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INVESTIGATION OF THE LATE IONIZATION GROWTH IN Ne-FILLED DIODE WITH THE ELECTRICAL BREAKDOWN TIME DELAY MEASUREMENT

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Abstract. *The results of the late ionization growth in the low pressure glow discharge formatting are presented in this paper. The investigation considers the ionization growth (for the latest 30 % of the total current growth on the potentiometer) in Ne-filled diode at 1 mbar pressure. The measurements were carried out for the total current from 0.15 mA up to 0.60 mA. The electrical breakdown time delay measurement method is used and the results are analyzed due to the statistical theory of the electrical breakdown which put the relation between the mean statistical time delay and the ionization rate in the diode gap. The results show that the increase of the total ionization in glass diode tube can last for a second and that establishing of the stationary regime in such a diode is much longer then the discharge formative time. In particular, in the diode glow time (for the last 30% of current growth on the potentiometer), the total ionization in diode tube increases about 36 times for the saturation current 0.15 mA and about 10 times for the 0.6 mA.*

1. INTRODUCTION

The electrical breakdown time delay t_d consists of the statistical time delay t_s and the formative time t_f ($t_d = t_s + t_f$). According to the statistical theory of the electrical breakdown [1], the mean value of the statistical time delay t_s is in opposition to gas ionization rate:

$$\langle t_s \rangle = \frac{1}{YP},$$

where Y stands for the ionization rate (yield) and P denotes the electrical breakdown

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possibility (which is always lower than one and is constant for the constant overvoltage). Since the time delay value has statistical nature, the analysis was based on a number of independent and successive measurements under the unchanged experimental conditions. In the great number of cases it is satisfied that $t_s >> t_f$. Because of that the mean values of the total time delay can be related to the ionization rate Y in the moment when the electric field is applied to the diode. It was shown that the time delay is in opposition to the applied overvoltage [2] and increases with the relaxation of the diode [3]. When the applied overvoltage and the relaxation time are constant, time delay can be related with the ionization rate Y_0 at the moment of the interruption of the previous discharge. That fact is used in this investigation to determine the relative growth of the ionization in the latest phase of the glow discharge formation.

2. EXPERIMENT

The measurements are performed with high purity Ne-filled diode under the pressure of 1 mbar and $T = 300$K temperature. The volume of the diode tube is about 300 cm^3 with Cu electrodes. The electrodes are cylindrical, with the diameter of 1cm, facing each other with their bases and the gap between them is 1.1 cm. The surfaces of the electrodes are electrochemically coated with the 100 nm Au layer.

The goal of this investigation is schematically shown in Figure 1 (the diagram is not in scale). The breakdown is recorded at the moment when the current i_0 is passing through the diode. The preliminary measurements indicate that the saturation current is for 30 % higher than the i_0. It is assumed that the diode glows from the moment when the current exceeds the value i_0 and the time t_g are controlled by the computer in range from 10 μs up to 10 s. After that the glow is interrupted and the diode relaxes for one second. In Figure 1, the image of the diode ionization changes through the measurement cycle is presented with the dash curve. The rate of the existing ionization, which is in relation to the moment of the glow interruption Y_0, is determined on basis of the next breakdown time delay in the diode. That enables determination of the relative growth of the ionization during the time interval from 10 μs to 10 s after the appearance of the current i_0.

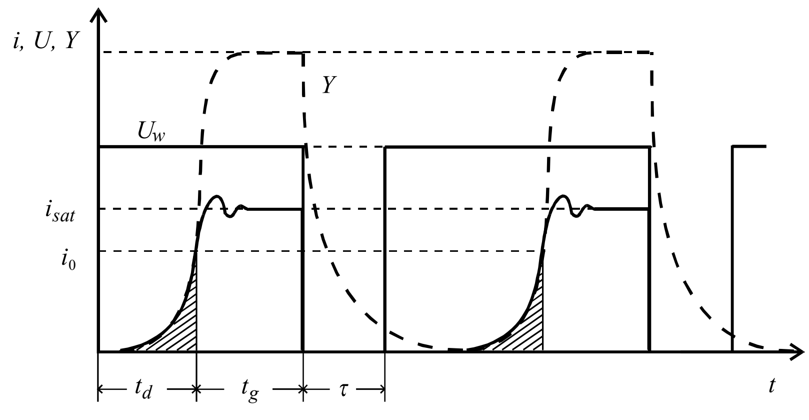

Fig. 1. Diode voltage, current and ionization diagram (not in scale).

The measurements were carried out according to the schematic diagram presented in Figure 2. In order to determine the constant relaxation time and the glow time with high precision, the experiment was controlled by the computer via the custom made interface. High voltage is applied to the diode by means of the computer controlled electromechanical relay. The moment of voltage appliance and the appearance of the current i_0 defined the diode time-delay.

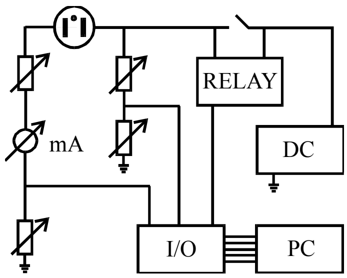

Fig. 2. The layout of the experiment.

For every set of parameters the mean time delay values of the 100 successive and independent measurements were performed. In our experiment, the saturation current in diode were 0.15 mA, 0.2 mA, 0.3 mA and 0.6 mA.

In this experiment, the static breakdown voltage was determined according to the definition where, U_s is the highest working voltage U_w, for which the time-delay $t_d$is equal the infinity, and the breakdown probability is equal the zero, what formally may be drown by relation:

$$\lim_{\substack{t_d \to \infty \\ P \to 0}} (U_w) = U_s ,$$

where P represents the breakdown probability, an for all the other parameters being the same as in the main experiment. We determined the static breakdown voltage of the diode to be 232 V while the measurements were done with 10% overvoltage. The breakdown probability of discharge was not especially determined in this measurements.

3. RESULTS

The results of the experiment are shown in Figures from 3 to 5. In these figures the lines are only for guide-eye.

In Figure 3 the dependence of the mean time delay on glow time is shown. It can be noticed that there are no important changes of the $\langle t_d \rangle$ values on t_g in period from 10 μs to 1 ms and in period after 1 s.

The results of preliminary measurements show that in this case the condition $t_d >> t_f$ is fulfilled, so t_d is approximately equal to t_s and t_s^{-1} is proportional to present ionization (under constant P which is satisfied in this case).

Dependence $\langle t_d \rangle^{-1}$ on the glow time is shown in Figure 4. There is no important changing of ionization rate at interval from 10 μs to 1 ms. It can bee seen that the rates of this ionization have different levels for different current values.

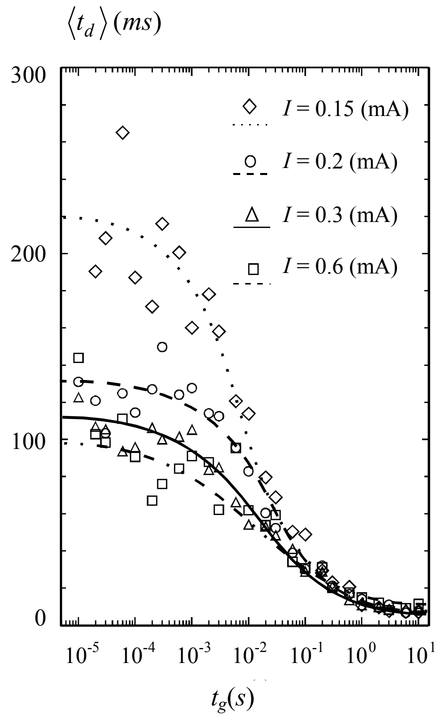

Fig. 3. The mean time delay values in function of the glow time.

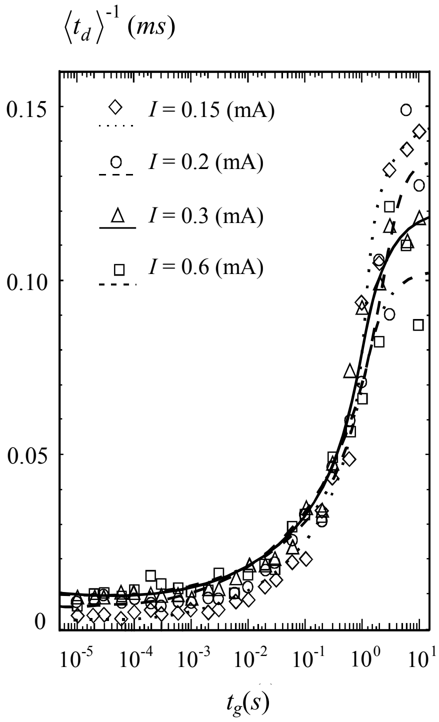

Fig. 4. The opposite of the time delay mean values as a function of the glow time.

In order to establish the relative ionization growth for different diode current, we equalized their initial values on the same level.

In Figure 5 the relative ionization growths $n = Y(t_g)/Y(t_{g,miin})$ what is approximately equal to Y/Y_0 are shown (see the linear t_g scale) and the relative ratios can be determined as 10 times for the diode current of 0.6 mA and up to 36 times for the 0.15 mA current.

We assumed that the found behaviour of $\langle t_d \rangle$ and n has to be in relation with the production of the $1S_5$ metastable particles of Ne atoms. These metastables have the dominant role in establishing the glow discharge in Ne at lower overvoltages. The presence of these metastables in gas allows so called "step by step" ionization in which the low energetic electrons can lead to the breakdown [4].

The mean radiative life of $1S_5$ atoms is 24 s [5] and their presence in the gas lasted for the 10^3 s after the glow had been registered. Their concentrations in glow-discharge on the 1 to 10 mbar pressure are 10^{11} to $10^{12}\,cm^{-3}$ [6]. The increasing production of the electrons, ions and metastables which caused the lowering the $\langle t_d \rangle$ and the relative increase of the ionization rate n.

With increasing the diode total current, the glow is spreading across the diode tube increasing the total ionization in the tube and same extra time is needed far saturation condition (and current) to be formatting. In this kind of diode, with the total volume being much longer of the gap and on a low pressure, the diffusion processes is important.

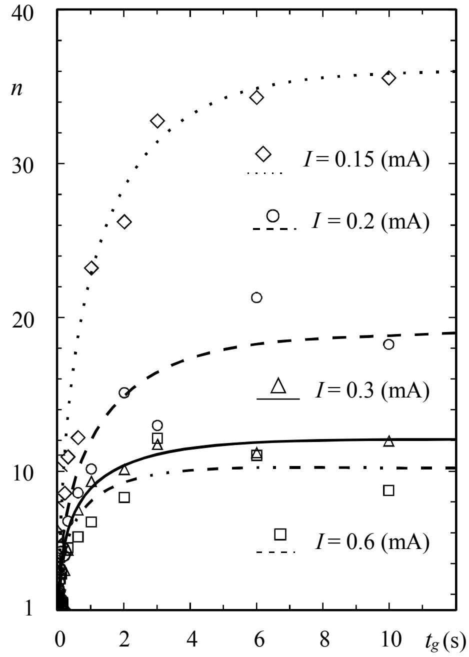

Fig. 5. The relative ionization growths as a function of the glow time.

The ionization growth is smaller for the bigger total diode current what we assumed to be with the bigger enclosing to the stationary regime in whole diode tube.

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ISTRAŽIVANJE KASNE FAZE PORASTA JONIZACIJE U DIODI PUNJENOJ NEONOM MERENJEM VREMENA KAŠNJENJA ELEKTRIČNOG PROBOJA

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U ovom radu su prezentovani rezultati merenja kasne faze porasta jonizacije u formiranju pražnjenja na niskom pritisku. Istraživanje je obuhvatalo zadnjih 30% porasta ukupne struje (na potenciometru) u diodi punjenoj neonom na pritisku od 1 mbar. Merenja su vršena za ukupnu struju od 0.15 mA do 0.60 mA. Korišćen je metod merenja vremena kašnjenja električnog proboja a rezultati su analizirani na osnovu statističke teorije električnih probija koja daje vezu između srednje vrednosti vremena kašnjenja i porasta jonizacije u diodi. Rezultati pokazuju da porast ukupne jonizacije u diodi može da traje sekundu a uspostavljanje stacionarnog režima traje mnogo duže nego vreme formiranja pražnjenja. Praktično, za vreme gorenja cevi (porast zadnjih 30% struje na potenciometru pratećeg kola) ukupna jonizacija u diodi poraste oko 36 puta za struju saturacije od 0.15 mA i oko 10 puta za struju od 0.60 mA.