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Mini Review

Diffuse Discharges in Tip-Plane Gaps Filled with Atmospheric Air

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Abstract

Diffuse discharges formed in atmospheric air by short voltage pulses are described. Based on our new experimental data and known data the discharge basic properties are analyzed. It has been established that diffuse discharges are formed from wide streamers developed from an electrode with a small radius of curvature. Data on the appearance of particle tracks from electrodes with small radius of curvature and the ignition of carbon black deposited on the surface of a flat anode are discussed. Generation of runaway electrons and X-rays in the diffuse discharges has been reported, as well.

Keywords: Diffuse discharge; Tip-plane gap; Nanosecond pulses; Non-uniform electric field; Atmospheric air

Introduction

Non-equilibrium low-temperature plasma formed in gas at atmospheric pressure currently finds various applications and continues to be studied [1, 2]. Homogeneous low-temperature plasma can be obtained in various ways. High-voltage pulses with nanosecond duration and gaps with a non-uniform electric field are the most commonly used for formation of the diffuse plasma. The possibility of forming diffuse pulsed discharges in helium [3] and air [4] at atmospheric pressure has been known since the middle of the last century. Although such discharges are used for surface treatment of various materials [5-7], the discharge properties, as well as their formation conditions, require further study.

Formation of relatively homogeneous discharges in various pressured gases in non-uniform electric field occurs for several reasons. In particular, this is due to the generation of fast and runaway electrons, respectively (FE) and (RAE), as well as X-ray radiation due to bremsstrahlung of high-energy electrons. RAE are electrons which gain more energy than they lose in collisions with gas particles, when moving in a non-uniform electric field [8]. As is known, high-energy electrons in collisions with matter cause bremsstrahlung and characteristic radiation. X-ray radiation was recorded during the formation of diffuse discharges in [3, 4]. When high-voltage pulses with short fronts are applied to gaps with non-uniform electric field, FE and RAE are generated in the region of enhanced electric field, primarily near an electrode with a small radius of curvature. Fast electrons are usually called electrons with increased energy, which lose their energy gained near an electrode with a small radius of curvature when moving in the gap. The runaway electrons gain enough energy in the gap to pass through thin anode foils, and they leave the discharge region. Runaway electrons in atmospheric air were first recorded using a current shunt in [9]. The deceleration of electrons with increased energy at the anode and in the gas leads to the appearance of X-ray radiation, which also preionizes gas in gaps with a non-uniform electric field. The conditions for obtaining RAE in various gases are described in detail in review [10].

An important feature of the diffuse discharge formation is formation of wide streamers during breakdown processes in the gap [11]. However, it is known that formation of the streamers and subsequent ionization waves in pressured gases leads to discharge contraction and closing of the gap with a spark (heated channel with low resistance) [12, 13], which is not suitable for uniform surface treatment of various materials [5–6]. During discharge formation initiated by high-voltage pulses of short duration in the tip-plane gaps a wide streamer is first evident at the tip electrode, which then transformed into a diffuse discharge [11]. Glow of the wide streamer at the tip (WSt), as well as diffuse discharge (DD) in the gap, cathode sport (CSp) and anode sports (ASps) are seen in the photograph of the discharge shown in Fig. 1a.

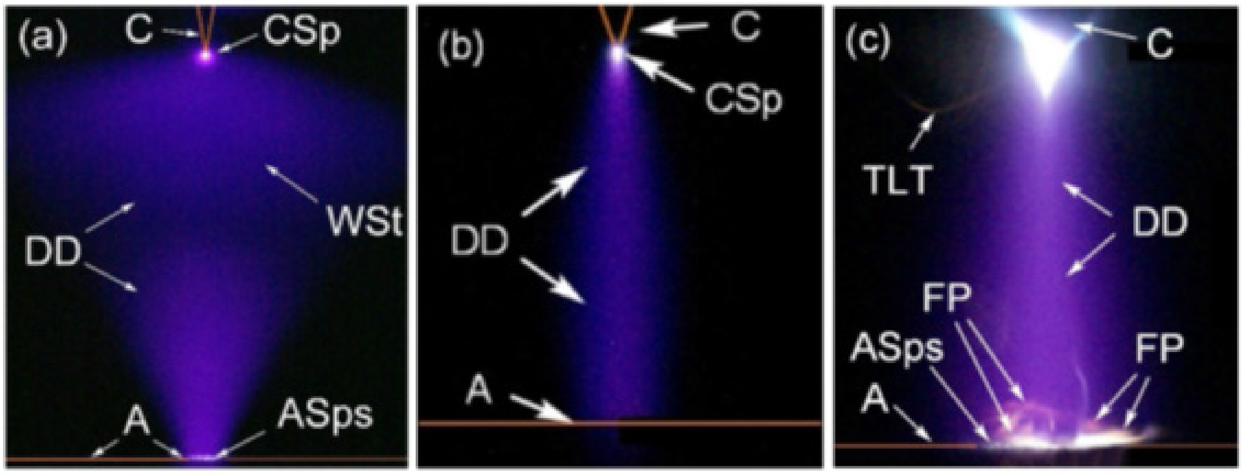

Figure 1: Photographs of the discharge glow in the tip-plane gaps filled with atmospheric air by one pulse: (a) – gap d = 6 cm, voltage pulse from the RADAN-220 generator with amplitude $U_0 \approx 200$ kV ; (b) – d = 8 mm, voltage pulse with $U_0 \approx 38$ kV from the NGP-18/3500N generator; (c) – d = 4 mm, voltage pulse with $U_0 \approx 38$ kV from the NGP-18/3500N generator. C – cathode, A – anode, CSp – cathode spot, DD – diffuse discharge, WSt – wide streamer, ASps – anode spots, FP – frame plume, TLT – thin luminous track.

WSt is part of the diffuse discharge [11]. By optimizing both the amplitude, the voltage pulse duration and the gap size, it is possible to exert a uniform impact on the flat electrode [14]. Integral photograph of this impact mode is shown in Fig. 1b.

The aim of this publication is to draw attention to new data on the properties of diffuse discharges formed in a non-uniform electric field during the breakdown of the tip (cathode) - plane (anode) gaps, part of which were described in the article [14], as well as in [15, 16]. The results obtained in [14-16] are important for the practical application of diffuse discharges. Let us briefly comment on these properties.

1. In [14], it was convincingly shown that it is possible to exert a uniform impact on a flat anode by a diffuse discharge in atmospheric air, using high-voltage pulse with a nanosecond duration. This discharge mode, as we have already noted, is shown in Fig. 1b. A uniform effect is achieved with the correct choice of the amplitude and duration of the voltage pulse, along with the gap length. There are no bright spots on the anode, including when a thin layer of carbon black deposited to it, see Fig. 1b. Applying a thin layer of carbon black to increase the sensitivity of determining inhomogeneities on the anode when exposed to a diffuse discharge was proposed in [17]. A homogeneous impact in [14] was implemented by increasing the gap length with constant amplitude and duration of the voltage pulse from the NGP-18/3500N generator.
2. The appearance of particle tracks against the background of a diffuse nanosecond discharge, recorded in [15], at low specific deposited energy turned out to be a surprise. Note that erosion of electrodes during the formation of electrode spots under conditions of spark discharges has been known for a long time [18]. However, long tracks of particles during diffuse discharges in atmospheric air have not been previously reported, see, for

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example, [19]. In [15] it was possible to record the scattering of particles with both polarities of pulse generators due to the use of a long-distance microscope with high spatial resolution and correction of the brightness and contrast of photographs. Filming a discharge with an ICCD camera in [15] showed that particles from the electrodes, forming particle tracks, appear with a delay of a few microseconds after the voltage pulse arrives at the gap. The glow of steel electrode particles lasted tens to hundreds of microseconds, apparently, due to their oxidation by atmospheric oxygen. It should be noted that one of the reasons for the formation of particles during a breakdown between flat electrodes in a vacuum is considered to be the appearance of mechanical defects in the surface layer of a flat cathode with an increase in the electric field [20].

3. Further experiments on the effect of a diffuse discharge on a flat anode covered with a layer of carbon black [16] made it possible to obtain the ignition of the carbon black both on the anode surface and in the gap. The glow duration of diffuse plumes (FP) reached hundreds of microseconds. The appearance of glow on the anode surface and in the gap is shown in Fig. 1c. The glow color of the FP regions on the anode surface and in the gap is different. Individual colored jets are observed in the gap, while individual spots of white color are visible on the flat anode. Note that appearance of the FP was observed when the discharge current density and specific energy input were increased. This was achieved in [16] by reducing the interelectrode gap.

In conclusion, we note that the results obtained in [14-16] are important for practical use in various fields and further study of the effects of diffuse discharges is required.

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Conflicts of Interest

None.

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