F ions doped with 524keV was estimated to be at 810 – 840 nm depth. The F ions doped with 1024keV was estimated to be around at 1185 nm depth.

Table 3: 1st Resonance (872keV)

	B	C
Energy	524	1024
Resonance	932	959
	60keV	87keV
Average Energy Loss	(932→872) 74.2keV/ μ m	(959→872) 73.6keV/ μ m
Equivalent Depth	809nm	1182nm

Table 4: 2nd Resonance (935keV)

	B	C
Energy	524	1024
Resonance	995	1019
	60keV	84keV
Average Energy Loss	(995→935) 71.3keV/ μ m	(1019→935) 70.8keV/ μ m
Equivalent Depth	841nm	1182nm

Student Experiment Program

The demonstrated experimental set up was applied to the student experiment program for the master course of the department of Nuclear Engineering [3].

The results were very simple and helpful to understand the interaction between ions – target or ions – materials, thus very educational.

SUMMARY

1. A NRA (Nuclear Reaction Analysis) system was developed at the RAPID accelerator facility, The University of Tokyo to meet sensitive quantification of light elements.
2. The NRA system has several features:
1) Chamber design for high counting efficiency.
2) Effective electron suppression.
3) Effective avoidance against charge-up by using fine copper mesh.
3. We found that the mesh acts not only as charge-up inhibitor but also as an electron suppressor. This indicates a possibility for the sophisticated sample holder without additional electron suppressor electrode.
4. The NRA experiments using ^{19}F(p, αγ)^{16}O reaction were successfully demonstrated. Since the results were clear, this experimental setup was applied to the student experiment program.
5. The newly developed NRA system has great potential for the frontier research for the materials science and functional material process engineering

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