6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

Controlled guiding and focusing of high current plasma ion beams by micro-glass capillaries: Quantum beams for physics and applications

Sushanta Barman and Sudeep Bhattacharjee
Department of Physics, Indian Institute of Technology, Kanpur
e-mail (speaker): sushanta@iitk.ac.in

Guiding of charged particles through insulating micro-glass capillaries becomes an important tool for manipulating ion beams. Capillary guiding has many applications, such as beam steering, cell surgery, fabrication of nanopores, and single biopolymer detectors [1]. The key mechanism of the beam guiding is based on self-organized charged patches on the capillary inner wall induced by the incident beams. The transmitted beams not only get bent along the tilting angle of the capillary but also get focused without changing their initial charge state and energy [2]. Focusing of ion beams through glass capillaries provides several advantages over ion beam focused by electrostatic or magnetostatic lenses, such as simple arrangement, minor beam divergence, and less sensitivity to the spherical and chromatic aberration due to the initial energy spread.

However, the transmitted beams sometimes become unstable due to the blocking of the beams by repulsive Coulomb forces exerted by the charge patches and discharge of the charges, which limits the application of such systems. Several attempts have been made to obtain stable beam transmission [2]. One key technique is to control the dynamics of the charge patches by employing multiple electrodes on the outer surface of the capillary and biasing them with electric potentials. The dynamics of the surface charge density (σ) at the inner wall of the capillary is given by [3]

$$\frac{\partial \sigma}{\partial t} = -k_b E_r - k_s \left(\frac{1}{R} \frac{\partial E_\theta}{\partial \theta} + \frac{\partial E_z}{\partial z} \right) + \gamma \quad , \qquad (1)$$

where R is the inner radius, k_b and k_s are the bulk and surface conductivity of the capillary, respectively. The first term on the right-hand side stands for the charges driven by the radial electric field. The second term describes the migration of charges along the inner surface driven by the angular and axial electric fields. γ is the source term due to injected current density. It is clear that the dynamics of the charges patches depends on the electric field distribution.

In the present work, Ar$^+$ beams are extracted from a plasma ion source based on electron cyclotron resonance, where the plasma is produced using microwaves of frequency 2.45 GHz and confined in an octupole magnetic multicusp [4, 5]. A compact electrostatic lens system is employed to extract the ions from the plasma and focus the beam with the required energy (~30 KeV). The schematic diagram of the system is shown in Fig. 1(A). Experiments are performed to obtain stable transmission of Ar$^+$ beams having energy 10-30 keV, through micro-glass capillaries of length 7 cm, inlet inner diameter 860 μm and outlet inner diameter 5 μm - 44 μm. The transmitted beam currents are measured using a Faradaycup (National Electrostatics Corporation, USA) placed after the capillary. The evolution of the charge patches are controlled by employing voltages to the electrodes attached to the capillary as shown in Fig. 1(B).

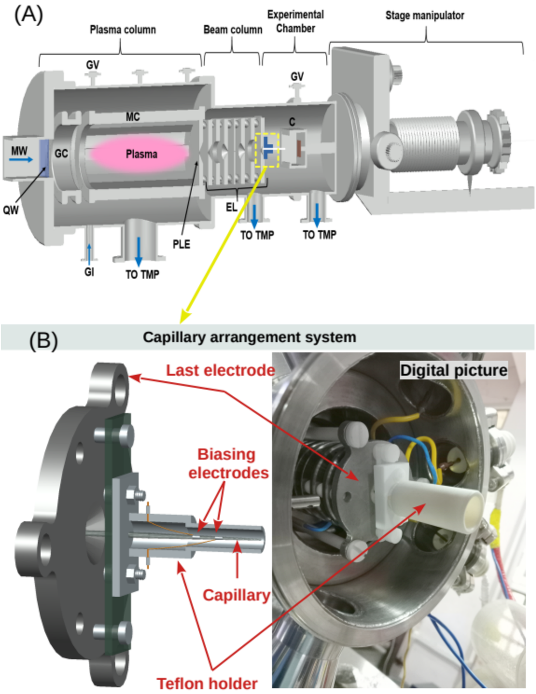

Figure 1. (A) Schametic diagram of the microwave plasma-based ion beam system [4]. (B) Capillary arrangement system.

In order to obtain nanometer size quantum beams, the focusing factor of the capillary is controlled by changing the biasing voltages. Spots are created on poly methyl methacrylate (PMMA) substrate and measured using scanning electron microscope (SEM). The results of nanometer size quantum beams will be presented in the conference.

References

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