Energy dependence of MeV-ion microbeam size extracted from tapered glass capillary optics

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Tapered glass capillary optics, which is known as the cell injection needle in life sciences, is capable of producing micrometer-sized MeV ion beams. One of the advantages of this microbeam optics is that the target can either be in vacuum, air, or liquid because the end-window at the capillary outlet keeps the vacuum level inside the capillary. The end-window is fabricated to be thin enough to enable the passage of ions. It also contributes in the close approach of the capillary outlet to the target even in air/liquid so that the broadening of the microbeam size due to multiple-scattering is minimized. An irradiation experiment on a small organ such as an insect's skin using a few MeV energy H/He ions provided by the RIKEN Pelletron accelerator is scheduled to investigate the gene functions relevant to the development of the organ. The combination of MeV ions and the capillary realizes the damage confinement in depth as well as the pin-point lateral damage in the order of μm to ensure that microscopic observation can be performed to find any change in the shape of the organ after the ion irradiation. We aim at a spot size of several tens of μm at an irradiation distance of 1 mm or beam divergence of 1°. This report introduces the measurements of the spot sizes and their positions.

Figure 1 shows the plastic end-window of the used capillary whose inlet/outlet sizes were 1.8 mm/9.9 μm, respectively. A 2.8 MeV H^+ beam entered the capillary mounted at the beam port of BL-W30 line (Fig. 2(a)). The port has a θ-ϕ (horizontal and vertical) tilting system. The microbeam size and position were measured by the knife-edge method with a step of 75 μm, assuming Gaussian shape. The extracted ions were counted by a PIN photodiode, connected to the pre- and main-amplifiers, discriminator and visual scaler.

Capillary optics is known to have a beam guiding effect. For keV ions, the ion transmission was observed even when the capillary was tilted by up to 80 mrad.[1)] The effect for 2.8 MeV H^+ was tested for the first time in this energy region. The measured bending angle reconstructed from the spot position in Fig. 2(b) shows the guiding for up to 9.0 mrad. However, the measured angles for a larger tilting exhibited degradation due to the asymmetric tails of the spots.

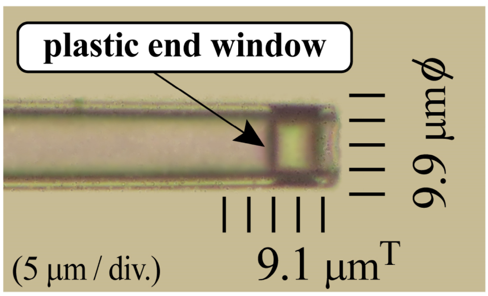

Fig. 1. Outlet of the capillary. The inner diameter and the thickness of the end-window are 9.9 μm and 9.1 μm, respectively. Inner diameter looks larger owing to the refraction index of borosilicate (1.473) for $\lambda = 587.6$ nm.

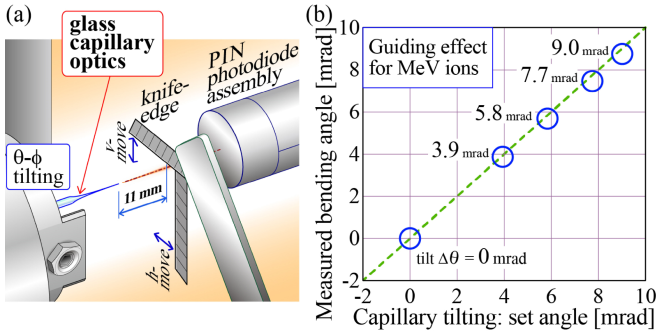

Fig. 2. (a) Measurements of the size and position with knife-edge method. (b) The blue circles show the bending angles as a function of the horizontal tilt angle.

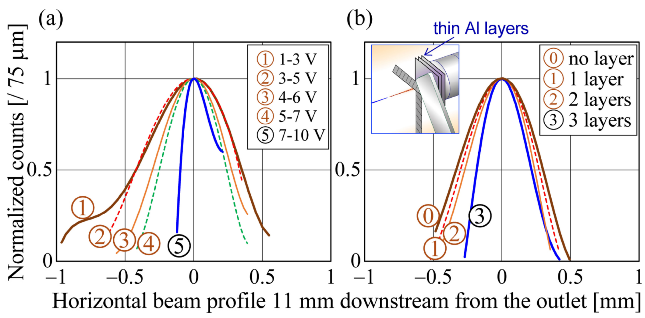

Fig. 3. Microbeam profiles according to (a) ion energy and (b) number of thin Al layers.

The measured spot sizes according to the ion energy are shown as lines named 1–5 in Fig. 3(a). The ion energy was selected by the pulse height of the main-amplifier output between the low-energy (1–3 V) and high-energy (7–10 V). Line 5 that represents the minimized energy-loss events is the narrowest peak. The peak becomes wider for lower energy events. To obtain narrower microbeams by cutting the low-energy events, a stack of Al-degrader foils was introduced behind the knife-edge. Figure 3(b) shows the beam profiles changing the number of foils of 11 μm thickness each. No ion was counted for more than three layers. The narrowest peak (398 μm in FWHM) was obtained by three layers. The corresponding beam divergence is approximately 1° for each side, which is comparable to that of 3° of the laser microbeam extracted from the same capillary for the laser sight system.[2)] The average energy and standard deviation of the ions at the PIN photodiode are 1.08 MeV and 51.7 keV, respectively, estimated by SRIM code.[3)]

References

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