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MEMORY EFFECT IN AIR IN THE PRESENCE OF VACUUM BREAKDOWN MECHANISM

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Abstract. Investigation of memory effects in air at 0.7 mbar pressure in the presence of vacuum electrical breakdown mechanism has been performed in this paper. The memory effect has been followed using the time delay method.

1. INTRODUCTION

Low-pressure nonequilibrium plasmas of air and $N_2 - O_2$ mixtures are currently attracting the attention of many scientific groups due to their relevance in different fields, from the study of the Earth's ionosphere to the reactivity in the boundaries of hypersonic vehicles or the sterilization of surgical equipment (de Benedictis et al. 1996, Castillo et al. 2004). During the electrical breakdown and discharge in air, positive and negative ions, vibrationally excited molecules and electronic excited atoms and molecules, as well as atoms in ground state are created. It is shown (Pejović et al. 2002) on the basis of the secondary emission of electrons due to the bombardment of the cathode surface with positive ions and some neutral active particles that their presence in afterglow can be followed by the electrical breakdown time delay measurements as a function of afterglow period (memory curve).

2. EXPERIMENT

The time delay t_d measurements have been performed on air-filled cylindrical glass tube with inner radius $R = 2.5\,cm$ and tube length $L = 22\,cm$, connected with two cylindrical iron electrodes with spherical surface facing (10 mm radius) each other and $d = 0.1$ mm gap length between them. Before evacuation the air has been residence in the tube at atmospheric pressure. The air evacuation was performed by mechanical pump until 0.7 mbar pressure. The static breakdown voltage was estimated using the discredized dynamic method (Pejović 2005) and its value was 545 V. The breakdown voltage and time delay were measured at room temperature by electronic systems shown in paper Pejović 2005.

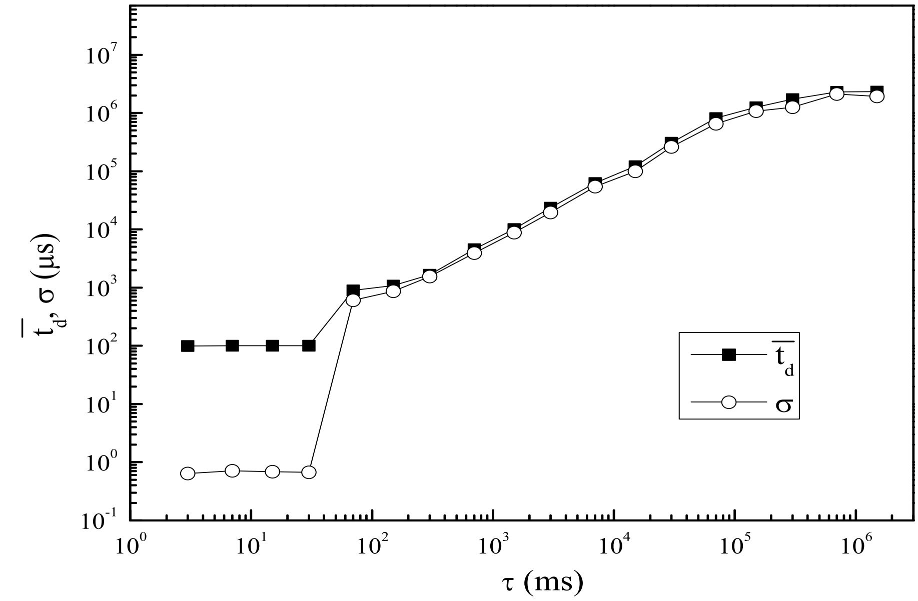

Figure 1: Dependences of the mean value of time delay $\overline{t_d}$ and standard deviation σ on the afterglow period τ.

3. RESULTS AND DISCUSSION

Vacuum breakdown mechanism (VEB) occurs when the breakdown initiation and self-sustenance are origin of electrodes and it appears when the ratio of electron mean free path $\overline{\lambda}_e$ to interelectrode gap d is greater then unity (Osmokrović et al. 2007). This type of breakdown is initiated either by electron emission or by microparticles when the primary and secondary effects are electrodes effects. Beyond the gas electrical breakdown (GEB) appears when $\overline{\lambda}_e/d < 1$. In this case for low pressures the initiation of breakdown is caused by positive ions or neutral active particles which in the collision with cathode emitting electrons which formed the avalanche in gas (Townsend mechanism). In order to determinate which of mechanism is dominate in our experimental conditions, it can estimate value of electron mean free path using the formula $\overline{\lambda}_e = 4\sqrt{2}\,\overline{\lambda}_g$ (von Engel 1965), where $\overline{\lambda}_g$ is the mean free path of air molecules. The calculation shows that $\overline{\lambda}_e \approx 0.6$ mm for air at 0.7 mbar pressure. Also, it indicates that for distance $d = 0.1$ mm the electrical breakdown is aided by vacuum electrical breakdown mechanism initiating of electrons from the cathode. This type of mechanism is probably a consequence of cold electron emission from the cathode microspikes, which is a quantum mechanical effect (Pejović et al. 2008). In this case the presence of high local electric field in the vicinity of microspikes with extremely small radii of curvature leads to decrease of potential barrier for cold electron emission.

The dependences the mean values of time delay $\overline{t_d}$ ($\overline{t_d}$ is the mean value of 100 t_d for every τ value) and the standard deviation σ v.s. afterglow period τ for overvolatge

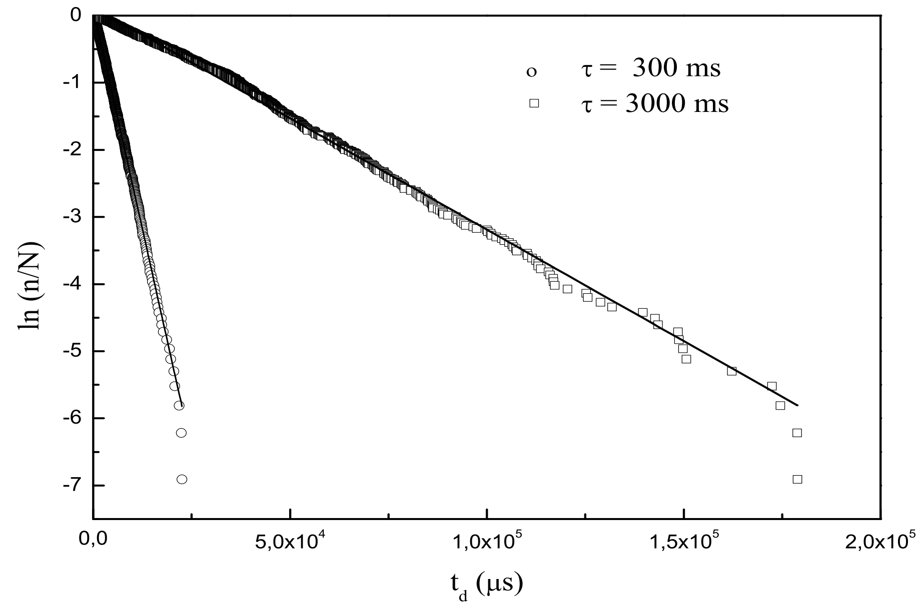

Figure 2: Laue distribution of time delay for afterglow periods of 300 and 3000 ms.

of 50 % are shown in Figure 1. As can be seen from this figure, in time interval of afterglow period from $3-30\,ms$, the curves have plateaus and $\overline{t_d}$ and σ slightly depend on τ. In this interval, σ is less then $\overline{t_d}$ for two order of magnitude. In τ interval from $3\,ms$ to $30\,ms$ low values of σ indicate that $\overline{t_d} \approx t_f$ (t_f is the formative time), i.e., statistical time delay is $\overline{t_s} << t_f$ and $\sigma = \overline{t_s}$ (Llewellyn-Jones et al. 1953). This indicates that the secondary emission of electrons is dominantly induces by positive ions formed in afterglow by reactions (Kossyi et al. 1992):

$$N_2(A) + N_2(a') \rightarrow N_4^+ + e \tag{1}$$

$$N_2(a') + N_2(a') \rightarrow N_4^+ + e \tag{2}$$

$$O + N(^2P) \rightarrow NO^+ + e. \tag{3}$$

The ions, due to their high drift velocity, reach the cathode almost immediately after the application of the voltage on the tube. As τ increases, the concentration of $N_2(A), N_2(a')$ metastable molecules and $N(^2P)$ metastable atoms decrease and the probability of reaction (1)-(3) also decreases. For $\tau > 30\,ms$ the influence of positive ions on breakdown initiation is insignificant. Beyond the nitrogen is at most presence gas in the air, it can be suppose that $N(^4S)$ atoms are responsible for this process for $\tau > 30\,ms$ and its recombination on the electrode can release the secondary electrons from the cathode (Pejović et al. 2004). During this τ period (Fig. 1) σ and $\overline{t_d}$ have the same order of magnitude. Than, the formative time can be neglected, and $\overline{t_d} \approx \sigma = \overline{t_s} = \frac{1}{YP}$ (Meek et al. 1978), where Y is electron yield in electrode gap caused by neutral active species and P is the probability of one electron caused breakdown. Due to the fact that the breakdown probability caused by $N(^4S)$ atoms existence is considerably smaller than one caused by both ions and neutral active states, $\overline{t_d}$ rapidly increases. For given voltage on the electrodes, $P = const.$, while Y is directly proportional to concentration of neutral active species in gas. When τ increases, the concentration of these particles in afterglow decreases and $\overline{t_d}$ increases.

Our assumption that for $\tau > 30\,ms$, $t_f << t_s$ and $t_d \approx t_s$ is in accordance with the Laue distributions of t_d shown in Fig. 2 which relate to the statistical time delay. Laue distributions have been obtained for 1000 data of t_d for afterglow periods of 300 and 3000 ms and overvoltage of 50%. The insignificant variance of experimental points from straight lines indicates the validity of Laue distribution.

For $\tau > 7 \times 10^6\,ms$ memory curve $\overline{t_d} = f(\tau)$ (Fig. 1) reaches the saturation and it is a consequence of the significant decrease of neutral active species concentration in afterglow. In this case the dominant role in breakdown initiation have a cosmic rays which flux has insignificant changed. Memory curve shown in Fig. 1 reaches the saturation faster then in the case when the tube was filled by nitrogen under the same experimental conditions. It can be concluded comparing this memory curve with memory curve for nitrogen (Pejović et al. 2004). This is a consequence of efficient lost of $N(^4S)$ atoms by oxygen atoms formed in air during discharge as well as oxygen molecules. The two most important reactions which lead to lost of $N(^4S)$ atoms are (Kossyi et al. 1992):

$$N(^4S) + O_2 \rightarrow NO + O \tag{4}$$

$$N(^4S) + O + O_2 \rightarrow NO + O_2. \tag{5}$$

Also, the saturation of memory curve is faster because of addition electron yield initiated by VEB mechanism presences in our experiment.

4. CONCLUSION

On the basis of memory curve the contribution of positive ions, neutral active particles and cosmic rays on the breakdown initiation has been separated in air at 0.7 mbar pressure. The analysis has shown that the breakdown initiation also aided by the vacuum breakdown mechanism.

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