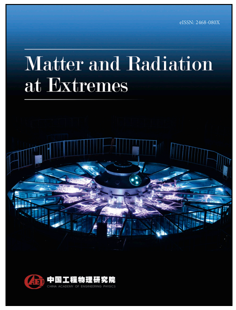
Accepted Manuscript



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Andrey V. Kozyrev, Vasily Yu. Kozhevnikov, Natalia S. Semeniuk

PII: S2468-080X(16)30075-9

DOI: 10.1016/j.mre.2016.10.001

Reference: MRE 27

To appear in: *Matter and Radiation at Extremes*

Theoretical simulation of high-voltage discharge with runaway electrons in sulfur hexafluoride at atmospheric pressure

Andrey V. Kozyrev[a*], Vasily Yu. Kozhevnikov[a,b], Natalia S. Semeniuk[a,b]

[a]*National Research Tomsk State University, Tomsk 634050, Russia*
[b]*Institute of High Current Electronics, Russian Academy of Sciences, SB, Tomsk 634055, Russia*
**Corresponding author: kozyrev@to.hcei.tsc.ru*

Abstract: The results of theoretical simulation of runaway electron generation in high-pressure pulsed gas discharge with inhomogeneous electric field are presented. Hydrodynamic and kinetic approaches are used simultaneously to describe the dynamics of different components of low-temperature discharge plasma. Breakdown of coaxial diode occurs in the form of a dense plasma region expanding from the cathode. On this background there is a formation of runaway electrons that are initiated by the ensemble of plasma electrons generated in the place locally enhanced electric field in front of dense plasma. It is shown that the power spectrum of fast electrons in the discharge contains electron's group with the so-called "anomalous" energy.

PACS Codes: 52.80.-s, 52.65.Ww

Keywords: Pulsed gas discharge; Breakdown of high-pressure gas; Fast electrons in gas discharge; Runaway electrons in plasma

1 INTRODUCTION

The phenomenon of runaway electrons generation in high-pressure gas discharges is widely studied in recent years [1-4]. Mostly it is connected to the progress in the field of high-voltage pulse generation with a short rise time of the voltage amplitude and the appearance of experimental equipment with picosecond time resolution [1,2].

The main factor affecting the amount of fast electrons is the possibility of creating a strong overvoltage of a discharge gap at the initial stage of the current growth in the gas diode. Multiple overvoltage (compared to static breakdown voltage) is achieved for a short time during the application of a large amplitude voltage pulse with a sub-nanosecond duration of the leading edge to the discharge gap. At present the fact of fast (runaway) electrons detection can be firmly established at the initial stage of high pressure gas breakdown in gaps with strongly non-uniform distribution of the electric field. At the same time, researchers have obtained fast electron current pulses with largely spread parameters: amplitudes from 0.1 up to tens of amperes with durations from tens of picoseconds to nanoseconds [1,2]. As the number of runaway electrons depends strongly on several critical parameters, i.e., gas type, geometric enhancement of the electric field near the sharp edges of electrodes, scales of field-enhancement regions, time resolution of the experimental equipment, so the experimental results of fast electrons detection will also differ considerably.

Essential non-stationarity and spatial three-dimensionality in real experiments pose a great challenge for theoretical modeling. Simple zero-dimensional and one-dimensional theoretical models [4,5] could demonstrate the mechanism of runaway electron beam formation, but do not allow a proper comparison with the existing experiments.

The simplest geometry was chosen for theoretical analysis of the discharge having strongly inhomogeneous electric field. We have applied a previously developed hybrid theoretical approach (refer to Ref. [4]) to coaxial geometry of sub-nanosecond discharge gap in sulfur hexafluoride (SF_6) at atmospheric pressure.

This gas has a molecule with a high energy of electron affinity that facilitates rapid attachment of free electrons to the molecule forming stable negative ions. Attachment of free electrons leads to a significant increase of static breakdown value of the reduced electric field strength. For atmospheric pressure, it equals to 89 kV·cm^{-1}·atm, which is more than twice higher of breakdown fields in pure nitrogen (35 kV·cm^{-1}·atm). Moreover, the conversion of a free-electron conductivity of plasma into being ionic will drastically reduce plasma column conductivity, beneficial to maintain a relatively high electric field strength. All of the above improves the probability of transition electrons entering into the continuous acceleration regime. Although complex molecule SF_6 has a relatively high elastic cross-section, the high field strength allows us to observe a certain number of fast electrons [6,7].

2 MODEL OF GAS DISCHARGE WITH RUNAWAY ELECTRONS FLOW

2.1. Description of discharge dynamics

Main physical approximations of the discharge model and the corresponding computational method of runaway electrons distribution function have been previously described with respect to one-dimensional planar discharge geometry in nitrogen in our paper [4]. Here we have applied this model to one-dimensional axisymmetric geometry of the discharge gap filled with electronegative gas.

Since in all cases of calculations all significant processes occurred at characteristic sub-nanosecond time scales, we neglected the motion of ions in the mathematical description of current transporting (special calculations have