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Measurements of an ion beam diameter extracted into air through a glass capillary

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ABSTRACT

To establish techniques for in-air materials analysis using a glass capillary, we studied the beam distribution extracted in air as a function of the distance between the exit of the capillary and the target. We measured three-dimensional intensity distributions of the extracted beams, and compared the observed results with the model calculation. The comparison showed that the glass capillary technique is designed to reduce a divergence of the beam extracted into the air by a beam-focusing effect.

1. Introduction

Particle induced X-ray emission (PIXE) is a well-known material analysis method that uses MeV ion beams [1]. This method is simple and allows for simultaneous analysis of multiple elements in a sample, quantitatively and nondestructively, with high sensitivity. Owing to these advantages, PIXE is widely used in the fields of medicine, biology, and environmental problems [2]. Recently, PIXE is also applied to samples in a liquid phase, under atmospheric pressure [3]. Because this method provides sufficient beam current without damaging specimens, the development of in-air PIXE could be a possible breakthrough solution to the common problem of specimen overheating. Biological samples tend to lose volatile elements from heat, and thus the disruption of palletized targets from charge-up and out-gassing can be problematic. Hence, the in-air-PIXE could be especially useful in the field of the biology.

In general, ion beams are extracted into the air by way of a thin film that is used as a vacuum window [4]. Recently, a glass capillary was found to be an efficient tool to extract micron-sized ion beans into air without the use of a vacuum window [5]. Since this technique is simple and effective, it has been employed in various fields of research. Previous studies using glass capillaries have reported transmission properties of the ion beam for many kinds of ions, at various energies [6–9]. In a previous work, we had also studied the transmission properties of ion beams through various capillaries and we developed a material analysis including a 2D elemental mapping in-air-PIXE [10]. Throughout all of these studies, it was repeatedly determined that ion beam profiles extracted in air are important for accrual 2D mapping.

In this present work, we measure the intensity distribution of a 3.0 MeV proton beam extracted into air with a glass capillary, as a function of the distance between the exit of the capillary and the target. Furthermore in order to examine the beam-focusing effect of the capillary, model calculations for the situation has been performed.

2. Experimental setup

Experiments were carried out using a 1.7 MV tandem van de Graaff accelerator at Nara Women's University [11]. We installed a beam line equipped with a differential pumping system and set the capillary at the end of the beam line. Fig. 1 shows details of the end station of the beamline. The experimental setup is almost identical to that described in the proceedings at the ICACS-24 conference [10]. Briefly speaking, we have used a glass capillary whose inlet diameter is 2 mm and outlet is 200 µm. It is noted in our previous work that the effective thickness of the air contained in this capillary was about 5.2 mm at 1 atm [12]. In this setup, the distance between the exit of the capillary and the target, l_t, is adjustable and ranges from 1.0 mm to 10.0 mm. The detector is set about 135°with respect to the beam axis, and the sensitive area of the detector is about 3.1 cm^2. The distance between the target and the high-purity Ge detector, l_d, is about 3.5 cm to 4.1 cm when the distance l_t is from 1.0 mm to 10.0 mm, respectively. X-ray absorption in air between the target and the detector can be

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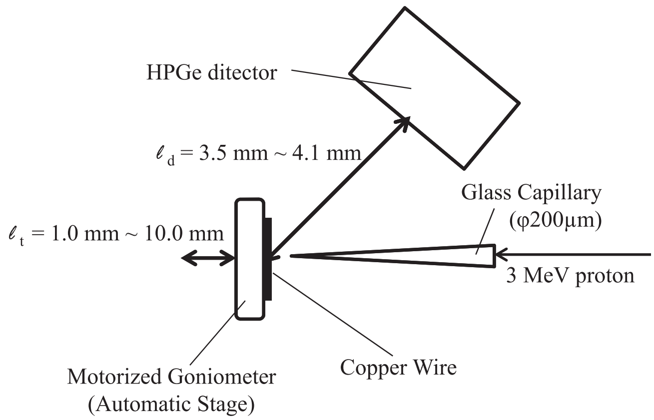

Fig. 1. Schematic of the setup for measurement of ion beam diameter. A copper wire on the automatic stage is movable in the directions along the incident beam and perpendicular to it with 1 mm steps.

ignored since it is 96.5% for l_d = 3.5 cm and 96.0 % for l_d = 4.1 cm, respectively [13].

We used a 3.0 MeV proton beam as the incident ions and a copper wire of 25 μm in diameter as a target. This target was fixed on a motorized goniometer (TSDM60-20X, by SIGMA KOKI). By measuring the induced characteristic X-ray from the target as a function of the target position normal to the beam axis, we determined the intensity distribution of the extracted ions.

3. Results and discussion

Fig. 2 shows the intensity of the extracted beam depending on the target position: the (X) axis indicates the position of the target normal to the beam axis, the (Y) axis indicates the distance, l_t, ranging from 1.0 mm to 10.0 mm, and the (Z) axis indicates the X-ray yield (arbitrary scale). It should be noted that the beam distribution appears to have a Gaussian shape and becomes broader with increasing distance, l_t. As a result, the peak X-ray yield decreases with increasing distance l_t.

The residual air in the capillary spreads the ion beam and this spreading contributes to the lateral straggling of the extracted beam such that the beam diameter is equal to that of an ion beam diameter emitted by a window without a capillary wall. In this case, the full widths at half maximum (FWHMs) are larger than the results reported in this work. Additionally, we performed model calculations to estimate the beam distributions we obtained experimentally. In order to investigate the beam-focusing effect of the capillary in air, we assumed for the model that the effective thickness of the air is the same as that which the extracted beam penetrated. Schematic diagram of this situation is shown in Fig. 3(a). The model assumes that the residual air does not contribute to the lateral straggling. The residual air is assumed to work only as an genergy degrader,h which is an imaginary degrader without the occurrence of the spread of the incident beam.

The distribution of the extracted beam was estimated in the following manner. The exit area of the circular-shaped capillary was divided into the infinitesimal strips. The area of each strip, dS, whose distance from the center of the capillary and width are x_s and dx_s, respectively, is given as

$$dS = 2\sqrt{(R^2 - x_s^2)}dx_s, \tag{1}$$

where R is the radius of the capillary. Here, we assumed the broadening of the ion beam to be expressed by a Gaussian function,

$$g(x) = \frac{1}{\sqrt{2\pi\sigma_{Air}^2}} \exp\left(-\frac{(x-x_s)^2}{2\sigma_{Air}^2}\right), \tag{2}$$

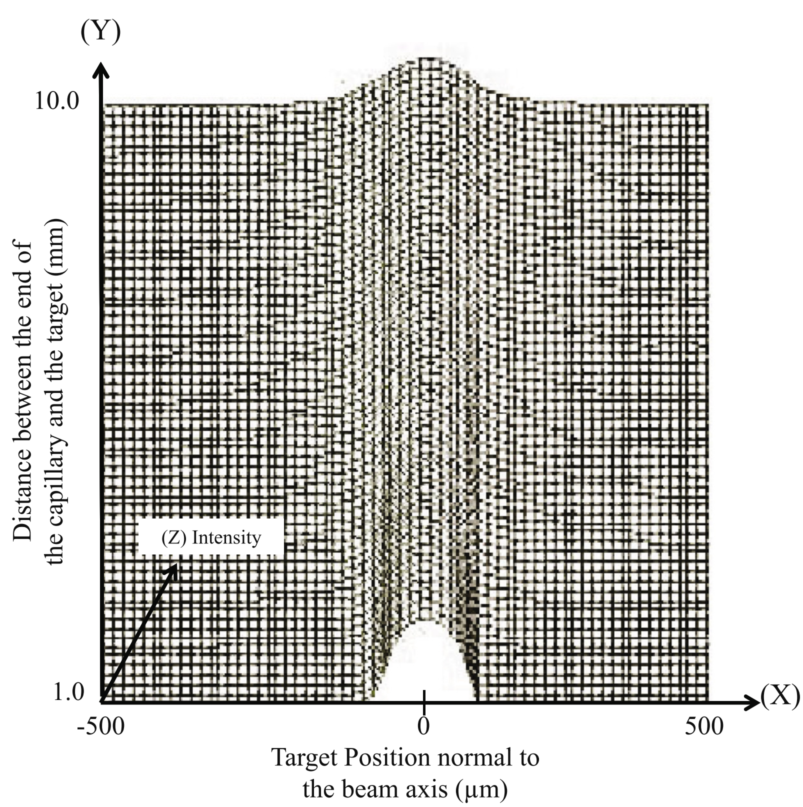

Fig. 2. Profiles of the ion beam extracted into air through the glass capillary. The profiles were determined by counting the characteristic X-ray from the copper wire whose diameter is 25 μm. (X) represents ion beam diameter normal to the beam axis. (Y) represents the distance between the exit of the capillary and copper wire, l_t. The position of Cu wire was changed along the direction of (Y) with a 1 mm step. (Z) represents the counts of the X-ray yield with an arbitrary scale.