Plasma Structures in Electrode Microwave Discharge at Reduced Pressures in Molecular Gases

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1. Microwave electrode discharges are the discharges produced in the vicinity of powered electrode (antenna/exciter) when characteristic dimension of plasma region is much less than dimensions of the discharge vessel. This is the fundamental difference from conventional discharges where the plasma volume is controlled by the discharge vessel. This discharge property defines peculiarity both the electrodynamics of the discharge and plasma parameters and leads to generation of plasma structures.

First results on studying of such a discharge were published in 1997 [1]. During last years a lot of experimental results were obtained [2-12] but the physical processes occurred in the discharge are still far from a complete understanding. Some results of plasma chemical applications for diamond growth and CNx-coatings deposition are presented in [1, 4].

One of important features of these discharges is the absence of electrode erosion in contrast to the electrode discharges at lower frequencies [1].

2. Detail description of experimental set-up is presented in [1,2]. Plasma gases were Ar, Ne, H2, N2, O2, CH4, C2H2, air, and their mixtures at pressures 0.5-400 Torr. Gas flow systems were used with total gas flow rate <1000 sccm. A tubular and solid stainless steel and copper electrodes of different shapes (direct and bent cylinder, trident, spiral, etc.) with diameters of 0.5-6 mm have been used as the antennas. Microwave power (2.45 GHz) was transmitted from the magnetron generators with output powers up to 200 W.

3. Degree of H2 dissociation (<1%) was defined by actinometry method [8]. Gas temperature of H2 plasma was defined through the relative intensities of Q-branch emission for diagonal (ν'=ν''=0,1,2) bands of Fulcher α-system H2(d2Πu→a3Σg). The temperature has the flat radial distribution and does not exceed 800 K at pressures below 10 Torr [12]. Some results on parameters of electron component of plasma and distributions of DC voltage in the discharge were obtained by double electric probe measurements [1,2,6,7].

4. Electrode microwave discharge appears near the antenna and has non-uniform structure: the exciter is surrounded by the bright narrow plasma sheath which is covered by less
emissive plasma region with sharp external boundary. The latter is ball-shaped in molecular containing gases when the diameter of exciter is less than the plasma dimensions.

**Figure 1.** Discharge photos. 

*a* – H$_2$; *b* – N$_2$; different $W_{\text{INC}}$, 1 Torr, 6 mm-tube electrode. 

*c* – H$_2$, different expositions, 300 Torr, needle electrode, $W_{\text{INC}}$ ($W_{\text{ABS}}$) = 200 (6) W.

Dark space characterized by exponential spatial decay of the electron density surrounds the luminous plasma.

5. Quasi-static modeling showed the partial qualitative agreement with results of experiments (increase of plasma diameter with power, slight change of electron density) only in the presence of plasma resonance (collision frequency less than mw one) [10].

6. Double probe measurements in the dark space near the plasma ball in H$_2$ showed the exponential decay of electron temperature with increasing the distance from the plasma region [2]. This result was explained by the presence of surface wave in the vicinity of the plasma ball. The same shape of electric field distribution was obtained in modeling at angle of 90° (fig. 2). This direction is the same as it was in the experiments.

So, the field distribution outside the plasma ball corresponds to the structure of surface wave. Due to a finite size of the plasma ball this structure is distorted both at larger and smaller angles.

**Figure 2.** Radial distribution of time-averaged electric field along different polar angles in r-z plane, counted anti-clockwise from the center of a plasma ball. Calculation. 0.5 Torr, $r_{\text{ball}}$=1 cm, $n_e=4n_{\text{cr}}$

7. Method of relative intensities of line emission was modified to the conditions of electrode microwave discharge to measure the electron density and electric field strength profiles. Light emission of H$_{\alpha}$, H$_{\beta}$ and Ar lines were used. Homogeneous Boltzmann equation was used to define excitation coefficients under the direct electron impact [11] (see fig. 3).
8. Results of self-consistent modeling of self-sustained near-electrode microwave plasma, namely the spatial distributions of specific absorbed power (fig. 4, 5) are in good agreement with observed distributions of plasma emission (fig. 1, 6).

Figure 3. Radial distributions of electric field strength and plasma density. Axis Z is directed to generator (see fig.2), at the tip of the electrode z=0. H$_2$+5%Ar, tube electrode diameter 6 mm, 1 Torr, incident power 80 W.

$a,b$ – $z= 0.6$ mm; $c,d$ – $z=-1.6$ mm; $i, j$ – $z=-9.4$ mm


Sharp decrease of plasma density and DC potential observed at the discharge boundary can be explained by the presence of a double electric layer.

Figure 4. Spatial distribution of specific absorbed power in electrode microwave plasma in H$_2$. Calculations. 1 Torr, total incident (absorbed) power 30 (18) W
Figure 5. Radial distributions of specific absorbed power in electrode microwave discharge. Calculations. \( \text{H}_2 \), incident (absorbed) power 30 (18) W, 1 Torr. Distances \( z \) from the tip of the electrode: 1 – \( z = -0.3 \) mm; 2 – \( z = -0.6 \) mm; 3 – \( z = -1.8 \) mm

Figure 6. Radial distributions of excited H-atoms in n=4 state (from \( \text{H}_\beta \) 486.1 nm emission). Experiment. Incident (absorbed) power 80 (11) W, electrode diameter 6 mm, \( z = -1.6 \) mm

References

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