Study on nanosecond pulsed electron beam generation

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Abstract. The paper presents the findings of an investigation on volt-ampere characteristics of the diode with explosive emission cathodes of different constructions (blade metal-dielectric (MD-cathode) and solid graphite cathodes) under the change of the anode-cathode gap in wide ranges. The investigations were carried out using the TEA-500 pulsed electron accelerator. The total current of the electron beam was measured using the Faraday cup (FC). A 0.5-mm foiled glass fiber laminate was used as an emitting edge of the cathode in the experimental study with the explosive emission blade MD-cathode. Based on the obtained results, the conclusion was made that the graphite cathode has the most effective efficiency factor.

1. Introduction

Radiation technologies are applied in many fields of science and technology: radiation treatment of medical articles, radiation doping of semiconductors, ion implantation, radiation treatment of the articles of electronic engineering, application of the ionizing radiation in environmental protection, radiation treatment of food products, etc.

The application of the powerful electron accelerators which generate the submicrosecond electron beams with the current amplitude up to several kA is rather promising [1]. Nowadays, different types of cathodes are developed and used. For example, the authors of [2-3] suggest using the planar cathodes from different metals (copper, tungsten, molybdenum) as electron sources. The works [4-5] present the investigation findings of the explosive emission cathodes made from carbon-based material. The disadvantages of such a type of the cathode are emission instability from a pulse to a pulse and emission distribution nonuniformity over the cathode area.

In [6], the diode with a multipoint explosive emission cathode located at external magnetic field. The duration of an optimal pulse is reached when $R > 15\ \Omega$. The authors emphasize that the increase in R up to several kΩ causes the increase in pulse duration by 15 %. In [7], the research results of the volt-ampere characteristics (VAC) of the planar diode with a multipoint explosive emission cathode under the agreement of the diode impedance with an output resistance of the nanosecond generator are shown. The diode impedance with needle multipoint cathodes and carbon-based cathode is obtained during the electron beam generation. The investigations are performed using the TEA-500 pulsed electron accelerator. In [8], the research results of the VAC of the planar diode with a graphite explosive emission cathode of the TEA-500 pulsed electron accelerator are presented.

The work of the diode during the electron beam generation can be divided into two stages. At the first stage, after the voltage is applied to the diode, the diode current is limited by the emissivity of the cathode. For the graphite cathode with a diameter of 45 mm, the duration of the first stage is 15-20 ns, and the increase is possible up to 30-40 ns when the voltage amplitude is decreased. The diode perveance at the first stage of the diode operation is much less than the perveance calculated according to the Child-Langmuir ratio. The TEA-500 pulsed electron accelerator used in [7-8] is also used in the current work. The purpose of the current work was the experimental study of VAC of the diode with the explosive emission cathodes of different construction (blade MD and solid graphite cathodes) under the change of the anode-cathode gap within wide ranges from 10 to 20 mm.

2. Experiment

The works on the study of the generation of the pulsed nanosecond electron beam were performed on the TEA-500 accelerator. The main parameters of the accelerator: an accelerating voltage from 350 kV to 500 kV; an electron beam current from 6 kA to 11 kA; a half-amplitude pulse duration of 60 ns; a pulse energy to 200 J; a pulse repetition rate up to 5 pulses per second [9]. In the investigations, we used the diode with explosive emission blade MD-cathode [10]. A 0.5-mm foiled glass fiber laminate was used as an emitting edge of the cathode (figure 1). The effective diameter of the cathode is 62 mm, the height of MD-blades is 10 mm, and a number of blades is 11 pieces. The value of the accelerating gap changed within the interval from 12 to 22 mm. The application of metal-dielectric enables to initiate the explosive electron emission in triple points of the emitting edge of the cathode, that is it enables to increase the stability of the parameters of the electron beam during a large amount of pulses. To limit the impact of the edge effect on the generation of the electron beam in the construction of the cathodes, the shield is used.

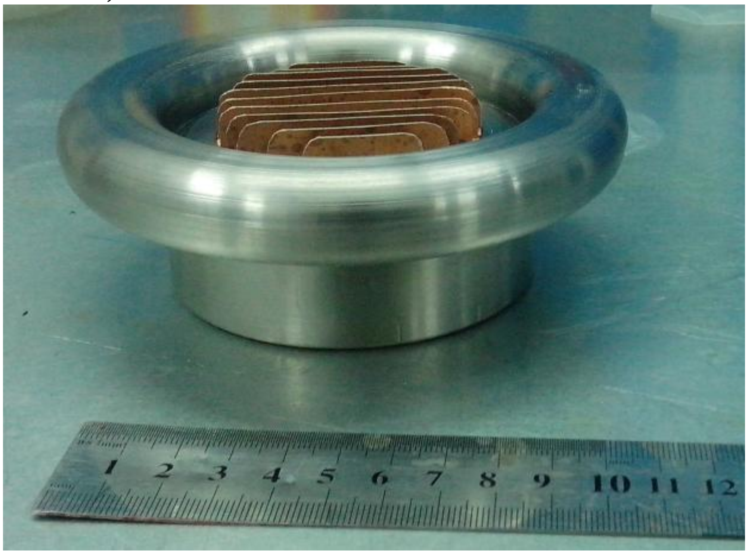

Figure 1. A blade MD-cathode with a shielding electrode of the TEA-500 pulsed electron accelerator.

The application of the shield in the suggested geometry makes it possible to decrease the electron emission from the peripheral part of the cathode, that is varying the location of the shield enables to change the diode impedance under the constant values of the cathode-anode (C-A) gap. Consequently, the parameters of the generated pulsed nanosecond electron beam are changed.

3. Results and discussions

An optimal cathode-anode gap was chosen by determining the maximum energy applied to the explosive emission diode with a blade MD-cathode. Figure 2 presents the dependence of the energy on a C-A gap, the energy was calculated by 10 averaged pulses, the dispersion of the parameters did not exceed 7 %.

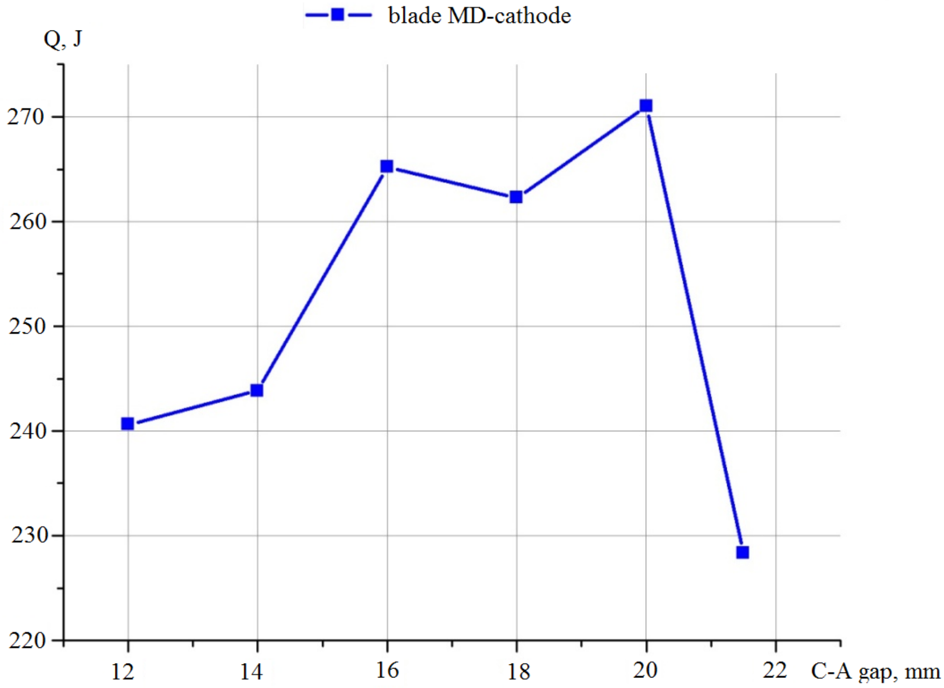

Figure 2. The dependence of the energy on the cathode-anode gap.

Figure 2 shows that the maximum energy applied to the explosive emission diode with a blade MD-cathode is achieved when the C-A gap is 20 mm. The oscillograms presented in figure 3 are obtained with this C-A gap:

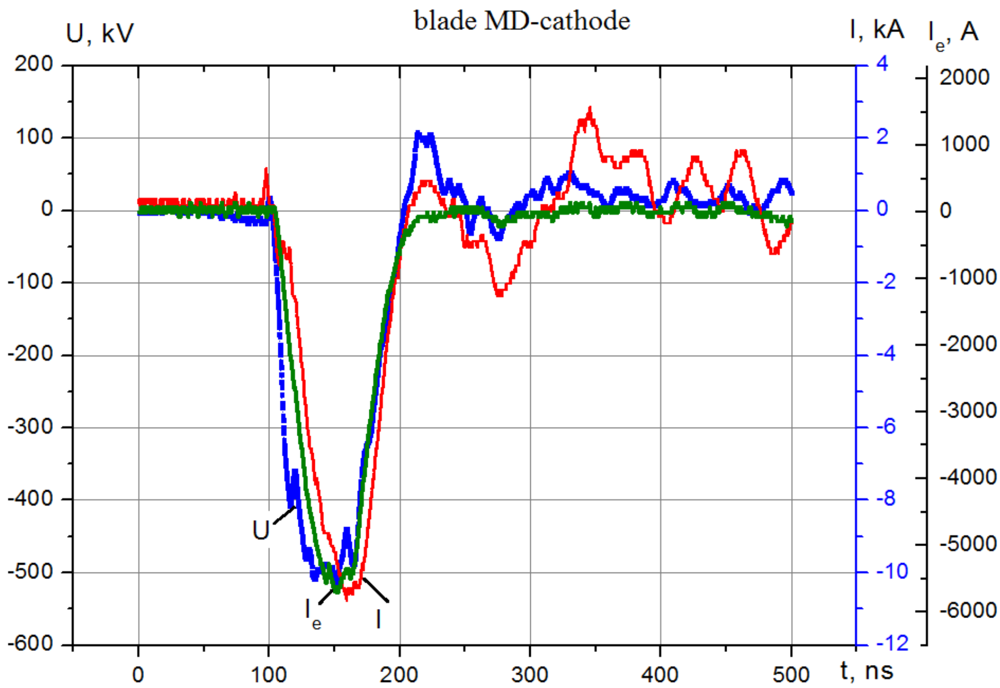

Figure 3. The voltage and current oscillograms which are typical to the 20-mm C-A gap. The MD cathode.

The oscillograms show that the value of the electron beam current was ~5.5 kA. However, this value is lower compared to the case of using the graphite cathode with a diameter of 60 mm in the explosive emission diode. Figure 4 presents the oscillograms obtained at a C-A gap of 14 mm, and figure 5 shows the experimental impedances for the diodes with a blade MD cathode at a C-A gap of 20 mm and with a planar graphite cathode at a C-A gap of 14 mm.

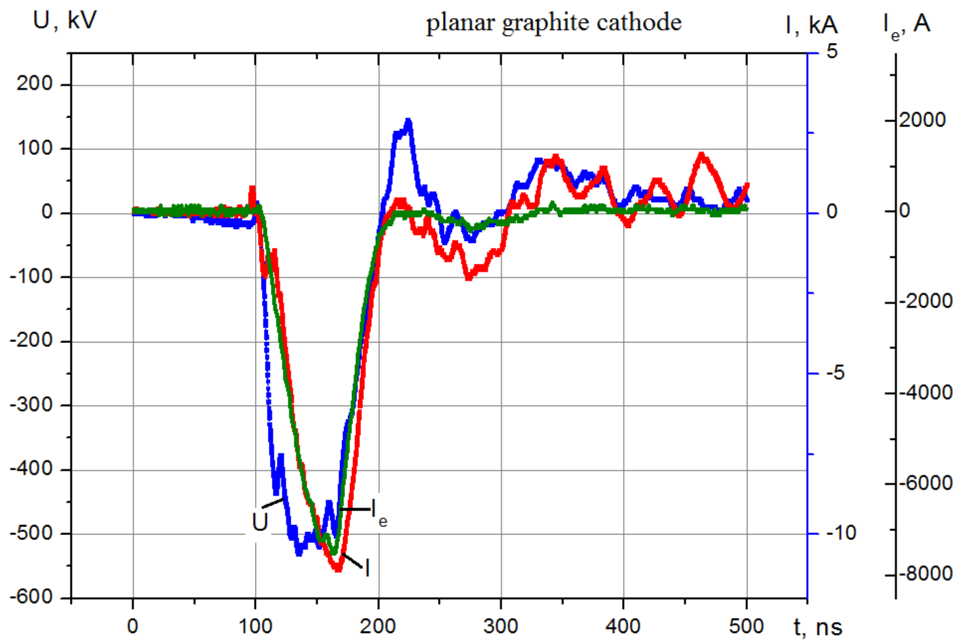

Figure 4. The voltage and current oscillograms which are typical to the 14-mm cathode-anode gap. The graphite cathode.

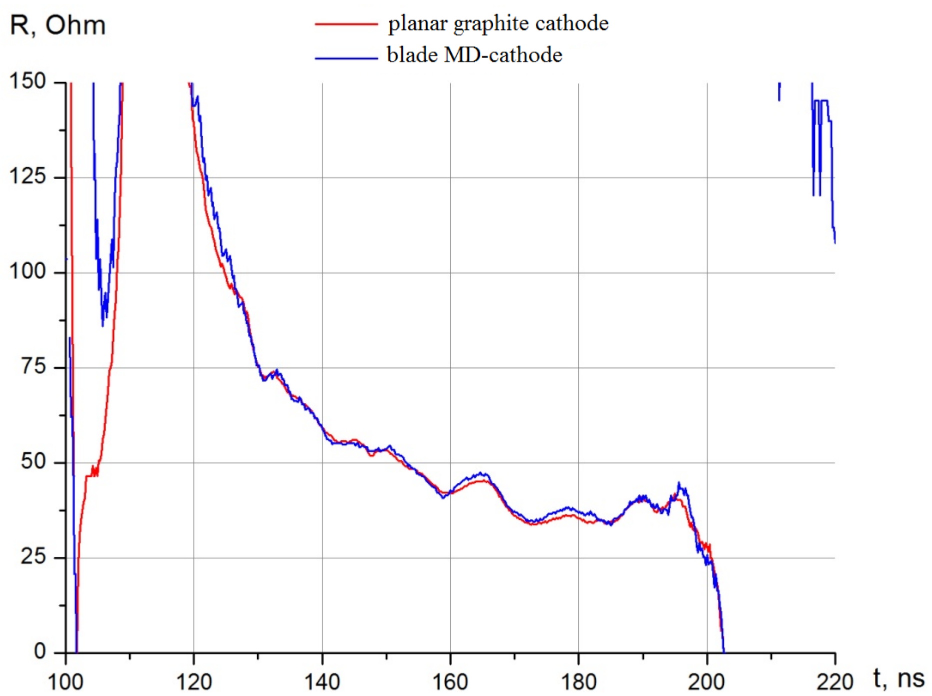

Figure 5. Comparison of the experimental impedances for different cathodes.

The decrease in the electron beam current is caused by the large C-A gap in the case of using the MD-cathode, and as a consequence, the major part of the electrons does not hit the output window (90 mm). To determine the impact degree of the electric field distribution on the efficiency of the electron beam ejection into the atmosphere, we carried out the experiments with a blade cathode with a shielding electrode moving to different V (figure 6). The value V=0 corresponds to the case when the shield is at the same level with the surface of the cathode. In the experiments, V was of the following values: 2; 4; 5; 7 mm (the cathode is dipped into the shield).

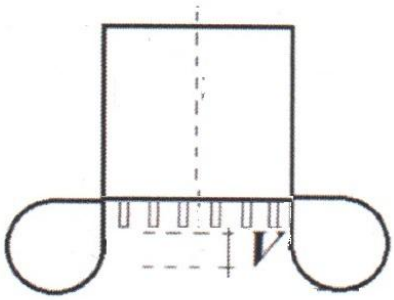

Figure 6. The escape of the shielding electrode from the cathode.

Figure 7 presents the oscillograms of the currents of the electron beam ejected into the atmosphere under different value of V.

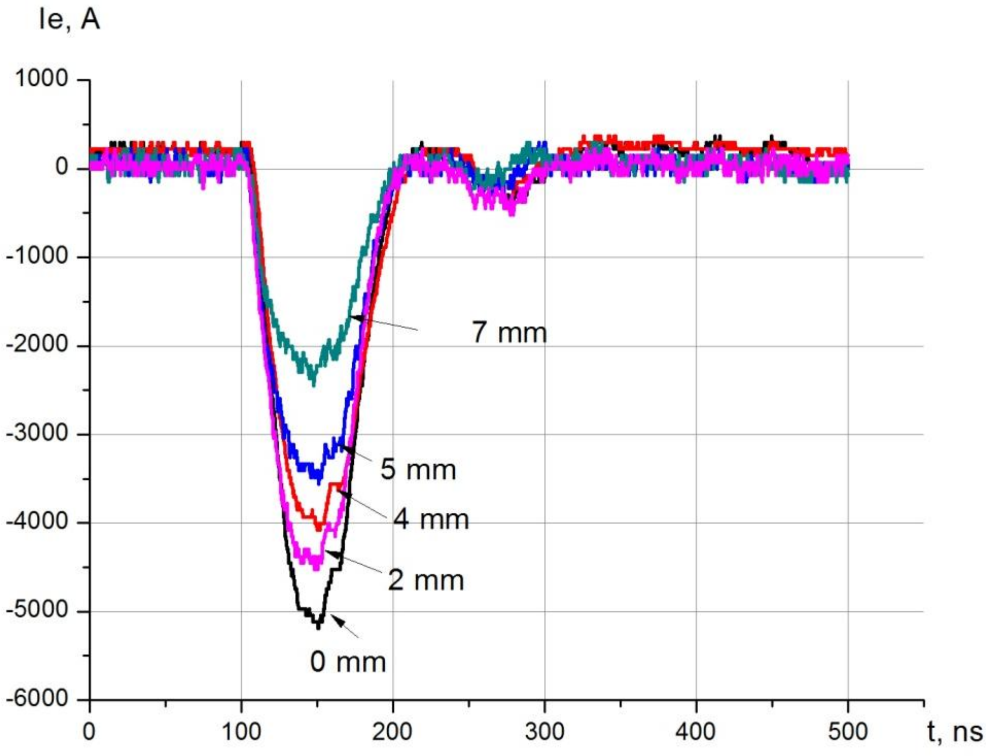

Figure 7. The electron beam current oscillograms under different value of V.

Figure 7 shows that the increase in the shielding electrode escape in relation to the cathode causes the decrease in the electron beam current, that is associated with the increase of the emitting surface (a shielding electrode), and consequently the smaller part of the electrons hit the output window.

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4. Conclusion

The obtained results show that when the blade MD-cathode is used, the ejected current is less compared to the graphite cathode. The voltage and current variations after the main pulse for the blade MD cathode (figure 3) are higher than in the case of using the graphite cathode (figure 4), that indicates the limited matching of the accelerator operation mode. The application of the shielding electrode did not enable to increase the electron beam. The maximum value of the electron beam was ~ 4.5 kA, when the blade MD-cathode with the shielding electrode is used. The given value is 1.5 times less than the values of the electron current obtained when using the graphite cathode. For the given construction of the TEA-500 pulsed electron accelerator, which is used in plasma chemical processes, the graphite cathode is best applied. The further work in improving the cathode will be directed to the increase of the blades with the same geometrical size, that will enable to increase the emissive surface and thus to decrease the C-A gap.

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