Generation and focusing of a strong-current electron beam in a low-impedance diode

V. I. Liksonov, Yu. L. Sidorov, and V. P. Smirnov

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Results are presented on the generation of an electron beam in a low-impedance diode. There is no conventional cathode for such diodes. The construction of the cathode amplifies the influence of the preliminary charging pulse on the formation of the plasma current carrying channel between the electrodes of the accelerating gap. A beam current density $>5\times10^6$ A/cm^2 was obtained at a power flux $\gtrsim 10^{12}$ W/cm^2. The amplitude of the preliminary discharge pulse current was $\lesssim 30$ kA.

To realize some of the proposals of pulsed thermonuclear fusion[1,2] it is necessary to focus an electron beam with current density 10^8–10^{10} A/cm^2. Focusing of an electron beam in a low-impedance diode, to a current density 5×10^6 A/cm^2, has been reported in[3]. A distinguishing feature of the performed experiments is the combination of the conventional cathode used for low-impedance diodes with a resistive plasma channel created beforehand with the aid of a laser,[4] or produced by exploding a thin tungsten wire stretched between the cathode and the anode.[3]

We present here results on the generation of an elec-

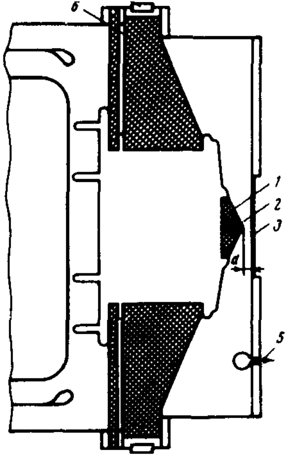

FIG. 1. Diagram of the diode of the "Triton" accelerator: 1—polyethylene cone, 2—nickel tube, 3—anode plate, 4—diode shunt, 5—magnetic probe, 6—ohmic divider.

tron beam in a low-impedance diode without using the conventional cold-emission cathode. The construction of the cathode enhances the influence of the preliminary charging pulse (120 nsec, ~70 kV) on the formation of the plasma current-carrying channel between the electrodes of the accelerating gap.

The experiments were performed with a "Triton" accelerator.[5] The high-voltage generator of the accelerator is based on a Blumlein water shaping line with output resistance 2.3 Ω. The amplitude of the voltage used to charge the shaping line is 500 kV, and the rated pulse duration is 30 nsec.

The diagram of the diode part of the accelerator is shown in Fig. 1. The plasma channel is produced by a polyethylene cone 1 with an aperture passing through it. The height of the con is 16 mm, and the base diameter is 62 mm, the aperture diameter is 1 mm. The aperture is lined with a nickel tube 2 of wall thickness 50 μ. The distance *d* between the top of the cone and the anode plate 3 usually exceeded 8 mm. The experiments were performed at pressures $(3-7)\times 10^{-5}$ mm Hg in the accelerating tube.

The diode current was registered with a shunt 4 and a magnetic probe 5. The voltage was monitored with an ohmic divider 6, with a solution of cuprous oxide as the high-voltage arm. The hard bremsstrahlung was registered with a plastic scintillator combined with a coaxial FEK-11 photocell. The time resolution of the x-ray pickup was not worse than 5 nsec. The diameter of the electron beam was determined from the erosion tracks on the anode plate and from integral photographs obtained with a pinhole camera and the x-rays. The camera pinhole diameter was 0.3 mm and the focal length was 180 mm.

The x-ray pictures of the electron beam were photographed behind a stainless-steel anode plate 1 mm thick. The beam diameter was ~1.5 mm. The dimensions of the crater produced as a result of the interaction of the electron beam with the anode plate correspond approximately to the diameter of the x-ray image. Fracture plate, thus evidencing the intensive evaporation of the metal.[6]

An increase of the beam current density leads to a local overheating of the surface and evaporation of the anode-plate material, since the cooling due to thermal conductivity is proportional to the beam diameter and does not play a noticeable role at the focusing observed in our experiment. Each shot pierced a hole through the 1-mm stainless-steel anode plate; fractures were observed on the periphery of the hole. To estimate the beam energy, a calorimetric body of aluminum was placed at a distance 3 mm from a titanium anode foil 50 μ thick. The sensitive thermocouple did not register an appreciable temperature rise, and the loss of mass of material per shot was 0.1 g. The damage produced on the surface of the aluminum was characterized by the absence of an aureole of molten metal. The depth of the crater was 1.4 mm, which is several times larger than the maximum electron mean free path. Taking into account the result of[7], we can assume that the mass loss of the calorimetric body is due mainly to evaporation of matter. In this case an estimate yields for the beam energy a value ~10^3 J.

The operating regime of the diode is characterized by a large value of the preliminary-pulse current. The amplitude of the preliminary-pulse current in the experiment was ≲ 30 kA. The presence of a through aperture in the dielectric cathode determines the development and the localization of the plasma channel in the course of the preliminary pulsed discharge. However, the diode impedance was determined by the distance *d* between the tope of the cone and the anode plate. Figure 2 shows oscillograms for $d = 9.5$ mm (I) and $d = 11$ mm (II). In-

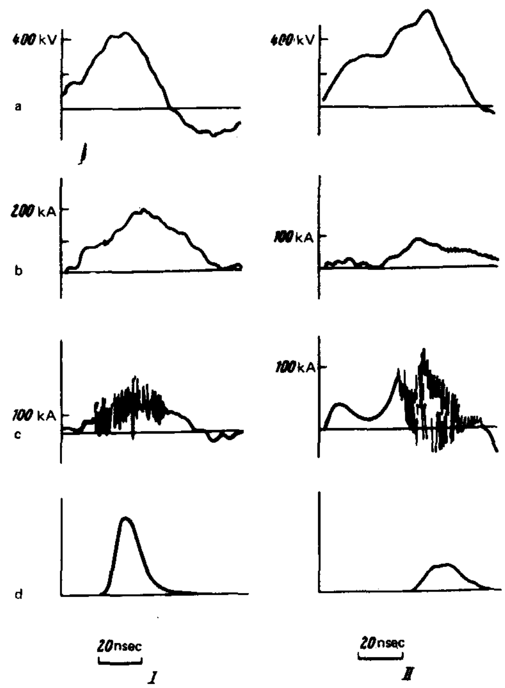

FIG. 2. Influence of the length of the discharge gap *d* on the diode impedance: I) $d = 9.5$ mm, II) $d = 11$ mm. a) Voltage oscillograms, b) diode current oscillograms, c) magnetic-probe signals, d) x-ray pickup signals.

creasing the gap by 1.5 mm increased the impedance at the maximum of the current from 1.9 to 6 Ω. The inductive component was not subtracted from the voltage oscillograms (Fig. 2a). It follows from the results of experiment with a diode short circuited by a conductor of 4 mm diameter that the inductance of the structure itself did not exceed 4×10^{-8} H. Figure 2b shows oscillograms of the diode current.

The magnetic-probe signals, Fig. 2c, reveal high-frequency oscillations, and the critical current corresponding to the start of the oscillations was approximately constant in all experiments at 60—70 kA. Notice should be taken of a correlation between the high-frequency oscillations and the hard x-ray signals, Fig. 2d. The kinetic energy of the electron beam, as follows from estimates of the hardness of the x-rays by a filter method, does not exceed the applied voltage, and the termination of the x-ray pulses, Fig. 2d, coincides with the decrease of the diode voltage to zero.

To determine the beam current, control measurements of the x-ray intensity were performed with the "MS" accelerator[5] operating in the usual regime. From the results of the comparison it follows that that beam current is not less than 75% of the diode current, and the averaged beam current density at the instant of the x-ray pulse maximum exceeds 5×10^6 A/cm^2. Thus, by using a preliminary pulse discharge to produce a plasma channel, we succeeded in obtaining a current density $>5\times10^6$ A/cm^2 at a power flux $\gtrsim 10^{12}$ W/cm^2.

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