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Simulation of the microwave resonant plasma source for ISPSC

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Abstract

In the present paper, the microwave resonant plasma source has been designed to provide the ionosphere like condition inside the Iranian Space Plasma Simulation Chamber (ISPSC). This chamber contains plasma with 1×10^{11}-7×10^{16} m^{-3} and 1-15eV electron density and temperature, respectively. In order to reach these plasma parameters inside the Iranian Space Plasma Simulation Chamber, the plasma source cylindrical cavity mode TE_{112} is used. Then, the produced plasma is transferred into the Iranian Space Plasma Simulation Chamber through the holes created on the end wall of the cavity. Since the plasma characteristics in the resonant cavity depend on the gas pressure and the input power, the microwave and plasma interaction, power absorption, electron density and temperature were evaluated by the Comsol Multiphysics and obtained results have been presented.

Keywords: Plasma Source, Cavity, Comsol, Space Plasma

Introduction

The space plasma simulation device has been constructed to provide the plasma with a close characteistic to the space plasma. This device has main role in invastigate of the fundamental physics of space plasma such as space plasma waves and instability, modeling of the earth and planetary space environments, simulation of the ionospheric heating, magnetic field, generation and reconnection [1, 2]. During the years, many space plasma devices were designed and constructed such as LAPD [2], NRL-SPSC [3], MRX [4], KROX device [5], SESRI [6], FLARE [7], KSPEX [8], MPDX [9] and VINETA II [10]. Among the available sources, plasma sources based on the microwave have been developed because of the simplicity, choice of the different gases and ease of opreation. In this paper, simulation of the large volume microwave plasma source based on the resonant cavity has been described. In this paper, COMSOL Multi-physics software has been used for the theoretical studies [21]. This software has the capability to simulate a Microwave discharge with the employment of the microwave-plasma module for electron density and energy calculations method [11, 12].

Iranian Space Plasma Simulation Chamber

ISPSC has been constructed to perform studies and simulations regarding plasma physics, ionosphere and magnetosphere. The device consists of a large volume chamber, a cylinder of length 5 m and diameter 1.8 m, equipped with plasma source. ISPSC is also appropriate to test the satellite, thruster, electronic board, space-borne instruments and sensors used in ionosphere. on the other hand, due to large chamber and therefore quiescent plasma production, used for calibration and test of the plasma diagnostics. The generated plasma is monitored by Langmuir Probe, Optic Emission Spectrometry, Interferometry and etc. The schematic ISPSC has been shown in Figure 1.

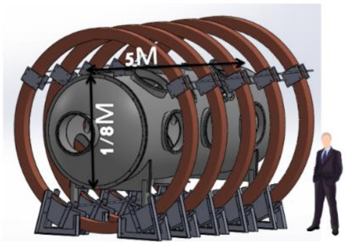

Figure 1. Schematic of the ISPSC

Plasma Source Design and Simulation

It is worth mentioning that the source should has a large size and constant ionization rate. In accordance with the ISPSC size, the source diameter would be near 40 cm. The depth of the cylindrical cavity is determined by the resonant mode and magentron frequency. Whereas the magnetron frequency is fixed (2.45GHz), a resonance mode which generate a constant electric field as function of the radius has been selected. We choose a TE_{112} cylindrical cavity mode. The frequency of a TE mode resonance in cylinderical cavity is given by [20]

$$f_{TE_{nml}} = \frac{c}{2\pi}\left(\frac{q'_{nm}}{R^2} + \frac{l^2\pi^2}{L^2}\right)^{1/2}$$

Where, c is the speed of light and q'_{nm} is the zero of the derivative of the Bessel function. We settled on a TE_{112} cylindrical cavity mode whose electric field components for n=1, m=1, l=2, R=35.6 cm and $q_{11} = 1.841$ is the first zero of Bessel function.

The cavity has been designed to have a somewhat lower resonant frequency than the magnetron frequency in order that cavity tuning could occur. An increase in the resonant frequency occurs when volume in the cavity is tuned by the stub. In this source, the cavity length (L) and the resonant frequency of the TE_{112} mode are are 12.35 cm and 2.41 GHz, respectively. By increase of 0.15 cm to the overall cavity length, the center frequency reach 2.45 GHz. The center frequency of cavity is 40 MHz below the expected center frequency of the magnetron (2.45±0.01 GHz) and allows for cavity tuning by stub adjustment. The stub tuning is a cylindrical (diameter~10.2 cm, L~2.5 cm) that has been attached to NW 16 ports. According to the microwave-plasma module of the COMSOL Multi-physics software,

$$\nabla \times \mu^{-1}(\nabla \times E) - k_0^2\left(\varepsilon_r - \frac{i\sigma}{\omega\varepsilon_0}\right)E = 0$$

Where, σ is the plasma conductivity tensor, E is the electric field, k_0 is the wave number of free space, ε_r is the relative dielectric tensor, ω is the angular wave frequency, and ε_0 is the permittivity of vacuum.

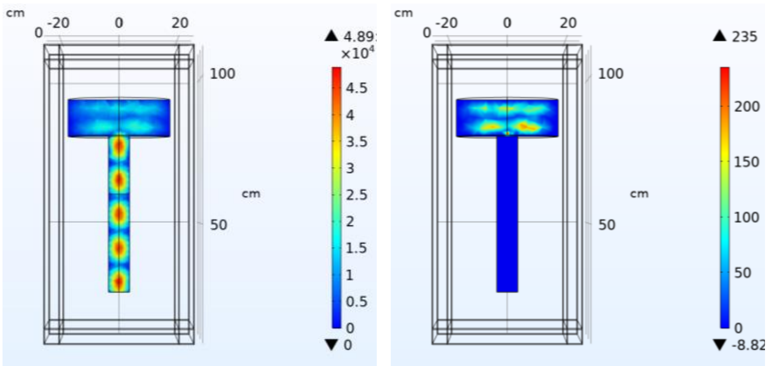

Figure 2. The magnitude of the electric field produced by the TE_{112} mode for 2.41 GHz (left) and absorbed power (right) for 800 W input power.

In addition, three-dimensional simulations have been performed to analyze the microwave discharge by modeling the microwaves-plasma interaction. With this aim, the computational domain consisted of a cylindrical cavity (diameter~35.6 cm, L~12.35 cm), as well as a microwave injection WR284 waveguide operating in TE_{10} mode of 2.45 GHz. The cavity walls had been assumed as the perfect electric conduction. Initially, the magnitude of the microwave electric field on the cavity was calculated as shown in Figure 2. This shows the TE_{112} mode was excited for 2.41 GHz on the cavity.
Argon was chosen as the filling gas. This gas can absorb some portions of the microwave power, while reflecting the rest of it due to plasma generation leading to a total power reduction in the waveguide. Because of this power absorption and reflection, an amount of electric field energy would be stored in the chamber. The microwave propagation and absorption have been simulated. The initai condition of the simulation were presented in .

Table 1. initial condition of the simulation

Electron Density	1×10^{13} 1/m^3
Electron Temperature	4 eV
Pressure	0.05 Pa

The distribution of the absorbed microwave power has been shown in Figure **2**. It can be seen from the figures that the microwave power is absorbed at high electric field of the cavity.
Also S_{11} was -2 dB. This impact is severe due to the generation of a local dense plasma with the high reflection of the power. This reflection power should be matched with the stub tuner.

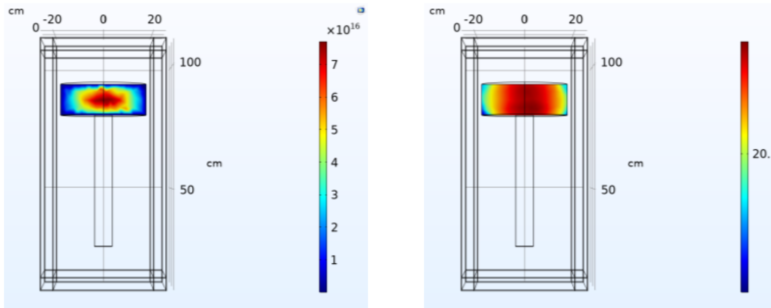

Figure 3. The electron density (left) and the electron temperature (right) of the plasma at 0.05 Pa and with 800 W input microwave.

The peak electron density at 0.05 Pa is around 7 × 10^{16} m^{-3} that is below the critical plasma density (7.4 × 10^{16} m^{-3} at 2.45 GHz) and the peak electron temperature is 12 eV.

Conclusions

The resonant cavity plasma source that is able to produce space plasma like in ISPSC was designed and simulated. The center frequency of the cavity was changed by stub tuner adjustment. The cavity mode was TE_{112} and able to produce plasma with 7×10^{16} m^{-3} and 12 eV electron density and temperature, respectively.

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