Back trace of ions ejected from glass capillary optics using super-high-resolution nuclear emulsion

T. Shiraishi,[*1,*2] T. Ikeda,[*2,*1] H. Miyazaki,[*3,*2] Y. C. Dowdy,[*3,*2] K. Inayoshi,[*3,*2] K. Saeki,[*3,*2] H. Suzuki,[*3,*2] T. Naka,[*3] and W.-G. Jin[*3]

Tapered glass capillary optics have been utilized for producing micron-sized ion beams in the keV to MeV energy scale at the RIKEN Pelletron accelerator facility in the Nishina R&D Building.[1,2] In particular, for MeV ion beams, a plastic end window with a thickness of a few tens of μms is attached to the outlet of the glass capillary. The MeV ions can then penetrate through this window, which allows for ion irradiation in air or liquids. This technique can be applied, for example, to elemental mapping such as the micro-particle induced X-ray emission, and local irradiation of a single cell or organs. However, the transportation of MeV ions inside the capillary is difficult to predict due to complex processes such as Rutherford scattering on the inner glass wall, penetration through the thin wall,[3] and multiple scattering at the end window. Therefore, kinematic parameters such as the position, direction, and energy for individual ions close to the outlet are important factors for designing the capillary shape and quadrupole magnet surrounding it to improve the beam's focus. Here, we report a new MeV ion irradiation experiment using a super-high-resolution nuclear emulsion detector called the nano imaging tracker (NIT)[4] to extract ion kinematics from the 3-dimensional trajectories of ions ejected from the outlet (back trace). In this experiment, we used a short capillary with a large outlet of 50-μm in diameter to reduce the scattering during the ion transportation.

The NIT comprises AgBr:I crystals the size of several tens of nanometers that are dispersed with a density of 10^3–10^4 crystals/μm^3 in a medium of gelatin and polyvinyl alcohol.[4] Each crystal acts as a sensor to visualize the trajectory of charged particles. This makes the NIT a unique solid tracking detector with a spatial resolution of 100 nm, which is accurate enough for back tracing the ions to the 50-μm outlet. An automated readout system for the NIT has been well established, which is capable of acquiring 3D vectors for tracks longer than 1 μm, and equates to 100 keV in proton energy.[5] Tracking individual ions using this system enables measuring beam profiles and energy spectra even at high ion densities such as 10^7 ions/cm^2.

As shown in Fig. 1, 1.6/3.4 MeV H^+ beams from the Pelletron accelerator were irradiated to the NIT at a distance of 3/10 mm, and the ion tracks were back-traced to the capillary outlet. We define the impact parameter (IP) as the minimum distance of each ion track to the capillary outlet, which corresponds to the focusing of a beam. Its distribution is shown in Fig. 2. Ideally, the IP should distribute approximately the size of the outlet aperture, however, the prediction from the MC simulation using GEANT4 indicates that IP spreading is primarily due to the decrease in the angular accuracy caused by multiple scatterings inside the NIT. For higher precision measurements, we are considering the use of track angles near the NIT surface to suppress the scattering effect, and to shorten the irradiation distance as much as possible.

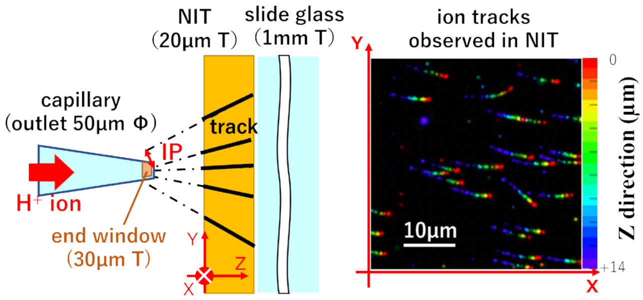

Fig. 1. A schematic of MeV ion beam irradiations to the NIT with the glass capillary. The right photograph shows an actual optical microscope image of ion tracks. The Z coordinate is displayed with a colored scale.

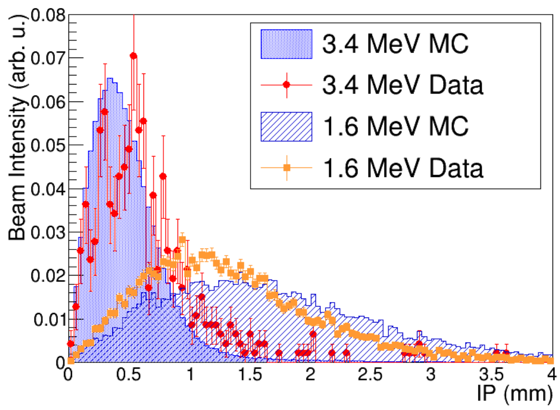

Fig. 2. A comparison of IP distributions between the data and MC simulations for 1.6 and 3.4 MeV H^+ beams at an irradiation distance of 10 mm.

References

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*1 Department of Physics, Kanagawa University
*2 RIKEN Nishina Center
*3 Department of Physics, Toho University

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