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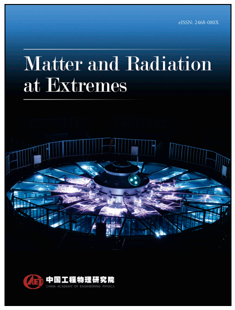

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Review of supershort avalanche electron beam during nanosecond-pulse discharges in some gases

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Abstract: Supershort avalanche electron beam (SAEB) plays an important role in nanosecond-pulse discharges. This paper aims at reviewing experiments results on characteritics of SAEB and its spectra in different gases in nanosecond-pulse discharges. All the joint experiments were carried in the Institute of High Current Electronics of the Russian Academy of Sciences and the Institute of Electrical Engineering of the Chinese Academy of Sciences. In these experiments, the generation of a SAEB in SF_6 in an inhomogeneous electric field was studied on three generators with pulse rise times of 0.3, 0.5 and ~2 ns. Firstly, the comparison of SAEB parameters in SF_6 with those obtained in other gases (air, nitrogen, argon, and krypton) is introduced. Secondly, the SAEB spectra in SF_6 and air at pressures of 10 kPa (75 torr), and 0.1 MPa (750 torr) are reviewed and discussed. Finally, 1.5-D theoretical simulation of the supershort pulse fast electrons beam in a coaxial diode filled with SF_6 at atmospheric pressure is described. The simulation was carried out in the framework of hybrid model for discharge and runaway electron kinetics. The above research progress can provide better understanding of the investigation into the mechanism of nanosecond-pulse discharges.

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Keywords: Runaway electron, Supershort avalanche electron beam（SAEB）, SF_6, Gas diode, High pressure, Simulation, Hybrid model

1. Introduction

In recent years, there have been a lot of investigations carried on generation of runaway electrons (RAEs) in laboratory gas discharges at increased pressure (e.g., see reviews [1, 2] and editor collection [3]). Most attention in the field in the last decade was focused on the parameters and properties of RAEs in atmospheric air and on the mechanism of their generation. New experimental data were obtained due to the development of measuring equipment and technologies. The runaway electron beams downstream of a foil anode was proposed to be called a supershort avalanche electron beam or shortly SAEB [4], which term we use throughout the paper.

Among the important results obtained since 2003, the most significant achievement is that the number of RAEs downstream of the anode measured in atmospheric air has increased substantially. In the previous work [5], the number of RAEs was 10^9, and subsequent works of this scientific group failed to increase this value [6, 7]. However, in 2003, about a ten-fold increase in the number of electrons and amplitude of the beam current were observed by the Institute of High Current Electronics (IHCE) [4, 8]. Note that the main data on the generation of RAEs and X-rays obtained till 2003 were reported in the monograph [6], and analysis of various RAE measuring techniques, including those used by IHCE, was given elsewhere [1, 9-15].

The generation of SAEBs with maximum amplitudes requires numerous electron avalanches in the gap which, when overlapped, form a dense diffuse plasma. The front of this plasma crosses the gap with a high velocity from the cathode to the anode, generating a SAEB between the dense plasma front and the anode. In atmospheric air, the highest SAEB amplitude till now was obtained on the SLEP-150 generator [16] and was ≅100 A downstream of Al foil anode [10]. The full width at half maximum (FWHM) of the SAEB pulse was ~100 ps and the number of electrons in the beam was more than 6×10^{10}. It should be noted that the SAEB amplitude and the number of RAEs mentioned above are not the limit and could be increased by decreasing the pulse rise time [1, 5] as well as by optimizing the cathode material [17] and cathode design [9, 10]. The effect of the cathode material and design on the SAEB amplitude was also studied in other works [1, 12, 14, 18-21]. In decreased pressures of nitrogen, hydrogen and helium, the SAEB amplitude from the entire anode foil on the SLEP-150 generator reached ~500 A with an FWHM of the SAEB of ~100 ps [22]. Images of RAEs and/or X-rays on films were obtained in nitrogen at a pressure up to 4 MPa [23].

The SAEB width (~100 ps) measured in atmospheric air was first reported in Ref. [18]. The SAEB width depended on the anode diaphragm diameter, interelectrode gap, kind of gas and gas pressure [1, 10, 13, 14, 22, 24-27]. When the SAEB was measured from a 1-mm-diameter diaphragm, the FWHM of SAEB current was 5 ps [26, 27]. However, the FWHM of SAEB measured from the entire anode foil surface in atmospheric air was ~100 ps. Furthermore, the SAEB was detected in the direction opposite to the anode when the cathode was a grid [28].

The RAEs were not only obtained in a single shot, but also observed at high pulse repetition frequency. For example, the X-rays produced by RAEs in batches of 1500 pulses were detected at a frequency up to 3 kHz at atmospheric pressure [29]. In a repetitive mode, the X-rays arose at a pulse repetition frequency of 1 kHz were measured in the Institute of Electrical Engineering of the Chinese Academy of Sciences (IEE) [30-36]. When the pressure decreased, SAEB was also measured by a collector at frequencies of 1 kHz [37]. The inception of RAEs and breakdown process in nanosecond pulse gas discharges was