Active discharging method for stable sub-micron sized beams of slow highly charged ions using tapered glass capillary with electrodes

Tokihiro Ikeda* [1], Takao M. Kojima *, Yoshio Natsume †, Jun Kimura ‡, and Tomoko Abe *

* RIKEN Nishina Center for Accelerator-Based Science, 2-1 Hirosawa, Wako, Saitama 351-0198 Japan
† Electron Tube Division, Hamamatsu Photonics KK, 314-5 Shimokanzo, Iwata, Shizuoka 438-0193 Japan
‡ Tokyo Branch Office, Hamamatsu Photonics KK, 3-8-21 Toranomon, Minato, Tokyo 105-0001 Japan

Synopsis Stable transmission of a 0.75 μm-sized Ar^{8+} beam of 10–100-keV energy through glass tandem optics was achieved. The optics consisted of a 4-electrode tapered capillary and a sub-μm-sized tapered capillary tip, arranged in series. To actively discharge the capillary, and thus obtain stable transmission, an electrode was applied with a mechanical relay closing at a 0.01–0.1 Hz frequency.

Slow (10–100 keV) highly-charged ion (HCI) beams have been widely used for processing and analysis of materials. In order to use the slow HCI in microscopic analysis and modification, small and stable micro-HCI beam generators are required. In 2006, we demonstrated a simple and convenient method for producing microbeams using a single tapered glass capillary with an outlet diameter of 24 μm. The beam transportation is based on self-organized charge patches on the inner surface of the capillary, which are induced by the incident beam itself [1]. However, transmitted microbeams sometimes become unstable and their transmission can be blocked or suddenly increased.

In order to solve the problem, a tandem glass-made optics consisting of a 4-electrode capillary, from Hamamatsu Photonics K.K. (Fig.1(a)), and a tapered capillary tip with a sub-μm sized outlet (Figs. 1(b)) was developed. The larger capillary had 4 ring-electrodes on its outer surface. The unstable transmission was expected to be due to too much charge-up around the position marked by a circle S in Fig.1(a). The outlet surface of the larger capillary and the inlet surface of the smaller one touched each other and were connected to *electrode-A*, so that the excess charge is removed toward the ground level periodically through a mechanical relay (active discharging, Fig.1(c)). The relay was controlled by TTL signals with a frequency f_{TTL} ~ 0.1 Hz [2]. Figure 1(d) shows the number of transmitted ions per second $N_{transmit}$ for a 104-keV Ar^{8+} beam at the Slow Highly Charged Ion Facility in RIKEN. During a period (3050-3350s) without relay operation, the transmission became gradually blocked and eventually stopped. When the TTL sending restarted, the transmission also started again and remained constant until the input beam stopped.

When only a 4-electrode capillary was used, the density of the extracted beam became up to 14 times larger than that of the input beam. A transmission efficiency up to 70% was observed with good reproducibility when the electrodes were biased with appropriate voltages.

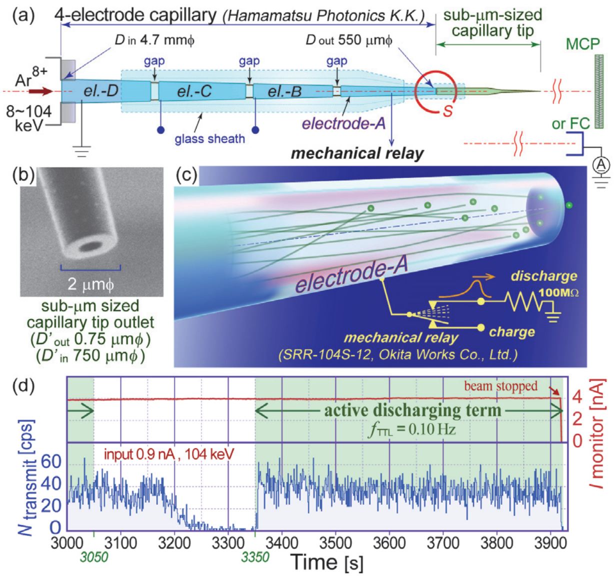

Figure 1. (a) A 4-electrode capillary (larger capillary) and a sub-μm-sized capillary tip (smaller one) were in series. (b) A magnified view of the tip outlet. (c) Charge flow around a circle S in Fig. 1(a). (d) The time evolution of the transmission with or without the active discharging. Regarding the stable $I_{monitor}$ (red curve) measured at an entrance aperture of the experimental chamber, input current to the larger capillary was estimated to be stable.

References

[1] T. Ikeda *et al.* 2006 *Appl. Phys. Lett.* **89** 163502
[2] T. Ikeda *et al.* 2016 *Appl. Phys. Lett.* **109** 133501

[1] E-mail: tokihiro@riken.jp