The effect of the thin film at the electrodes on the sheath size and ion flux in an argon plasma afterglow

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The effect of the thin film deposition on the sheath size and ion flux to the electrodes was studied theoretically for an argon plasma afterglow. The input parameters for the model are the experimental values of discharge parameters in an argon pulsed plasma. It was found that the sheath size increases more slowly and the average ion flux to an electrode becomes larger with growing film thickness. The dependence of the calculated ion flux on the film deposition time is in a good qualitative agreement with the dependence obtained in experiment.

It has been experimentally observed that the thin film deposition influences the discharge properties in radio frequency reactive plasmas, like electron density, electrode self-bias voltage or Ar* metastable density [1]. To improve the understanding of the processes in the plasma afterglow, the theoretical study was carried out by using experimental results of time dependent electron density, electrode self-bias, electron temperature T_e and plasma potential V_p as input parameters. The experimental data were obtained for a 13.56 MHz low-pressure capacitively-coupled argon discharge, as explained in [2]. The signal from the RF generator was square-wave modulated and was pulsed with frequency 100 Hz and 50% duty cycle. The RF input power was 20 W and the argon gas pressure was kept constant at 0.1 mbar. A hydrocarbon film on the electrodes was deposited by adding ~5% of acetylene in chamber for different time intervals. The growth rate of the film was estimated to be about 1.5 nm/min, which was separately measured by optical ellipsometry. The ion flux was measured by measuring change of electrode self-bias voltage and its decay time in the plasma afterglow, similar to the RF biased planar electrostatic probe [3].

The sheath size *s* as a function of time *t* near the electrode in the plasma afterglow was calculated using equation (16.4.2) of Ref. [3]:

$$n_s\left(\frac{ds}{dt}+u_s\right)=\Gamma_i \tag{1}$$

where n_s and u_s are the ion density and velocity at the sheath edge. $\Gamma_i=\varepsilon_0\left(\frac{4\pi e\lambda_i}{m_i}\right)^{1/2}\frac{V^{3/2}(t)}{es^{5/2}(t)}$ is the ion flux density to the electrode, ε_0 is the permittivity of free space, *e* is the electron charge, λ_i and m_i are the ion mean-free path and mass, respectively. *V(t)* is the absolute magnitude of the electrode voltage relatively to the bulk plasma. In the experiment, we measured the electrode voltage relatively to the ground V_f(t). It was found [1] that the time-dependence of the measured voltage may be presented in the following form:

$$V_f(t)=V_{f0}+\Delta V_f(1-\exp(-t/\tau_V)), \tag{2}$$

where V_{f0} is a steady-state dc-bias voltage at the end of the power-on phase, ΔV_f is the change of voltage during the afterglow and τ_V is the decay time of the voltage in the plasma afterglow.

The plasma potential V_{p0} and electron temperature T_{e0} in the power-on phase were measured by Langmuir probe. The electron temperature dependence in the afterglow is taken in the form $T_e(t)=T_{e0}\exp(-t/\tau_T)$, where $\tau_T = 50$ µs is characteristic decay time. In the calculations it was assumed that in the afterglow phase the plasma voltage decay time is the same as electron temperature decay time. In the late afterglow, the electron temperature is taken to be 0.1 eV. The absolute magnitude of the electrode voltage relatively to the bulk plasma in the afterglow was taken in the following form: $V(t)=-V_f(t)+V_{p0}\exp(-t/\tau_T)$.

Using (1) and experimental dependences for the electron density $n_e(t)$ and voltage $V_f(t)$, the sheath size as a function of time was obtained for different thicknesses of the film on the electrodes. In Fig. 1, the dependence *s* (*t*) is shown for 3 film deposition times: 0, 10 and 30 min.

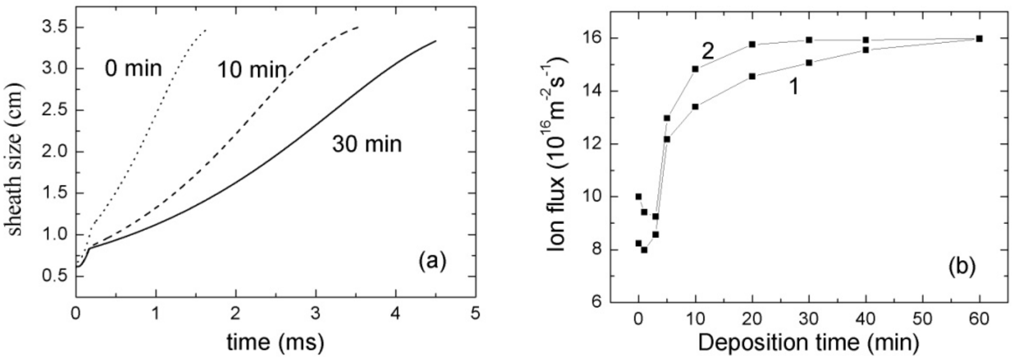

Fig. 1. (a): The sheath size as a function of time for different times of film deposition. (b) The average ion flux obtained using (4) and experimental results (curve 1) and that calculated using (1).

One can see from Fig.1(a) that the sheath size increases more slowly with time with the growing film thickness. With the growing film thickness the electron density decay time in the plasma afterglow increases [1] and sheath size develops less rapidly. The Ar* metastable density in the afterglow behaves the same as electron density [2] suggesting that with the film thickness increasing the density of impurities decreases. It seams that both metastable and electron losses in the afterglow are strongly related to the presence of impurities. The main sources of impurities are the chamber walls and electrodes. After 5 min of film deposition the electrode surfaces are covered with one monolayer of the thin film and the experimental conditions change, which is indicated in the Fig. 1 (b) by the increase of ion flux to the electrode.

Using the calculated dependence $s(t)$, the time-dependence of the ion flux density $\Gamma_i(t)$ was obtained also. For the experimental conditions considered $ds/dt << u_s$, the dependence of $\Gamma_i(t)$ in the late afterglow is similar to the n_s dependence.

The voltage of the electrode V_f changes in the plasma afterglow according to: $\frac{dV_f(t)}{dt} = eA(\Gamma_i - \Gamma_e)/C,$ where Γ_e is the electron flux and A is electrode area. If the electrode has a large negative potential relatively to the plasma bulk, the electron flux is negligible, and

$$dV_f(t) = (eA\Gamma_i / C)dt\ . \tag{3}$$

Integrating (3) in the time interval $[\tau_T, \tau_V]$, we will get the average ion flux for the time interval:

$$<\Gamma_i> = \int_{\tau_T}^{\tau_V} \Gamma_i dt / (\tau_V - \tau_T) = \frac{C\Delta V_f (\exp(-\tau_T/\tau_V) - \exp(-1))}{eA(\tau_V - \tau_T)}. \tag{4}$$

Note that for our experimental conditions $\tau_V >> \tau_T$, and the average ion flux may be found from the experiment measuring ΔV_f and τ_V. Using the measured parameters, from (4) we calculated the average ion flux as a function of the film deposition time (curve 1 in Fig. 1 (b)) and compared with the dependence obtained from (1). The dependence calculated using (1) is presented by the curve 2 in Fig. 1 (b). The dependences are in a good qualitative agreement.

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