Proceedings of the 6th International Conference on Theoretical and Applied Nanoscience and Nanotechnology (TANN'22)
Niagara Falls, Canada – June 02-04, 2022
Paper No. 115
DOI: 10.11159/tann22.115

Study of Ion Beam Characteristics According to Coil Position of Xe Plasma FIB

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Abstract **-** The conventional FIB systems which utilize liquid gallium ion sources to achieve nanometer scale resolution can no longer meet the various requirements raised from such a wide application area such as low contamination, high throughput and so on. In order to extract high current density and angular intensity compared to gallium ion source, plasma focus ion beam using Zenon or Argon gases has been developed to control ion beam current of several microamperes by using an ion source of inductively coupled plasma (ICP). This paper describes the application and optimization of a Zenon inductively coupled plasma (ICP) ion source that is more efficient for large-area processing than a conventional ion source (LMSI) in FIB. By v1arying the RF coil position with this device configuration, the characteristics of the ion beam current value according to the CL applied value were investigated, and the difference in processability was also tested.

Keywords**: :** Xe Plasma, Crossover, ICP, Ion beam current, Spot size

1. Introduction

For over decades, focused ion beam (FIB) has been playing a very important role in microscale technology and research, among which, semiconductor microfabrication is one of its biggest application area. As the dimensions of IC devices are scaled down, it has shown the need for new ion beam tools and new approaches to the fabrication of small-scale devices [1].

Commonly used electron and scanning probe microscopes (SEM, TEM, and SPM) are used to meet nanoscale resolution for failure analysis (FA) in these semiconductor processes. The preparation of cross-section sample is needed for electron microscopes analysis. There are some technologies such as laser ablation, focused ion beam (FIB) which uses gallium ion beam, broad-beam argon ion milling and etc. for sample preparation techniques. The conventional FIB systems which utilize liquid gallium ion sources to achieve nanometer scale resolution can no longer meet the various requirements raised from such a wide application area such as low contamination, high throughput and so on. In case of liquid metal ion source (LMIS) which is conventional FIB, compared with laser ablation, it has advantages of less thermal damage and precise milling compared with broad-beam argon ion milling. But gallium ion beam-based system has a drawback that it has a relatively low milling rate with a maximum beam current of ~ 65nA[4]

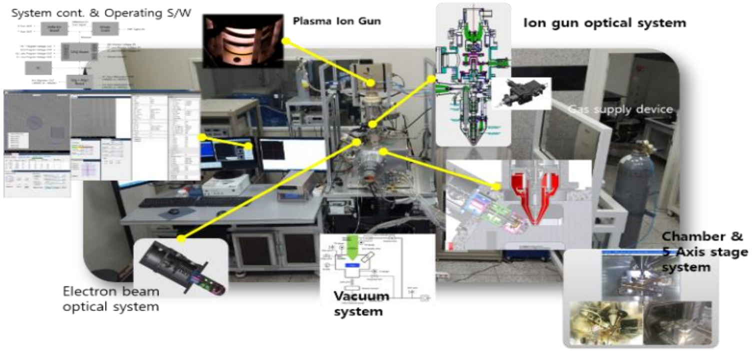


Fig. 1 Configuration of the developed plasma focused ion beam

For the past decades, state-of-the-art focused ion beam systems have depended on the high brightness, moderate energy spread, ease-of-use, and robustness of the gallium LMIS[2]. These FIB systems typically deliver beam currents ranging from 1 pA to 20 nA , focused into spot diameters of approximately 5–400 nm at 30–50 keV[2]. Korea electronics-machinery convergence technology Institute (KEMCTI) has developed zenon and argon plasma focused ion beams (PFIB) to overcome low milling rate of typical LMIS FIB caused low ion beam current. The developed PFIBs are designed to control ion beam current of several microamperes by using an ion source of inductively coupled plasma (ICP) using Argon or Zenon gas, which can extract ion beam with high current density and angular intensity compared with gallium ion source [3].

This paper describes the application and optimization of a Zenon inductively coupled plasma (ICP) ion source that is more efficient for large-area processing than a conventional ion source (LMSI) in FIB. ICP ion source is applied to the FIB column, and the Faraday Cup is placed on the sample stage. The device was configured to measure and compare the current value by applying it. By varying the RF coil position with this device configuration, the characteristics of the ion beam current value according to the CL applied value were investigated, and the difference in processability was also tested.

2.1 Structure of PFIB System

In general, the FIB system consists of an ion source, a vacuum chamber, and a work chamber [5]. For the developed ICP ion source, Ion beam is extracted through a three-electrode(plasma acceleration electrode, extractor electrode)[6]. It consists of radio frequency (RF) power supply, matching box, and mass flow controller (MFC) which can inject argon gas for plasma discharge[6]. The ion column is made up of two electrostatic lenses: condenser lens (CL) and object lens(OL), a carriable aperture, a beam alignment, a stigmator, a deflector. The vacuum system consisted of two turbomolecular pumps, one rotary pump and valves (gun valve, gate valve, rotary pump valve, turbomolecular pump valve and vent valve). The work chamber combines the ion column with the five-axis stage of loading and unloading of the samples and vacuum in the middle 10^{-5} torr range is maintained.

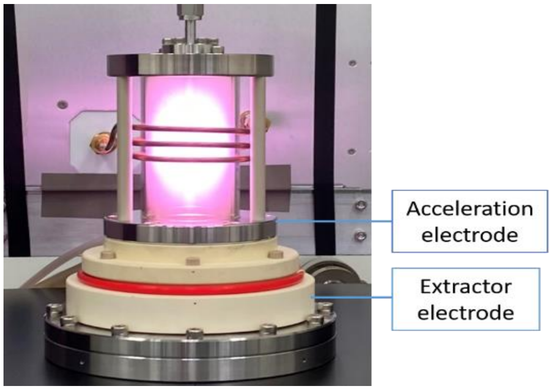


Fig. 2 Structure of developed PFIB ion source

2.2. Setting of ion beam condition

In the FIB system, images can be obtained by scanning method like SEM in a region of interest. The difference between FIB and SEM is that etching using ion beam is possible by scanning high energy ion beam in case of FIB. The removal of sample material is achieved using a high ion beam current. The result is a physical sputtering of sample material by scanning the beam over the substrate, an arbitrary shape can be etched[7]. This paper aims to develop the PFIB system with a milling rate which is 20-100 times higher than the Ga ion beam-based FIB system. Ion beam current and spot size are the main factors that determine the etching characteristics of FIB including the milling rate. The factors that determine above characteristics are high voltage (HV) of the plasma acceleration electrode and the extractor electrode and RF power of the ion source part and the CL HV and variable aperture hole size of ion column part. In this paper, the optimized conditions of the current ion source, plasma acceleration electrode HV and extractor electrode HV were fixed at 25keV, Ground and RF power of 50W. Then, experiment has conducted by varying the CL HV, to measure the changing ion beam current and the change in machinability is investigated.

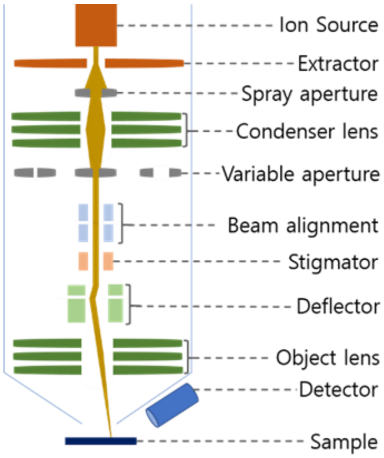


Fig. 3 Schematic diagram of developed PFIB ion column.

3. Experiments

3.1 Ion beam current.

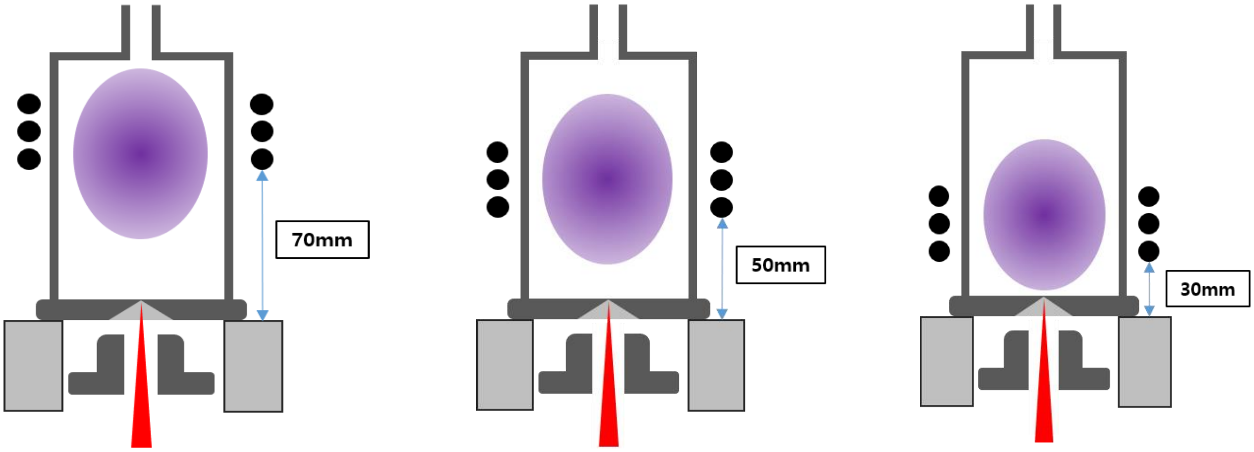


Fig. 4 RF coil positioning (from left) upper, middle, lower

Three coil positions were selected as shown in Fig. 4 above. RF coils are 30mm, 50mm, and 70mm apart from the bottom surface shown in the figure, and are called Top, Middle, and Bottom respectively. In the developed PFIB, the ion beam current focuses ion beam by CL which is composed of an Einzel lens using a deceleration-acceleration mode with a positive high voltage [7]. The ion beam current is then controlled through a region confined to a variable aperture orifice size [7]. Xe plasma is generated by applying an acceleration voltage of 25kV to the PFIB gun. RF Power was set to 50w. 50um was used for the variable aperture, and the voltage of the condenser lens was sequentially applied from 0kV to 23kV.

The degree of vacuum was measured in a Faraday Cup set to 5.0x10E-5 Torr, and the ion beam current value was set to WD 8mm.

The following table and figure show ion beam current values and comparative graphs according to each measured RF coil position.

Table 1. Comparison of ion beam current values according to coil position

a) Ion Beam Current Measurements at Coil Top Position

CL (kV)	0	2	4	6	8	10	12	14	16	18	20	22	23
Current (nA)	0.17	0.196	0.222	0.263	0.413	0.88	2.01	7.06	0.571	0.111	0.044	0.025	0.022

b) Ion Beam Current Measurements at Coil middle Position

CL (kV)	0	2	4	6	8	10	12	14	16	18	20	22	23
Current (nA)	0.24	0.24	0.27	0.315	0.433	1.27	2.19	19.7	1.062	0.174	0.061	0.036	0.034

c) Ion Beam Current Measurements at Coil bottom Position

CL(kV)	0	2	4	6	8	10	12	14	16	18	20	22	23
Current (nA)	0.55	0.55	0.57	0.65	0.8	1.36	3.2	65	6.05	0.576	0.167	0.086	0.074

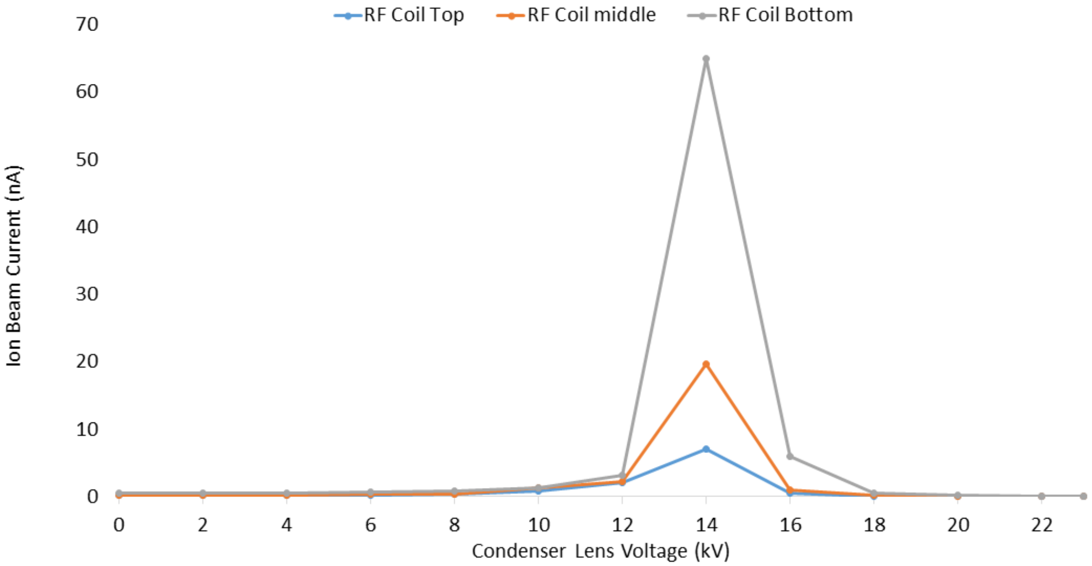


Fig. 5 Current comparison according to RF coil top, middle, and bottom positions

The maximum current value of the ion beam was measured about 14kV, and the current value was significantly lowered in the section except for that section. The maximum ion beam current value at the top position of the coil was 7.06nA at CL 14kV, 19.7nA at CL 14kV at the middle position, and 65nA at CL 14kV at the bottom position. It is considered that the ion beam current value measured in the Faraday Cup was measured to be higher as the Xe plasma generated according to the FIB characteristics of the ICP type, where the plasma generating position varies according to the coil position, approaches the extraction part from which the ion beam is ejected.

In the CL 0-10kV section, the ion beam current value gradually increases, and in the 12-16kV section, a sharp change can be seen. In the 16-23kV section, the ion beam current was significantly lowered. The model of this graph is the crossover phenomenon caused by the Condenser Lens[8]. These data are important for selecting an ion processing beam.

3.2 Comparison of Ion Beam Machining Experiments

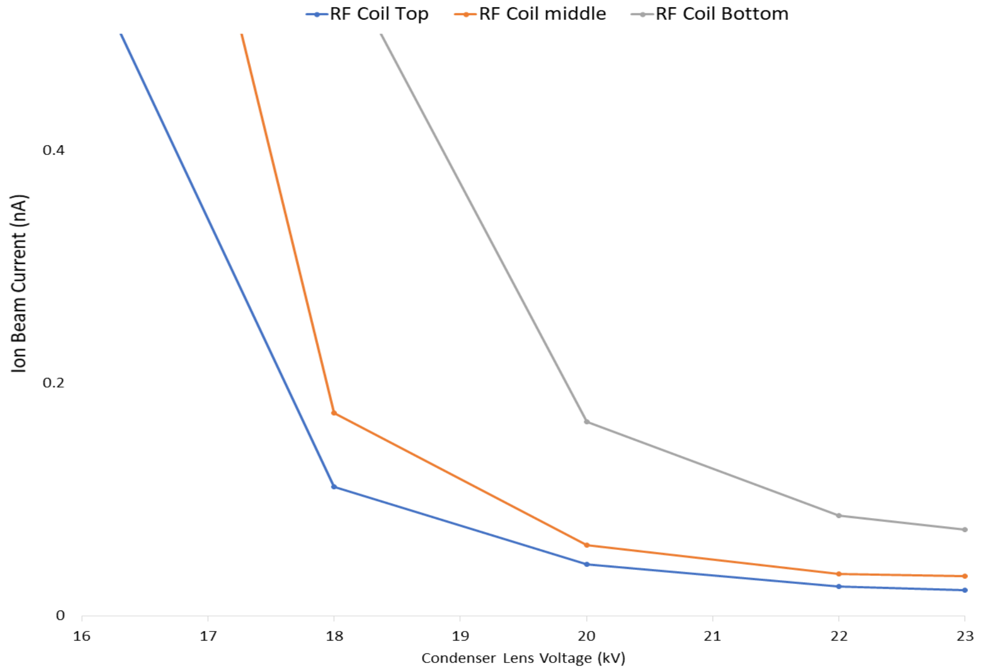


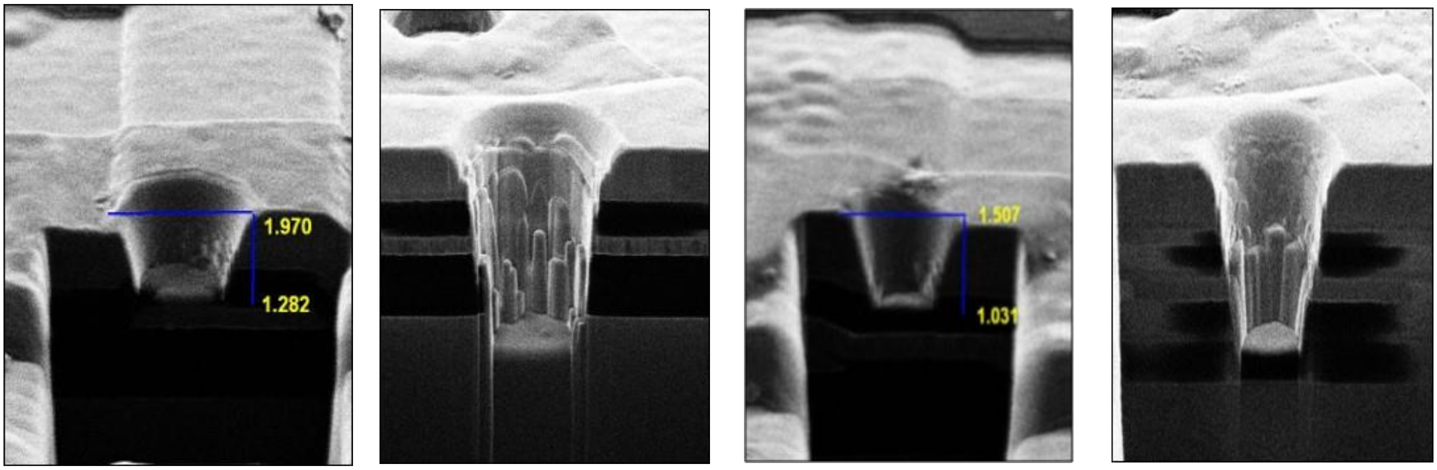
Fig. 6 Zoom in on the graph. Comparison of ion beam current values from CL 16kV to 23kV

As shown in Fig. 5, the resolution in the 12kV-16kV section was remarkably low, and the high current value of the ion beam had problems such as a sharp deterioration in the lifespan of the equipment's internal aperture. Therefore, the section after 16kV where the optimization of the machining beam can be expected along with the reduction of the spot size in the area after the crossover point, which can have high resolution, was selected as the ion machining beam[8].

The selection of the machining beam according to the ion beam current value is an important factor in optimizing the machining speed and large-area machining capability.

In order to confirm the machinability of the increased ion beam current value, processing was performed on the sample. The sample is used in the semiconductor industry and an OLED sample in which a metal layer and an insulating layer are mixed was adopted.

25kV of accelerating voltage was applied to the gun in PFIB and the samples shown in the figure were processed at CL 17kV and 18kV, respectively, based on the vacuum degree of 5.0×10^{-5} Torr, and the machinability at the coil middle position and the bottom position was compared. In the case of the machining test for the ion beam current value at the top of the RF coil, the machinability of this sample was remarkably poor, so it was excluded from this comparison group.



a) CL 17kV Coil middle position

b) CL 17kV Coil bottom position

c) CL 18kV coil middle position

d) CL 18kV Coil bottom position

Fig. 7 Comparison of 10 second machining of the lower middle spot at sample CL 17kV and 18kV (LMSI FIB face machining)

After the crossover point is created, the difference between the ion beam processing results according to the RF coil positions of CL 17kV and 18kV is clearly seen in Fig. 7.

The four results performed in the above sample processing are as follows.

a) Measured ion beam current of 0.372nA, cutting width 1.970um, depth of processing 1.282um,

b) Measured ion beam current of 1.5nA. Cutting width 3.030um, cutting depth, 3.151um

c) Measured value of ion beam current 0.174nA, cutting width 1.507um, cutting depth 1.031, and

d) Measured value of ion beam current 0.575nA, cutting width 1.220um, cutting depth 2.320 um.

As the above picture shows, when the same voltage is applied to CL, the difference in ion beam current is shown, and the processing width and processing depth are also clearly different. This shows that the more the current value of the ion beam is secured, the more advantageous the processability is. The comparison of sample processing in different CL value areas can be clearly compared in the following graph.

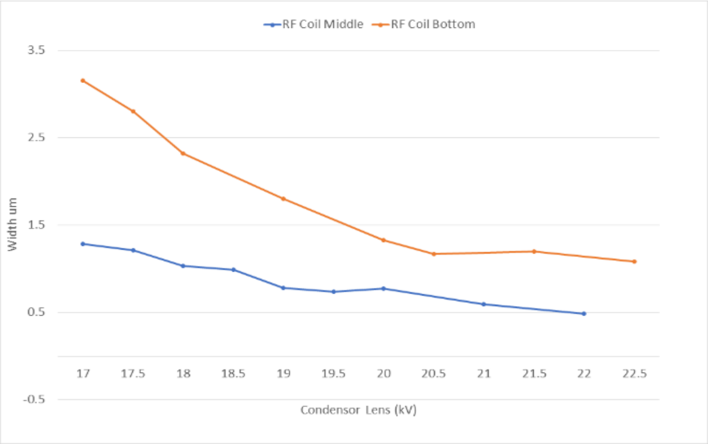


Fig.8 Interruption of RF coil according to CL value, comparison of cutting depth at the middle and bottom position

Fig.9 Interruption of RF coil according to CL value, comparison of cutting width at the middle and bottom position

The above graph shows the comparison of machinability at the middle and bottom position of the RF coil in the CL 17kV~22.5kV section. As the CL value approaches 17 kV in both the middle and lower parts, the ion beam current value increases and the machinability increases. And the gap between the two graphs also increases a lot. Both the processing width and the processing depth increased as the ion beam measurement value measured increased as the RF coil was closer to the bottom except ion beam milling rate.

4. Conclusion and Discussions

By confirming the difference in the characteristics and processability of the ion beam current value according to the location of the RF coil, we were able to secure the data that is the basis for the optimization of the ion beam column of the PFIB, which is developed to overcome the shortcomings of the LMIS FIB, which is the purpose of this study. In addition, it can be expected that the spot size and processing depth can be adjusted according to the CL applied value and processing time through this experiment.

The LMIS FIB can control the precise milling position and direction, but the source cost is high and the milling speed is low. The KEMCTI is developing PFIB by optimizing xenon ion beam to meet the demand for accurate and fast ion beam etching equipment as FA of 3D packaging.

Acknowledgement

This work was supported by Manufacturing Based Production System Project funded by the Ministry of Trade, Industry & Energy (MI, Korea, Development of Micro-Chip Repair System for Micro-LED Display Yield Improvement)

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