ELECTRON ENERGY DISTRIBUTION FUNCTION OF A PULSED INTENSE ELECTRON BEAM

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The time-resolved energy distribution function of a pulsed intense electron beam generated in a channel-spark discharge was determined. The electron energy distribution is polyenergetic, with a dominant high-energy electron component at earlier times and a contribution of lower energy electrons increasing towards later times.

1. Introduction

Transient hollow cathode discharges, as pulsed electron beam sources, operate on the left hand branch of the Paschen curve, at low gas pressure (10^{-3} -10^{-1} mbar) and high-applied voltage (few kV - up to tens kV). The channel-spark discharge is used for thin film deposition, as an alternative to pulsed laser deposition [1, 2]. The beam energy spectrum is essential to help the physical understanding of the complex phenomena at the pulsed electron beam-target interaction.

Experimental methods to determine the energy distribution of pulsed intense electron beams produced in preionized controlled open-ended hollow cathode discharges were developed in previous works [3,4].

The aim of this paper is to investigate the energy distribution function of the pulsed electron beam generated in a channel-spark discharge.

2. Experimental method

The channel-spark discharge consists of a hollow cathode, a capillary tube (6 mm diameter and 90 mm length) and a grounded anode (figure 1). The external capacitor was 16 nF and the applied voltage was 16 kV. The capacitor was discharged between the cathode and the anode, with a frequency of 1-2 Hz. The working gas was argon at a pressure of 10^{-3}-10^{-2} mbar. The electron beam current was measured with a Faraday cup positioned axially at 10 mm from the anodic end of the capillary tube. An aperture of 6 mm diameter was placed in front of the Faraday cup

The time-resolved energy distribution of the electron beam was obtained using the method described in reference [3].

The Faraday cup connected to ground through a resistor (R_P), in series with a 0.3 Ω shunt (R_S), is self-biased with respect to ground to a negative potential $V_{sb}=R_P \times I(t)$, where $I(t)$ is the electron beam current. Hence, the slow electrons are repelled and only the electrons with energies higher than eV_{sb} are collected by the Faraday cup. Varying the value of R_P different self-biased potentials are obtained.

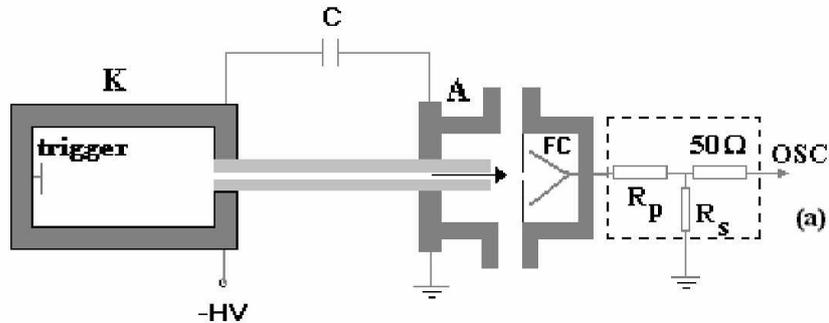[*] Corresponding author: mnistor@infim.ro

Fig. 1. Experimental set-up: K-hollow cathode, CT-capillary tube, A-anode, C-capacitor,
FC-Faraday cup, OSC-oscilloscope.

The relation between the beam current of electrons with energies higher than eV_{sb} and the electron energy distribution g is:

$$I(t) = c \int_{V_{sb}(t)}^{\infty} \sqrt{E} g(E,t) dE \qquad (1)$$

where E is the electron energy and c is a constant.

In reference [3] only the beam current I(t) was measured for different values of the R_p. The self-biased potential V_{sb} was calculated taking into account the effect of the stray inductance of the overall measurement chain including the Faraday cup.

To avoid this problem in our experiments both the beam current I(t) and the self-biased potential $V_{sb}(t)$ were measured for each value of R_p between 5 and 350 Ω. The beam current was measured from the voltage fall on the 0.3 Ω shunt and V_{sb} (t) was measured with a Tektronix P6015A high voltage probe coupled to the Faraday cup.

3. Results and discussions

Typical oscillograms of the discharge voltage, electron beam current and the self-biased potential V_{sb} for R_p=350 Ω are presented in Fig. 2.
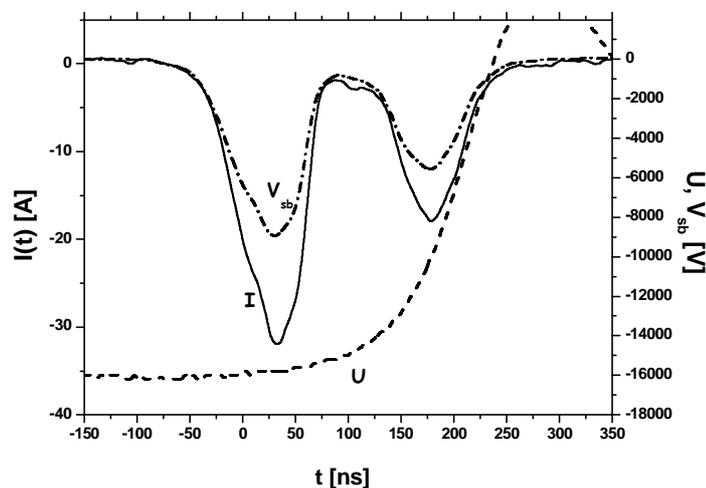

Fig. 2. Oscillograms of the discharge voltage U, electron beam current I and the self-biased
potential V_{sb} for R_p=350 Ω.

The discharge voltage fall lasts about 200 ns and the electron beam current has a double-peaked structure. The first current peak has a maximum intensity of 32A and appears early on the voltage fall. The corresponding maximum self-biased potential is 8800 V, hence the current of 32 A is due to electrons having energies higher than 8800 eV. The second current peak has a maximum intensity of 18 A and the corresponding self-biased potential is only 5500V.

A set of oscillograms $[I(t)]_{Rp}$ and $[V_{sb}(t)]_{Rp}$ were recorded for R_p values between 0.3 and 350 Ω. From these oscillograms we obtained the curves $[I(V_{sb})]_t$ of the current of electrons with energies higher than V_{sb}, in function of V_{sb}, for different times t.

For the first peak of the beam current the curves $[I(V_{sb})]_t$ for four values of time: t= -10 ns, 10 ns, 30ns and 40 ns are presented in Fig. 3.
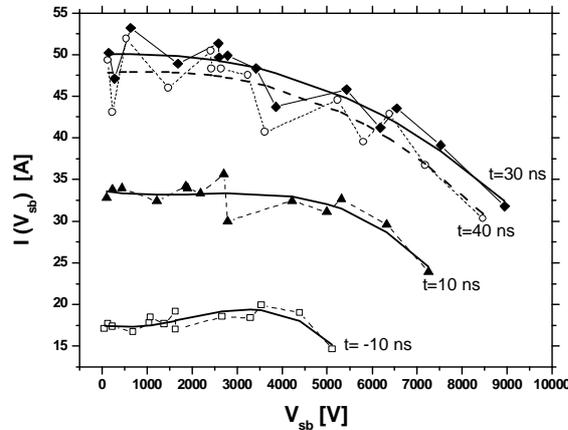

Fig. 3. $[I(V_{sb})]_t$ curves for t= -10 ns, 10 ns, 30 ns, 40 ns.

The values of the electron beam current at earlier times (t= -10 ns and t=10 ns) are almost constant for energies lower than about 3 keV.

The deconvolution of the eq.(1) gives the electron energy distribution of the beam:

$$g(E,t) = -c \frac{dI / dV_{sb}}{\sqrt{V_{sb}}} \qquad (2)$$

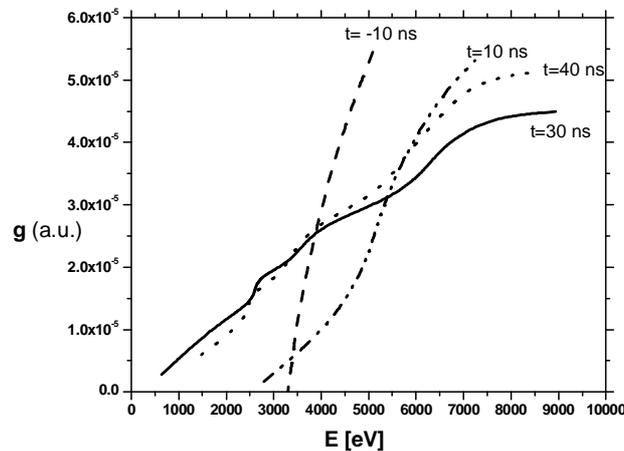The time evolution of the electron energy distribution is presented in figure 4.

Fig. 4. Energy distribution curves for t=-10 ns, 10 ns, 30 ns and 40 ns.

The electron energy distributions at earlier times (t= -10 ns and t=10 ns) show that the beam is composed of high-energy electrons with energies higher than about 3 keV. At later times, around the maximum of the beam current (t=30 ns and t=40 ns) the electron energy distributions are composed both from high-energy electrons and from lower energy electrons. The slope of g is less pronounced than in previous case (t= -10 ns and t=10 ns). Hence, the contribution of lower energy electrons is higher at later times.

The second peak (Fig. 1) produces lower self-biased potentials due to lower currents and lower energies of electrons.

4. Conclusions

The time-resolved energy distribution function of the pulsed electron beam generated in a channel-spark discharge was obtained with a method based on the Faraday cup self-biasing. The self-biasing method has an upper limit of the energy domain, at each time t, given by the maximum value of the self-biased potential in that moment.

Our measurements prove that the energy distribution of the electron beam is polyenergetic, with a dominant high-energy electron component before the maximum of the current. The contribution of lower energy electrons is higher at later times. The range of the high-energy electrons of the beam in the target gives the order of magnitude of the thickness of evaporated material in ablation experiments. Having a polyenergetic energy distribution the electron beam gives an energy deposition profile with a maximum below the target surface [1]. Most of the high-energy electrons in the beam are concentrated in a diameter smaller than 2 mm, in accordance with the trace observed on the surface of the target due to the beam - target interaction.

Acknowledgements

References

[1] G. Müller, M. Konijnenberg, G. Krafft, C. Schultheiss, World Scientific Publ. Co. PET. LTD, 89 (1995).
[2] E. Dewald, K. Frank, D. H. H. Hoffmann, A. Tauschwitz, IEEE Trans.Pl.Sci. **30**, 363 (2002).
[3] G. Modreanu, N. B. Mandache, A. M. Pointu, M. Ganciu, I. I. Popescu, J. Phys.D: Appl. Phys. **33,** 819 (2000).
[4] M. Nistor, P. Charles, M. Ganciu, M. Lamoureux, N. B. Mandache, A. M. Pointu, Plasma Sources Sci.Technol. **11,** 183 (2002)