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Explosive-emission cathode with resistive decoupling in a high-current plasma-filled diode

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Abstract. In the paper, the results of investigations of operation of multi-emitter explosive-emission resistively decoupled cathode in a plasma-filled diode are presented. The integral glow, current rise rate, and energy density distribution via cross section of a non-relativistic, high-current electron beam have been studied. It has been shown, that resistively decoupled cathodes look very perspective for improvement of stability and uniformity of high-current electron beams.

1. Introduction

Resistive decoupling is a well-known method stabilizing an operation of explosive-emission cathodes [1, 2]. This method allows one to suppress so-called emissive centers-leaders, consistently appearing while operation of wide-area explosive-emission cathodes. Availability of centers-leaders reduces a number of concurrent emission centers and therefore degrades the homogeneity and stability of the cathode operation. To suppress centers-leaders it is needed to limit the current through all emitters since the location of leaders may change from pulse to pulse. Current of each center may be limited by a space charge of electron flux emitted by respective center [3], or by connecting of active resistance in series to the circuit of each emitter. The first method may be realized at low current density (less than 30 A/cm^2) only, which is not suitable for us. Therefore, the second method was chosen. But the use of resistive decoupling in a plasma-filled diode requires a careful isolation of the cathode substrate because the emission can be initiated on a flat surface located under plasma. Therefore, the emission centers on the substrate may shunt the resistors placed in the emitter circuit which is unacceptable.

The cathode with resistive decoupling was firstly developed and applied for a high-current plasma-filled diode in [4]. This cathode represented a packet of resistors TVO-0.125 (made in Russia; 0.125 means 0.125 W of dissipated power) glued with epoxy compound. The diameter of emitting part of the cathode was 1.5 cm. The ends of the resistors were cut and polished to expose the carbon core, which served as emitter. However, carbon erosion products, which may deposit to the treated target, are usually undesirable. Therefore, we have developed an analogous cathode but with metal emitters. The present paper is devoted to investigations of high-current electron gun operation with this cathode.

2. Cathode design

Experiments were carried out on the "RITM-U" facility described in [5]. To create plasma anode, an usual high-current Penning discharge in argon [6] and hybrid discharge matching high-current Penning discharge with vacuum arcs [5] were used.

The cathode has been manufactured of TVO-1 resistors at face-value from 2.7 Ω to 5.6 Ω; their wire outputs of 6 mm in length serve as emitters (Figure 1). The opposite outputs of resistors were soldered with a brass disc. Total number of resistors was 156 and effective diameter of emitting area was about 58 mm. To avoid the contact of the plasma anode with the screen electrode, a diaphragm with the same diameter was installed on the anode edge addressed to the cathode. The packet of resistors was inserted into Teflon holder on which the screen electrode made of stainless steel was built-up. The gullets between Teflon holder and resistors were filled with sealant. Two versions of the cathode design are given in Figure 1. The second version (Figure 1, b) distinguishes from the first one (Figure 1, a) by the fact that the end surface of Teflon holder is protected by the ledge of the screen electrode.

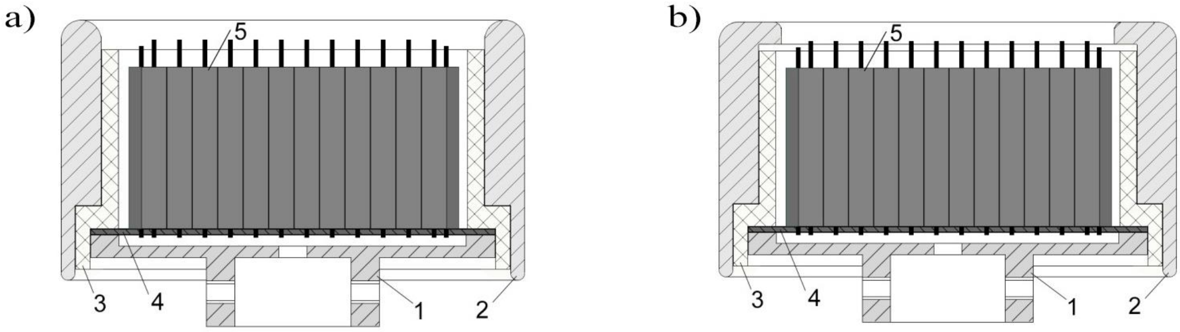

Figure 1. Explosive-emission cathode based on TVO-1 resistors. 1 - cathode holder; 2 - screen electrode; 3 - Teflon ferrule; 4 - brass disc; 5 - resistor TVO-1.

3. Results and discussion

3.1. Current rise rate

The current rise rate (*dI*/*dt*) is one of the key parameters characterizing the cathode operability. Evidently, the current rising is caused by the increasing of a number of emission centers and their emitting area. It was important to compare the *dI*/*dt* value of our new cathode with *dI*/*dt* provided by traditionally used cathode made of copper braid of radiofrequency cable [5, 6].

Typical waveforms of accelerating voltage and total cathode current are given in Figure 2. The studying of big number of waveforms has shown that in similar conditions, the current rise rate in the front of the pulse is higher by a factor of 20-30% than for the case of copper braid cathode.

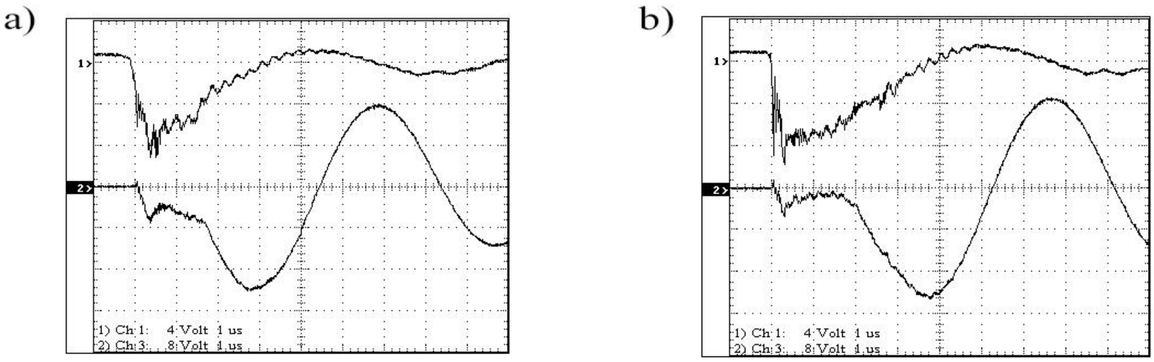

Figure 2. Typical waveforms of accelerating voltage (16 kV/div, upper traces) and cathode current (24 kA/div, lower traces). Plasma anode based on high-current Penning discharge (a) and plasma anode based on hybrid discharge (b). Argon pressure is 0.5 mTorr (a) and 0.4 mTorr (b). Guide magnetic field B_z = 0.106 T.

3.2. Cathode glow

Cathode glow integrated per pulse was registered with **CASIO QV-3000EX/Ir** digital camera in open shutter mode. Photographing of the glow was performed from the face of electron gun. At that, the trip-out of the beam electrons was performed onto tubular collector with magnetic cut-off analogously to the method described in [7]. To prevent camera from over-illumination, an interferometric light filter of type **HC-9** with thickness of 3 mm was installed in front of it.

Characteristic photos of the glow are given in Fig. 3. Rather bright spots referring to emitters can be seen on the diffused background. Note, these spots are observed practically on all emitters stably that confirms good operation of the cathode. Such behavior of the emitters is characteristic to both types of plasma anode.

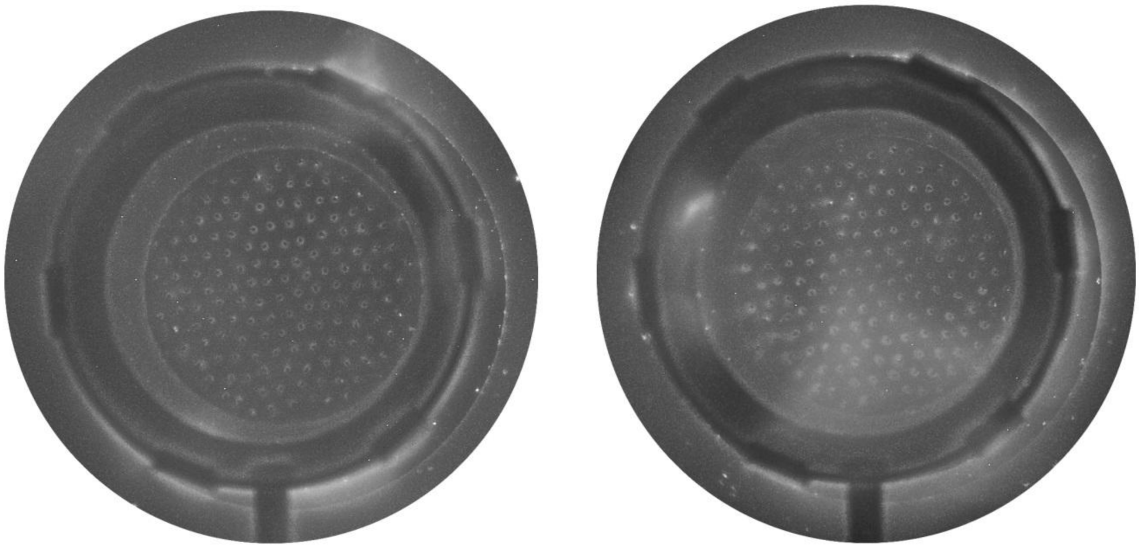

Figure 3. Photos of glow. Argon pressure is 0.4 mTorr. Guide magnetic field induction B_z = 0.106 T.

It is logically to assume that bright spots localized on the emitters represent the glow of plasma of emissive centers or, in other words, cathode spots. Supposing that at the end of the current rise time all emission centers operate, it is easy to estimate the current per center as 70-150 A. At such a current, the lifetime of emission center is much more than pulse duration of the beam [8] which is positive factor for cathode operation. The voltage drop on resistors makes up 250-500 V and this is enough for "grab effect", i.e. appearance of a new emission center stimulating by plasma of the neighbor emission center.

Average distance between emission centers is defined by cross dimensions of the resistor and makes up about 3.6 mm, so the density of emission centers (number per area) is about 6 pcs/cm^2. In the case of the cathode made from copper braid, the density of emission centers is approximately 1.7-2 times lower [7]. If the cathode will be manufactured from resistors TVO-0.5 having lower cross sectional dimensions, so the density of emission centers may be increased twice - up to 11-12 pcs/cm^2. However, it increases expenses of the cathode manufacturing.

3.3. Energy density distribution

The uniformity of the beam energy density distribution, *W*(*r*), is a key (and difficulty achievable) parameter. In the present work, the energy density distributions were studied with thermal imaging diagnostics according to procedure described in [9, 10]. The block-scheme of measurements is given in Figure 4. 210-μm stainless steel foil served as beam collector (thermal imaging target). To increase the emissivity, the back side of the foil has been covered with black dull paint (20 μm).

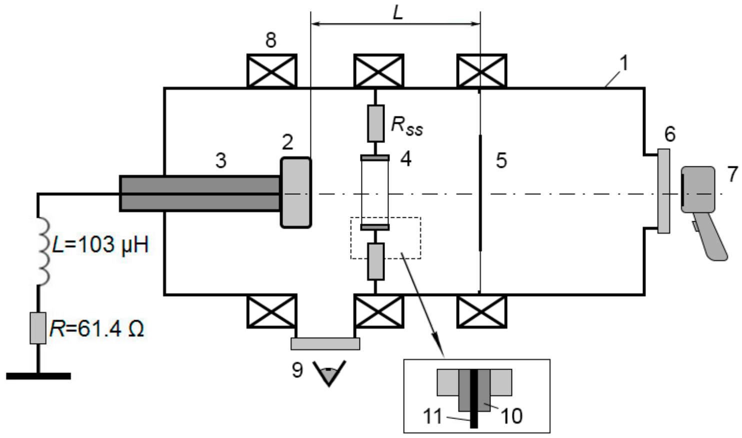

Figure 4. 1 – body of electron gun; 2 – cathode of electron gun; 3 – isolator; 4 – anode unit; 5 – collector (target); 6 – window made of CaF_2; 7 – thermal imager TESTO 875-1; 8 – solenoid; 9 – window for visual observation; 10 – ceramic tube; 11 – cathode of the arc source. R_{ss} = 110 Ω – resistor.

In the Figures 5 and 6, the thermal images (at the left) and corresponding energy density distributions (at the right) along dashed cross sections are given. The most uniform distributions have been obtained for the case of hybrid anode (Figure 5) at B_z = 0.106 T, which corresponds to the results obtained in [5]. The diameter of uniform part at the level of 0.9 from maximum value of energy density makes up 5.2 cm and this is the best our result achieved ever. In the case of Penning anode (without arc plasma sources in the anode), this diameter is lower - about 3.5 cm. If B_z value decreases to 0.06 T, so the beam uniformity becomes worse: the distribution $W(r)$ looks like bell (Figure 7).

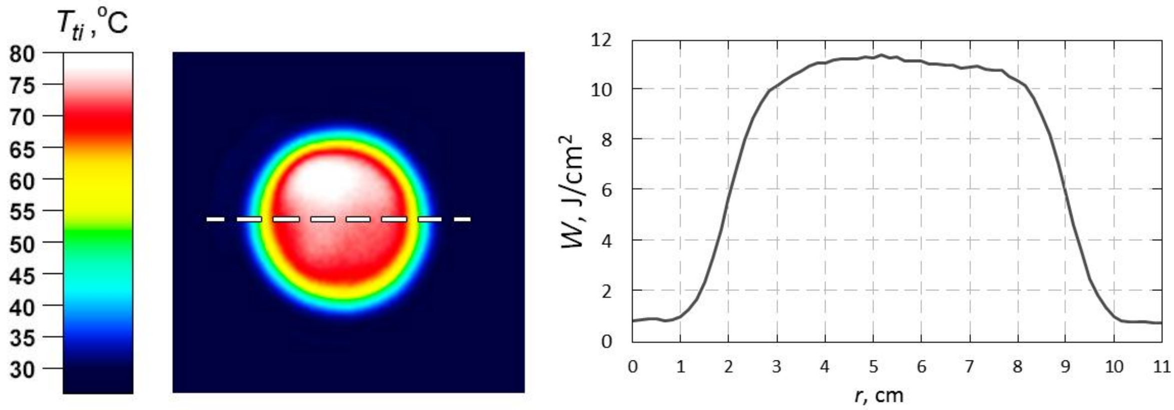

Figure 5. Thermal image and corresponding energy density distribution via horizontal cross section. Plasma anode based on hybrid discharge. Argon pressure is 0.4 mTorr. Guide magnetic field induction B_z = 0.106 T.

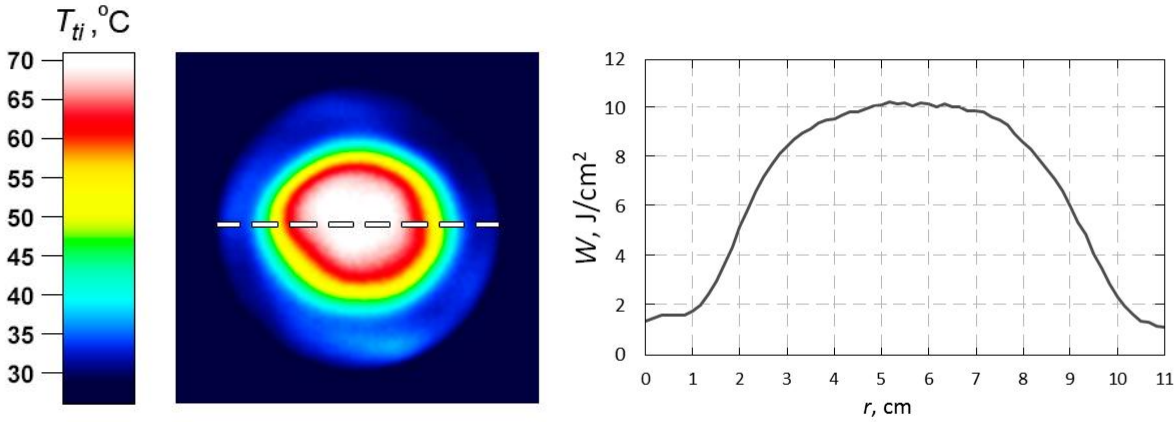

Figure 6. Thermal image and corresponding energy density distribution via horizontal cross section. Plasma anode based on high-current Penning discharge. Argon pressure is 0.5 mTorr. Guide magnetic field induction $B_z = 0.106$ T.

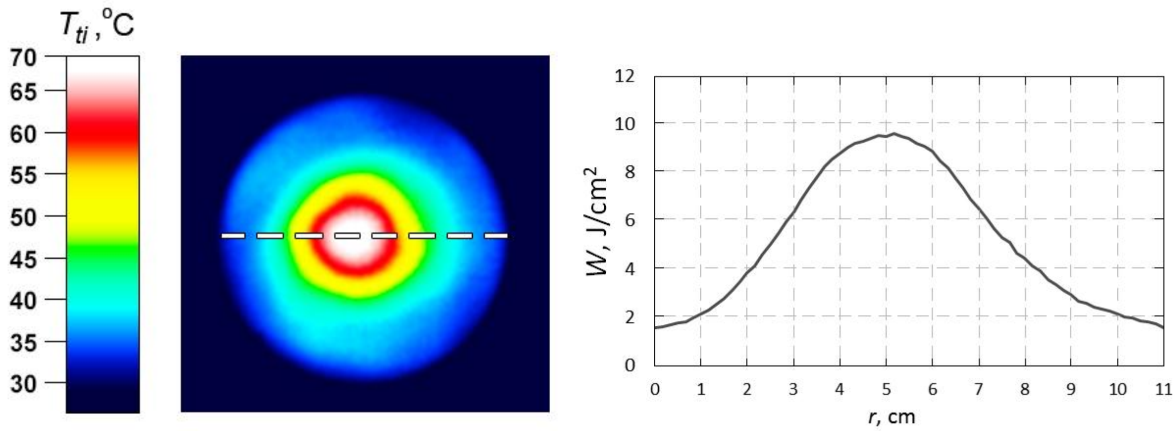

Figure 7. Thermal image and corresponding energy density distribution via horizontal cross section. Plasma anode based on hybrid discharge. Argon pressure is 0.4 mTorr. Guide magnetic field induction $B_z = 0.06$ T.

It should be noted that one can control the energy density distribution by varying the resistance in the circuit of each emitter. In our present experiments, the resistance of the resistors in the central part was twice higher than for peripheral part of the cathode. It has given some effect, and for further modification of the cathode, this difference in resistance will be increased for further improvement of the beam uniformity.

4. Conclusions

The main results of investigation of multi-point, explosive-emission cathode with resistive decoupling operation in a plasma-field diode are as follows.

- A stable operation of explosive-emission cathode with resistive decoupling of emitters based of resistors TVO-1 in a plasma-filled diode has been demonstrated.
- For this cathode, the current rise rate in the front of the pulse exceeds in average by a factor of 20-30% the corresponding value for multi-wire copper cathode.
- Satisfactory uniformity of energy density distribution in cross section of high-current electron beam has been obtained. The further improvement of the beam uniformity may be provide by

the increasing of the resistance in the circuits of emitters located in the central part of the cathode.

Acknowledgment
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