Pulse Discharge and Submicrosecond E-Beam Actin on Metal Surfaces

M.A. Shulepov, S.B. Alekseev, I.M. Goncharenko, N.N. Koval', V.M. Orlovskii, V.F. Tarasenko

Institute of High Current Electronics
2/3, Akademicheskii Ave., 634055.Tpomsk, Russia

Abstract – The studies on simultaneous action of a pulse discharge and submicrosecond e-beam on anode surface have been performed. It has been shown that color of anode surface becomes changed and erosion traces are visual resulting from such action. Besides that, cathode material transfer to anode is observed.

1. Introduction

The experiments carried out in 2002 have shown that electron beams of small duration are formed in gas diodes at atmospheric pressure of helium, air, nitrogen and CO_2–N_2–He and short voltage front [1–3] (super-short avalanche electron beam – SAEB [4]). Amplitude of the beam current was tens – hundreds amperes, and energies of electrons were tens – hundreds keV. On formation of a submicrosecond e-beam in a gas diode, there was observed a volume discharge (volume avalanche discharge initiated by an electron beam – VADIEB discharge) [4], and duration and amplitude of discharge current exceeded more than by an order duration and amplitude of an electron beam [4–6]. Specific powers of energy input higher than 0.4 GW/cm^3 have been realized in the volume stage of discharge under the pressure of air of 1 atm.

The goal of this work was to study simultaneous action of a subnanosecond electron beam and gas diode plasma on anode (metal surface). Interaction with metal surface of a single subnanosecond e-beam formed in a gas diode was investigated as well. Besides that, the studies of peculiarities of subnanosecond e-beams and volume discharge formation were continued. Particularly, such continued studies have revealed that in an uniform electric field under the short voltage pulse front and nanosecond pulse duration a volume discharge and an electron beam are also formed without any additional preionization source in various gases under pressures higher than atmospheric (helium – 6 atm, nitrogen – 3 atm).

2. Experimental Set-up and Methods

Two generators with which voltage pulses with duration of several nanoseconds and front of 0.5 ns and less were formed and various construction gas diodes were used in our experiments. The gas diodes have a flash anode and a small-sized cathode that provided additional gain of an electric field in the near-cathode area. The pulse generator 1 [7] (SINUS) had an additional transfer line installed in it having wave impedance of 40 Ohm, and it was also foreseen to increase pressure in a gas diode up to 6 atm. Retrofitted generator formed a 40-Ohm pulse on a matched load with the first peak voltage of ~180 kV and its duration at FWHM of ~1.5 ns, at voltage pulse front of ~0.5 ns. The cathode was made in the form of a cylinder with the diameter of 6 mm from Ti foil 50 μm in thickness.

The generator 2 was similar to RADAN-220 generator [8], but had the less pulse duration of ~1 ns, and the minimal in such conditions sizes of a gas diode (Fig. 1). The experiments with the generator 3 were carried out with the same cathode. An anode for all three generators was formed from AlBe foil 40 μm in thickness or polished stainless steel or copper disks. Gas gap distance was set in the range of 11–25 mm.

Pretreated anodes were investigated by using a MMR-4 microscope. Anode surface was photographed with a digital camera at various image enhancements.

For signals control from a capacitive divider, collectors or shunts there were used 4 GGz, 20 GS/s (20 points per 1 ns) TDS-7405 oscilloscope or 0.3 GHz, 2.5 GS/s (2.5 points per 1 ns) TDS-334 oscilloscope. Discharge glowing was photographed by a digital camera. Influence of the exposed area of the cathode material, number of generator shots and diode gas filing was studied.

3. Experimental Results

As it was earlier shown in [1–6], in the non-uniform electric field with a small-sized cathode at the short voltage front at a gap, there forms an electron beam with an amplitude of tens – hundreds amperes. At that, a volume discharge is being observed in the gap looking like a cone or several cone-like filaments with bright spots on the cathode. Metallic samples set instead of the anode bear influence of the volume discharge plasma and electron beam. Specific energy input in the discharge plasma contacting with the anode reaches 1 J/cm^3, and specific power of the energy input may exceed 400 GW/cm^3. In addition to the discharge plasma the anode is affected by an electron beam having three electron groups by energies as hundreds, tens, and unities of keV.

As a preliminary with the generator 2 and a gas diode filled in with air at pressure of 1 atm, action on a titanium sample by a single subnanosecond electron beam was studied. For that before the samples 40 µm thickness AlBe foil absorbing electrons with the energies up to 45 keV and preventing plasma contact with the samples under study was set. Interaction was made by only an electron beam with the energy of tens – hundreds keV, and the maximum of the electrons distribution by their energies corresponded to electron energy of about 70 keV. On action made by a single electron beam after 5000 shots there were no observed any significant changes in samples surface due to the small energy of the beam.

On simultaneous action by plasma and electron beam (the same conditions, only AlBe foil was absent) just after 200 pulses one could observe changes of sample surface. With pulse number increasing up to 500 the changes in surface structure became more expressed. Fixed were the zones of melt and metal surface modifications.

The experiments on the set-up 1 were performed at simultaneous action by an electron beam and a volume discharge in helium at pressure in the chamber of 1 atm. A cathode (titanium foil of 50 µm in thickness convolute in tubule 6 mm in diameter) was set at a distance of 22 mm from the anode. The anode was made from a copper disk 60 mm in diameter and 5 mm in thickness. The discharge current duration was 2 ns and its amplitude was 4.3 kA. Generator no-load voltage was ~390 kV, pulse repetition rate was 4 Hz, and anode plane was perpendicular to the central cathode axis. The action was performed in a pulse repetitive mode by 20400 pulses. Under such action and given gap distance and pressure there were visually observed bright anode spots.

A photo of a sample is shown in Fig. 1, where it is possible to distinguish three main zones. The exposed area consists of several concentric zones nested one into another.

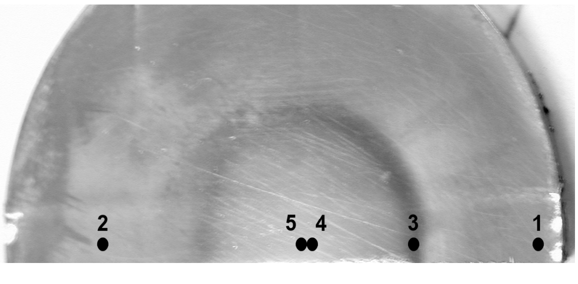

Fig. 1. A photograph of a sample (diameter is 60 mm)

The 1-st zone. At the anode end where electron beam and discharge are minimally intensive (see Fig. 2), color of the anode surface has slightly changed (darker than the color of the initial sample), and traces of weak surface erosion are seen. The surface dried without effort reveal under thin coating a bright film having weak adhesion properties (Fig. 3).

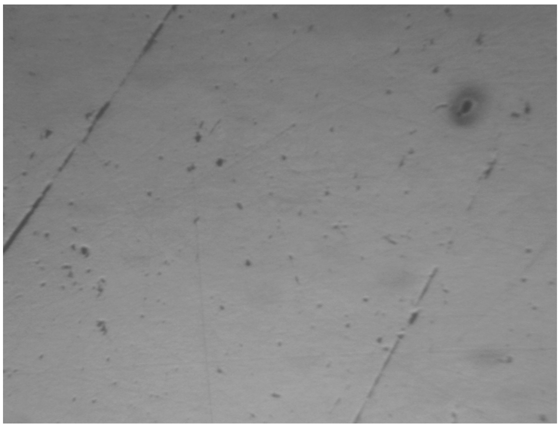

Fig. 2. Zone 1 of exposed area (point 1), enlargement is 54 times

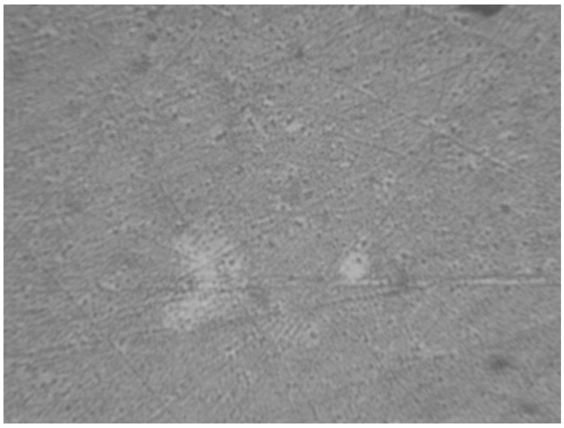

Fig. 3. Zone 2 of exposed area (point 1) after being dried by the dry cambric, enlargement is 967 times

The 2-nd zone. The circular zone is situated closer to exposed area center, the background is dark-red, the diameter is 26 mm. Erosion traces are not found. Surface color is far darker than the initial sample has (Fig. 4).

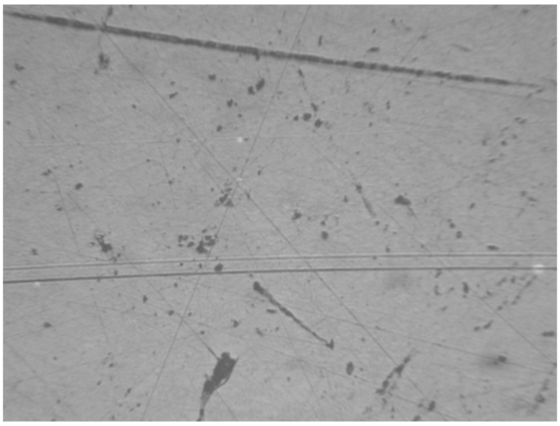

Fig. 4. Zone 2 of exposed area (point 3), enlargement is 156 times

The 3-rd zone. It is situated in the center of the exposed area having a diameter of ~12 mm and white color. The third zone contains traces of erosion (anode spots). More distant from the center the surface color becomes darker. Probably, the white color is the result of sputtering and implantation of titanium on the anode surface (Figs. 5–7). It is seen from Fig. 7 that such sputtering ingress has either occurred in the scratch.

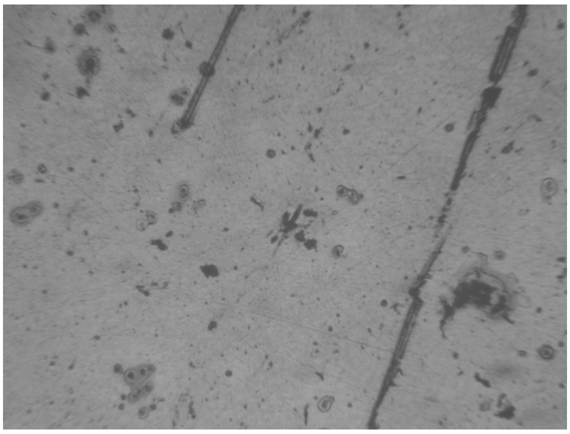

Fig. 5. Zone 3 of the exposed area (point 4), enlargement is 156 times

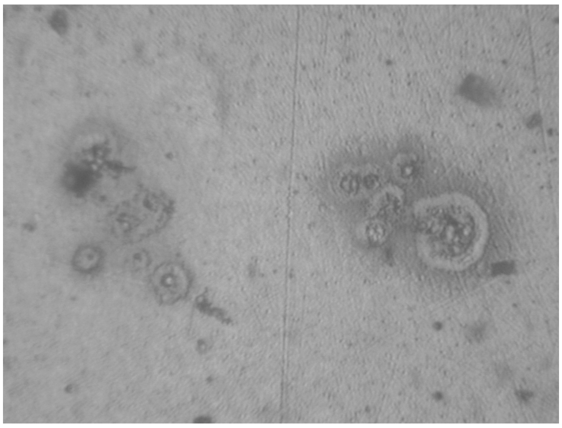

Fig. 6. Zone 3 of exposed area (point 4), enlargement is 778 times

Conclusions

The studies carried out have shown that simultaneous action by VADIEB and SAEB have influence upon anode surface resulting in its color change, and

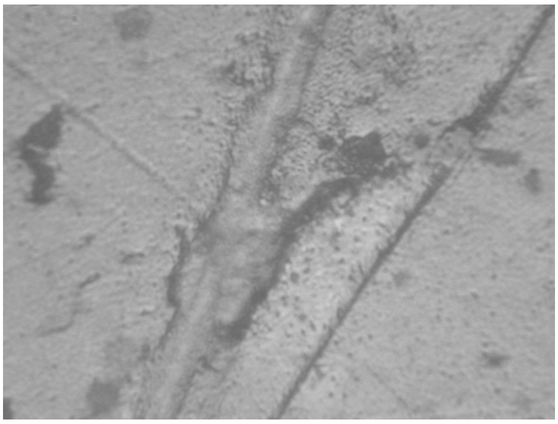

Fig. 7. Zone 3 of exposed area (point 5), enlargement is 778 times

erosion traces are visual. Besides that, cathode material transfer to anode takes place. Action of this type is supposed to have application in the number of technological processes, so, the studies performed in this direction are planned to be continued.

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