Design of compact microwave plasma ion sources for focused ion beam

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Key Words : Focused Ion Beam, Microwave Plasma Ion Source, Cavity Resonator, Insulated Antenna

Abstract

Two types of compact microwave plasma ion sources (MWPIS) for focused ion beam (FIB) have been developed. Cavity resonator type plasma ion source is subjected to make resonant electric field in order to ignite plasma efficiently. The optimum length of resonator and antenna, and position of quartz and antenna have been designed by both simple calculation and computer simulation. The other source consists of a cylindrical dielectric discharging chamber and an insulated co-axial antenna. To maximize electric field inside discharge chamber, both shape and length of antenna are determined. A magnet system is designed to provide the resonant magnetic field for electron cyclotron plasma.

1. Introduction

Focused ion beam (FIB) has been widely used for the industrial field of nanofabrication.[1] Ion source is an essential part of the performance for the FIB since its current determines the process yield and the emittance controls the resolution. Most commercial FIB systems utilize liquid metal ion source (LMIS) using gallium because of its high brightness on the order of 10^6 in amperes/cm^2sr.[2] However, various drawbacks such as gallium contaminations have been continuously reported, requiring new types of ion sources for other ion species such as inert gas, hydrogen, and oxygen.[3] Also, the need for a multi-beam ion source to accommodate quasi-parallel processes has been grown. Accordingly, alternative ion sources substituting the LMIS have been required and the plasma ion source could be one of the most attractive candidates due to its desirable characteristics for FIB such as possibilities of various operable species and multi-beam extraction. In SNU, a noble inductively coupled plasma (ICP) ion source has been developed for high brightness ion source using bias method.[4]

Conventional FIB systems, especially hybrid devices of FIB and SEM (scanning electron microscope), require compact ion source. ICP ion source is hard to satisfy the condition in size due to the large matching system for efficient RF power transfer. Moreover, RF power makes unwanted noise on the sensitive devices such as DC power supply for electrostatic lens which require low ripple level. Replacing ICP, microwave plasma can be a desirable choice to overcome these obstacles. Microwave plasma does not need such a big matching network but only a small stub to control the power coupling and also its oscillating frequency is too fast (over an order of GHz) to disturb electrostatic field in lens system. Although average density of microwave plasma is generally lower than that of ICP, bias method[4] can enhance the ion beam current.

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2. Design of Microwave Plasma Ion Sources

Two types of microwave plasma ion sources (MWPIS) and their designs are introduced. One is adapting cavity resonator and the other source is importing cylindrical insulated chamber with co-axial antenna. Both sources are using coaxial cable, not using waveguide, considering compactness for ion source.

2.1 Cavity Resonator type MWPIS

MWPIS utilizing cavity resonator is shown as Fig. 1 (a).[5] Except cavity resonator, all parts are same with those of ICP ion source[4]. Instead of coil to deliver RF power to plasma, cavity resonator is employed. The rectangular cavity resonator made of copper is designed in order to generate standing wave of which mode is TE_{102}. For 2.45 GHz microwave, the rectangular cavity is adequate when it is 50 mm, 25 mm, and 155 mm in width, height, and length, respectively. Cavity length can be controllable from 135 mm to 160 mm by moving cavity door. When the microwave power is driven, the standing wave which has two peaks (highest Electric field) along the direction of cavity length at center of quartz and antenna is formed by superposition of waves. Fig. 2 (b) shows the simulation result of electric filed strength inside cavity resonator by HFSS. Using the simulation tool, optimum position and length of antenna is designed with consideration of existence of quartz. Also, installation

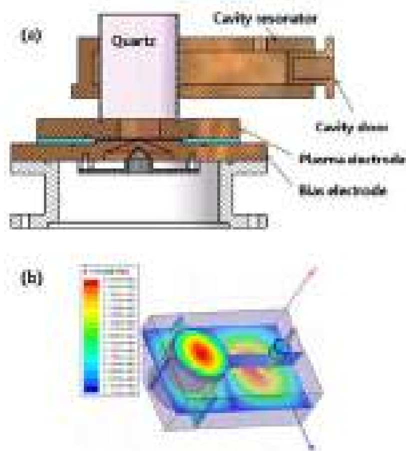

Fig. 1 (a) cross sectional view of MWPIS employing resonance cavity, (b) simulated electric field inside cavity [5]

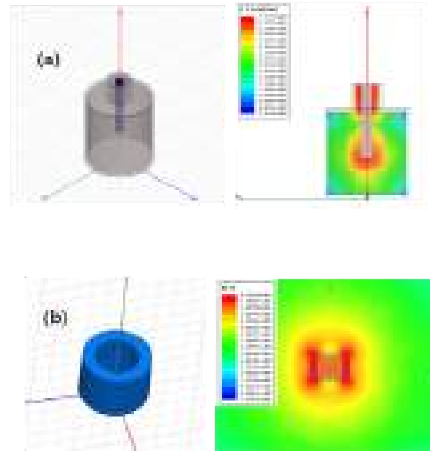

Fig. 2 Simulation results in insulated antenna type MWPIS: (a) electric field and (b) magnetic field

position of discharging quartz is determined by simulation result in order to maximize the central electric field in it.

2.2 Insulated antenna MWPIS

Discharging chamber which basically looks like an upside down cup having protruded bottom is made of glass such that the charged particles do not touch with any conductors except plasma electrode, and thus microwave coupling antenna does not suffer from damage by plasma. Length of cylindrical copper antenna is determined from simulation result. And the end of antenna is completed with disk of about 10 mm in diameter which reduce useless gap between antenna and inside wall of cavity shell and thus higher electric field could be formed at same power. Cavity shell made of stainless steal is subjected to confine microwave and help it to be transferred to plasma. Under these configurations, calculated electric field strength is shown as Fig. 2 (a). Microwave power is delivered through coaxial cable. And the cable can be connected to N-type connector where the insulated antenna is molded which is vertically movable in order to control the power coupling. Also ring-shape permanent magnets installed around cavity shell form the axial magnetic field. The axial magnetic field enhances confinement of charged particle and thus advantages in increasing plasma density and lowering breakdown power would be expected. Also, the maximum magnetic field strength could be set over 875 Gauss corresponding to the electron cyclotron resonance (ECR) frequency at 2.45 GHz as show in Fig. 2 (b), such that ECR plasma which is low pressure and high density plasma can be generated.

3. Conclusion

Two types of microwave plasma ion sources have been designed utilizing bias electrode for the electron sheath plasma. The first one employing cavity resonator is subjected to make resonance wave and thus maximize the electric field in order to generate plasma efficiently. The other source has cylindrical discharging chamber with axial antenna insulated from plasma. Ring magnets are installed around the source to generate ECR plasma as well as off-resonance plasma.

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