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Experimental study on the surface wave driven plasma antenna

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ABSTRACT

This experimental study examines the characteristics of a plasma antenna. For these experiments, we use a surface wave excitation at 450 MHz with RF power levels up to 40 W and gas pressure between 0.25 mb and 0.6 mb. Measurements of visible light from the plasma column confirm that the length of the antenna is linearly proportional to the square root of the excitation power and the proportionality factor is a function of gas pressure. Observations of the VSWR of the antenna show that decreasing the excitation power and increasing the pressure lead to the reduction of the resonant length of the antenna. The gain of the plasma antenna was measured between 110 and 300 MHz. The results show that the gain of a plasma antenna is considerably less than a conventional monopole antenna.

1. Introduction

The difficulty in changing the antenna element in different application with various frequencies is a concern for communicating. During the last few years, research on the plasma antennas has greatly expanded [1–3]. One reason is that the researchers and engineers now realize that relative to the conventional metallic antenna, plasma antennas, in particular the surface wave driven (SWD) ones, can generally be more flexible in operating conditions for special technical applications. Plasma antennas find its applications in variety of fields such as military applications, faster internet, public safety networks, radio and television broadcasting and space communications.

The properties of the SWD depend on the amount of power absorbed per unit length of the plasma column and on the discharge conditions, namely the composition and the pressure of the gas, the dimensions of the plasma tube, the wall material and the excitation wave mode and frequency [4]. Although the specific design of the wave launcher does not affect the plasma parameters, the launcher determines the efficiency of the power transfer from the power generator to plasma and, to some extent, it imposes wave propagation mode [4].

Recent progresses with numerical simulations of SWDs in [5] lead us to the experimental study to better understanding of the physical process and proving the previous investigations. Experiments were undertaken over the ranges of pressures and excitation powers, considering constant excitation frequency of 450 MHz to determine the major characteristics of a SWD plasma antenna including the antenna height, the resonant length, VSWR and gain values.

This paper is organized as follows. Section 2 constrains a short review of the principal theory in a SWD plasma antenna, with the corresponding equations. In Section 3, we concentrate on the experimental setup. Section 4 is devoted to the description of experimental results including measurement of the antenna height (Section 4.1). We then characterize the VSWR and the resonant length of the antenna in Section 4.2 and the radiation pattern and gain of the antenna will be discussed in Section 4.3. This investigation will be summarized in Section 5.

2. Theory

In a cylindrical configuration, the possible modes of propagation of surface waves along the plasma column are defined by their field intensity dependence upon the azimuthal angle φ. According to [4,6], the mode selection relies essentially on the value of the product $f \cdot R$, where f is the excitation frequency and R is the radius of the antenna. When this value is less than approximately 2 GHz cm, the plasma column can be sustained only with the $m = 0$ surface wave. This product value is independent of the gas nature and pressure. When $f \cdot R$ is increased starting from 2 GHz cm, one can achieve the discharge with dipolar mode ($m = 1$). Increasing $f \cdot R$ repeats the preceding situation with the larger modes.

A condensed analysis of the plasma radiation and power launching constraints on excitation of a surface wave on a plasma column were presented in [7,8]. The case of a plasma column excited below ω_p, the angular plasma resonance frequency, leads to a

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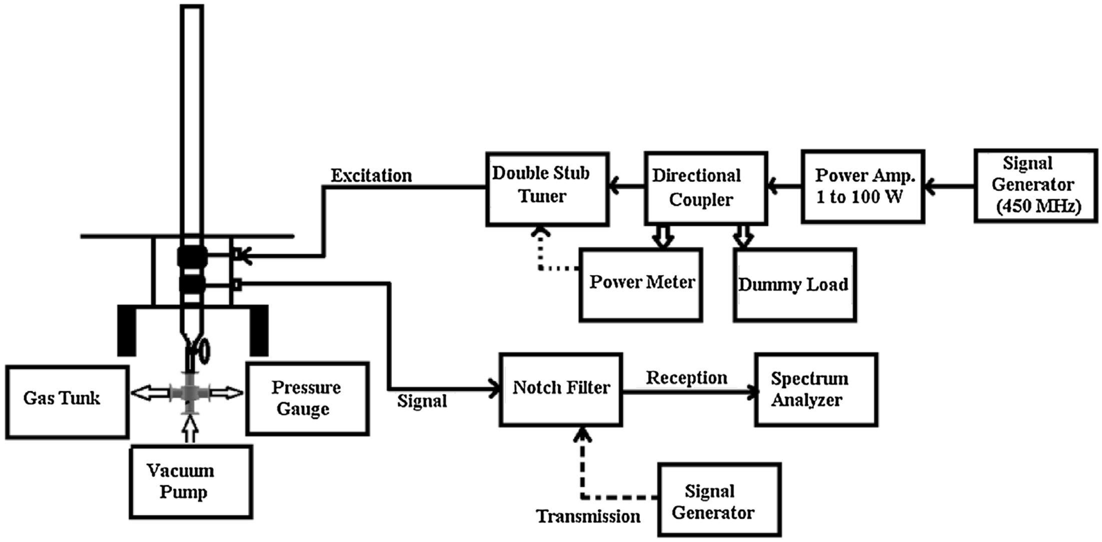

Fig. 1. Experimental setup of a SWD plasma antenna.

negative permittivity and permits the propagation of a surface wave along the column. Let ω be the angular excitation frequency, when $(\omega_p/\omega) \gg 1$, the plasma occludes the wave as if it were as a perfect conductor.

Following the analysis of [9], for a given pressure, the height of the antenna should increase as the square root of the applied RF power and may be written as:

$$h \approx B(p)\sqrt{P_0} \quad (1)$$

where theoretical slope $B(p)$ derived from global model as:

$$B(p) = \sqrt{\frac{2}{CK(p)\upsilon_m(p)}} \quad (2)$$

C is a constant with a value of $C \approx 5 \times 10^9\ \text{m}^{-4}\ \text{S}$ [10]. $\upsilon_m(p)$ is the electron-neutral collision frequency for momentum transfer and $K(p)$ is a function of pressure for a given geometry. Eq. (1) shows that for a given pressure, controlling the resonant length of the antenna is possible by excitation power.

Ref. [9] shows that the plasma electron density n_0 at the base of the antenna is:

$$n_0 \approx A(p)\sqrt{P_0} \quad (3)$$

where,

$$A(p) = \sqrt{\frac{2C\upsilon_m(p)}{K(p)}} \quad (4)$$

The electron density steadily decreases away from the launcher and the plasma column is axially non-uniform. The minimum density n_D below which the wave no longer propagates is [10]:

$$n_D = 1.2 \times 10^4(1 + \varepsilon_g)f^2\ (\text{cm}^{-3}) \quad (5)$$

where f, the applied excitation frequency is expressed in MHz and ε_g is the tube relative permittivity.

3. Experimental setup

Surface wave driven plasma monopole antenna was employed in this investigation using the arrangement shown in Fig. 1. This arrangement consisted of a 1 m Pyrex tube with the thickness of 1 mm and permittivity of 4.82, and the diameter of 25 mm connected to a rotary vacuum pump of VARIAN DS602 with pumping speed of 25 m^3/h and ultimate total pressure of 2×10^{-3} mbar. A pirani pressure gauge with the pressure range of 10^{-3} to 760 torr and a gas handling system that admitted Argon at different pressures are also connected to the tube in order to determine an optimum pressure for the antenna.

The surface wave launcher consisted of a copper collar of length 30 mm mounted less than 4 mm below a circular hole cut in the top of a grounded box. RF power up to 40 W at 450 MHz was applied via a directional coupler and a double stub tuner. The reflected power was measured using a power meter connected to the coupled port of the directional coupler. By controlling the stub length of the double stub tuner, it was possible to decrease the reflected power to a minimum value. So, in measurements, the reflected power was less than 0.01 of the applied power.

The gas can be ionized using the intense electric field developed in the gap between the collar and the box and igniting the plasma along the column.

A second coupling collar (for transmission or receiving) was mounted 40 mm below the pump collar which was used to apply communication signals to the antenna via a band stop filter with a center frequency at 450 MHz. The filter attenuated the 450 MHz RF power signal up to 70 dB.

Tests were conducted using the plasma column as a receiving or transmitting antenna over the range from 80 to 300 MHz. Experiments were undertaken for different RF power levels and plasma pressures to determine the antenna characteristics.

4. Experimental results

4.1. Antenna height

The height of the plasma antenna as a function of the applied RF power was determined by observing the visible light from the plasma. Fig. 2 plots the height of the antenna (h) as the square root of the applied power at the pressure of 0.4 mb. The used origin of this measurement is the top part of the launcher. The plot shows that the height of the antenna increases linearly proportional to the square root of the applied power and the slope of the plot, $B(p)$, in this case is around $6.77 \pm 0.04\ \text{cm/W}^{1/2}$, which was predicted by the global model as $6.4\ \text{cm/W}^{1/2}$ [9,10]. The comparison shows that the results with argon column at 0.4 mb agree, approximately, with the global model. It is noticeable to mention that the resulting slope in