Development of In-Air-RBS Method with Tapered Glass Capillary

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Introduction

Developments of In-Air-analysis methods with MeV ion beam have received increasing attention in various fields such as biology, nano-technology and archaeology due to preventing the specimen from desiccation, destruction and so on. Recently a tapered glass capillary has been developed by Nebiki et al to extract ion beam in air and they have performed In-Air-PIXE (Particle Induced X-ray Emission) for the sea sludge[1].

On the other hand, the RBS (Rutherford Backscattering Spectrometry) is well known as one of the useful material analysis method with MeV ion beam[2]. In the conventional RBS method, one measure the energy of a few MeV He ions after large angle scattering at the surface of the target in vacuum chamber and can find the composition of materials as a function of depth from the surface.

In this work, we have attempted to develop In-Air-RBS method with the tapered glass capillary. Here, we introduce procedure, preliminary results, estimated detection limit, and the future plan of In-Air-RBS method.

Experimental Setup

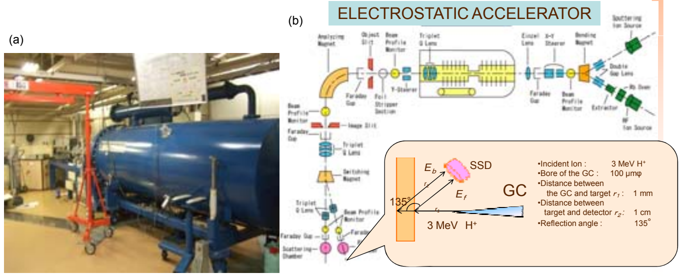

Figure 1: a)The picture of a 1.7 MV tandem electrostatic accelerator in Nara Women's University and b) schematic diagram of beam line with the detail of In-Air-RBS setup.

Results and Discussions

Thin Foil Measurements

Since we measure the energy of reflected protons with the SSD by the pulse height analysis mode, we perform the energy calibration by measuring various thin foils such as Pb, Au, Sn, Ag, Cu and Al. In a conventional RBS, the K-factors indicate the energy ratio of ions between before and after scattering which is determined only by the masses of the projectile and target atom and the scattering angle. In present "In-Air-RBS", we have to consider the energy loss in the air between capillary and detector so that we use the data table for ranges of protons in Figure and perform energy calibration.

$$K=\frac{E_1}{E_0}=\left[\frac{M_1\cos\theta+\sqrt{M_2^2-M_1^2\sin^2\theta}}{M_2+M_1}\right]^2 \qquad E_f=K\left[E_0-\int_{r_1}\left(\frac{dE}{dx}\right)_{Air}dx\right]-\int_{r_2}\left(\frac{dE}{dx}\right)_{Air}dx$$

The In-Air-RBS spectrum for various foils is shown in Figure 2. The peaks at higher energies are corresponding to energies of reflected ions from the foils and each plateaus at lower energies are those from the air. It is clear that the positions of peaks are shifted to higher energy side with increasing the mass of the target foils due to K-Factors.

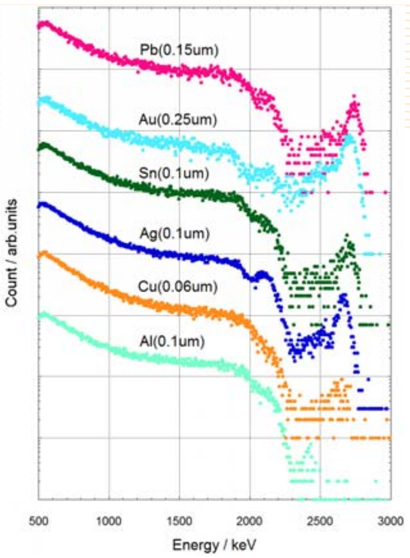

Figure 2: In-Air-RBS spectrum for thin films of Pb, Au, Sn, Ag, Cu and Al.

Table 1: K-factors for several targets

Material	Mass	K-factor
Pb	207	0.983
Au	197	0.982
Sn	119	0.972
Ag	108	0.969
Cu	63.5	0.948
Al	27	0.881

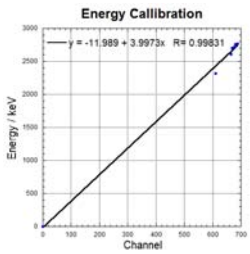

Figure 3: Energy calibration for measured proton energy.

Ranges of protons

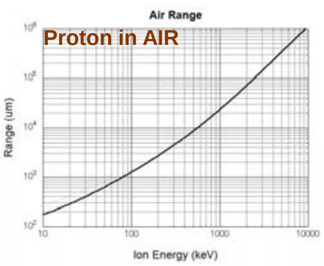

Figure 4: Range of the proton in the air.

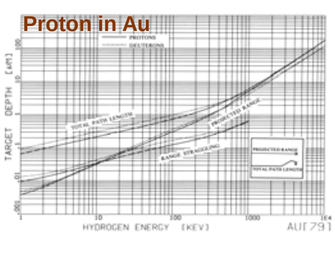

Figure 5: Range of the proton in the Au.

Thickness Measurement

In order to develop one of application fields for In-Air RBS, we perform thickness measurements for several Au foils with different thicknesses. Figure 6 shows In- Air- RBS spectra for Au foils with several thicknesses which are 0.75, 1.0, 2.0, and 5.5 um. Note that we use 0.75 and 1.0 um Au target supported by the acrylic foils so that there are second peaks in these spectra. The arrows with E_f and E_b in the figure indicate the estimated energies of reflected ions from surface and back face of Au foils and the E_f and E_b are given as follows,

$$E_f=K\left[E_0-\int_{r_1}\left(\frac{dE}{dx}\right)_{Air}dx\right]-\int_{r_2}\left(\frac{dE}{dx}\right)_{Air}dx$$

$$E_b=K\left[E_0-\int_{r_1}\left(\frac{dE}{dx}\right)_{Air}dx-\int_{d}\left(\frac{dE}{dx}\right)_{material}dx\right]-\int_{d'}\left(\frac{dE}{dx}\right)_{material}dx-\int_{r_2}\left(\frac{dE}{dx}\right)_{Air}dx$$

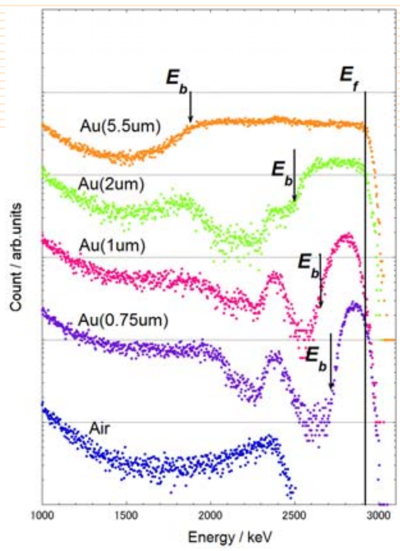

Figure 6: In-Air-RBS spectrum for Au foils with various thicknesses .

As is shown in Figure, the estimated arrows are in good agreement with experimental results.

Here we have estimated the limit of measurable thickness in the present In-Air-RBS method. The considerable causes of the ion energy spread in "In-Air-RBS" are the detector resolution, finite detection angle in present geometry, energy straggling in air before/after the scattering and energy straggling in Au foils. Typical values are tabulated in Table 2.

The compound energy spread of protons is estimated around 41 keV in FWHM. This corresponds to 0.1um thickness in the case of Au foils.

Table 2: Considerable energy spread of protons in FWHM.

Detector Resolution	14 keV
Detector Geometry	21 keV
Straggling in Air	32 keV
SUM	41 keV

SUMMARY

We have developed In-Air-RBS method with tapered glass capillary. At first, we have measured "In-Air-RBS" spectra for six different metal foils and then have performed energy calibration taking into account energy losses of ions in air. Second, we have performed the thickness measurement for Au foils with several thickness. Estimated energies are good agreement with experimental results.

It is concluded that present "In- Air-RBS" method is useful to determine the thickness of thin metal from 0.1 um to several microns. Furthermore this method is quite gentle to the specimen (Air around the beam spot as a cold gas) and there are no restrictions of sample size. (We don't need any chamber for samples). This method is especially expected for archaeological samples in the future

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