

Behavior specificities of the plasma in the REB – polymeric anode interactions.

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Abstract. To study Relativistic Electron Beam (REB) interaction with a set of polymeric targets we have made experiments for the investigation of the plasma dynamics in high-voltage diode of high-current generator. It is necessary for applied goals, such as correction of mathematical models of high power density deposition in the matter, for testing materials reaction under the powerful impulse of ionizing radiation, etc. An electron-optical streak camera (EOC) was used to measure the velocity of the visible light border of the plasma glowing. It was estimated to be from 10 to 35 km/s at the energy-release density in range of 200 – 800 J/cm². In a few of experiments, besides regular motion of contrast border in the direction from electrodes to the middle of the diode, the motion from the middle to the periphery of the high-voltage diode with velocity up to 500 km/s was observed. It was by an order of magnitude greater than regular one.

1. Introduction

Investigation of the various material properties is necessary for a wide number of scientific and technical purposes. These studies are especially important for material technologies, radiation resistance of the electronics. Experimental data in this field is also essential to obtain parameters and coefficients in equations of state for polymeric materials and for mathematical models verification [1], [2]. Moreover, the experiment reveals interesting details are to be introduced in models. For example, we demonstrated that materials with similar chemical composition may have very different response to the same powerful pulse impact [3], [4].

One of the most important parameters, which can be measured, is the velocity of ablated target material. The glow of expanding matter was registered in visible range by streak-camera.

The choice of material was based on importance in different applications and on existence of worked out equations of state for the polymeric materials such as epoxy. The second type of targets was made of polystyrene. View of a set of polymeric targets is presented in figure 1.

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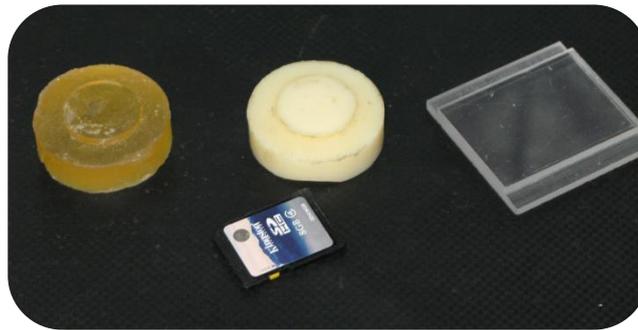


Figure 1. Types of targets. From left to right: amber-colored epoxy resin; milk-colored epoxy; polystyrene. SD-card is given for scaling.

2. Experimental set-up

This experiment was carried out on high-current generator “Calamary” with the following parameters: current was above 25 kA; output voltage up to 300 kV; maximal electron’s energy was 350 keV (median energy of Calamary potential); pulse duration on FWHM was 100 ns [5].

The Calamary is completely simple in construction. Basic element of device is double forming line (DFL) with electrical length 70 ns. DFL’s forming spark-gap switch is powered by the 20 stage Marx generator, containing 140 capacitors of 0.1 μF in each. There are a lot of electromagnetic interference (EMI) on the Calamary machine caused by air spark-gap switches using in the generator. Distilled water is used in DFL as a dielectric: its specific resistance is $2 \times 10^6 \Omega \times \text{cm}$.

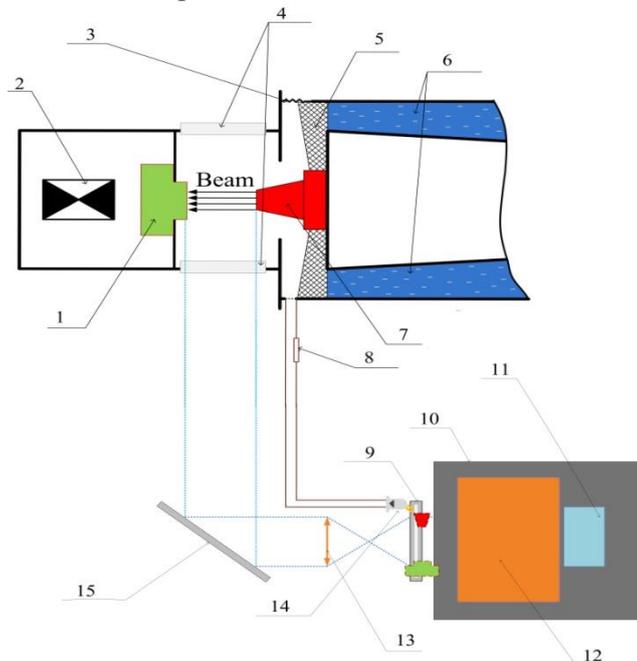


Figure 2. Diagnostics scheme: 1 – target (anode); 2 – pinhole camera; 3 – current instrument shunt; 4 – glass windows for observation; 5 – insulator; 6 – distilled water; 7 – brass cathode; 8 – resistor; 9 – entering slit of EOC; 10 – EMI shield; 11 – photo camera; 12 – EOC; 13 – lens; 14 – LED; 15 – mirror.

Diagnostics, which scheme is sketched in figure 2, consists of X-ray pinhole camera 2 (see in figure 3) and electron-optical streak camera 12 equipped by mirror 15, focusing lens 13 and placed in shielding box 10 against EMI. An image of EOC screen is captured by photo camera 11. Light emitting diode 14 (LED) – novelty in our registration system. LED is used for synchronization of generator current with EOC streak and powered from current shunt 3 via the resistor.

Energy-release area on the sample surface was measured by the double-film pinhole X-ray camera. The second X-ray film was situated behind the amplification luminophor inset [6]. The density of energy release was measured in range from 200 to 800 J/cm² [7].

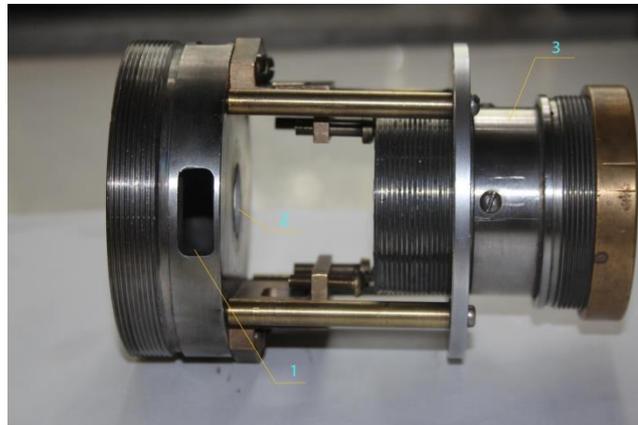


Figure 3. Diode unit: 1 – viewing hole; 2 – target place; 3 – pinhole camera.

3. Experimental results

In figure 4 EOC images from experiments with different sample materials are seen. Images were given as typical, to present common form of illuminated area. In these images plasma from the anode arises a bit later then from the cathode, and its velocity is rather constant.

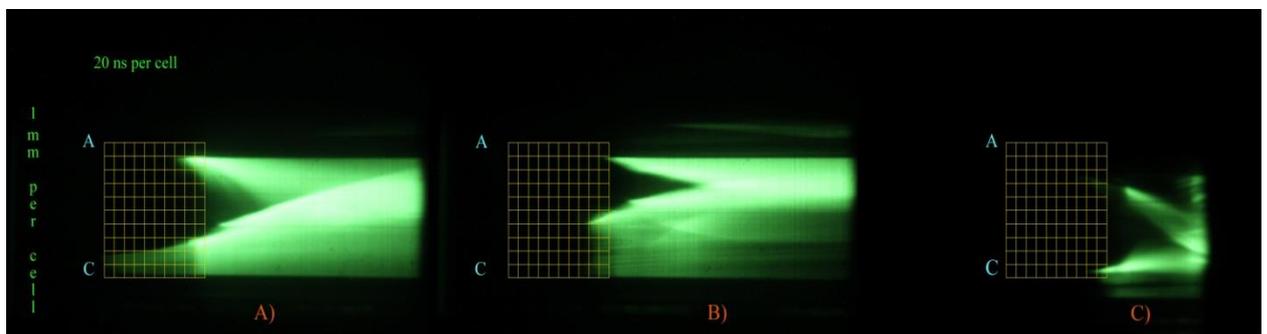


Figure 4. Examples of EOC records: A – two aluminum foils are as a target; B – two Al foils with smaller gap; C – epoxy target.

However, when the diode gap was of 7-8 mm the phenomena presented in figure 5(a, b) in experiment with polystyrene anode was observed. Weakly lighting matter moves regularly up to the reversal of diode voltage polarity. Then we observe the flashout near the diode axis and glow expansion from the axis to the electrodes with the velocity approximately of 500 km/s.

This effect is also observed on epoxy targets (in figure 5 (c, d)). We called it as “Cobra’s teeth” – that’s why EOC images looks like it. It should be noted that “Cobra’s teeth” for epoxy targets is reproduced more stable than for polystyrene anodes.

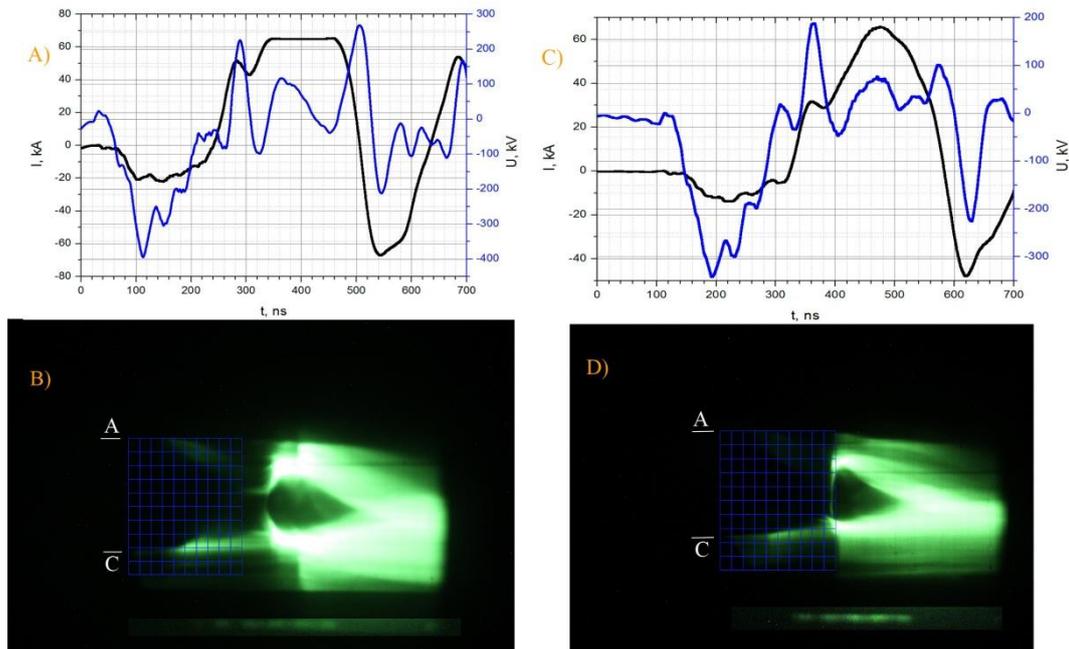


Figure 5. Experimental results: A and C – waveforms of the generator current (black graph) and voltage (blue graph) for polystyrene (A) and epoxy (C) targets; graphs were synchronized by the time with located below EOC images; B and D – “Cobras’s teeth” on polystyrene and epoxy anodes respectively.

4. Conclusion

In several experiments we observed not only the typical motion of glowing matter from electrodes to center of high-voltage diode, but also we saw the motion from center to the periphery of the diode with velocity by an order greater than typical one – hundreds of kilometers per second. It occurs after the diode polarity reversal.

We suppose that the cause of this phenomenon consists in the non-radiating matter collection near the diode axis during the first half-period of the discharge and initiation of the discharge glow through well conductive plasma after the diode polarity reversal at high current magnitude. For checking hypothesis, we planned to enrich diagnostics by the laser shadow photography and by the second pinhole camera (perpendicularly to the first camera).

Acknowledgements

This work was supported by grant of RFBR No. 15-02-03544-A.

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