SIMULATION OF ION BEAM OPTICS FOR FOCUSED ION BEAM SYSTEM

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Abstract

A low energy focused ion beam system based on RF plasma ion source is designed and developed for micromachining applications. The ion beam is extracted using a single aperture two electrode system. Ion beam focusing column consists of a single Einzel lens and a beam limiting aperture. The beam limiting aperture of 250 micrometer diameter is placed before the Einzel lens to allow ion beam with only ± 1.25 mrad to pass through the Einzel lens and thereby minimizing the aberrations. The simulation of the ion beam extraction and electrostatic focusing is carried out using 2D ray-tracing code – IGUN and OPTICS. The ion beam properties such as emittance, brightness, current density profile etc. are obtained by IGUN and the aberration analysis by OPTICS and are discussed in this paper. These results are also compared with the experimentally obtained data.

INTRODUCTION

Ion beam of micron order dimension generated by focused ion beam systems (FIB) plays important role in various fields of research and technology like secondary ion microscopy, fabrication of micron devices, semiconductor failure analysis etc. [1]. Ion beam interact with surfaces in different ways depending on the energy of impinging beam, mainly causing either sputtering, deposition or secondary particle generation. In all these applications of ion beams, lateral resolution depends on the beam dimension and thus Ion optics for such system need to be designed and optimised with utmost care.

An FIB is under development in VECC, Kolkata for micro machining applications [2, 3]. The main feature of the system is the plasma based ion source unlike traditional FIB system which employs field emission ion sources (FEIS) [4]. A single lens ion optical column for focusing the beam to micron order is designed and developed and the preliminary tests are carried out.

SIMULATION OF ION OPTICS

We have used IGUN [5] for the extraction geometry design and OPTICS [6] for the design of low energy ion beam optical column. IGUN is specially designed ray tracing program for simulating the plasma region for the extraction of ion beam and it also support the simulation of focusing lenses. IGUN can handle 2D rectangular and axisymmetric problems with space charge considerations. OPTICS is a software package developed by MEBS ltd. for computing the optical properties of complete electron and ion beam columns, containing any combination of electrostatic and magnetic lenses and deflectors. The electrostatic fields are computed by the first-order finite element method (FEM). The program computes geometrical aberrations of third order, and the chromatic aberrations of first order.

EXTRACTION SYSTEM

The extraction of ion beam from Inductively Coupled Plasma ion source is done with single aperture two electrodes. In order to have small source size, extraction aperture is kept very small. To get a uniform curvature of field across the aperture, a conical edge is used and this improves the beam quality. The system is simulated in IGUN. Optimisation for getting maximum brightness of Argon 1+ ion beam is done by varying the electrode gap, aspect ratio, aperture size, extraction voltage etc.

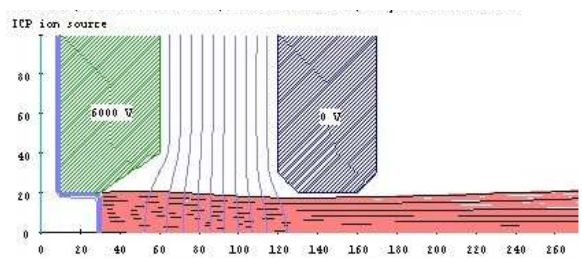

Figure 1: Ion beam trajectory from Extraction system.

Figure 1 shows the optimized extraction geometry with ion beam trajectories. Electrodes are having aperture radius of 0.5 mm and are kept at 1.5 mm gap. Figure 2 shows the variation of extracted current and RMs emittance as a function of extracted voltage for this geometry. Emittance has an optimum at 6 kV for this geometry, though current showed a tendency to increase with extraction voltage (Vext). Brightness at 6 keV was found to be around 12700 A/m^2sreV.

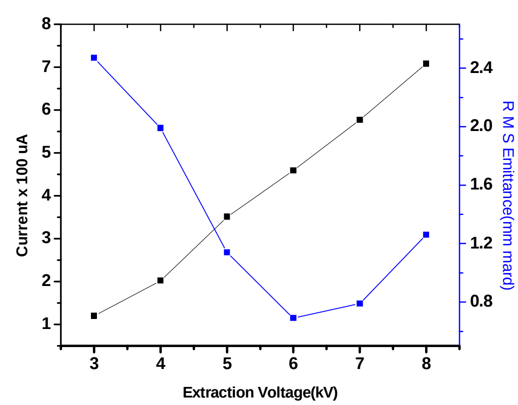

Fig. 2 Variation of current and RMS emittance with Vext

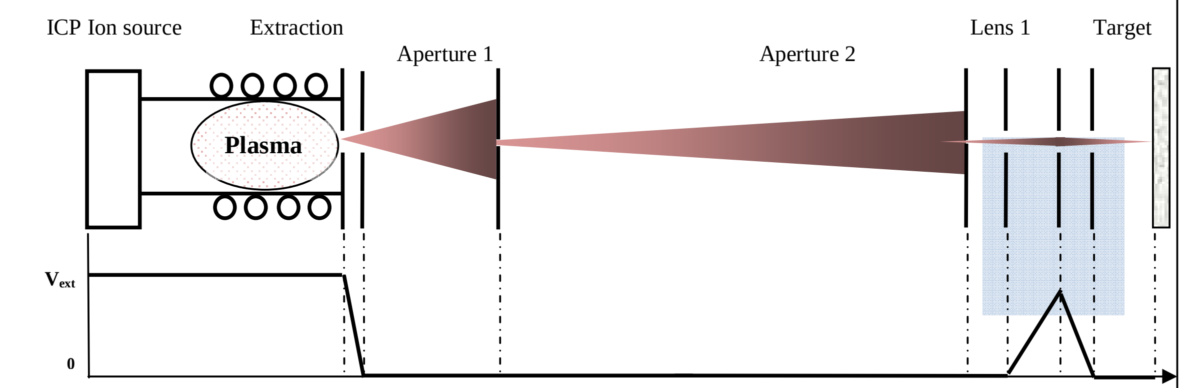

Figure 3: Schematic of the ion source and the optical column.

FOCUSING COLUMN

The purpose of the optics is to form an image of the source on to the focal plane where source is the virtual source from where the ions appear to emanate from. This will be many times smaller than the real extraction aperture and unlike in the FEIS, in plasma based ion sources the location and dimension of the virtual source can be optimised. In the case of our system the virtual source size is measured to be 10 to 15 micron and to obtain a nanometer sized beam at target plane, a demaginification factor of 1000 is to be incorporated which is possible by 3 lens geometry. For getting an experience of fine focusing of beam with electrostatic lens, single lens geometry is designed with a demagnification factor of 20. Figure 2 shows the schematic of the optical column. First source of aberration in the beam is from the edges of extraction aperture and beam limiting apertures are used to remove the abberated beam from the periphery. The beam limiting aperture of 250 micrometer diameter placed before the Einzel lens is to allow ion beam with only ± 1.25 mrad to pass through the Einzel lens.

Calculations from OPTICS code show that over a wide range of ion energies, single power supply operation is possible since for a particular working distance, 4 mm in the present design, optimum focusing voltage is same as ion beam extraction voltage. This fact has been verified experimentally for ions with energy range of 1 KeV – 6 KeV. With the increase of working distance the aberrations increase and especially the spherical aberration increases exponentially, which affect the final image size. For an optical column as shown in the schematic, with 6 KeV argon ion beam, the evolution of these aberrations with change in the working distance, are evaluated using Munro's code as shown in Fig. 3. It is seen that at working distance of 4 mm, Cc and Cs are 54 mm and 228 mm respectively and aberrations blur due to these two factors is less than 250 nm. Focused ion beam size almost doubles over 10 mm working distance and is largely due to the contribution from Gaussian image size d_g rather than from aberrations. Simulations show that the magnification is almost doubled and increase in the contributions from aberrations is only 10% i.e, 250 nm – 280 nm. This shows for the plasma based ion source, it is essential to keep the working distance as small as possible.

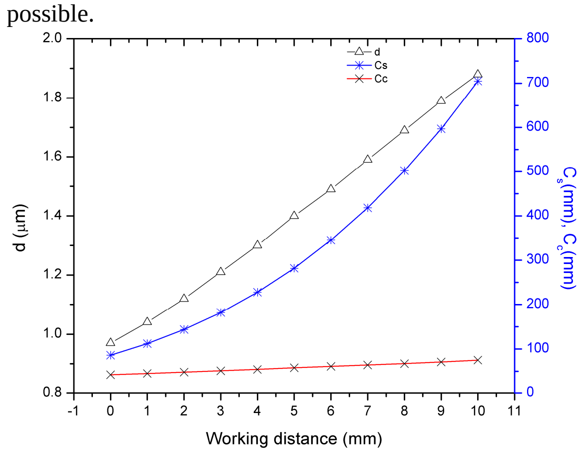

Figure 3: Evolution of spot size, Cc, Cs with increase in the working distance.

EXPERIMENTAL RESULTS

The electrodes are machined in stainless steel and an arrangement is made to fit the electrodes along with the extraction electrode with alignment precision of ±10μm. The insulators are made of Teflon. Below the focusing column, knife edge sweep scanning system for measuring the size of the beam is assembled. Change in the ion beam current was measured as a function of knife edge position by using secondary electron suppressed Faraday cup. Knife edge measurements show that, at a working distance of 4 mm, the spot size of 2 μm was achieved. In this experiment, 11.9 nA of Argon was obtained at focal plane.

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