Evolution of the electric potential of an insulator under charged particle impact

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Synopsis We present a combined experimental and theoretical study that show that glass micro-capillaries can reach potentials that exceed 500V, even in the case of singly charged ions, opening the possibility of high transmission rates and providing a renewed sight into ion beam transport by conical capillaries.

When an ion beam is injected into a tapered glass capillary, most of the injected charge is stored in the dielectric and its electric potential rises. A recent theoretical study showed that the transmission through conical-shaped capillaries increases when the self-organized electric potential approaches about 80% of the extraction potential of the ion source, as the focal point is moved from infinity to the exit of the capillary [1]. It was found that for a low enough beam emittance, transmission rates of a factor 20 well above the geometrical one are expected. Knowing the potential of the capillary is thus crucial for the study of the lens effect in conical capillaries. We present a setup and a technique, able to monitor simultaneously the time-evolution of the electric potential and the transmitted beam intensity of a tapered capillary during the charging up, in a non-destructive way. Meanwhile, this study also evidences that stray electrons can be a strong discharge mechanism that helps stabilizing the electric potential and avoiding Coulomb-blocking. Eventually, it permits to quantify the leakage current due to stray electrons during the charging process.

As projectile we used 3 kV Ar^+ ions with beam intensities varied between 1–20 pA. We used a borosilicate glass micro-capillary of 75 mm length, whose first segment of 35 mm is cylindrical while the end was conical-shaped (see Fig. 1). The diameter of the outlet of our conical capillary is 26 μm and is 33 times smaller than the diameter of the inlet (860 μm), reducing the geometrical transmission fraction to about 0.1%. The outer surface of the capillary was electrically connected to an electrode placed right behind the exit hole of the capillary, acting as a deflector plate with another grounded electrode. When the incoming ion beam starts to charge up the insulator surface, as a direct consequence, the plates deflect the transmitted ions. The larger is the accumulated charge on the inner surface the larger is the deflection. We used the deflection of the transmitted beam as an ideal electrometer to monitor the potential of an insulating surface, which in our recent case was the inner surface of the tapered glass capillary, under charged particle impacts as a function of time. Simultaneously we recorded the transmitted beam intensity. Our measurements show that a tapered glass capillary is able to accumulate enough charge to generate electric potentials that approach the extraction potential of the source. The capillary starts to act like an Einzel lens and transmission rates 20 times above the geometrical one are achieved, opening a whole new field for ion beam transport by conical-shaped glass capillaries.

Figure 1. Electrode setup of conical-shaped borosilicate capillaries with deflection plates. The 3 mm insulator gap of about 10^{15} Ohm separates the grounded entrance from the floating electrodes.

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