

Probe measurements of magnetron discharge parameters

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Abstract. Langmuir probe measurements have been carried out in a positive column discharge of a planar magnetron with a titanium target. In this work concentration and temperature of electrons is measured in positive column of magnetron discharge with Langmuir probe. Concentration of electrons is found to be on the level of 10^{16} m^{-3} at a notable distance (over 200 mm). Two groups of electrons exist: «cold» and «hot» with average temperature of 16 000 and 41 000 K respectively. Dependence of discharge parameters on working gas pressure is measured.

1. Introduction

Probing method of measuring of plasma parameters has been used for almost hundred years. It is applied in investigations of different parameters of gas discharges. The method is known to be a reliable instrument for measuring local temperature and concentration of charged particles and plasma electric potential [1–6]. In this work concentration and temperature of electrons is measured, in positive column of magnetron discharge, by a single probe.

2. Experimental details

Dependence of the parameters on gas pressure and current density is investigated. The experiments were performed using an oil-diffusion pumped vacuum chamber with a diameter of 550 mm and a height of 500 mm. A schematic of the experimental chamber is shown in figure 1.

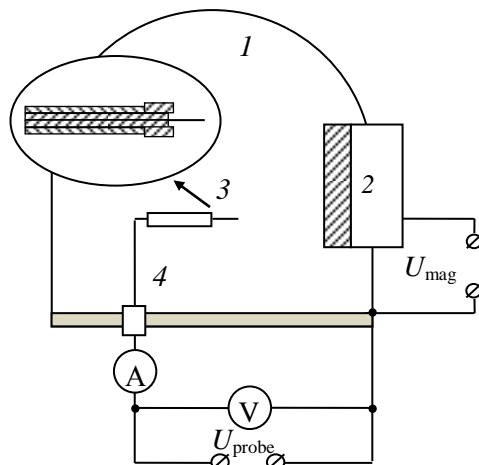


Figure 1. Schematic picture of discharge investigation by probing method: 1 – vacuum chamber (anode); 2 – magnetron; 3 – Langmuir probe; 4 – vacuum entrance.

The chamber was evacuated prior to the measurements to a base pressure of 0.02 mTorr. Target is made of titanium (purity 99.99 %) and working gas is argon (purity 99.998 %). Argon gas was introduced through a leak valve so that the desired pressure of the sputtering gas was achieved. A 160 mm diameter Ti target was mounted on the magnetron cathode. The probe material is molybdenum wire 0.5 mm diameter and 4 mm length.

The probe (cylindrical electrode) was situated horizontally against the target's erosion area. Measurements were conducted at distances, where magnetic field's influence is negligible, and conditions are similar to plasma (positive column). This was confirmed by I - V measurements of the probe at distances of 200, 250 and 300 mm. Obtained results are different not more than by 10 %. That confirms homogenous distribution of positive column's parameters. To eliminate error, connected to polluting of collector with titanium, a removable head of the probe was periodically replaced.

3. Result and discussion

Figure 2(a) shows current-voltage curves of a single probe. Voltage was swept in the range of $-50 \dots +50$ V. Current in the circuit is provided by negatively charged particles – electrons, if the probe potential is positive. Negative potential on the probe leads to ionic current, which is significantly less than electronic. Relatively high positive probe potential (over +40 V) leads to an intensive heating of the probe (its color changed to orange-red).

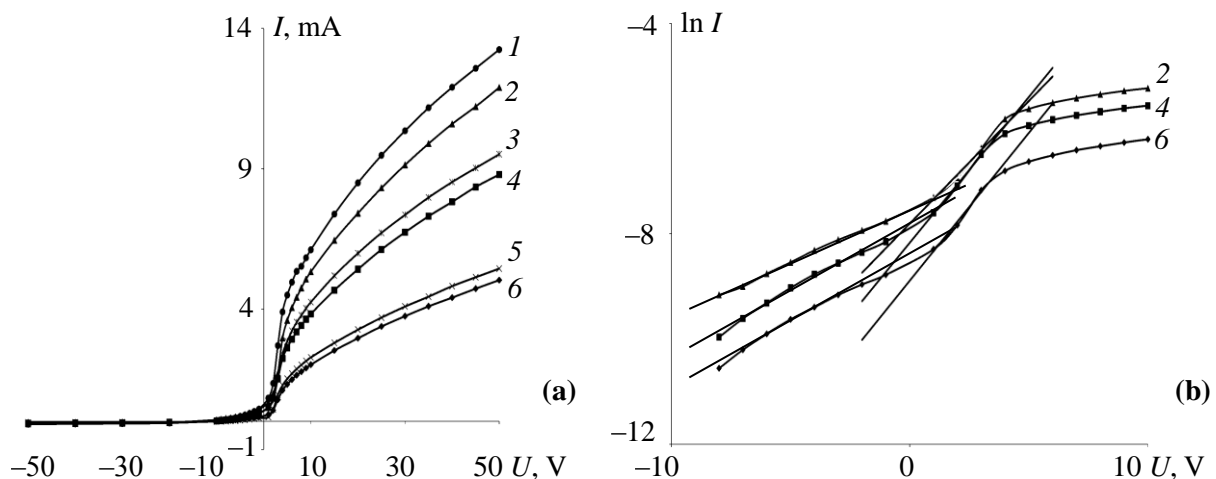


Figure 2. I - V characteristics of a single probe (a) at current density (A/m^2): 1, 2 – 640; 3, 4 – 430; 5, 6 – 220 and Ar pressure (mTorr): 1, 3, 5 – 6; 2, 4, 6 – 3; (b) logarithmic I - V characteristics of single probe in Ar pressure of 3 mTorr.

To calculate electron temperature and concentration, a classical probing method theory (Langmuir 1923) was used [1–6]. Two specific areas are observable in logarithmic current-voltage characteristics (figure 2(b)). This is peculiar to the occasion, when there are two groups of electrons (with different average temperatures) in the medium. Such electrons are called «hot» or «cold» in the literature [2, 4, 6]. Concentration and temperature were calculated for these groups of electrons. Figure 3 shows dependencies of concentration and temperature of «hot» and «cold» electrons on discharge current density for two different gas pressures.

Experimental data processing has shown two groups of electrons («hot» and «cold») in positive column of magnetron's discharge. Temperature of «cold» electrons (argon pressure 3 mTorr) raises from 16 500 to 20 200 K with current density increasing from 200 to 600 A/m^2 . Their concentration is increases from $8.8 \cdot 10^{15}$ to $2.2 \cdot 10^{16} \text{ m}^{-3}$. Temperature of «hot» electrons with same current density increasing (argon pressure 3 mTorr) raises from 42 000 K to 47 700 K and concentration raises from $5.5 \cdot 10^{15}$ to $1.4 \cdot 10^{16} \text{ m}^{-3}$.

As a result, two groups of electrons in positive column of magnetron's discharge were shown. Concentration of «cold» electrons is ~ 1.6 times higher in average than concentration of «hot» ones

and their temperature is lower ~ 2.5 times. Amount of ionized gas atoms increases with the increase of discharge current density. That explains the increase of electron concentration inside the investigated medium. This can be clearly seen in presented figures. Increase of working gas pressure entails increase of electron concentration and decrease of their average temperature. This is applied to both «hot» and «cold» electrons.

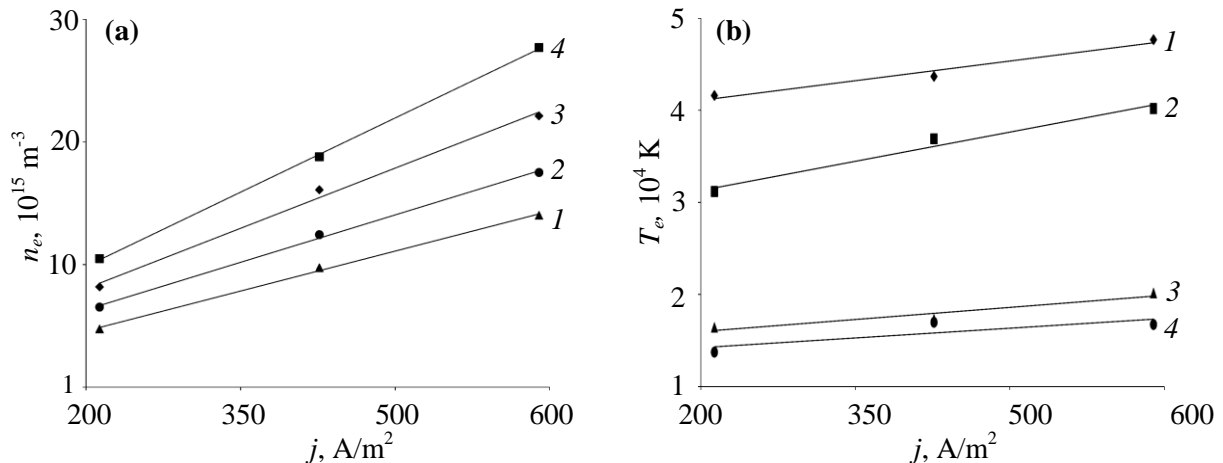


Figure 3. Dependence of concentration (a) and temperature (b) of «hot» (1, 2) and «cold» (3, 4) electrons on current density of magnetron discharge with different Ar pressure (3 mTorr (1, 3) and 6 mTorr (2, 4)).

4. Conclusions

In this preliminary study a Langmuir probe has been used to measure of the positive column parameters (T_e , n_e) in a DC magnetron discharge. Results show a number of interesting features, which warrant further investigation. Langmuir probe measurements have been performed in a planar magnetron system. The electron density, electron temperature, of «cold» and «hot» groups of electrons has been determined in various argon pressures in the range from 3 to 6 mTorr and current density in the range from 200 to 600 A/m².

The work makes it possible to determine an electron energy distribution function in the discharge. That can be used to develop a theoretical model of a gas discharge. It is possible to compare results, obtained with usual magnetron sputtering mode, to results, obtained with «hot target» sputtering mode and high-power pulsed sputtering.

Acknowledgments

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