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Capillary guiding and plasma sheath nonlinearity in achieving submicron focusing of ion beams from plasma ion source

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A focused ion beam is an inevitable tool for research and applications in nanoscience and technology such as milling, patterning, high-resolution imaging, including implantation. Conventionally, liquid metal ion source (LMIS) based FIB is used for nanofabrication, however, slow volume milling, small beam currents (1 pA – 10 nA), and metallic contamination to the target sample are major issues. To overcome these limitations, a versatile microwave plasma based multi-element focused ion beam (MEFIB) system has been developed in our laboratory that can deliver ions of a variety of gaseous elements such as Ar, Kr, and Ne of beam size ~3 µm and significantly large beam currents in the range 1.5 nA – 10 µA [1]. Further, submicron focusing of plasma ion beams can be achieved, which is important for fabrication below the micrometer length scale and for the enhancement of the applicability of the materials. To obtain a submicron beam, guiding of high current density plasma ion beams (J ~600 Am^{-2}) through micro glass capillary has been demonstrated over a tilt angle of 5°. Self focusing of the beam is observed (maximum beam size compression ~81%) which can be employed to reduce the object (source) size (plasma electrode (PLE) aperture) for further demagnification [2]. The investigation reveals that inward radial forces of the charges that get smeared on the capillary inner wall dominate over the Coulomb repulsion of the beam's space charge, and therefore the beam is self focused. Hysteresis in beam current with ion energy is observed and charge dissipation is evaluated theoretically during a hysteresis cycle. Particle in cell simulations are performed to interpret the experimental results of self focusing. Further, the effect of plasma and beam parameters on focal dimensions (focal length and beam size) is investigated by employing experiments, beam simulations (AXCEL-INP and SIMION), and theoretical models, which is important as the samples are kept at the focal point during processing. A new effect of nonlinear demagnification is observed when the plasma electrode aperture size is reduced to smaller than the Debye length of the plasma as shown in Figure 1 [3]. Finally, employing this plasma sheath nonlinearity and minimizing space charge effects in the beam, submicron focusing (beam size ~500 nm) is realized for a constant focusing field [4].

References

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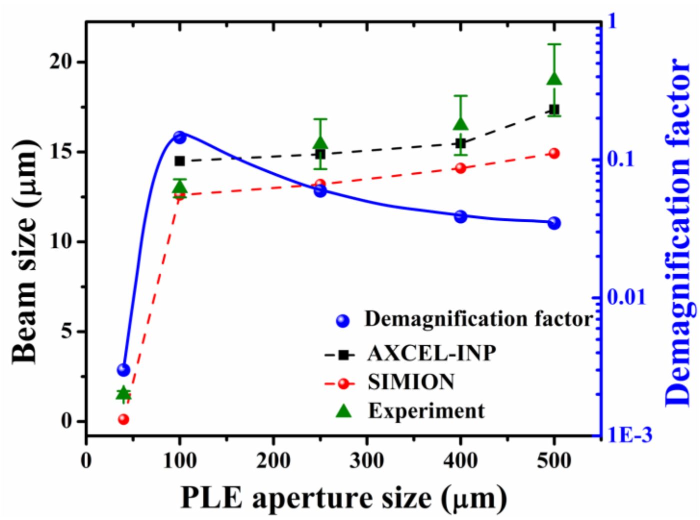

Figure 1. Variation of beam size and demagnification factor with the PLE aperture (source) size, which shows nonlinearity in demagnification.