Analysis of the tuning characteristics of low-power microwave device for generation of plasma sheet

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Abstract: A novel, recently patented plasma source with unique shape of plasma (i.e. *plasma sheet*) is presented in this paper. The source generates non-thermal plasma under atmospheric pressure using the 2.45 GHz microwaves. The unique shape of the plasma sheet is very convenient for surface treatment. This work is focused on analysis of the tuning characteristics of the microwave device for generation of the plasma sheet.

keywords: computer simulations, energy efficiency, plasma sheet, tuning characteristics

1. Introduction

Plasma sheet is called the plasma generated in a form of plane. This plasma is produced inside a narrow channel which walls are made of dielectric (dielectric box). Through the dielectric box flows the working gas [1-3]. In view of the unique shape of the generated discharge, the plasma sheet is convenient for industrial applications of materials surface treatment. Depending on application, the microwave power for initiating the discharge can be supplied to the dielectric box in two ways: by symmetrical strip line (incident microwave power P_I less than 500 W) or by rectangular waveguide (P_I can be greater than 500 W).

The main purpose of this work is to characterize the electrodynamic properties of the presented plasma source. The goal will be achieved by performing experimental measurements and modelling (using the Comsol Multiphysics software [4]) the tuning characteristics of the device. The tuning characteristics is a dependence of reflected microwave power P_R to the incident microwave power P_I as a function of a position l_s of movable plunger (tuning element) [1]. In general the plasma source is efficient when the ratio P_R/P_I is low (approximately equal to zero) and its stable in operation when this ratio does not depend on movable plunger position l_s. The aim of the modelling is to find a model of plasma that will allow to calculate the tuning characteristics consistent with those measured experimentally. This finding allows to estimate the electron concentration n_e and electron collisions frequency ν in the generated plasmas [5]. This modelling is a first step in increasing the energy efficiency of the device, as the cost of the generated discharge is one of the main factor that determine the usefulness of microwave plasma in the industry [5-6].

2. Experimental setup

The construction of investigated plasma source is based on a standard rectangular waveguide WR-340. The dielectric box (made from quartz) passes through the wider walls of the waveguide through two rectangular slots. The slots were cut centrally and perpendicular to the waveguide wall. The working gas is introduced into plasma source by two inlets at the bottom of quartz box, Fig. 1.

To measure the tuning characteristics, an experimental setup was arranged: microwave generator (magnetron, HV supply) coupled with a circulator and a microwave power measurement system (directional coupler, double digital incident and reflected microwave power meter, two measuring heads), Fig. 1. The incident microwave power P_I from magnetron to the plasma source was supplied by standard rectangular waveguide WR-340. The supply line was terminated by movable plunger. In used experimental setup the plasma sheet was generated by microwave technology 2.45 GHz at atmospheric pressure.

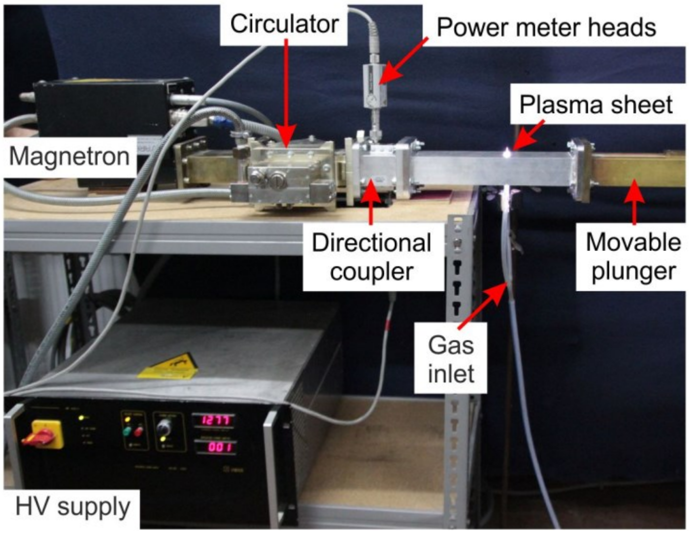
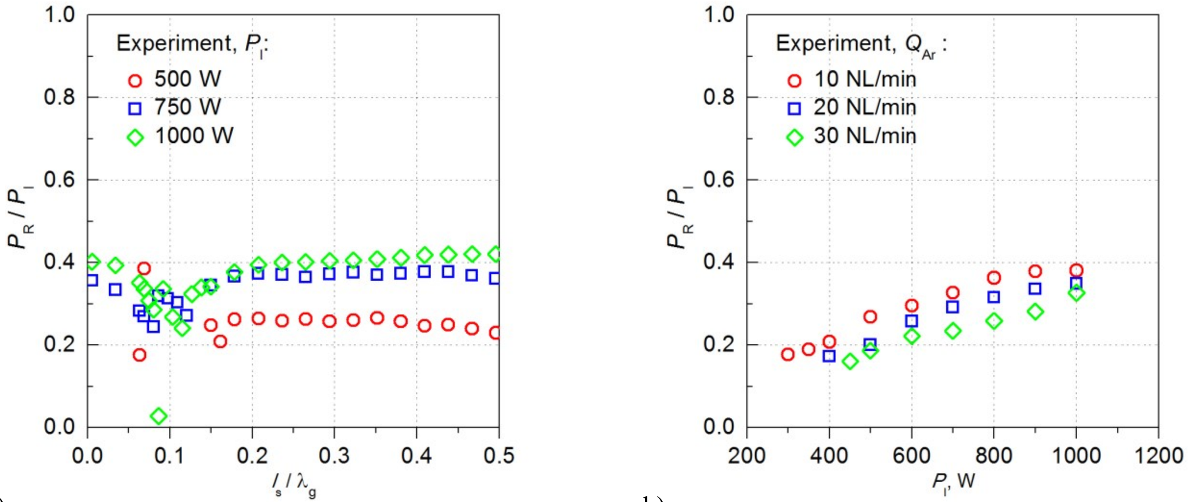


Fig. 1. A photo of experimental setup

Using above described setup the relationship P_R/P_I vs. l_s was measured, Fig 2a. As the working gas argon was used. In contrast, Fig. 2b shows the ratio P_R/P_I as the function of the P_I. The measured characteristics from the Figure 2a was normalized to the 2.45 GHz frequency wavelength λ_g in the waveguide WR-340 (λ_g = 173.4 mm) [1].

As can see from Figure 2 the measured characteristics showed a highly undesirable tendency, namely the increasing value of P_I decrease the efficiency of the microwave energy absorbed by the plasma [5, 6]. Keeping in mind the future possible application this efficiency decrease indicates higher costs of device use. Due to industrial requirements regarding low cost of generated discharge the preliminary tests pointed out that improving the device in order to increasing its energy efficiency is necessity. The maximization of the absorption of the microwave power by the generated plasma will be the main criterion of this improvement.



a) b)

Fig. 2. a) Measured tuning characteristics for three values of incident power P_{I}, argon flow rate Q_{Ar} = 20 Nl/min, b) relationship $P_{\mathrm{R}}/P_{\mathrm{I}}$ as a function of P_{I}, for three values of argon flow rate Q_{Ar}, normalized position movable plunger $l_{\mathrm{S}}/\lambda_{\mathrm{g}} = 0.06$

3. Results of simulations

The improvement of plasma source could be done by appropriate construction design of the device or/and by using so-called matching systems (e.g. three-stub tuner). This can be done experimentally, which is expensive or first by theoretical research (e.g. numerical modelling). Manifestly the theoretical results must be verified experimentally.

In this work the presented tuning characteristics are the basis for numerical modelling. In this modelling plasma was assumed as homogeneous with a relative permittivity ε_{p} described by the Lorentz formula [5]. For calculating the tuning characteristics the Nowakowska method [6] was used. Comparison of measured and calculated tuning characteristics allowed to determine parameters of the adopted microwave plasma model: concentration n_{e} and collision frequency of electrons ν. In case of P_{I} = 750 W, the best fit was obtained for the parameters n_{e} and ν of $2{,}6\times10^{14}$ cm^{-3} and $1{,}5\times10^{11}$ s^{-1}, respectively, Fig. 3. While in the case of P_{I} = 500 W and P_{I} = 1000 W, obtained values of n_{e} and ν parameters were: 7.5×10^{13} cm^{-3} and 1.1×10^{11} s^{-1}; 5.2×10^{14} cm^{-3} and 2×10^{11} s^{-1}, respectively. The obtained results indicate that increasing the incident microwaves power P_{I} causes slight augment values of n_{e} and ν in the generated plasma. These results are consistent with those obtained by optical emission spectroscopy [3].

The performed analysis is a first step in the process of the device energy efficiency improving. This work allowed to obtain synthetic model of plasma sheet [5]. The obtained model will be used in numerical simulations of the electromagnetic field distribution inside the plasma source in order to increase the microwave power transfer from the supply line to the generated plasma by improving the plasma source structure. These simulations allow obtain so-called *map of stable area of plasma generation*. This map is presentation of the calculated tuning characteristics in a form of two-dimensional contour plot, where the ratio P_R/P_I depends on the normalized plunger position l_S/λ_g and electron density n. The map of stable area of plasma generation allows for quick analysis of the efficiency and stability of the MPS. The numerical simulations of the electromagnetic field distribution will be the subject of our next work.

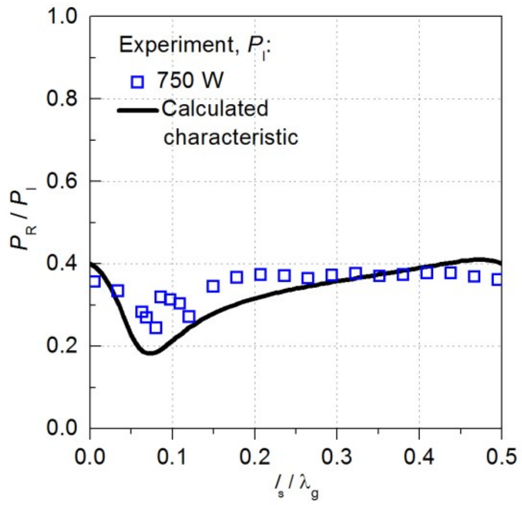


Fig. 3. Comparison of measured and calculated tuning characteristics of the plasma sheet source

4. Conclusions

The preliminary tests showed that the device requires improvement in order to increase its energy efficiency. Therefore, presented in this work investigation is the first step in a process of the device energy efficiency improving.

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