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Low Power Microwave Plasma Source at Atmospheric Pressure

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Abstract A compact microwave plasma source operating at low power regime at atmospheric pressure is experimentally investigated. The argon plasma is created in dielectric tube with inner diameter of 1 mm and this tube is an extension of open-ended coaxial structure. Microwave power at frequency 2.45 GHz is coupled into the source applicator at power levels 5-20 W. The plasma source operates as a plasma torch in case of plasma column longer than the dielectric tube length. The source maintains discharges over a wide range of neutral gas flow and works in cw and pulse regimes of the input microwave power. The radio-physical and optical methods are applied for characterization of the plasma source. The dependences of absorbed power, column length and plasma parameters on the gas flow and on the input power level are discussed. Advantages of this source are self ignition at threshold power level, effectiveness and stable matching at the conditions of the experiment.

Introduction. The surface wave (sw) discharges at atmospheric pressure [1- 4] produce high density non-thermal plasma but high microwave power is usually applied. In this study we present a small plasma source which produces plasma at atmospheric pressure at low power levels by means of surface wave discharge in a ceramic tube with high permittivity. The high thermal conductivity and high working temperature of the discharge ceramic tube allow permanent work of the source cooled by air and ensure stable plasma parameters independent on the ambient conditions for a long period.

2. Experimental set-up. Microwave signal at frequency f = 2.45 GHz from generator through the double directional coupler Narda-3022 and triple stub is fed to the source (Fig. 1). Our source is resonant structure of Stonies *et al* (2004) type [5], which is built only by pieces of coaxial lines. The dielectric of the exciter of the surface waves is a ceramic tube with inner diameter of D= 1mm and outer of 2 mm of alumina ceramic with dielectric constant ε_d = 9.3, which is also used as a discharge tube. This material reduces significantly the exciter dimensions l_1 to the length of 10 mm ($l_1 \sim \lambda_0/4\sqrt{\varepsilon_d}$, λ_0 – wave length in the free space).

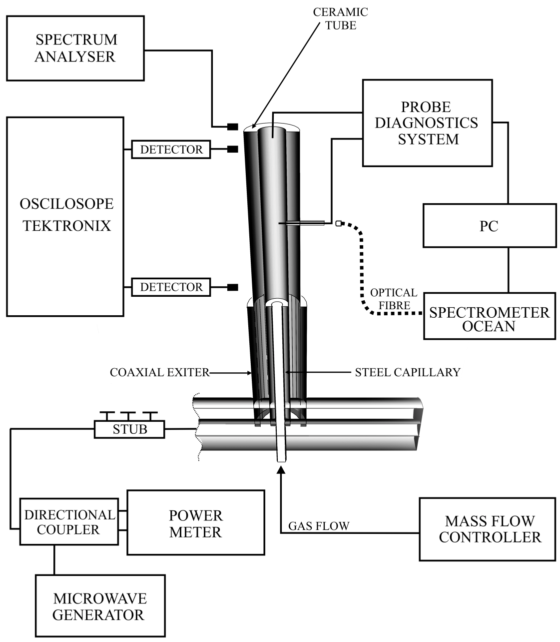

Figure 1. Experimental set-up.

The initial precise tuning of the source at frequency 2.45 GHz and by the triple stub leads to good matching over a wide range of neutral gas flow and microwave power. After this procedure the plasma source is self-ignited at sw and pulse regimes at specific threshold value of the input power. The radial component of the electric field of surface waves is registered by two radial microwave probes positioned outside the tube. Received signals from the probes at pulse regime of the source operation after quadratic detection are recorded with oscilloscope Tektronix TDS 360. The argon gas and argon-helium (50:50) gas mixture are used in the experiments. Electron temperature of $T_e \sim 1.9$ eV and density of $n_e \sim 3.9\times10^{14}$ cm^{-3} are estimated from asymmetric double probe characteristics. The first probe is tungsten cylindrical wire with length of 0.6 mm and radius of 0.1 mm positioned perpendicular to the column through the small hole (~0.5 mm) in the tube wall. The second probe is steel capillary with length of 3 mm and radius of 0.5 mm positioned inside the discharge tube at its top. Optical emission spectroscopy observation of argon discharge in continuous and pulse regimes of the source are realized by HR Ocean Optics Spectrometer. The light from the plasma column is collected by lens system (through the same small hole) coupled to optical fibre, which is connected to the spectrometer.

3. Results and discussion

Measurements of the length L of the plasma column with increase of the forward power value for neutral gas flow in the range 100-250 sccm are presented in Figure 2 for discharge tube length l_2 =11 mm and argon gas. Results show that the applied microwave power is responsible for the produced plasma volume while the gas flow has a minor contribution to the column length. Such behavior of the plasma column length is observed in sw discharges [1- 4] for low gas flow velocity. The propagation of sw is proved by antenna measurements of propagation and shape evolution of microwave pulses along the plasma column. The pulse microwave signal with period 50 ms and duration 5 ms from the generator is applied to the source.

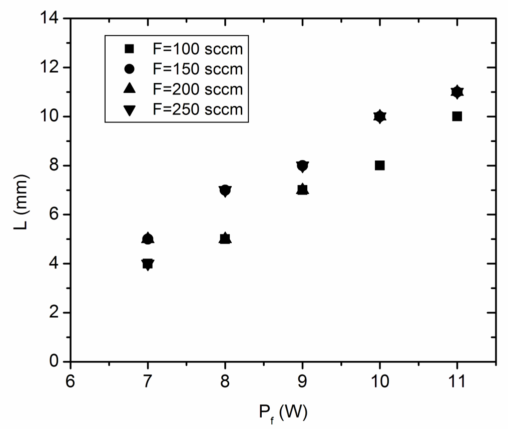

Figure 2. Dependences of the column length on the forward power and neutral gas flow.

If the power is insufficient for igniting of the discharge the signal from probe 1 has rectangular shape while probe 2 receives very small signal (figure 3). Without plasma column surface waves are not observed along the tube. After the ignition of the discharge (with length equal to the tube length) the signals received

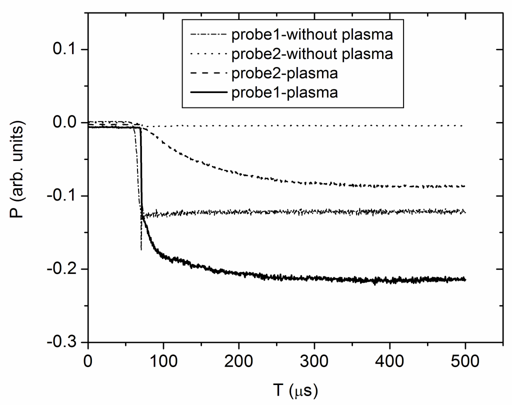

Figure 3. Evolution of the pulse shape along the discharge tube.

by both probes are higher than before especially the signal from probe 2 which manifests the sw propagation. The forward and reflected power is measured in cw regime (Fig. 4). This small source reaches high efficiency ($\eta = \frac{P_A}{P_f} \approx 0.93, P_A$ - absorbed power) at forward powers P_f < 10 W for F≥150 sccm.

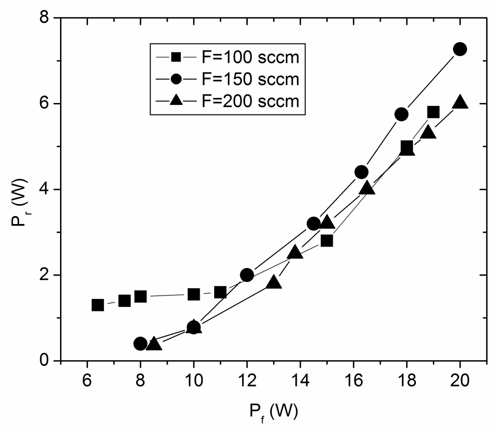

Figure 4. Reflected and forward power for three values of gas flow.

At higher values of P_f the plasma column is longer that the tube and the plasma jet (figure 5) is observed in cw and pulse regimes but the reflected power increased.

Argon spectra are recorded over wavelength range (200÷1000) nm at different experimental conditions, explored in the study. The spectra are clearly dominated by atomic argon lines in the red/near-infrared (690 ─ 900) nm region, due to the contribution of the radiative transitions

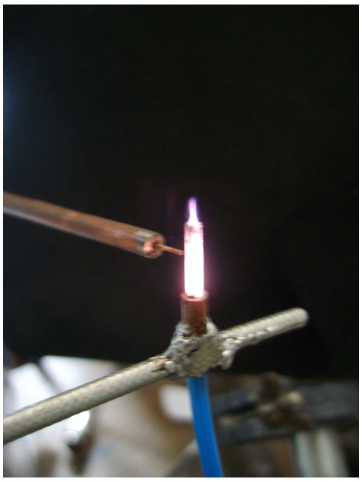

Figure 5. Plasma jet above the tube at power $P_f \geq 11$ W.

between the excited levels of the *3p*^{5}*4s* and *3p*^{5}*4p* configurations. There is a contribution of the highly excited argon states *5p* to *4s* and *5d, 6d, 7d* to *4p* in the violet (400 – 430) nm and (518 – 603) nm regions respectively, as well as argon ions lines recognized in the pulse regime spectra, detected from the side hole, but did not find in the spectra of the plasma jet. In the continuous regime of the discharge, the ultraviolet molecular NO and N_2 bands from 200 nm to 400 nm prevail in the spectra (figures.6(a) and (b)).

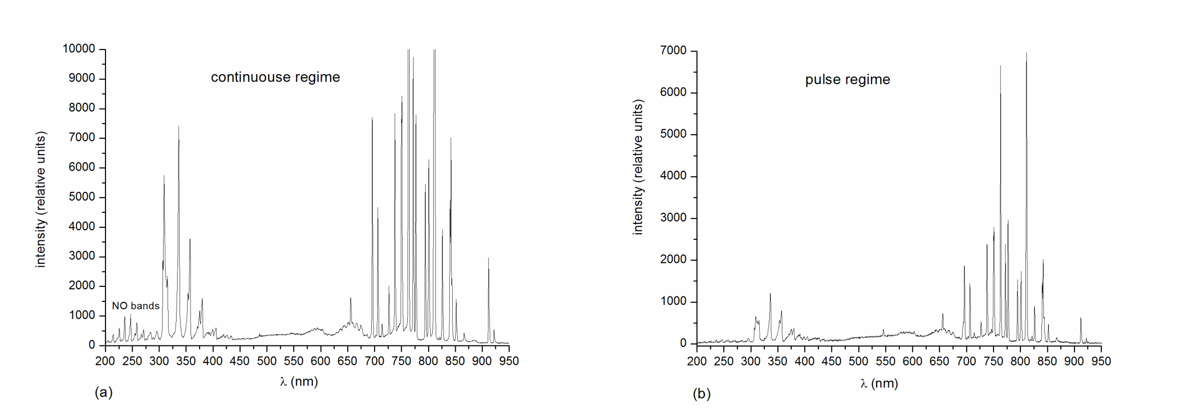

Figure 6. Spectra of argon plasma from side hole in (a) continuous regime and (b) pulse regime at P_f = 20 W and gas flow F=100 sccm.

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