Stable transmission of slow highly charged ions through tapered glass capillary with active discharging method for sub-micron sized beams†

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Slow (10–100 keV), highly charged ion (HCI) beams have been widely used for the processing and analysis of materials. Such ions have the advantage of being "soft" ionizers for target molecules.[1)] When a slow HCI hits a molecule, the ion captures some electrons from the target molecule, which causes the specific breaking of relatively weak bonds. The low kinetic energy of the ion limits damage to the target. In order to use the advantage in microscopic analysis and the modification of the material surface, small, simple, and stable micro-HCI beam generators are required.

In 2006, we demonstrated a simple and convenient method for producing microbeams of slow HCIs (8-keV Ar^{8+}) using a single tapered glass capillary with an outlet diameter of 24 μm.[2)] The key mechanism for beam transportation is based on self-organized charge patches on the inner surface of the capillary, which are induced by the incident beam itself. The transmitted beam had the same diameter as the capillary outlet and kept the initial charge state and energy. The intensity of the transmitted beam was several times larger than that expected from the cross-section ratio of outlet to inlet (focusing effect). Using capillaries, one can easily determine the beam position under a microscope because the beam position coincides with the capillary outlet. However, transmitted microbeams occasionally become unstable, and their transmission can be blocked[3)] or suddenly increased. These instability problems need to be solved for the use of this method in a slow micro-HCI beam generator.

The experiments were performed at the Slow Highly Charged Ion Facility in RIKEN. A large capillary made of soda lime glass, from Hamamatsu Photonics K.K., had an outer surface and the inlet and outlet surfaces which were coated with conductive material to allow operation as ring (or tube-shaped) electrodes, as indicated by 4 orange arrows in Fig. 1(a). A small capillary made of soda lime glass with D'_{out} = 0.75 μm (Figs. 1(a) and 1(b)) was used. The inlet surface of the small capillary was coated with conductive paste and placed in contact with the outlet surface of the large capillary. When the beam enters the optics, the charge on the inner surfaces near *el*-A increases. Some of the charge can flow on the inner surface and then reach the edge of the inner surface, which is the border between the inner surface and outlet surface. Once the charge reaches the outlet surface, *el*-A and the outlet surface gradually accumulate charge. To remove the excess charge from *el*-A, a mechanical relay switch was installed between *el*-A and the ground (Fig.1(c)). The relay was controlled by TTL signals with a frequency f_{TTL} = 0.1 Hz, called *active discharging*. For a 104-keV Ar^{8+} beam, Fig. 1(d) shows the number of transmitted ions per second $N_{transmit}$ (blue line). Based on the stable $I_{monitor}$ (red curve) monitored at an entrance aperture of the experimental chamber, the input current to the large capillary I_{input} was estimated to be stable. The TTL signals were sent before 3050 s and after 3350 s (light green zones). During the 300-s time without relay operation, the transmission became gradually blocked and eventually stopped. When the TTL sending restarted, the transmission also started again with almost the same $N_{transmit}$ and remained constant until the input beam stopped.

To confirm the effect of the active discharging we tested the transmission stability through the large capillary without the small capillary by measuring the transmitted beam current $I_{transmit}$ with a Faraday cup (FC). The same effect due to the active discharging was found with some density gain.

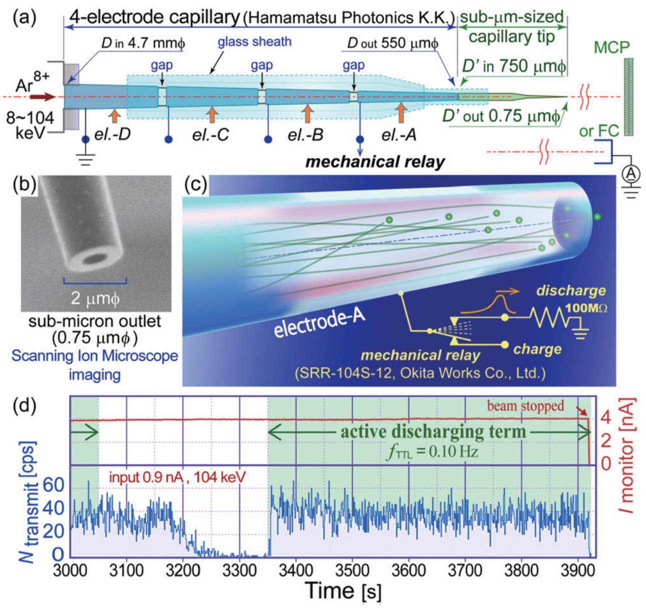

Fig. 1. (a) The glass tandem optics consisting of a 4-electrode capillary (large capillary) and a sub-μm-sized capillary tip (small capillary). (b) A magnified view of the tip outlet. (c) The active discharging maintains the charge below the level at which blocking is induced. (d) The number of transmitted ions as a function of time with or without the active discharging.

References
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