Probe characteristics of probes from different materials in glow discharge in helium

E I Prokhorova, A A Platonov, V S Ignakhin and A I Nazarov

Petrozavodsk State University,
Russia, 185910 Petrozavodsk, Lenina Avenue, 33
prokhorova@petrsu.ru

Abstract. Dust plasma is of particular interest due to the wide technological application and extraordinary properties. Probe method is often used for plasma diagnostics [1, 2]. At the same time, a probe is similar to a dust particle and there are emission streams on its surface, which make corrections to determination of plasma parameters. Despite essential development of the probe theory, when calculating plasma parameters for experimentally received volt-ampere characteristics emission of electrons is not considered, in many respects because of serious complication of the mathematical apparatus. The authors present the probe characteristics of probes from different materials in glow discharge in helium. The analysis of the chemical composition of the probe material is made. It has been shown experimentally that the material of the probes and the state of their surface (degree of roughness) have practically no effect on the results of probe measurements.

1. Introduction
The glow discharge is a classical object of studies in the field of gas electronics. One of source of particles charge is emission of electrons from their surface. Electrons can emit from the surface of particles at the expense of secondary, ion-electronic, photo and thermautoelectronic emissions.

According to the authors of [3], the material and surface roughness of the probe can have a significant effect on the values of plasma parameters determined by the probe characteristics. In order to verify this hypothesis, the authors measured the current-voltage characteristics (CVC) of a single probe for 6 different probes. Three probes were made of different materials (Ni, W, Mo) with a clean factory surface and three probes of the same materials, the surface of which was abrasive treated.

2. Discharge tube
The dependence of the CVC on the material and the state of the probe surface in the glow discharge in helium was experimentally investigated. The CVC were measured in the cylindrical gas discharge tube (Fig. 1) with cold electrodes (tube length 65 cm, diameter 3 cm). The power to the tube was supplied from a stabilized current source. The distance between the anode and cathode was 57 cm. A replaceable single probe (length 5 mm) was placed on the tube axis at a distance of 25 cm from the anode.
Figure 1. Gas discharge tube: 1 – anode, 2 – cathode, 3 – removable probe, 4 – non-removable probe.

The electric field strength in the discharge was 3.6-4.2 V/cm. To determine it, a second probe was used, located at a distance of 5 cm from the interchangeable one.

Replaceable probes were made of wire (nickel, tungsten and molybdenum) with a diameter of 0.2 mm. The chemical composition of the wire was studied by the method of energy dispersive X-ray spectroscopy using a Hitachi SU1510 electron microscope with the Thermal Scientific 4495B-1UES-SN attachment spectrometer. Fig. 2 shows a photographic image of a molybdenum probe, obtained using an electron microscope, and an X-ray energy dispersive spectrum.

Figure 2. Photographic image of a molybdenum probe, obtained using a Hitachi SU1510 electron microscope (left) and an X-ray energy dispersive spectrum (right).

In addition to the nominal element of the wire material, the analysis showed the presence of small amounts of carbon for all the probes used, as well as oxygen in some spectra. This can be explained by contamination of the surface with organic matter, which is removed when training probes in plasma. In addition to them, the presence of insignificant fractions of impurities (~ 0.1 %) of other metals and a small proportion of aluminum (~ 1-2 %) were recorded. The latter circumstance is obviously related to the background from the microscope stage.

3. Investigation of probe surface

The working surface of the probes after measurements in the plasma and the isolated part of the wire was examined using an Integra-Prima atomic-force microscope NT-MDT using a DCP-20 cantilever. The measurements were carried out repeatedly for each sample in the contact and semi-contact modes, which gave, in general, similar results. The surface relief of industrially manufactured wire has an anisotropic character. The actual surface area, taking into account the wire micro relief, was calculated numerically using a full scan with dimensions of 50x20 µm² and 100x40 µm². The surface area element was calculated using the formula:

\[ dS = \sqrt{1 + \left(\frac{df}{dx}\right)^2 + \left(\frac{df}{dy}\right)^2} \ dx \cdot dy \]  

(1)
where \( z = f(x, y) \). In (1), at each point with the exception of the boundaries of the region, the average value of the derivative was taken from two derivatives found by the two-point scheme. The real area was the sum of all calculated elements.

For the molybdenum probe, the difference between the visible area \( S_{\text{vis}} \) and the real one \( S_{\text{true}} \), taking into account the curvature of the relief, was: \(~ 1.9 \% \) for the surface in contact with the plasma; \(~ 3.4 \% \) for the area isolated from the plasma. The investigation of the surface of the probes of nickel and tungsten gives similar results.

Fig. 3 shows profilograms of the surface relief of a commercial nickel wire with a diameter of 200 \( \mu \text{m} \), obtained in semi-contact mode. The scan size is 50x20 \( \mu \text{m}^2 \), where \( x = 50 \mu \text{m} \) is the scan length along the wire axis, \( y = 20 \mu \text{m} \) is the scan width in the direction across the axis.

![Figure 3. Profilograms of the raw nickel wire with a diameter of 200 \( \mu \text{m} \): scan direction a) along the axis of the wire, b) across the axis of the wire.](image)

To study the effect of the curvature of the probe surface, the wire was treated with an abrasive material. Fig. 4 presents the results of the study of the surface of the treated nickel wire. Estimates for surface roughness show that after abrasive processing, the roughness increases by about 2 times [3].

![Figure 4. Profilograms of the treated nickel wire with a diameter of 200 \( \mu \text{m} \): scan direction a) along the axis of the wire, b) across the axis of the wire.](image)

4. Probe measurement results
Stabilized analog current sources were used to power the probes. To measure the voltage and current of the probe, measuring instruments of accuracy class 0.2 were used. Thus, the measurement error associated with the instruments did not exceed 5 \%. For each probe, the characteristics were taken in several batches of gas. The measurements were repeated 8-10 times. The scatter of measurement
results for the maximum values of electron and ion currents for each probe was 3%. Figures 5 and 6 show the results of probe measurements obtained for various materials of the probe before and after the surface treatment of the probe with abrasive.

The measurements were carried out in helium at a discharge current of 30 mA and a gas pressure of 1 Torr. Anode voltage for different portions of gas differed slightly and was within the limits of 480-520 V.

The results of measurements of the CVC in atomic gas (helium) show that the probe material does not affect the probe characteristics under other constant conditions. Probe measurements performed after surface treatment of probes give similar results (Fig. 6).

![Figure 5](image1.png)  
**Figure 5.** Current-voltage characteristics of probes made of various materials with raw surface.

![Figure 6](image2.png)  
**Figure 6.** Current-voltage characteristics of probes made of various materials with a treated surface.

Using the slope of the probe characteristic in the electronic region, the electron temperature was calculated [4], the electron concentration was determined from the ionic part of the characteristic using the Bohm formula. The following results are obtained: $T_e = (3.2 \pm 0.1)$ eV and $n_0 = (4.2 \pm 0.1) \cdot 10^{10}$ cm$^{-3}$.

In this case, no dependence of these values on the probe material or its degree of roughness was revealed.

The degree of gas ionization in the plasma turned out to be $\sim 1,3 \cdot 10^{-6}$.

5. Conclusion

Studies have shown that the material of the probes and the state of their surface (the degree of roughness) have practically no effect on the results of probe measurements and should not have a noticeable effect on the values of the calculated plasma parameters.

In the future, we plan to conduct a similar study in molecular gas (nitrogen).

References
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