AXIAL STRUCTURE OF DC GLOW DISCHARGE NEGATIVE GLOW IN NITROGEN

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We registered axial profiles of electron temperature, plasma potential and concentration of the direct current glow discharge in nitrogen at different gas pressure and discharge current values. We observed that in a broad range of experimental conditions the plasma concentration experiences 15…16 times decrease along the negative glow length. Maximum values of plasma concentration and electron temperature are registered at the cathode end of the negative glow, and the electric field strength is small. On leaving the cathode the plasma concentration and electron temperature in the negative glow are decreasing, here a region with a negative field may also form.

PACS: 52.80.Hc

INTRODUCTION

Direct current glow discharge is widely applied in pumping gas lasers, for nitriding surfaces of various materials, tools, plasma sterilization etc. Broad application of the glow discharge in technologies requires deeper understanding of physical processes taking place in the discharge. Therefore recently there appeared a large number of papers devoted to studying the direct current glow discharge [1-4]. However, though the dc glow discharge seems to be studied quite well, there are a number of questions needing additional research. Therefore studies of glow discharge (as a whole and of some particular parts of it) are of great interest. This report employs a single Langmuir probe to register axial profiles of plasma parameters in a negative glow of dc glow discharge in nitrogen.

1. EXPERIMENTAL

Fig. 1 depicts the experimental device setup we employed. We performed our studies in nitrogen within the pressure range of p=0.05–0.5 Torr. The flat cathode and anode were spaced L=245 mm apart. The inner diameter of the cylindrical discharge glass tube was 56 mm.

We registered plasma parameter profiles with a single nichrome Langmuir probe 1.5 mm long and 0.18 mm in diameter. A generator fed a sawtooth potential to the probe. This potential was reduced with a resistive divider (containing resistors R_{d1} and R_{d2}) and then it was fed to 24-digit analog-to-digital converter (ADC). The probe current under measurement was reduced with a shunt (resistor R_{sh}) and was also sent to ADC. The ADC signal ran through a galvanic isolation device and reached a computer through the RS-232 interface.

We employed the following technique for the determination of plasma parameters. First, we found the second derivative of the probe current over the probe voltage and assumed as the plasma potential the voltage value at which this derivative runs through a zero. The ion branch I_i of the probe CVC is usually described with a power dependence [5] $I_i=a\cdot(\varphi_{pl}-U_{pr})^b$. Then we chose constants a and b in this approximation formula. After that we subtracted the ion current I_i from the registered probe current I_{pr} to determine the electron current to the probe $I_e=I_{pr}-I_i$. The dependence of the electron current logarithm $\ln(I_e)$ on the probe potential U_{pr} within the range between the floating and plasma potentials possesses a linear section (under the condition that cold electrons have a maxwellian distribution with the temperature T_e). Then the electron temperature was determined from the tilt angle of this linear section according to the formula $T_e=\Delta U_p/\Delta\ln(I_e)$ [eV], where $\Delta\ln(I_e)$ is the change in the electron current logarithm within the change of the probe potential ΔU_p, corresponding to this linear section.

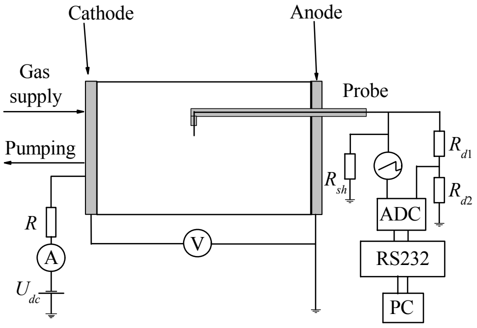

Fig. 1.Experimental device setup for studying the dc glow discharge

Plasma concentration n_i was calculated from the ion branch of the probe current I_{pr} and the measured electron temperature T_e according to the technique described in papers [6, 7]. For this we employed the formula $I_{pr,i}=I_i^*\cdot I^*$, where $I^*=A\sqrt{\frac{kT_e}{2\pi M_i}}n_i e$, $I_i^*=\gamma_1\gamma_2 I_L^*$, k is the Boltzmann constant, M_i is the ion mass; I^*_L is the Laframboise current, $I_L^*=\frac{2}{\sqrt{\pi}}\sqrt{\eta}$. The coefficients γ_1 and γ_2 are functions depending on ion concentration, electron temperature and gas pressure $\gamma_1, \gamma_2=f_{1,2}(n_i,T_e,p)$ [6, 7]. As a result we have a cumbersome equation the left-hand side of which contains the probe current we register, and the right-hand side depends on gas pressure, electron temperature and plasma concentration. Numerical solution of this equation permitted us to determine the concentration of positive ions. Here we employed the values of electron temperature and ion probe current determined from the probe CVCs.

2. EXPERIMENTAL RESULTS

Consider the axial profiles of plasma parameters shown in Fig.2 for the nitrogen pressure of 0.05 Torr. Here the anode is located to the left, and the cathode is to the right. Under these conditions the glow discharge consists of a cathode sheath and a negative glow approaching the anode surface (the maximum possible negative glow length might be larger but only a part of it found its place inside this inter-electrode gap). The electron temperature T_e was 0.3…0.5 eV almost within the total discharge gap but near the negative glow-cathode sheath interface we observed a sharp T_e increase. Electric field is usually small in the negative glow what is supported by the axial potential profile we registered. One observes in Fig.2 that the voltage drop across the total negative glow amount to about 3 V. The average field intensity was approximately 0.15 V/cm.

The axial profile of the positive ion concentration possesses a maximum in the negative glow not far from the cathode sheath boundary. Moving away from the cathode the ion concentration falls uniformly almost to the anode according to the power law $1/z^{0.8}$, if the z coordinate is counted from the cathode surface. And only near the anode surface the ion concentrations falls fast to zero.

Probe measurements in the cathode sheath are impeded because the electron concentration is small and ions are moving to the probe surface as a directional flow. This leads to a perturbation of the ion branch form and the technique for treating the probe CVC we use becomes incorrect.

Now consider a case with higher gas pressure. Fig.3 presents the data for the nitrogen pressure of 0.3 Torr, here the discharge current was 5 mA. Electron temperature in the negative glow decreases from the cathode sheath boundary and it approaches the smallest value T_e≈1.2 eV at the anode end of the negative glow. Along the negative glow the plasma potential lowers by about 5 V. Axial profile of plasma concentration possesses a maximum in the negative glow near the cathode sheath boundary similar to the case of low pressure. Along the negative glow the plasma concentration decreases by about 16 times and it approaches its minimum in the transition region to the dark Faraday space. Note that the plasma concentration decrease by 15…16 times was observed at all nitrogen pressure and discharge current values when the negative glow completely found its place within the inter-electrode gap.

Fig. 4 shows the normalized axial profiles of plasma density in the negative glow for different pressures of nitrogen and discharge currents. These profiles are well superimposed on each other.

The ratio of the maximum plasma density in the negative glow to the density at its boundary with the Faraday dark space is approximately equal to 15.8.

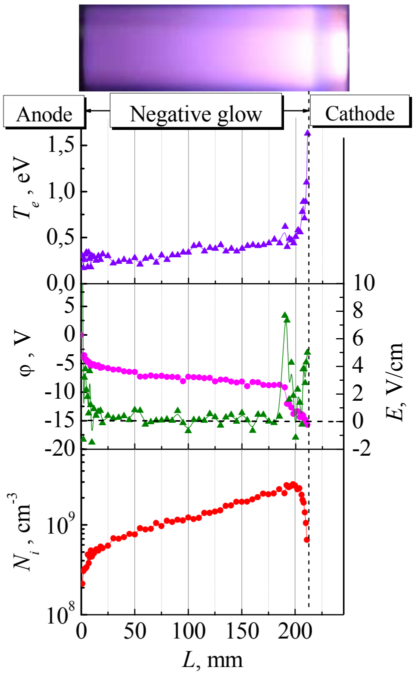

Fig. 2. Axial profiles of electron temperature, plasma potential and concentration of positive ions at nitrogen pressure of 0.05 Torr and the discharge current of 1 mA

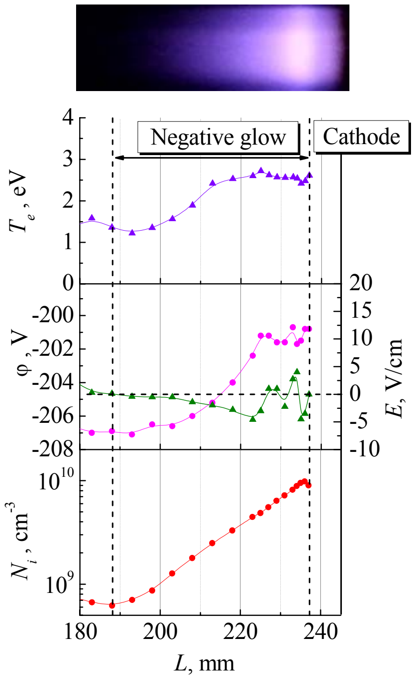

Fig. 3.Axial profiles of electron temperature, plasma potential and concentration of positive ions at nitrogen pressure of 0.3 Torr and discharge current of 5 mA

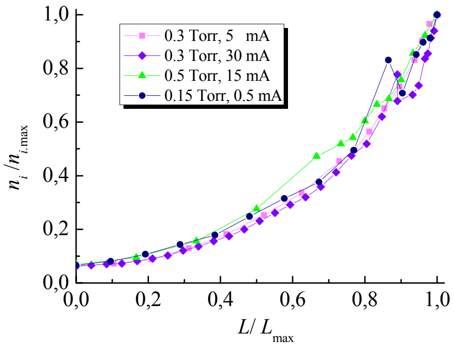

Fig. 4. The normalized axial profiles of plasma density in the negative glow for different pressures of nitrogen and discharge current

CONCLUSIONS

Thus this paper reports the studies with a Langmuir probe technique of axial plasma parameters such as electron temperature, potential and plasma concentration of dc glow discharge in nitrogen at different gas pressure values. It demonstrates that in the negative glow the electric field strength is small and axial profiles of plasma concentration and electron temperature possess maxima. These parameters approach their minima at the negative glow- Faraday dark space interface. Along the negative glow the plasma concentration is found to decrease 15…16 times et al gas pressure and discharge current values we studied.

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Article received 20.09.12

АКСИАЛЬНАЯ СТРУКТУРА ОТРИЦАТЕЛЬНОГО СВЕЧЕНИЯ ТЛЕЮЩЕГО РАЗРЯДА ПОСТОЯННОГО ТОКА В АЗОТЕ

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Осевые профили температуры электронов, потенциала и плотности плазмы тлеющего разряда постоянного тока в азоте измерены методом ленгмюровского зонда при различных значениях давления газа и разрядного тока. Показано, что в широком диапазоне экспериментальных условий на длине отрицательного свечения плотность плазмы уменьшается в 15-16 раз. Максимальные плотность плазмы и температура электронов наблюдаются на катодном конце отрицательного свечения, а напряженность электрического поля мала. При удалении от катода плотность плазмы и температура электронов в отрицательном свечении уменьшаются, здесь же может сформироваться область с отрицательным полем.

АКСИАЛЬНА СТРУКТУРА НЕГАТИВНОГО СВІТІННЯ ТЛІЮЧОГО РОЗРЯДУ ПОСТІЙНОГО СТРУМУ В АЗОТІ

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Осьові профілі температури електронів, потенціалу і густини плазми тліючого розряду постійного струму в азоті виміряні методом ленгмюрівського зонда при різних значеннях тиску газу і розрядного струму. Показано, що в широкому діапазоні експериментальних умов на довжині негативного світіння густина плазми зменшується в 15-16 разів. Максимальні густина плазми і температура електронів спостерігаються на катодному кінці негативного світіння, а напруженість електричного поля мала. При віддаленні від катода густина плазми і температура електронів в негативному світінні зменшуються, тут же може сформуватися область із негативним полем.