LANGMUIR PROBE MEASUREMENTS OF PLASMA PARAMETERS IN A PLANAR MAGNETRON WITH ADDITIONAL PLASMA CONFINEMENT

Petr Špatenka[a], Igor Leipner[b], Jaroslav Vlček[b], Jindřich Musil[b]

a) University of South Bohemia, Faculty of Biological Sciences, Branišovská 10, 370 05 České Budějovice, Czech Republic
b) University of West Bohemia, Faculty of Applied Sciences, Americká 42, 306 14 Plzeň, Czech Republic

The paper deals with the Langmuir probe measurements in a planar magnetron sputtering system in which the plasma confinement near a target can be improved by means of an assembly of permanent magnets placed above the target. This configuration makes possible a desirable low pressure operation of the magnetron. The electron density, electron temperature, plasma potential and the electron distribution function are measured in various position between the target and a substrate under various conditions in the discharge.

Introduction

Magnetron sputtering is a very efficient method convenient for a high rate of deposition of thin films. In spite of the fact that it is now already currently used for industrial fabrication of many different metallic, dielectric and compound films, the magnetron is still improved. A new type of planar magnetron with additional magnetic confinement has been developed which can be operated at argon pressures under 10^{-1} Pa [1]. The aim of

this paper is to investigate the plasma parameters using the Langmuir probe in various positions between the target and substrate and to compare them with a conventional magnetron.

Experimental

The magnetron was a standard conventional magnetron (CM) with a round Ti target of 60 mm diameter and an electromagned placed under the target plate. The plasma confinement above the target was ensured using a system of 8 permanent magnets (PM) located on a diameter of 87 mm at the distance of 20 mm above the target. All the magnets were of the same polarity with internal poles opposite to the polarity of the periphery poles of the CM magnet. The discharge current and the electromagnetic coil current were kept constant at 0.75 A and 2 A, respectively.

The probe characteristics were recorded by a computer controlled data acquisition system described in Ref. [2]. The sampling of a complete characteristic took less then 1 second. A tungsten probe of 0.05 mm diameter and 7 mm length was used. The probe characteristics were evaluated by a computer program. The characteristics were smoothed by digital filters and twice differentiated. The plasma potential and electron temperature were determined from the zero point and the slope of the semilogarithmic plot of the second derivative of the probe current, respectively. The electron density was calculated from the slope of the electron saturation current assuming the orbit motion limit (OML) regime and the ion density according to the Laframboise theory from the ion current.

Results and discussion

Probe characteristics and their second derivatives were measured in several positions above the magnetron at the argon pressures of 0.4 and 5 Pa (see Fig. 1).

In the plasma generated at the pressure of 0.4 Pa the electron distribution function (EDF) in axial region close to the target was Maxwellian with the electron temperature of 6.8 eV. In higher

Fig. 1: The probe characteristics and their second derivatives at the pressure 0.4 Pa

distances above the target a structured EDF was developed. In these cases the EDF can be represented axa distribution with two Maxwellian groups of electrons. The temperature T_1 of the low-energy group decreased from 2.5 eV at 30 mm above the target to 1.1 eV at 80 mm, whereas the corresponding value of T_2 for the high-energy group changed from 5.9 eV to 5.2 eV.

At the pressure of 5 Pa the Maxwellian distribution was found even at larger distances from the target (see Fig. 2). The value of the electron temperatures varied within the limits of 1.8 eV and 2.6 eV. The two-group distribution was found only at the distance of 80 mm from
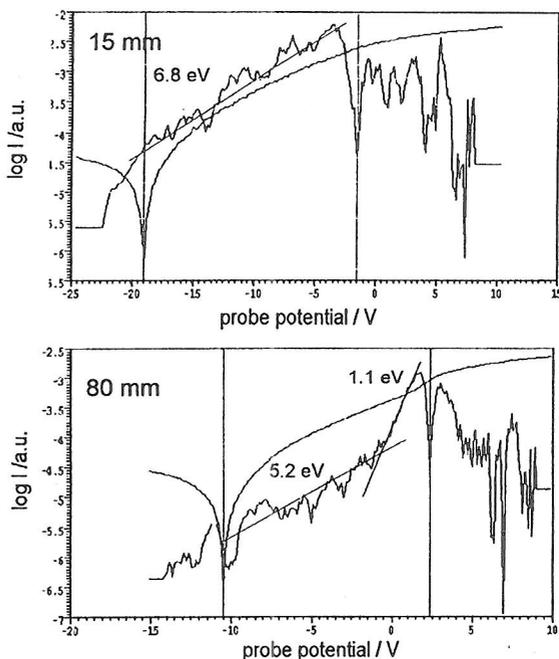
489

the target, but the low-energy group was much less pronounced than in the plasma generated at 0.4 Pa. This may be explained by the effect of electron-electron collisions which equalize the temperatures of the two electron groups and the importance of which grows with higher electron density at 5 Pa.

The electron density profiles are shown in Fig. 2 and 3 for both values of pressure. As

Fig. 2: The probe characteristics and their second derivatives at the pressure 5 Pa

expected the electron density decreases with higher distance from the target. The maxima of the electron density in the 15 mm distance above the target correspond to the erosion zone. The electron density profile becomes flat with higher distance from the target. A small maximum in the center of the magnetron was formed as a result of zero magnetic field in the center of the cylinder with the permanent magnets.

A configuration without the additional permanent magnets was also investigated to found the differences both systems. Our experiments proved that the additional confinement leads to approximately two-times higher electron density and strong enhancement in the electron temperature, especially far from the target. For example,
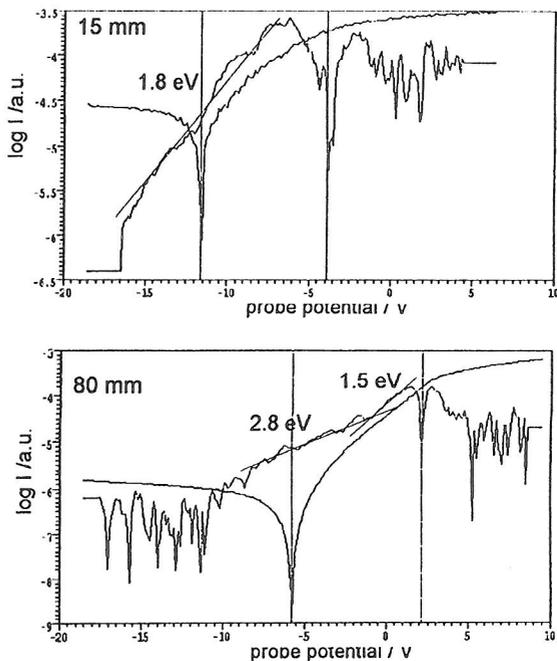
at the position of 80 mm above the target the Maxwellian distribution with low electron temperature (below 1 eV) was found in the classical magnetron.

In order to estimate the extent of the magnetic field influence on the probe data as derived, we calculated the lower bound of the Larmor radius r_L in our experimental conditions. The strongest magnetic field for the lowest probe position at 15 mm above the target was in the center of the magnetron. The measured value of the magnetic field B was 250 G and the lowest electron temperature obtained in this position was 1.8 eV. The corresponding Larmor radius r_L was 100 μm. Because the probe radius r_P was 25 μm, the lower limit of
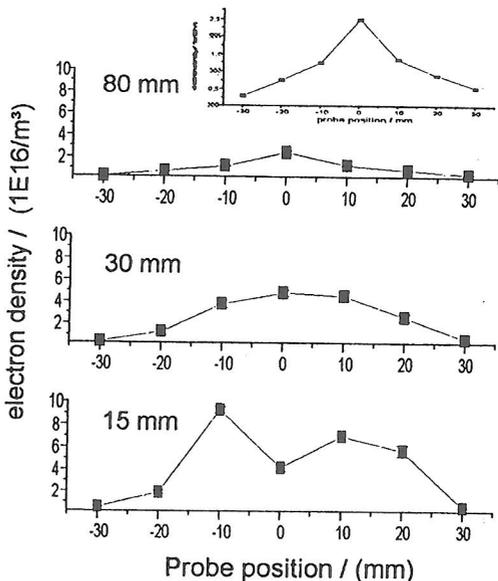

Fig. 3: The electron density profiles
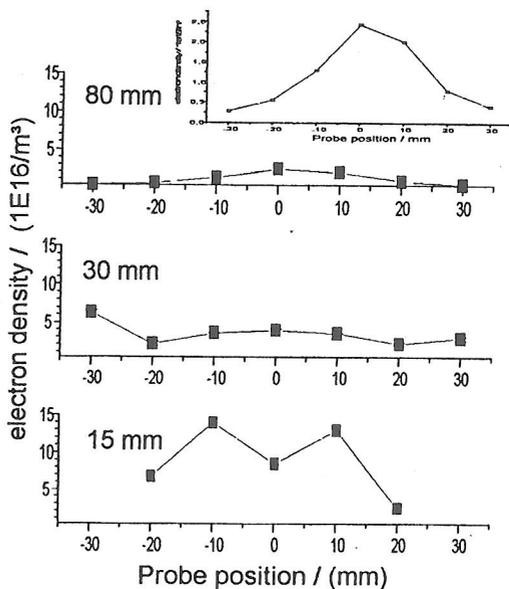at the pressure of 0.4 Pa

Fig. 3: The electron density profiles
at the pressure of 5 Pa

491

ratio $\beta = r_p/r_L$ was 0.25. Owing to the fact, that the probe was almost perpendicular to the magnetic field lines, the influence of the magnetic field could be neglected in accordance with Ref.[4]. Above the erosion zone the probe was almost parallel to the magnetic lines, but the magnetic field was approximately one half of the magnetic field above the center of the target and thus $\beta \approx 0.1$. According to Rubinstein and Laframboise [4] the electron saturation current is unaffected if the normalized potential is higher than 2. This was taken into account in the determination of the electron density.

References:

[1]   J. Musil, K. Rusňák, V. Ježek and J. Vlček: Vacuum 46 (1995) 341

[2]   P.Špatenka, R.Studený and H.Suhr: Meas.Sci.Technol. 3 (1992) 704

[3]   N. Herskowitz: How Langmuir Probes Work. *in* Plasma Diagnostic, Vol. 1 (O. Auciello and D.L. Flamm eds.), Academic Press 1989

[4]   J. Rubinstein and J. G. Laframboise: Phys. Fluids 21 (1978) 1655