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Tuning characteristics of coaxial microwave plasma source operated with argon, nitrogen and methane at atmospheric pressure

***Abstract**. The coaxial microwave plasma source (MPS) is a device used to produce high temperature plasma at atmospheric pressure and high working gases flow rates. In our experiment the plasma was generated with 2.45 GHz microwaves at powers between 600 W and 5600 W. At optimal positions of movable plunger, the use of argon, nitrogen and methane as the working gases caused, that 2 %, 1 % and 5 % of the incident power was reflected, respectively. The MPS can be used in gas processing applications.*

***Streszczenie.** Prezentowany współosiowy mikrofalowy generator plazmy jest urządzeniem wytwarzającym plazmę o wysokiej temperaturze pod ciśnieniem atmosferycznym, przy wysokich przepływach gazów. Plazma wzbudzana jest mikrofalami o częstotliwości 2,45 GHz i mocy od 600 W do 5600 W. Odpowiednio dla argonu, azotu oraz metanu przy optymalnym położeniu ruchomego zwarcia moc fali odbitej wynosiła 2%, 1% oraz 5% mocy fali padającej. Generator plazmy może być używany m.in. do obróbki gazów. (**Charakterystyki strojenia współosiowego mikrofalowego generatora plazmy w argonie, azocie i metanie pod ciśnieniem atmosferycznym**).*

Keywords: plasma sources, microwave discharges, tuning characteristics, gas processing.
Słowa kluczowe: generatory plazmy, wyładowania mikrofalowe, charakterystyki strojenia, obróbka gazów.

Introduction

Recently, microwave plasma sources (MPSs) operated at atmospheric pressure have been developed [1-16]. Such devices were used in spectroscopy, technological processes like surface treatment, deposition of thin films and sterilization. They also found applications in the processing of various gases. Treatment of hazardous gases [17-19] and production of hydrogen via methane conversion [20, 21] in microwave atmospheric pressure plasmas were reported lately.

This paper presents results of experimental investigations with the waveguide-based coaxial microwave plasma source (MPS) [13] operated at atmospheric pressure at high gas flow rates. The MPS can be used in gas processing applications.

Microwave plasma source (MPS)

The sketch of the coaxial microwave plasma generator is shown in Fig. 1. The generator was based on a standard WR 430 rectangular waveguide with a section of reduced-height, preceded and followed by tapered sections. The plasma in a form of a flame was generated on the end of a cylindrical electrode which penetrated microwave plasma generator through circular gaps on the axis of the waveguide wide wall and protruded below bottom waveguide wall. The flame was enclosed in a quartz cylinder surrounded by a cylindrical metal shield with a slit for visualization. The inner and outer diameters of the quartz discharge tube were 26 mm and 30 mm, respectively. The working gas was flowing through the internal electrode creating axial gas flow. Nitrogen swirl flow was used as a additional for cooling the quartz tube. The discharge was initiated using the metallic rod entered to the discharge area to increase local electric field. In case of methane the discharge was initiated in nitrogen or argon and then gases were changed.

Experimental setup

The photo of the experimental setup is presented in Fig. 2. The main parts of the experimental setup were: microwave generator (2.45 GHz and maximal power of 6 kW) secured with water insulator, rectangular waveguide (WR 430) as a feeding line, directional coupler equipped with diode sensors and dual channel power meter, coaxial MPS terminated with movable plunger, ensuring the short at the end of microwave line and gas supplying and measuring system.

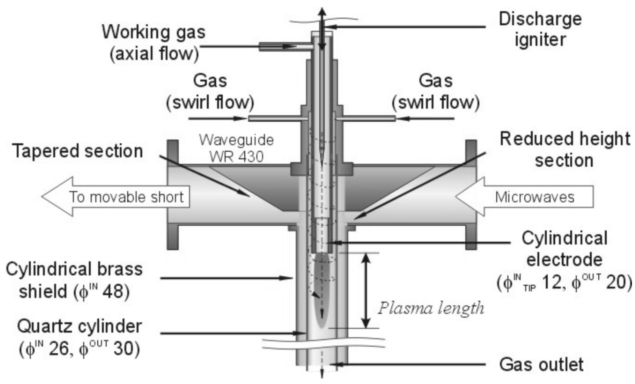

Fig.1. The sketch of coaxial microwave plasma source

The microwave power P_A absorbed by the plasma was determined from (P_I - P_R), where P_I and P_R are the incident and reflected microwave powers, respectively. The tuning characteristics are defined as the dependence of the reflection coefficient P_R / P_I as a function of the distance l between the plasma axis and the movable short. This function is recurrent, with period λ_g / 2, where λ_g is the waveguide wavelength (147.7 mm for WR 430 waveguide).

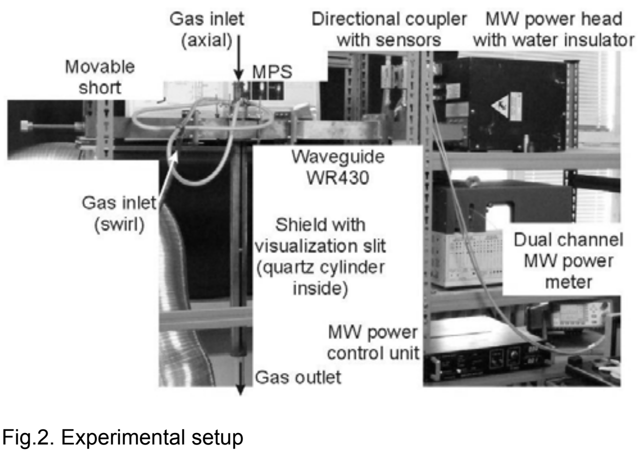

Fig.2. Experimental setup

The working gas flow rates were between 50 l/min and 200 l/min for argon and nitrogen and 88 l/min and 175 l/min for methane. Nitrogen swirl flow rate was 50 l/min. The absorbed microwave power was varied from 600 W up to 5600 W.

Results

Minimal microwave absorbed powers required for sustaining plasmas were about 600 W for argon, 700 W for nitrogen and 1000 W for methane. Fig. 3 shows the photos of nitrogen and methane plasmas.

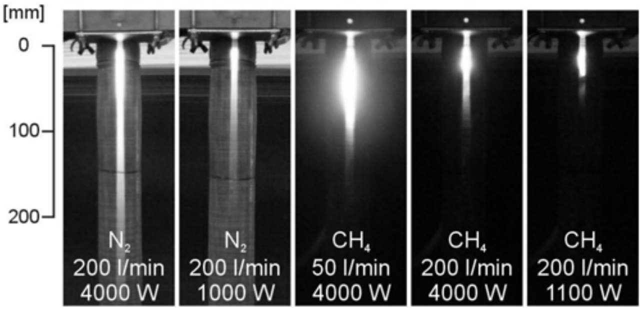

Fig.3. Microwave nitrogen and methane plasmas

The length of the plasmas were 50 - 150 mm, 30 - 130 mm and 20 - 90 mm for argon, nitrogen and methane as the working gas, respectively. As it is seen in Fig. 4 the length of the plasma increased linearly with increasing microwave absorbed power. In case of methane plasma a slope of the increase was dependent on axial methane flow rate. The plasma length decreased with increasing methane flow rate. For argon and nitrogen the differences in the plasma length for axial working gas flow rates 50 and 200 l/min were not significantly.

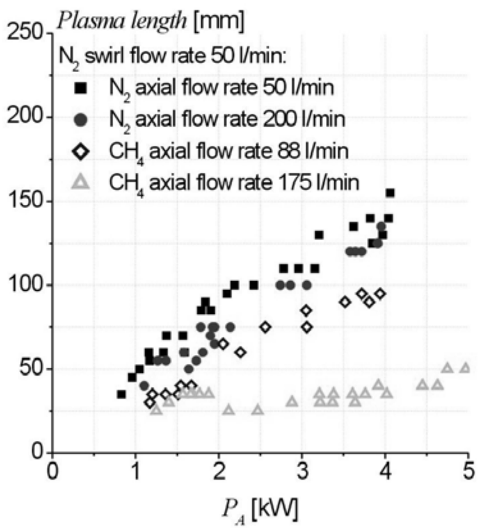

Fig.4. The length of nitrogen and methane plasma (measured from electrode) as a function of microwave absorbed power P_A ($P_A = P_I - P_R$) for different axial flow rates and incident microwave powers

The tuning characteristics is recurrent function, related with the half of the waveguide wavelength λg (147.7 mm for WR 430 waveguide). Thus, it could be normalized and presented as a $l / \lambda g$ function. The period of this function is then 0.5. Fig. 5 presents the normalised tuning characteristics of the coaxial MPS operated in argon, nitrogen and methane for different microwave incident powers and gas flow rates. These characteristics were almost independent on discharge conditions. Obviously, the lower value of the reflection coefficient P_R / P_I indicates higher efficiency transfer of the microwave energy to the plasma. The minimum of the reflected coefficient P_R / P_I were 2%, 1% and 5% for argon, nitrogen and methane as a working gas, respectively. The use of argon as the working gas caused, that the tuning characteristics were the widest. Argon plasma required less microwave power to sustaining. The important fact is that the tuning characteristics for methane were also wide and the position of movable plunger was not critical for sustaining the plasma (see Fig. 5c). It indicates the stable work of the MPS with methane as a working gas.

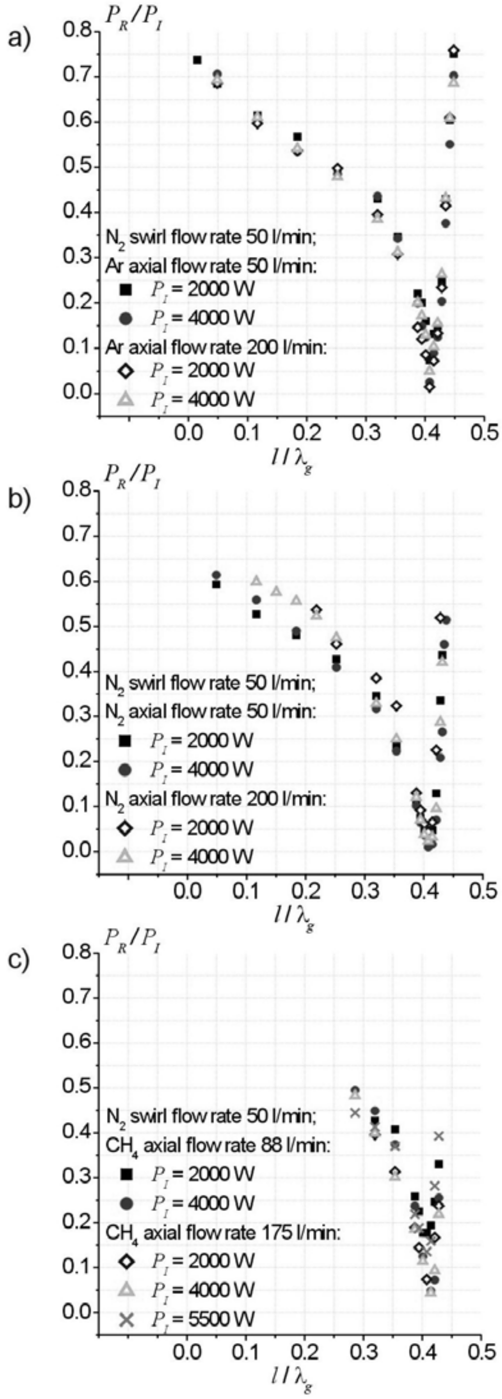

Fig.5. Normalized tuning characteristics of the coaxial microwave plasma generator operated in argon *(a)*, nitrogen *(b)* and methane *(c)*, l – distance between the plasma axis and movable plunger, λ_g – waveguide wavelength (147.7 mm)

The fraction of the incident power reflected at the MPS input as a function of incident power for different gases at fixed position of movable plunger (l/λ_g ~ 0.41 - minimum of tuning characteristics from Fig. 5) is shown in Fig. 6. The coaxial MPS worked very efficiently for entire range of microwave powers and argon and nitrogen as working gases. For methane as a working gas MPS worked efficiently at microwave powers above 3000 W.

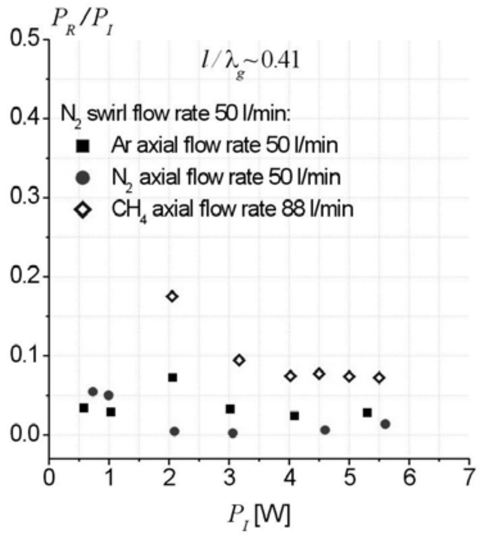

Fig.6. The fraction of the incident power reflected at the MPS input as a function of incident power for different gases at fixed position of movable plunger l/λ_g ~ 0.41

Conclusions

This paper concerns the tuning characteristics of the coaxial MPS operated with argon, nitrogen and methane at atmospheric pressure. Investigations of the tuning characteristics showed that at optimal positions of movable plunger, the use of argon, nitrogen and methane as the working gas caused, that 1-2 %, 1-4 % and 5-18 % of the incident power was reflected, respectively according to the discharge conditions. It could be improved by further optimization.

The investigated coaxial MPS works very stable with various working gases. Stable operation at wide range of parameters, as well as good impedance matching, allows the concluding that MPS can be very attractive tool for different gas processing at high flow rates. The device was successfully used for hydrogen production via methane decomposition [20, 21].

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