

Effect of Polarity of the Voltage Pulse on the Appearance of the Discharge at the Breakdown in the Nonuniform Electric Field

D. V. Beloplotov^{1, 2}, M. I. Lomaev¹, D. A. Sorokin¹, V. F. Tarasenko^{1, 2*}

¹*Institute of High Current Electronics, 2/3 Akademicheskoy Ave., Tomsk 634055, Russia.*

²*Tomsk State University, 36 Lenin Ave., Tomsk 634050, Russia.*

Authors' contributions

This work was carried out in collaboration between all authors. The author VFT made the estimations and wrote with the author MIL the manuscript. The authors DVB, MIL and DAS carried out the experiments. All the authors read and approved the manuscript.

ABSTRACT

At the pressures 0.5-3 atm of the air, nitrogen, argon and sulfur hexafluoride (SF₆) an appearance of the nanosecond discharge in the nonuniform electric field is investigated. In all gases at the negative polarity of the voltage pulses, supershort avalanches electron beam (SAEB) and (or) x-ray were registered. It is seen, that formation of the bright spots on the flat electrode at the negative polarity of the electrode with small radius of curvature is observed during the changing of the discharge current polarity. It was shown, that at the positive polarity of the electrode with a small radius of curvature bright spots on the flat electrode arise due to the participation of the dynamic displacement current in the gap conductance.

Keywords: Nonuniform electric field; runaway electron preionized diffuse discharge; air, nitrogen, argon and sulfur hexafluoride; dynamic displacement current; supershort avalanches electron beam.

1. INTRODUCTION

Formation of the diffuse discharge in the nonuniform electric field without using of additional sources of the preionization during the breakdown in the atmospheric air was shown to be due to the generation of the runaway electrons and x-ray [1-4]. Using of electrode with small radius of curvature allows obtaining runaway electrons in the various gases at the high pressures. It was shown [2], that diffuse discharge formation due to the applying of the high-voltage nanosecond pulses to the gap occurs for the both negative and positive polarity of the electrode with a small radius of curvature. Runaway electrons preionized diffuse discharge (REP DD) was obtained for the both in single shot [2, 3] and repetition rate [4]

* Corresponding author: Email: VFT@loi.hcei.tsc.ru.

modes. We consider that formation of REP DD at the positive polarity of the electrode with a small radius of curvature is related with generation of runaway electrons and x-ray as well. The aim of this paper is to investigate effect of the voltage pulse polarity on the appearance of REP DD in the SF₆, nitrogen, argon and air at the pressures 0.5-3 atm.

2.1 Experimental Details

In the setup the RADAN-220 generator [5] was used (Fig. 1). High-voltage pulses of the both negative and positive polarities from the pulser RADAN-220 applied across the gap. The pulser has an impedance of 20 Ω and produced high-voltage pulses with a FWHM of ~2 ns (with a matched load) in the discharge gap at rise time ~0.5 ns.

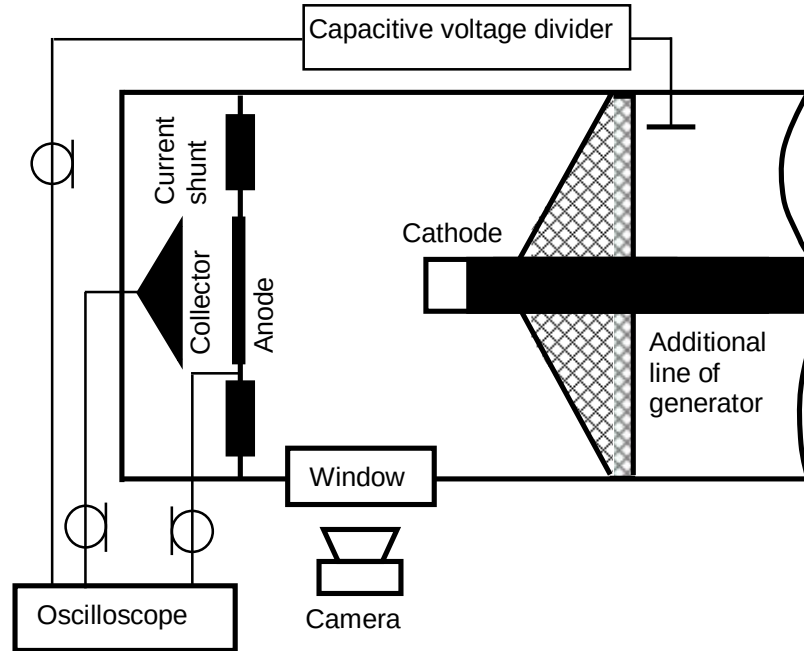


Fig. 1. The schematic diagram of experimental setup.

Amplitude of the voltage pulse depended on pressure and sort of the gas. Its value varies from 150 to 340 kV in these experiments. The potential tubular electrode of 6 mm in diameter was made of 100 μm thickness stainless steel foil. The plane electrode was an Al foil which was connected with the chamber case by means of current shunt made of chip-resistors. Measurements of the supershort avalanche electron beam (SAEB) amplitude were carried out with the collector located behind the Al foil. The gap was of 8 or 13 mm.

2.1 Methodology

The experiments were carried out in air, nitrogen, argon and sulfur hexafluoride (SF₆) at room temperature. The signals of applied voltage, current through gap, and supershort avalanche electron beam (SAEB) current behind the anode foil were measured by a digital oscilloscope Tektronix DPO70604 (6 GHz, 25 GS/s). Images of discharge glow were obtained with using of digital camera Sony A100 at an exposure time of 1 s. Typical waveforms of the voltage pulse, current through the gap and SAEB current at the argon pressure of 1 atm using negative polarity of the electrode with a small radius of curvature and interelectrode distance of 13 mm are presented in Fig. 2.

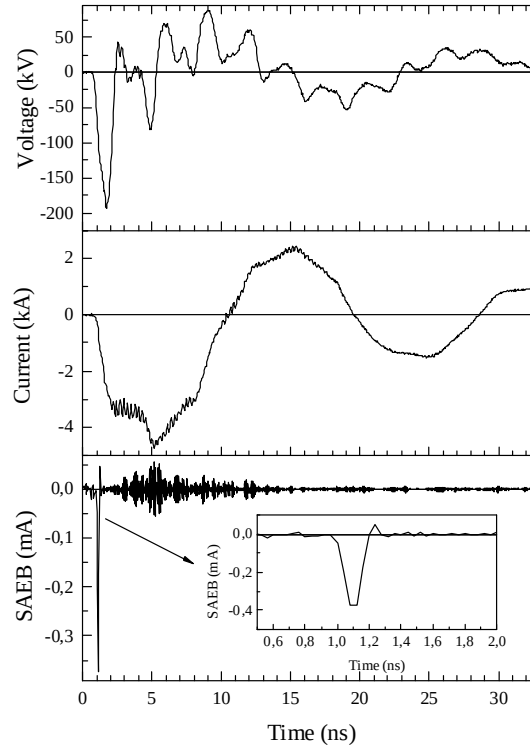


Fig. 2. Waveforms of voltage pulses, current through gap, and runaway electron beam behind foil (SAEB) with negative polarity of generator. Argon pressure is 1 atm, interelectrode distance is 13 mm.

3. RESULTS AND DISCUSSION

Integrated images of REP DD plasma glowing are presented on Fig. 3. All images for interelectrode distance 13 mm demonstrate diffuse discharge forming due to the propagation of the ionization wave bridged the gap in time less than 1 ns [3]. There are cathode and anode spots on the electrodes (images c, e, f, i, k). These spots may be absent on the flat electrode. As well as a spark leaders (a, g) and spark breakdown (d) can be observed on the background of the diffuse discharge. At the small repetition rate (<1 Hz) the following regularities of REP DD formation were established. Discharge appearance in some pulses can vary, but the probability of such deviations was small. Most easily REP DD is formed in the nitrogen and SF₆ at the negative polarity of the tubular electrode (e, i, k). When the polarity of the tubular electrode is positive, bright spots are appeared on the flat electrode (b, d, h, j, l). At the pressure 3 atm of the nitrogen only spots on the flat electrode were out (f). Bright spots on the flat electrode were appeared at the gap distance decreasing. As well as, bright spots on the flat electrode at the negative polarity of the tubular electrode are observed when gas pressure decrease (a). At the gas pressure and (or) interelectrode distance decreasing the impedance of the discharge gap decreases and oscillatory mode (voltage and current) is observed, Fig. 2.

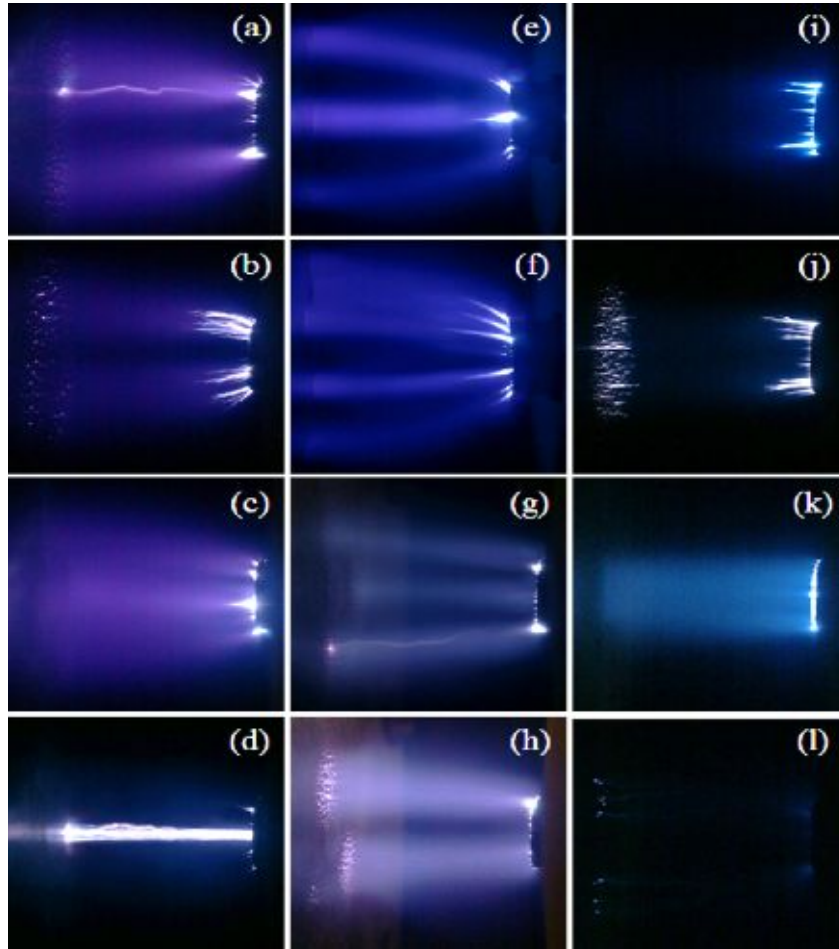


Fig. 3. Discharge glowing in: air at pressure of 0.5 atm (a, b), 2 atm (c, d); nitrogen at pressure of 3 atm (e, f); argon at pressure of 1 atm (g, h); SF_6 at pressure of 0.5 atm (i, j), 1.5 atm (k, l). Polarity of potential tubular (right) electrode is negative (a, c, e, g, i, k), positive (b, d, f, h, j, l).

In argon, bright spots on the flat electrode were observed at the both polarities of the voltage pulse (g, h) and throughout gas pressures range. It is related with less impedance of the discharge plasma and oscillatory mode of discharge in the argon, because of step ionization effect.

In all gases at the negative polarity of the voltage pulses, SAEB, Fig. 2, and x-ray were registered. Attempts to register SAEB and x-ray in these conditions at the positive polarity of the tubular electrode failed. However, we consider that generation of the SAEB and x-ray at the positive polarity of the voltage pulses is occurred in all gases. Preionization of the discharge gap at the positive polarity of the electrode with a small radius of curvature takes place owing to characteristic radiation [6].

Appearance of the bright spots on the flat electrode at negative polarity of the electrode with a small radius of curvature and oscillatory mode of the discharge current is due to the change of polarity of the flat electrode, which becomes cathode. Since in this case, discharge current is of some kiloamperes, the current from the flat electrode is also provided due to the explosive electron emission.

With positive polarity of the electrode with a small radius of curvature explosion of the microinhomogeneities on the anode is due to increase of the current through the gap during the dense plasma's front movement from the anode to the flat cathode. In this case, the current through the part of gap is provided by the charging of the compressible capacitor due to the participation of the dynamic displacement current in the gap conductance [7]. However, it is necessary to provide effective electron emission from the flat cathode after discharge gap closing by the dense plasma. Explosive electron emission facilitated this. Therefore, bright spots appear on the flat cathode.

4. CONCLUSION

It was found, that in the air and other gases bright spots on the flat electrode arise during the change of direction of the current through the gap and increase of the voltage pulse duration. It was shown, that at the positive polarity of the electrode with a small radius of curvature bright spots on the flat electrode arise due to the participation of the dynamic displacement current in the gap conductance.

ACKNOWLEDGEMENTS

We acknowledge financial supports from Russian Foundation for Basic Research (Project No. 12-08-00105-a) and Russian President Grant ScSci-1305.2014.2.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Tarasova LV, Khudyakova LN, Loiko TV, Tsukerman VA. Runaway electrons and X-rays of nanosecond discharges in gases at pressures of 0.1–760 torr. *J. Tech. Phys.* 1974;44(3):564–568.
2. Kostyrya ID, Tarasenko VF. Formation of a volume discharge in air at atmospheric pressure upon application of nanosecond high-voltage pulses. *Russian Physics Journal.* 2004;47(12):1314–1316.
3. Baksht EH, Burachenko AG, Kostyrya ID, Lomaev MI, Rybka DV, Shulepov MA, Tarasenko VF. Runaway-electron-preionized diffuse discharge at atmospheric pressure and its application. *J. Phys. D: Appl. Phys.* 2009;42:185201(9pp).
4. Shao T, Zhang Ch, Niu Zh, Jan P, Tarasenko VF, Bakst EKh, Kostyrya ID, Shut'ko YuV. Runaway electron preionized diffuse discharges in atmospheric pressure air with a point-to-plane gap in repetitive pulsed mode. *Journ. Appl. Phys.* 2011;109:083306.(7pp).
5. Zagulov FYa, Kotov AS, Shpak VG, Yurike YaYa, Yalandin MI. RADAN-small-sized pulse-repetitive high-current accelerators of electrons. *Prib. Tekh. Eksper.* 1989;23:146–149 Russian.
6. Kozyrev AV, Tarasenko VF, Baksht EKh, Shut'ko YuV. Soft X-ray generation and its role in breakdown of air gap at elevated pressure. *Technical Physics Letters.* 2011;37(11):1054-1057.
7. Shao T, Tarasenko VF, Zhang Ch, Burachenko AG, Rybka DV, Kostyrya ID, Lomaev MI, Baksht EKh, Yan P. *Rev. Sci. Instrum.* 2013;84:053506(7pp).