Comparison of different plasma chambers in microwave ion source for the intense neutron tube

JING Shi-Wei, LIU Lin-Mao
(Physics Department, Northeast Normal University, Changchun 130024)

Abstract The microwave absorption efficiency, which is relevant to magnet field and its distribution, is a major parameter of the microwave ion source (MWIS) for the intense neutron tube. Based on previous work, the relations between microwave absorption efficiency and plasma chamber structure and thickness of the microwave introduction window are studied. The microwave absorption efficiency reaches to 100% when plasma chamber is 100mm long and the window thickness is 30mm. The microwave absorption efficiency as a function of pressure is also presented.

Keywords Microwave ion source, Absorption efficiency, Plasma chamber
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1 Introduction

The neutron tube, as a small accelerator used as neutron source[1] and applied in many areas,[2-4] consists of an ion source, an accelerating system, a pressure adjustment device and a target system.[1] The ion source is a major component of the neutron tube and it is the basis for development of the intense neutron tube. The microwave ion source (MWIS) is of a new kind being developed in recent years. In comparison with the Penning ion source, the duoplasmatron ion source and the high frequency ion source employed in the intense neutron tube, the MWIS has main advantages such as higher atomic ions ratio, lower steady performance pressure, no electrode required and easy isolation from high voltage.[5] The total ion current in the target is lower when MWIS is used than that when the Penning ion source is used, if the neutron yield is equal. Therefore, it is easy to solve the problem of target cooling, and to increase neutron yield, lifetime, and stability.

We have designed the magnetic mode of the MWIS for the intense neutron tube,[6] and studied the relation between microwave absorption efficiency and magnetic field.[7] This paper describes the relations between microwave absorption efficiency and the plasma chamber structure, thickness of the microwave introduction window and pressure.

2 Experiment facilities

The experiment facilities are shown in Fig.1. The microwave power is generated by a CW power transmitter at a frequency f = 2.45 GHz and the forward microwave power can continuously vary from 300 to 1000W. The plasma chamber is made of 95%Al_2O_3 ceramic material which can transport microwaves without impedance and be isolated from high voltage excellently. The outer and inner diameter of the plasma chamber is 50mm and 40mm respectively. Three plasma chambers are employed whose length is 100mm, 80mm, and 60mm respectively.

The mode of magnetic field is an important parameter impacting the microwave absorption efficiency. A $\Phi 124\times\Phi 60\times 25$mm magnetic ring[6] is employed in our experiment. When the microwave energy accelerates free electrons, the ECR (electron cyclotron resonance) mechanism is utilized with B = 0.0875T for 2.45 GHz microwaves. Landau damping is the main mechanism of microwave absorption when intensity of the plasma is high.[8] Based on our study,[7] the microwave absorption efficiency is high when intensity of the magnetic field at the microwave introduction window is 0.093T. The axial distribution of magnetic field in the plasma chamber is changeable by varying position of the magnetic ring (Fig.1).

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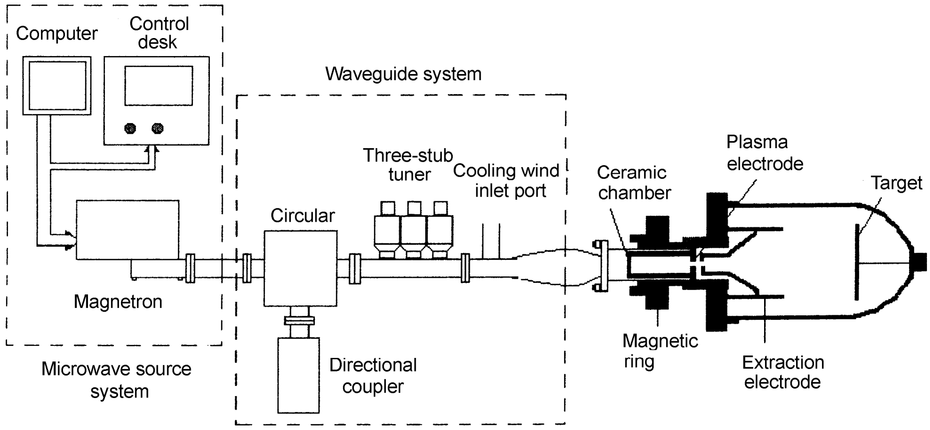

Fig.1 Scheme of the experiment facilities.

3 Experiment results

Position of the magnetic ring along the axis of the plasma chamber is adjustable so as to change magnetic field distribution, which affects the microwave absorption. The microwave absorption efficiency as a function of the microwave introduction window thickness and the pressure is studied. The microwave absorption of the three plasma chambers with different window thickness is shown in Fig.2 when the pressure is 2×10^{-3} Pa. The microwave absorption is shown in Fig.3 when the pressure is 3 Pa.

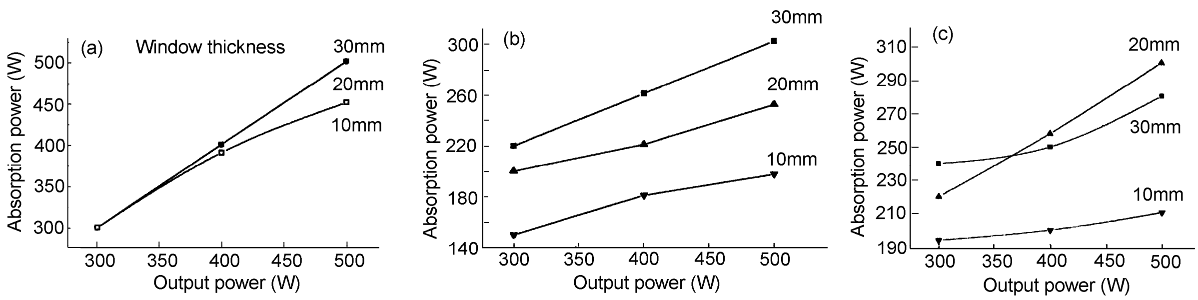

Fig.2 Microwave absorption as a function of output power at the pressure of 2×10^{-3}Pa for different plasma chambers: (a)100 mm chambers; (b)80 mm chambers; (c)60 mm chambers.

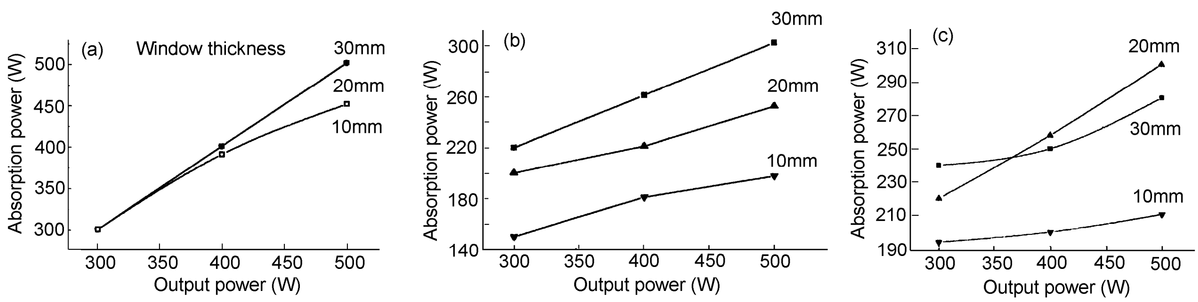

Fig.3 Microwave absorption as a function of output power at the pressure of 3 Pa for different plasma chambers: (a)100 mm chambers; (b)80 mm chambers; (c)60 mm chambers.

From Fig.2 and Fig.3, it can be seen that the microwave absorption efficiency is different for these plasma chambers, and it is best when the chamber length is 100 mm. For a certain chamber length, the microwave absorption is different for different window thickness and it is best when the window thickness is 30 mm. The relation between microwave absorption efficiency and pressure is not obvious. The absorption efficiency is better when the pressure is high because of much more absorption medium than that when pressure is low. Nevertheless, for the plasma chamber whose length is 100 mm and the window thickness is 30 mm, the microwave absorption efficiency is 100% no matter whether the pressure is high or low. Structure of this chamber will be the emphasis in our next study.

4 Discussion

The ion source is very important for the intense neutron tube. According to Popovs,[8] for 2.45 GHz microwave source, the minimal diameter of the discharge chamber is 12.5-25 cm. The microwave absorption efficiency is more than 90% in this condition. When plasma absorbs microwave radiation, the plasma is regarded as a medium, and its medium coefficient ε_p is given by

$$\varepsilon_p = 1 - [\,(\omega_{pe}/\omega)^2/(1 - \omega_{ce}/\omega)]$$

where ω is input microwave frequency, ω_{pe} is plasma frequency, and ω_{ce} is electron frequency, respectively.

With increase of ε_p the cutoff diameter for discharge in the ion chamber will decrease. We can make use of this characteristic to study the relation between microwave absorption efficiency and plasma chamber, whose outer diameter is about 50 mm, since a large plasma chamber can not be employed due to the limited volume of the neutron tube.

A major difficulty of the MWIS is its variable, nonlinear and often reactive discharge load. Thus, it is desirable to electrically separate the microwave power oscillator and the plasma load. The microwave source must be impedance-matched to efficiently produce the uniformly dense plasma. The impedance of plasma depends on the absorbed microwave power, the plasma parameters, and the superimposed magnetic field. Several tuning methods for better impedance match are as follows[9]:

(1) a three-stub tuner to stabilize the plasma by controlling the reflection coefficient;

(2) a multi-layer window of proper materials;

(3) a right-hand circularly polarized mode through a quarter wavelength thick window;

(4) a proper magnetic field and its distribution at the bottom of the microwave window; and

(5) a ridged wave-guide which is very efficient for increasing the extracted ion current density.

The three-stub tuner is placed in the maximum position and the plasma chamber is made of 95%Al_2O_3 ceramic material so as to study the relation between microwave absorption efficiency and the plasma chamber structure.

The optimal mode of the plasma chamber is 100mm long and with a window thickness of 30mm as shown in Fig.2(a). The microwave window becomes a 1/4 wavelength converter when its thickness is equal to 1/4 wavelength, which is proved by Stevens[10] and by our experiment, because 1/4 wavelength is about 30 mm for the 2.45 GHz microwave source.

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