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Probe diagnostic system for registration of high-energy electrons of gas discharge plasma

A.M. Astafiev[1, 2], C. Zhou[1], A.A. Kudryavtsev[1], V.M. Bakulev[1], A.S. Chirtsov[2], C. Yuan[1]
[1] Harbin Institute of Technology, China, [2] Saint Petersburg Electrotechnical University "LETI", St. Petersburg, Russia
e-mail (speaker): astafev-aleksandr@yandex.ru

Probe methods are the most efficient and informative in the study of low-temperature plasma. An important feature of probe methods is the possibility of determining the electron energy distribution function (EEDF). To find it, it is necessary to measure the probe voltampere characteristic and then to differentiate it twice by voltage [1, 2]. The main difficulty in finding the EEDF is to correctly determine the second derivative of the experimental data. A number of commercial automated probe systems for plasma diagnostics are currently available. They perform double differentiation in an automated mode and determine the EEDF, but the cost of such systems is tens of thousands of dollars. For this reason, the development of alternative technical means of probe diagnostics of gas-discharge plasma is an urgent task. One of the simplest means of probe characteristic registration can be performed on the basis of a sawtooth pulse generator and a digital oscilloscope, but until recently this approach was not characterized by sufficient accuracy. However, the situation has changed dramatically, and the technical characteristics of modern inexpensive digital oscilloscopes are quite capable of registering signals with the accuracy necessary to realize double numerical differentiation and subsequent correct reproduction of the EEDF, including its high-energy (non-Maxwellian) part.

Fig. 1 (left) shows a simple probe system that was assembled based on a high-resolution digital oscilloscope (Rigol DHO 4204), a signal generator (Rigol DG1022Z) and an amplifier (up to 190 V). The 10 mA DC discharge under study was ignited between flat electrodes in a discharge tube that was filled with helium with a small admixture of other gases at pressures from 25 to 35 Torr. The power was supplied from a regulated high-voltage source connected through a 5 kOhm resistor. Between the anode and cathode was placed a probe 5 mm long and 0.1 mm in diameter, which was connected to ground through a 10 kOhm resistor.

Fig. 1 (right) shows the results of double numerical differentiation of the measured probe voltampere characteristics. As can be seen, the red curve has characteristic peaks for discharge in helium at about 15 and 19 V, as well as peaks of residual oxygen at about 7.5 V [3] and molybdenum sputtered from the cathode at about 13 V. These peaks are formed by electrons generated in Penning ionization reactions and second-kind impacts involving metastable helium atoms. The addition of 1% carbon monoxide leads to the appearance of a large peak around 6 V, while the level of the other peaks decreases sharply and their shape smooths out (black curve). Thus, by double numerical differentiation of the oscilloscope data, it was possible to correctly restore the high-energy part of the EEDF, including the characteristic peaks from Penning ionization reactions.

References

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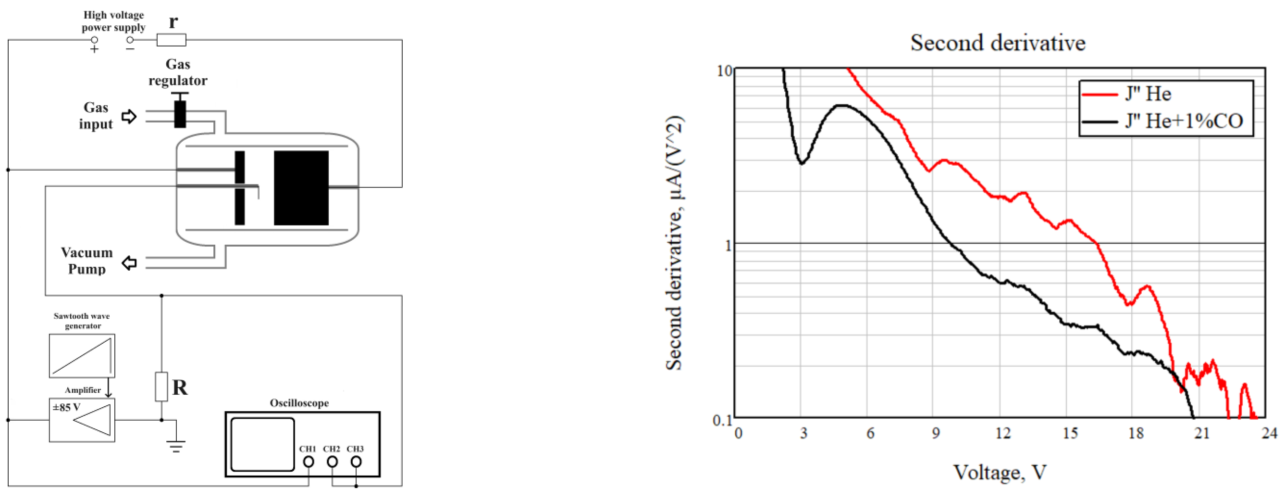

Figure 1. Left – probe diagnostics system based on high-resolution digital oscilloscope. Right – dependences of the second derivative of the probe current on voltage for 10 mA discharge in helium at 35 Torr pressure (red curve) as well as after addition of 1% carbon monoxide (black curve).