DESIGN OF HIGH CURRENT RF ION SOURCE FOR MICROMACHINING APPLICATIONS

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Abstract

Liquid Metal Ion Source (LMIS) and Gas Field Emission Ion Source (GFEIS) are the major ones in micromachining applications so far. They have limitations of contaminations and low throughput. Plasma based ion sources can produce heavier ions for higher throughput, lighter ions for fabrication of higher resolution structures, ions for doping, ion assisted direct writing of metallic, oxide, nitride and carbide layers and lines. Considering wide range of applications, a 13.56 MHz inductive coupled plasma (ICP) ion source for producing high brightness ion beams with very low energy spread has been developed. It is a very compact ion source with external helical antenna wound around a 30 mm quartz tube. 1 mA of Argon and 0.5 mA of proton ion beams have been extracted from 2 mm dia aperture in plasma electrode at 4.0 kV extraction potential and ~200W of RF power. Using LabView software an automated plasma diagnostic system has been designed and used to measure the plasma parameters. Retarding Field Analyser (RFA) has been designed and developed for ion energy spread measurements. This paper describes the features of the ion source, ion beams produced, some results of the plasma diagnostics.

INTRODUCTION

Ions in keV energies when incident on solid surface produce several effects such as sputtering of target atoms, secondary electron emission, inducing chemical reactions, creation of defects, implantation of ions and altering the surface properties. Some of these effects are put into use in the field of micro electro mechanical system (MEMS)/ nano electro mechanical system (NEMS) and semiconductor device manufacturing. The conventional lithographic techniques using UV, electron beam, X-rays have reached the limitations. Ion beams are most suitable to overcome these limitations as they have least proximity effect due to their low scattering and absence of diffraction effects. During 1950's Feynman [1] in his visionary speech proposed to use FIB for creation of structure of nanometer sizes. With the use of ion beams for the processes, resist can be avoided and the ion doses and energies can be varied accurately making them versatile in many applications. Development of liquid metal ion sources (LMIS) producing typical semiconductor dopants, broadened the field of applications [2], [3]. In case of resist based lithography, resists have higher sensitivity for ion beams facilitating higher throughput. Conventional LMIS has many limitations like, production of ion beams of a fewer elements, shorter life time of the source etc. Gaseous field ion source can give stable beam for longer time. But technology is cumbersome due to the involvement of cryogenics. The other problem using LMIS is that these metallic ions get trapped in the target producing impurities in the deposited films. To overcome the limitation of LMIS, Inductive Coupled Plasma (ICP) based ion sources are being developed for focused ion beam applications. These ion sources can produce ion beams of all the typical dopants for semiconductor fabrication applications and heavy gaseous ion beams for micromachining applications. A mini ICP with external helical coil, measuring 30 mm in diameter has been developed for this application. Small volume ICP source can produce very high density plasma at low powers. ICP based gaseous ion sources are one of the excellent tools to grow thin films of practically any materials with least contamination.

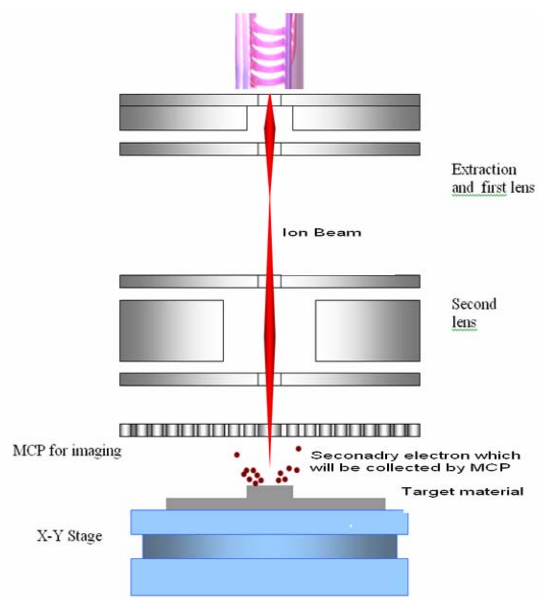

Figure 1: Schematic of focused ion beam system.

Fig 1. shows the schematic of focused ion beam (FIB) systems with the inductive coupled plasma ion source. This set up is being designed for micromachining applications in the micro and sub-micro scales. Typical FIB column consists of ion source, extraction system, focusing elements, ion beam scanning and blanking systems, micro channel plates for ion and secondary electron detection for real-time imaging of the surface by ion beam scanning and the precision x-y-z stage for positioning the specimen.

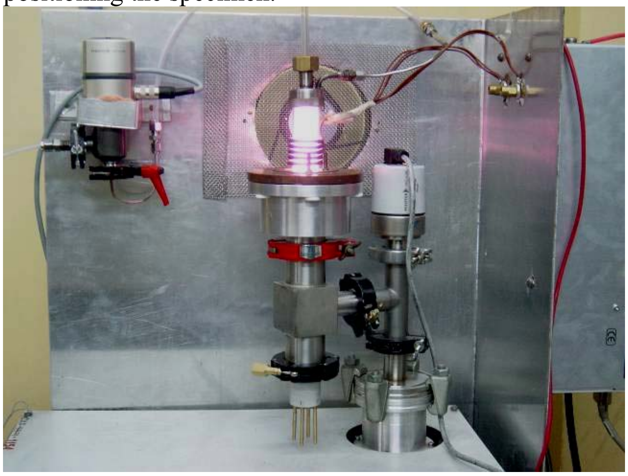

Figure 2: ICP ion source operating with 100W of RF power at 0.01 torr pressure.

Inductive Coupled Plasma Ion Source

Inductive coupled plasma source with external helical coil is chosen to be the ion source for micromachining applications as this can produce ion beams of various species with high intensity and the low energy spread. External helical coil is chosen to reduce the capacitive coupled discharge effect thereby reducing the ion energy spread. The plasma chamber is made of quartz tube of 30 mm diameter and 70 mm height. Top of the tube is connected with the gas feed system where fine gas control is done through motorised needle valve. Inductive coupling coil is made of 5 turns of water cooled hallow copper tube having R=0.7Ω and L=1μH. This is connected through the impedance matching network made by two 250 pf vacuum variable capacitors to the 13.56 MHz 1.2 KW RF power generator (Dressler make). Fig 2. shows the setup with the argon plasma operating at 0.01 torr of pressure. For producing the submicron size ion beams, the brightness of the ion source should be high. Brightness of an ion source depends on the plasma parameters such as n_e, n_i, T_e, V_p that are measured by using self compensated single Langmuir probe [7] and the double Langmuir probe. The results by single probe measurement are influenced by plasma potential oscillations at 13.56 MHz, higher current drain and the RF pick up by the measuring equipments. Use of double Langmuir probe overcomes the problems of single probe measurements with some limitations [8]. Experimental results of double probe are discussed in the following sections, which are approximately same as the single probe measurements that were carried out earlier.

Plasma Diagnostics by Double Langmuir Probe

Fig 3 describes the schematic of double Langmuir probe measurement system. Double probe is made in-house by sealing the tungsten wire of 0.25 mm diameter in the glass tube and protruding 10 mm into the plasma. Keithley pico-ammeter with voltage source (Model 6487) is used for the measurements. This is controlled by computer through serial port of meter. Acquired data is automatically analysed by using LabView application. Sufficient filters are introduced to eliminate RF pickup. Fig 4. shows the typical double probe characteristics acquired with argon plasma at 0.01 Torr and 100W of RF power. Double probe characteristics are obtained at different RF power levels at fixed gas pressure. It is found that electron temperature increases with increase in RF power. Electron temperatures of 5, 7.8, 12.5 eV are calculated from probe characteristics obtained with 50, 80 and 100W of RF powers respectively. Following the calculation in ref. [5] and assuming the ion temperature is equal to gas temperature which is about 1000^0 K. [6], for the graph shown in fig 4, the ion density is about $2x10^{18}/m^3$.

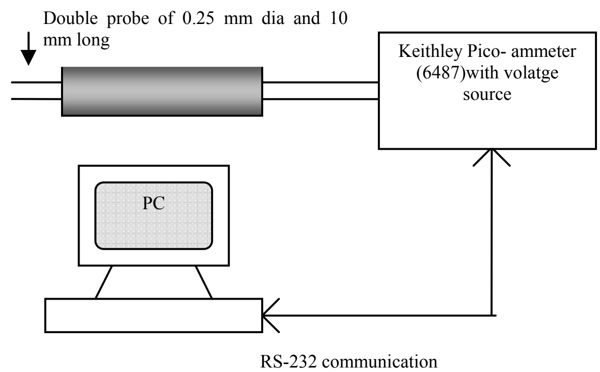

Figure 3: Schematic double probe measurement system.

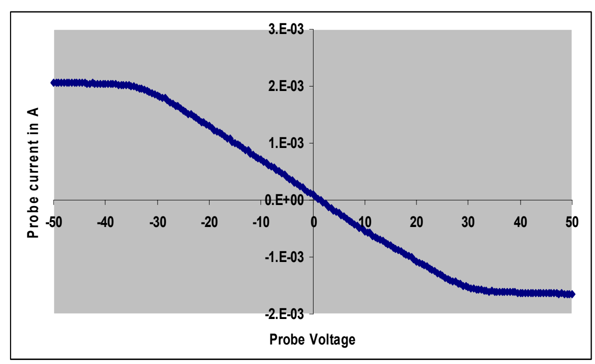

Figure 4: Typical double probe characteristics of argon plasma at 0.01 torr pressure and 100W RF power.

The single probe analysis carried out earlier with similar plasma conditions show that T_e= 6eV-12eV and n_i= 1 to $9x10^{17}/m^3$

Ion Energy Spread Studies by Retarding Field Analyser

Ion energy spread is the most important factor in developing the submicron ion beams. It is seen that 1eV ion energy spread produces around 4 micrometer diameter ion beam for the geometry described in [4] for the ion energy of 3 KeV. It is desirable to have as less as possible ion energy spread from the ion source to have least chromatic aberration contribution in the ion beam spot size. An effort has been made to measure the ion energy distribution by using multigrid retarding field analyser (RFA). RFA has been developed in-house. A special grid fabrication system has been developed. The grids are made by soldering 50 micron gold coated tungsten wire onto the copper ring of 30 mm ID, 40 mm OD and 2 mm thick. Wire to wire distance is 310 microns providing around 66% transparency. Wires are wound using a zig having 80 turns per inch pitch and having facility for alignment of the wires. Plasma electrode has 2 mm dia aperture. All electrodes are spaced 1.7 mm apart by Teflon spacers and assembled in Teflon housing.

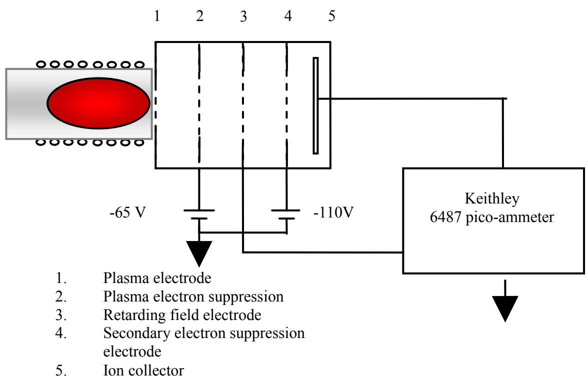

Figure 5: Schematic of retarding field analysis system.

First grid shown in the fig 5 is biased to -65V. for a maxwellian energy distribution at T_e ~ 5eV > 99% of plasma-born electrons are suppressed by -65V on the grid number 2. Grid number 3 is connected to the variable bipolar supply of the Keithley pico-ammeter (6487 model). Fourth grid is biased to -110 V to ensure good suppression of secondary electrons from the collector. Fig 6. shows the typical plot of ion beam current with retarding field voltage. Differentiation of the plot gives the ion energy distribution. This graph was obtained for argon plasma at 100W of Rf power and 0.01 torr pressure. From these plots the energy spread is calculated to be about 10 eV. The real ion energy spread is less than 10eV as lens effect of the grids contributes to the ion energy spread significantly. It needs more investigation with proper grids and grids spacing to get more accurate results.

Beams Developed

Various ion beams have been developed using the above described ICP ion source. Plasma electrode having 2 mm diameter aperture is floated at extraction potential and the second electrode at 5 mm is grounded. Various ion beams were optimised with different powers but with same extraction voltage of 4 kV. Proton, Oxygen, Nitrogen, Argon ion beams of 1, 2, 1.5, 2.2 mA respectively have been extracted. Fig 7. shows the comparison of theoretical (Child Langmuir relation) and experimentally extracted argon ion current density from at 0.01 Torr pressure and 100W of RF power. At higher extraction voltages the experimental values are approximately same as theoretical values.

$$j_v := 4\cdot\varepsilon_0\cdot\sqrt{2\cdot\frac{q}{m}}\cdot\frac{(v)^{\frac{3}{2}}}{d^2}$$

Where J_v is the current density, v = extraction voltage and d is distance between the plasma electrode and the extraction electrode. Efforts are being put to reduce the ion energy spread and increase the extracted current.

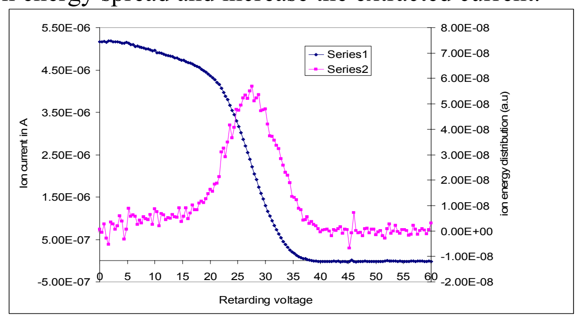

Figure 6: RFA characteristics and ion energy distribution from argon plasma at 100W and 0.01 Torr pressure.

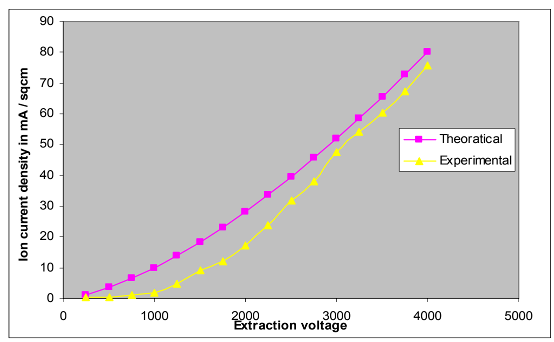

Figure 7: Comparison of theoretical and experimental extracted ion beam current density.

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