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DESIGN OF A 2.45 GHz SURFACE WAVE PLASMA SOURCE FOR PLASMA FLOOD GUN*

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Abstract

Microwave ion sources have the characteristics of high stability, high plasma density, no metallic contamination, long life, and low gas consumption, which make them excellent candidates for plasma flood gun (PFG) with superior charge neutralization performance for ion implanters. Attempt to develop a large scale PFG based on 2.45 GHz microwave driven sources was launched at Peking University (PKU). A prototype one is a miniaturized 2.45 GHz permanent magnet electron cyclotron resonance (ECR) source to produce point-like electron beam. In previous experiments, more than 8 mA electron beam has been extracted through an Ø6 mm extraction hole at an input microwave power of 22 W with argon gas. Recently, studies are focused on the possibility of producing of ribbon electron beams as PFG with 2.45GHz microwave driven surface wave plasma (SWP) source. A cylindrical chamber surface wave plasma generator with a cylindrical dielectric waveguide and a 70 mm×3 mm extraction slit was designed and fabricated. More details of this PFGs will be discussed in this work.

INTRODUCTION

PFGs are widely used to neutralize wafer charge during the doping process in modern ion implanters. Compared with traditional dc arc discharge with filament and RF discharge, the microwave driven source that has long lifetime and no metallic contamination is regarded as a potential choice of PFG. For an example, Axcelis has developed a microwave electron cyclotron resonance (ECR) PFG for low pressure wafer charge neutralization, a ribbon electron beam with current as high as 20 mA has been obtained with microwave power less than 70 W with xenon gas [1]. Besides, a miniaturized ECR plasma flood gun was developed at PKU, more than 8 mA point-like electron beam has been extracted from this ion source at an input microwave power of 22 W with argon gas [2].

However, there are still some challenges for ECR ion sources to generate large-scale uniform plasmas due to the existence of magnetic field [3], which limit their applications as PFGs in large-area wafers. Fortunately, it has been widely reported that large-area planar surface wave plasmas (SWPs) can be excited with 2.45 GHz microwave energy [4, 5]. In addition, there are some other advantages for the SWP sources compared with the ECR ones. On the one hand, large-area uniform plasmas can be easily obtained by the systematic design of the antenna. On the other hand, there are no external magnetic fields for the SWP sources, which make it simpler and more economic than the ECR sources. Therefore, the 2.45 GHz microwave driven SWP sources are expected to be the potential PFGs for charge neutralization of large-area wafers.

At PKU, a 2.45 GHz ECR ion source was designed for the production of high intensity singly charged ion beams. In this work, this source is updated to a SWP source for the generation of ribbon electron beam. More details of the microwave driven PFG will be discussed in this paper. In addition, some physical analysis including the microwave coupling and thermal analysis will be presented.

MICROWAVE DRIVEN PFG

A schematic diagram of the 2.45 GHz ECR ion source is presented in Fig. 1. It can be briefly divided into microwave matching parts, plasma chamber and permanent magnet rings. A dielectric microwave window is used for microwave coupling and vacuum sealing, which is composed of three pieces of alumina ceramic blocks (Ø32 mm×10 mm) and a piece of thick boron nitride (Ø32 mm×2 mm). The plasma chamber is made of stainless steel (SS) (Ø85 mm × L51 mm). In addition, two NdFeB permanent magnet rings are installed outside of the plasma chamber to provide a resonance magnetic field of 875 Gs. The plasma electrode is made by SS with an Ø6 mm hole.

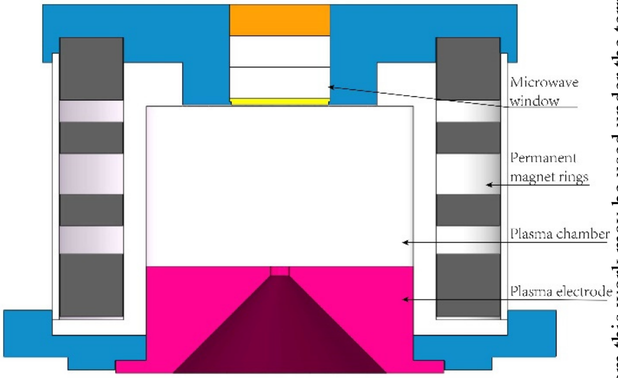

Figure 1. A schematic diagram of the 2.45 GHz ECR ion source at PKU.

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In this work, the ECR ion source shown in Fig. 1 is updated to a SWP source for large-area electron beam generation. To realize this function, as presented in Fig. 2, several important improvements are made in this microwave driven PFG.

- The boron nitride is replaced by a ceramic cylinder that stick into the plasma chamber with a length of 40 mm.
- The NdFeB permanent magnet rings are removed.
- A plasma electrode with a 70 mm×3 mm extraction slit is installed.

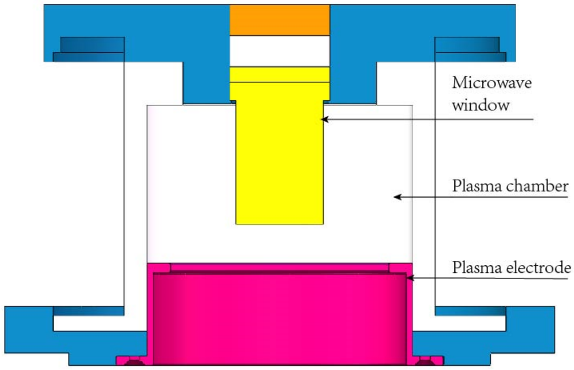

Figure 2. A schematic diagram of the 2.45 GHz the microwave driven PFG.

PHYSICAL ANALYSIS

Although the modification scheme of the microwave driven PFG is proposed, further analysis is necessary for the comprehension of this source. On the one hand, we want to know if the new microwave window is beneficial to the generation of SWP. On the other hand, we should make sure that the water-cooling is enough since the SWP sources usually work under continuous wave (CW) mode with higher microwave power. Therefore, the results of microwave coupling and thermal analysis will be performed in this section.

Microwave Coupling

According to the SWP theory, the surface wave can transmit along the interface between plasma column and dielectric without extra waveguide. The radius of the dielectric cylindrical ceramic rod is assumed as *a*, and electromagnetic wave propagating along the cylindrical rod can be expressed as [6]

$$R \le a \quad E_{z1} = E_{m1} J_m(k_d R)\cos m\varphi e^{-ik_z z}, \tag{1}$$

$$H_{z1} = H_{m1} J_m(k_d R)\sin m\varphi e^{-ik_z z}, \tag{2}$$

$$R > a \quad E_{z2} = E_{m2} K_m(k_p R)\cos m\varphi e^{-ik_z z}, \tag{3}$$

$$H_{z2} = H_{m2} K_m(k_p R)\sin m\varphi e^{-ik_z z}. \tag{4}$$

Here m is the number of standing wave of field in the circumferential direction, k_z is the wave number in the axial direction of dielectric rod, k_d and k_p are the wave number along the radial direction in rod and in plasma, respectively. In addition, the dispersion relations of cylindrical surface wave can be written as

$$k_d^2 = \omega^2 \mu_0 \varepsilon_0 \varepsilon_d - k_z^2, \tag{5}$$

$$k_p^2 = k_z^2 - \omega^2 \mu_0 \varepsilon_0 \varepsilon_p, \tag{6}$$

$$\begin{aligned} &\left[\frac{J_m'(k_d a)}{k_d J_m(k_d a)} + \frac{K_m'(k_p a)}{k_p K_m(k_p a)}\right]\left[\frac{\omega^2 \mu_0 \varepsilon_0 \varepsilon_d J_m'(k_d a)}{k_d J_m(k_d a)}\right. \\ &\left. + \frac{\omega^2 \mu_0 \varepsilon_0 \varepsilon_p K_m'(k_p a)}{k_p K_m(k_p a)}\right] = \frac{m^2 k_z^2}{a^2}\left(\frac{1}{k_d^2} + \frac{1}{k_p^2}\right). \end{aligned} \tag{7}$$

Here ε_d is the relative permittivity of rod, which equals to 9 for the ceramic, and ε_p is the relative permittivity of plasma and can be written as:

$$\varepsilon_p = 1 - \frac{\omega_p^2}{\omega^2}, \tag{8}$$

Where ω is microwave angular frequency and ω_p is plasma angular frequency that is proportional to square root of electron density and can be given by

$$\omega_p = \sqrt{\frac{e^2 n_e}{\varepsilon_0 m_e}}. \tag{9}$$

When the plasma density is low, k_p is an imaginary number which means the electromagnetic wave can propagate in both the axial and the radial directions. The electromagnetic energy can transmit into the plasma chamber and then ignite the plasma. When the plasma density increase to greater than the critical value, k_p becomes a real number. This state is called propagating mode, indicating that the electromagnetic wave will evanesce in the radial direction and propagate only in the axial direction. To verify if the microwave coupling scheme of our PFG is reasonable, the electric field distribution inside the plasma chamber is simulated for the ε_p=1. As presented in Figs. 3 and 4, the electromagnetic wave can transmit along the ceramic and then emitted into the chamber, and the highest electric field norm is about 800V/m.

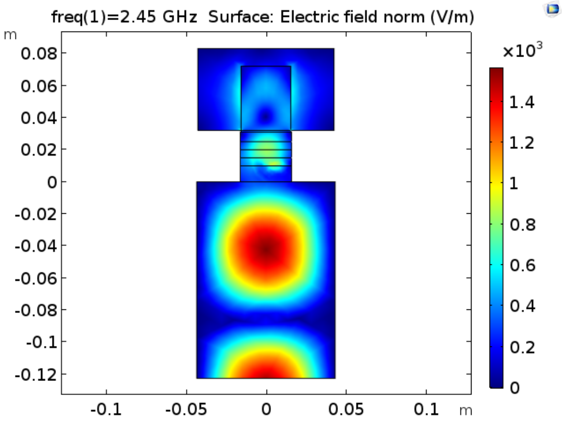

Figure 3. Simulated electric field (V/m) in the plasma chamber (X-Z plane).

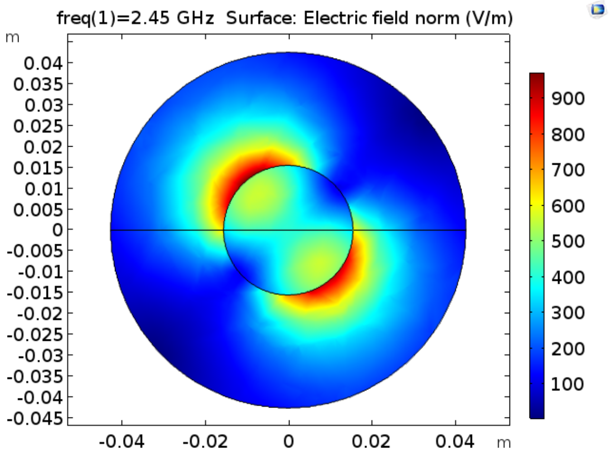

Figure 4. Simulated electric field (V/m) in the plasma chamber (X-Y plane).

Thermal Analysis

Due to the high CW microwave energy deposition during discharge, special design of the water cooling structure of this source is carried out. As presented in Fig. 5, the groove around the microwave window is used for the circulation of cooling water, which has a depth of 4 mm and a width of 5 mm. And a simulation with Ansys Workbench was performed to evaluate the effect of water cooling structure.

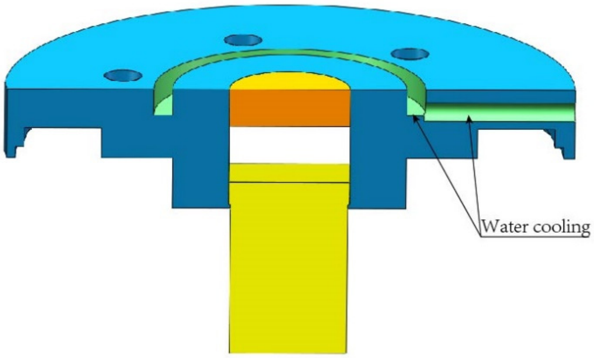

Figure 5. The water cooling structure of the microwave window flange.

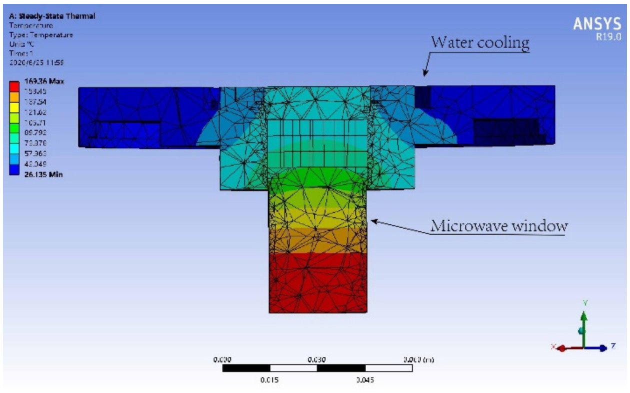

Figure 6. The temperature distribution of the microwave window flange.

The temperature distribution of the microwave window flange is presented in Fig. 6. Since the heat on the ceramic rod is mainly derived from the energy of the input microwave, we assume that the thermal power deposited on the ceramic rod is 100 W and the temperature of the cooling water is set to 22 °C. For the ceramic rod, the highest temperature is 169 °C at the end of the antenna and the lowest temperature is about 50 °C at the starting position of the antenna. The simulated results indicate that the water cooling design of the microwave window is reasonable.

DISCUSSION AND OUTLOOK

In this paper, to generate ribbon electron beams for charge neutralization of large-area wafers, a cylindrical chamber surface wave plasma generator with a cylindrical dielectric waveguide and a 70 mm×3 mm extraction slit was fabricated based on a 2.45 GHz ECR ion source at PKU. The details of this PFG are presented in this paper. In addition, the microwave coupling and thermal analysis are also discussed.

In the future, this microwave driven PFG will be installed and tested. The influence of gas pressure, microwave power, and antenna length on the electron current will be studied systematically. Also, the plasma physics inside this PFG will be followed with interest. All of these work are in process and will be presented later.

ACKNOWLEDGEMENTS

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