LARGE AREA, DIRECT WRITE FOCUSED ION BEAM LITHOGRAPHY SYSTEM

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Abstract

A system for maskless ion beam milling based on a high brightness RF plasma ion source and a compact focusing column using electrostatic elements is designed and developed. So far 1.5 µm spot size with current density of 350 mA/cm^2 could be achieved. Pattering is carried out by scanning the sample using high precision 3-axis stage. The size of the micropattering area is only limited by the span of the translation stage which is 25 mm x 25 mm in our case. Measurements to estimate the focused spot size and ion beam profile at the focal plane are carried out by using knife edge scanning method. This article describes the micromachining system, a few examples of micro pattering and possible future programs. This paper also addresses a few issues on focusing low energy beam from plasma sources to micron and submicron dimensions and challenges of measuring their sizes.

INTRODUCTION

Ion beams play a very vital role starting from ion implantation to circuit modifications. Ion beam micromachining is a concept where there are no traditional steps of chemical etching are required. This is also a single step process where the required features are directly sputtered (direct write) from any sample. In few applications, high current broad beam is required and in some other cases fine beam with high intensity is required. Enormous research has been carried out in the field of producing fine beams for milling by using Liquid Gallium based ion sources (LMIS). Although these systems offer submicron beams in a compact configuration and have been perfected over years, they suffer from serious limitations such as contamination of the sample, very limited life time and availability of limited ion species. To overcome these limitation, a new FIB systems using plasma based ion sources are being designed by various laboratories [1,2,3]. Recently in VECC, Kolkata, Inductively coupled plasma ion source FIB system is developed that can produce micron size beams of various gases. In this article, description of FIB system, some of the recent results and challenges of designing the plasma based FIB system are presented.

FIB SYSTEM

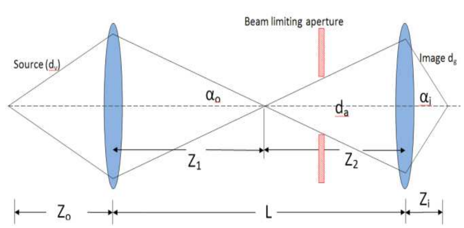

Figure 1: schematic of focusing column which consists of two einzel lenses and a beam limiting aperture. L = 150 mm d_a=250µm.

Focused ion beam system consists of Inductively coupled plasma based ion source operating at 13.56 MHz, focusing column with two electrostatic lenses and a three

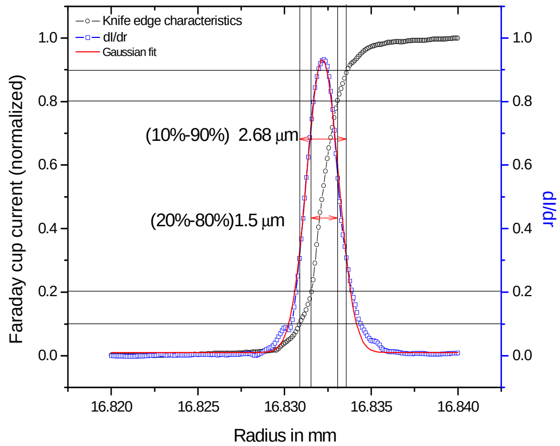

Figure 2: Integral of current intensity distribution as obtained by the knife edge and its derivative.

axis translation stage with a resolution of 50 nm. Ion source consists of quartz chamber of 30 mm diameter with external helical antenna. Ions are extracted using two electrode system trough 1mm aperture. Two einzel lenses are used in various configurations to achieve wide range of currents as well as sizes [4]. Schematic of crossover mode of operation is shown in Fig 1. The 250 µm aperture is placed before the second lens in such a way that ions with divergence of ± 1.25 mrad are only allowed to pass through the second lens. Second einzel lens is used to focus the beam at 1 mm working distance. Ion beam dimensions were measured by scanning the sharp steel knife edge across the beam and recording the Faraday cup current as a function of the position of the knife [5]. This gives the integral of the current density distribution as shown in Fig 2. Differential of this distribution gives the ion beam profile. This figure

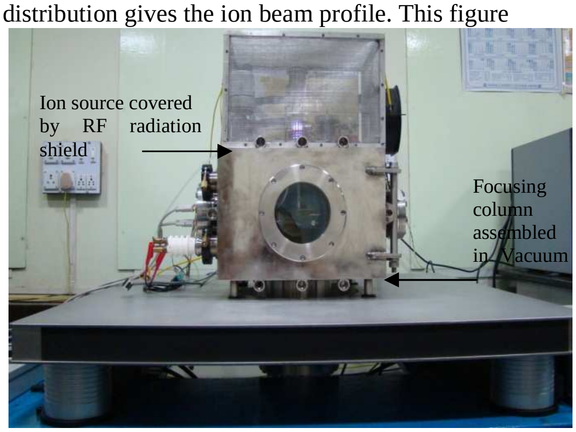

Figure 3: Focused ion beam system assembled on vibration isolation system. Argon discharge is seen through RF shield.

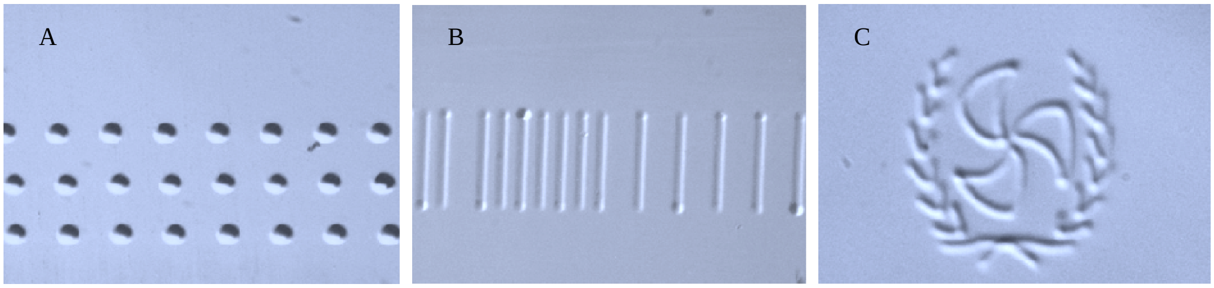

Figure 4: Optical images of regular patterns of lines and dots micromachined on Si wafer.

shows ion beam diameters corresponding to 10%-90% and 20%-80% rise distances are 2.68 µm and 1.5 µm respectively. Few scans across the beam used to permanently slice the knife giving rise to artificial increase in the beam rise. This was solved by choosing the fresh edge by scanning the knife in a direction perpendicular to the measuring direction at each scan. Vibrations generated by vacuum pumps, compressors caused more than 20% errors in the measurements in micron scales. Vibrations were almost completely eliminated by assembling the whole FIB assembly on active vibration isolation system. A special bellow is utilized to eliminate the vibrations from turbo molecular pump. This assembly is shown in Fig 3.

COMPLEXITIES IN PLASMA BASED FIB SYSTEMS

In the conventional FIB systems based on LMIS, because the ion emission is from submicron tip, the focusing column needs to transfer the source to image plane. So the optics remains relatively simple as the magnification of the whole column remains near unity. However in case of plasma based FIB systems, the virtual source size is 3 orders larger than that of LMIS and hence the focusing column needs to have demagnification of the order of 100 or more. Due to high demagnification, the working distance, i.e, sample distance from the last lens is too short. High demagnification also demands that the last lens to be strong having short focal length, which makes the design of the lens complex and adds more aberrations. High demagnification also requires that optical column be operated in crossover modes and each crossover has high current density thereby increasing the stochastic interaction in ion beams causing increase in the aberrations.

Another complexity is the design of ion beam extraction system. The beam quality depends on the plasma meniscus which in turn depends of plasma parameters where as in case of LMIS, the boundary of ion emission is fixed. However, complexities are too few as compared to the advantages, as plasma based systems can generate ions of all species of gases and even ions of metallic samples (needs q/m separator). We have used the same ion source for over 400 hours and still no deterioration in the performance is found.

MICROMACHINING BY ARGON BEAM

Few experiments were carried out to estimate the capabilities of the ICP-FIB by milling regular patterns on Si wafer such as dots and lines. Optical images of few of the patterns are shown in the figure 4. Fig 4A shows 30 µm diameters pits with 100 µm period. Fig 4B shows 25 µm wide and 500 µm long lines. Fig 4C shows official logo of Variable Energy Cyclotron Centre, milled on Si wafer in 200 µm x 200 µm area. Line width and depths are measured by atomic force microscope and found to be 6 µm and 1 µm respectively. By optimizing the focusing column 1.5 µm diameter spot was obtained and experiments were carried out to mill Si wafer and Cu foils. 10 µm thick Cu foil was drilled through forming 10 µm holes in just 200 seconds. Milling rates were measured to be > 1 μm^3/second.

All the experiments were carried out with Argon ions with energies ranging between 4KeV – 6KeV. A program is written in LabView to generate patterns and control the translation stage to achieve uniform milling in all directions. Array of patterns with different sizes can be automatically milled over 25mm x 25mm area. Position of ion beam spot while milling can be visualized in real-time. Work is in progress to optimize the ion beam extraction and focusing column to achieve submicron focused spot size with few A/cm^2 current densities.

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