Dariusz CZYLKOWSKI[1], Mariusz JASIŃSKI[1], Jerzy MIZERACZYK[1,2]

The Szewalski Institute of Fluid Flow Machinery, Gdańsk (1), Gdynia Maritime University, Gdynia (2)

On the role of the design and discharge conditions on the Surfaguide tuning characteristics

Abstract. *Stable operation of microwave plasma generator with a good efficiency of power transfer to the plasma needs to take into account a few of important factors. Namely the geometry of the wave launching region and discharge conditions. This report include experimental results on influence of this factors on the tuning characteristics of an atmospheric pressure Surfaguide-type plasma generator.*

Streszczenie. *Praca zawiera wyniki eksperymentalnego badania wpływu geometrii obszaru sprzęgania i warunków wyładowania na charakterystyki strojenia generatora plazmy typu Surfaguide. Od czynników tych zależą stabilna praca generatora plazmy i korzystny energetycznie transfer mocy mikrofal do plazmy. (**Wpływ geometrii i warunków wyładowania na charakterystyki strojenia generatora plazmy typu Surfaguide**).*

Keywords: atmospheric pressure discharge, microwave plasma, plasma generator, Surfaguide.
Słowa kluczowe: wyładowanie pod ciśnieniem atmosferycznym, plazma generowana mikrofalowo, generator plazmy, Surfaguide.

Introduction

Since seventies of the twentieth century when the surface wave sustained discharges were discovered as a new plasma source [1], they find practical applications in various fields. The most common are light sources, neutral and active species sources, surface treatment reactors, reactors for chemistry, deposition, etching etc. Today they are still of high interest. One of the promising application is the hydrogen production [2, 3]. Wide range of applications demands appropriate surface wave plasma generator suitable to operate under different discharge conditions. Stable and repeatable operation of such plasma generator with a high efficiency of power transfer to the plasma needs to take into account its geometry as well as discharge conditions [4, 5]. In our experimental study we investigated the influence of that factors on the tuning characteristics of the Surfaguide-type [6] plasma generator. Surfaguide is the waveguide based plasma generator in which plasma is generated inside a dielectric discharge tube due to the propagation of travelling surface wave. The tuning characteristics describe electrodynamic properties of the plasma generator, determine the efficiency of power transfer to the plasma and stability of its operation.

Surfaguide and experimental setup

We used the experimental setup as that previously described in [7]. Its photo can be seen in the figure 1.

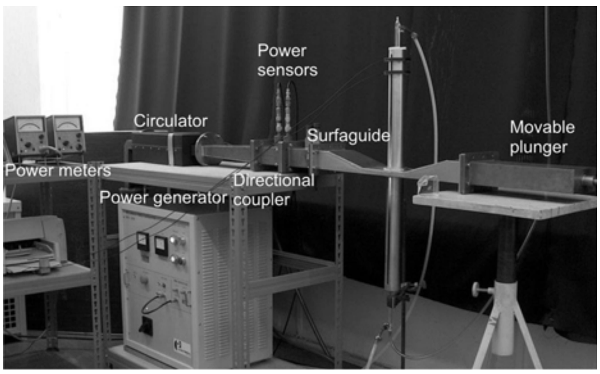

Fig.1. The photo of the experimental setup

The essential components of the experimental setup are: source of microwave power of frequency 2.45 GHz and maximal power of 500 W, microwave power balance measuring system (directional couplers, power heads, power meters), Surfaguide-type microwave plasma generator, impedance matching system (movable plunger), gas flow control and measurement system. The overall view of the Surfaguide-type plasma generator is shown in the figure 2.

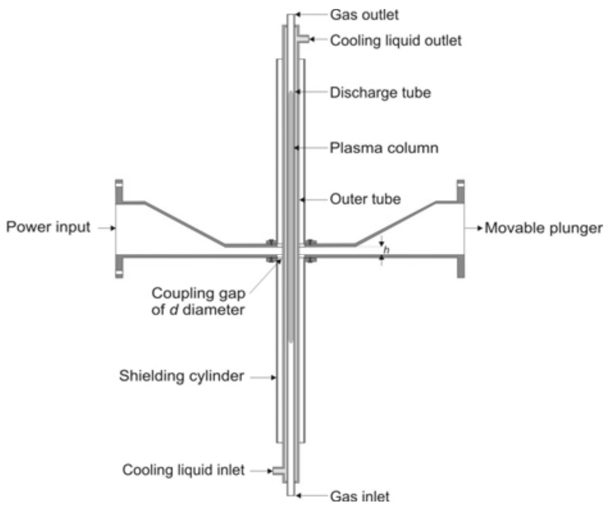

Fig.2. Cross sectional view of the Surfaguide

It is based on a standard rectangular waveguide with a reduced height section of height h and two tapered sections. Tapered sections ensure a smooth transition from standard waveguide to waveguide of reduced height. The discharge is sustained in a 1 meter long quartz tube with the inner and outer diameters of 1 mm and 5 mm, respectively. The discharge tube inner diameter is chosen to prevent breaking the plasma column into separate filaments. The discharge tube penetrated the reduced height section through circular coupling gaps of diameter d on the axis of the waveguide wide wall. The plates with a holes placed from both sides of the reduced height section allow us to change the coupling gaps diameter. The argon at maximal flow rate Q=6 l/min measured using mass flow controller is introduced from one end of the tube. The microwave power is transferred from the microwave generator to the plasma in a reduced height section thereby on both sides of that region extend plasma columns. Because of the gas flow rate the lengths of both plasma columns are not the same [7]. For initiate the discharge a high voltage spark source is used.

Experimental procedure

In this work we used standard experimental procedure. We measured, for various Surfaguide-type plasma generator configurations and discharge conditions, the tuning characteristics defined as the dependence of the fraction of power reflected at the plasma generator input P_R/P_I, on the normalized position of the waveguide plunger l_s/λ_g, where λ_g is the wavelength in the waveguide. Considering the role of different factors, we take into account the shape and width of the tuning characteristics, the minimum of reflected power coefficient P_R/P_I and the position of the tuning characteristics minimum on the l_s/λ_g scale. The best one tuning characteristics is that with minimum situated at P_R/P_I=0 and l_s/λ_g=0. Such tuning characteristics is the widest one and assures the best efficiency of microwave power transfer to the plasma.

Launching gap diameter d, height of reduced height section h and shielding cylinder are of geometry type factors taken into account in our experimental study. We tested Surfaguides with three different values of reduced section heights, namely h=8 mm, h=10 mm and h=12 mm. We checked out the influence of the diameter of the coupling holes d by using changeable plates with holes of diameters d=9 mm, d=14 mm and d=20 mm. We also measured how the presence of the shielding cylinder with the inner diameter of 46 cm placed coaxially with the discharge tube affects the Surfaguide tuning characteristics. The role of that shielding cylinder is to prevent against microwave radiation leakage due to safety reasons. In our experiments we also surrounded the discharge tube by cooling coat of diameter 12 mm. Cooling the discharge tube is widely used method when operate with higher microwave power levels. As it will be shown the usage of cooling liquid does not stay without any influence on the electrodynamics properties of the plasma generator. To investigate the role of the discharge conditions on the electrodynamics properties of the Surfaguide we measured tuning characteristics at different values of input microwave power P_I=200 W, P_I=400 W, P_I=500 W and argon flow rates Q up to 6 l/min.

Results

The role of the Surfaguide's design on their tuning characteristics was investigated for three values of heights reduced height section, namely h=8 mm, h=10 mm and h=12 mm. The corresponding results are shown on the figure 3, for incident microwave power of P_I=200 W and on the figure 4, for incident microwave power of P_I=400 W. For both, the argon gas flow rate was equal Q=1 l/min and coupling gap diameter was equal d=9 mm. As it can be seen the minimum of the reflected power coefficient P_R/P_I is the lowest in the case of Surfaguide with the highest value of h. The minimum of the measured characteristics moves toward the center of the l_s/λ_g scale with increase of h and simultaneously, the width of the tuning characteristics increase. From obtained results, clearly can be seen, that Surfaguide with h=12 mm height of reduced height section assures the best tuning characteristics.

Comparing the results presented in the figures 3 and 4 and collected in the table 1, the influence of the microwave input power P_I on the tuning characteristics can be seen. Any visible difference regard rather the position of the minimum of the reflected power coefficient P_R/P_I on the l_s/λ_g scale then the minimal value of P_R/P_I. In the case of microwave input power P_I=400 W all minima are located closer to center of the scale.

Figure 5 shows the noticed dependence of the tuning characteristics with the coupling gap diameter d. We tested three values of gap diameter, namely d=9mm, d=14 and 20 mm. All minima of the measured characteristics are located at the right hand side of the l_s/λ_g scale. With decreasing the gap diameter, the minimum moves to the left. Clearly, the minimum value of the reflection coefficient P_R/P_I does not remains the same but decreases with decreasing the gap diameter.

It was observed during our experiments that over applied range of gas flow rate Q from 0,5 l/min to 4 l/min the shapes of the tuning characteristics were almost the same. Although the gas flow rate Q, only slightly influences the measured tuning characteristics, we observed significant changes in plasma column lengths.

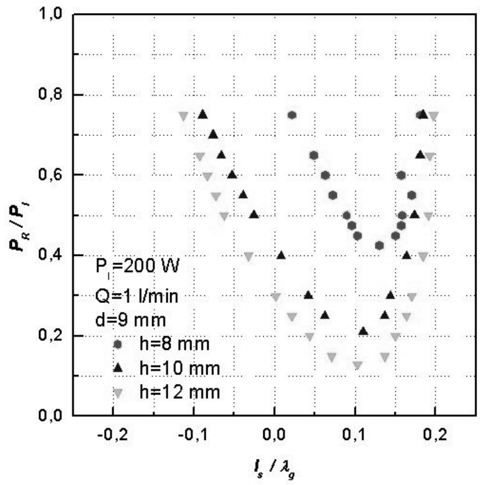

Fig.3. Dependence of measured tuning characteristics on the height of the reduced section

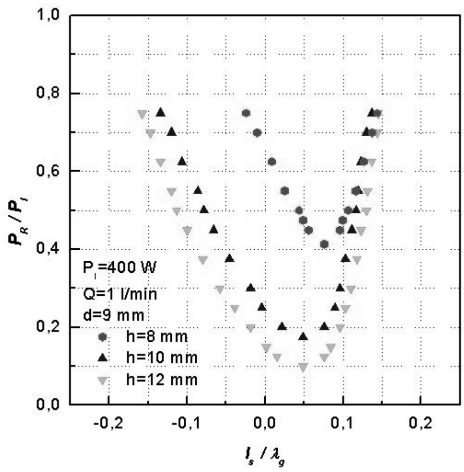

Fig.4. Dependence of measured tuning characteristics on the height of the reduced section

Table 1. The position of the minima of the tuning characteristics measured for two values of input microwave power P_I

	P_I=200 W		P_I=400 W	
	min(P_R/P_I)	min(l_s/λ_g)	min(P_R/P_I)	min(l_s/λ_g)
h=8 mm	0.43	0,13	0.42	0,08
h=10 mm	0.21	0,11	0.18	0,05
h=12 mm	0.13	0,10	0.10	0,05

To observe the role of another factors on the electrodynamics properties of the Surfaguide we used discharge tube surrounded with the metal shielding cylinder and discharge tube with a cooling enclosure. The discharge tube was enclosed in a cylindrical metal shield with the inner diameter of 46 mm. Using it during the experiments the density of electromagnetic radiation outside the discharge tube did not exceed 5 mW/cm^2.

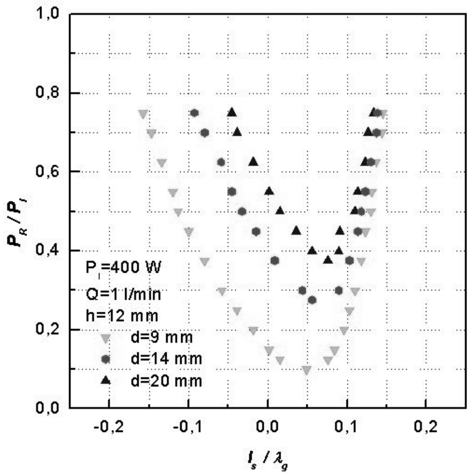

Fig.5. Tuning characteristics of the Surfaguide for three values of the coupling gap diameter d

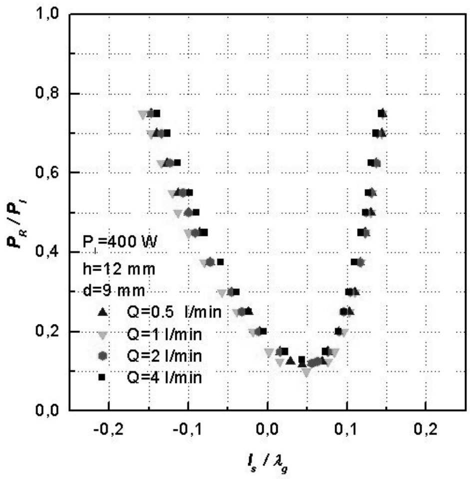

Fig.6. Tuning characteristics measured for the different gas flow rates

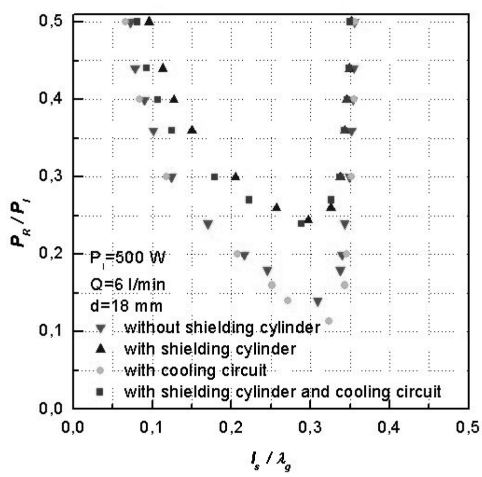

Fig.7. Tuning characteristics measured for different Surfaguide configurations. Incident microwave power P_I=500 W. Gas flow rate of 6 l/min

Comparing the tuning characteristics measured without and with shielding cylinder (see figure 7) the strong difference can be seen. The metal cylinder significantly affects the tuning characteristics. The better one obtained tuning characteristics is that measured for Surfaguide without shielding grid.

Next, the discharge tube was enclosed in an outer quartz tube. In that way they form in between a cooling jacket through which a low-loss dielectric liquid was circulated. When comparing the tuning characteristics measured for discharge tube with and without cooling (and without shielding grid) it can be seen that this first one are slightly lower situated in the P_R/P_I scale.

As it was stated in [8] the presence of cooling coat and shielding grid does not affect the discharge processes but it changes the conditions of wave propagation. It is reflected not only in the Surfaguide tuning characteristics but also, as it could be expected, in the plasma column lengths. Plasma column lengths measured for discharge tube without cooling and with cooling enclosure are quite different.

Conclusions

In this report we presented experimental results on influence of the geometry and discharge conditions on the tuning characteristics of the Surfaguide-type plasma generator. Accurate choice of them can significantly improve the efficiency of microwave power transfer to the plasma and the stability of operation. We conclude that results presented in this paper seems to be useful from practical point of view in designing microwave plasma sources based on surface waves propagation.

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Authors: *mgr inż. Dariusz Czylkowski, dr inż. Mariusz Jasiński, The Szewalski Institute of Fluid-Flow Machinery, Polish Academy of Sciences, ul. Fiszera 14, 80-952 Gdańsk, E-mail: dczylkowski@imp.gda.pl, mj@imp.gda.pl;*
prof. dr hab. inż. Jerzy Mizeraczyk, The Szewalski Institute of Fluid-Flow Machinery, Polish Academy of Sciences, ul. Fiszera 14, 80-952 Gdańsk and Gdynia Maritime University, Faculty of Marine Electrical Engineering, Morska 81-87, 81-225 Gdynia, E-mail: jmiz@imp.gda.pl.