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Investigation of breakdown voltage and electrical breakdown time delay in air-filled tube in presence of combined gas and vacuum breakdown mechanism

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ABSTRACT

This paper presents the experimental data of breakdown voltage and electrical breakdown time delay for air-filled tube at $p = 0.7$ mbar pressure. The breakdown voltage was measured for product $p \cdot d$ (d is inter-electrode gap) from 0.005 to 0.2 mbar cm, i.e. when breakdown was a consequence of gas and vacuum mechanisms combined. It was shown that the static breakdown voltage, which was determined from experimental data of the dynamic breakdown voltage, retains approximately constant value. The shape of the memory curve, which displays the mean value of electrical breakdown time delay $\overline{t}_d$ vs. relaxation time τ, is very similar to that previously obtained in the case of breakdown induced by Townsend's mechanism alone. UV and gamma radiation lead to the decrease of $\overline{t}_d$ values for values $\tau > 30$ ms and this decrease is larger in the presence of UV radiation. UV and gamma radiation shorten the relaxation time needed for memory curve to reach saturation. On the basis of exponential and Gaussian distributions of experimental data, the contribution of the statistical time delay and the formative time to total electrical breakdown time delay for different values of relaxation time is considered.

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1. Introduction

Electrical breakdown in gases comprises of processes of initiation and self-sustenance of electrical discharge. Based on the properties of these processes breakdown can be divided on vacuum and gas electrical breakdown [1,2]. Vacuum electrical breakdown is initiated by electron emission or microparticles [3,4] and the discharge proceeds in the atmosphere of metal vapour, originating from the electrodes, which fills the inter-electrode gap [5,6]. In the case of vacuum breakdown the length of the inter-electrode gap d is such that $\lambda/d > 1$ [7,8], where λ is the electron mean free path [5,6]. On the other hand, if $\lambda/d < 1$ gas electrical breakdown occurs. If the gas electrical breakdown is initiated at the cathode it is called the Townsend breakdown and if it is initiated in the gas it is called a streamer breakdown. Unlike vacuum breakdown both types of gas discharge proceed in the surrounding gas. A special case can occur when gas pressure and inter-electrode gap are both small. Then, the electrical breakdown is a combination of gas and vacuum breakdown mechanism [9].

Electrical breakdown in gases can be either static or dynamic [10]. Static breakdown occurs if the change of the rising voltage applied across the electrodes is much slower than the rate of elementary processes leading to breakdown. Static breakdown voltage is the voltage at which the discharge starts during a static breakdown. It is a deterministic quantity, independent of the shape of the applied slowly rising voltage. If a rapidly rising pulse voltage is applied across the electrodes, the dynamic breakdown occurs. Pulse breakdown voltage is the peak voltage (dynamic breakdown voltage) on the electrodes during a dynamic breakdown at which the gas electrical breakdown discharge starts. The value of the pulse breakdown voltage varies depending on the steepness of the voltage applied on the tube and it is a stochastic quantity. Our experimental results for nitrogen-filled tubes [11], neon-filled tube [12] and commercial gas discharge tubes [13] show that breakdown voltage is stochastic quantity even for small increasing voltage rate (in order to magnitude 2 V/s). Because of that the estimation of breakdown voltage as a deterministic quantity, has done by experimental results fitting of the mean value of breakdown voltage $\overline{U}_b$ as a function of the voltage increase rate k. The extrapolation of fitted curve to the intersection with the $\overline{U}_b$ ($k = 0$) axis shows the estimation of static breakdown voltage value.

Electrical breakdown in the gas-filled tube does not take place instantly upon applying voltage higher than static or dynamic

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breakdown voltage, but after a delay known as the electrical breakdown time delay t_d. t_d can be defined as the time elapsed from the moment when the applied voltage reaches the breakdown voltage to the moment when it starts to decrease due to the breakdown [14]. The definition of t_d in this paper, for practical purpose will be that t_d is the time between the moment when the operating voltage higher than breakdown voltage is applied on the tube and the moment when current starts to flow through the tube.

When the direct current glow discharges through the gas electron contribute to the production of positive ions and neutral active particles. The secondary emission of electron (SEE) due to the bombardment of the cathode surface with positive and neutral active particles has an important role in initiate of next breakdown in gas-filled tubes at low pressures. Based on the SEE process, the concentration decrease of these particles in afterglow can be followed by monitoring the memory curves, which represented as plot of the mean value of electrical breakdown time delay $\bar{t}_d$ as a function of relaxation time τ, constituting the basis of the time delay method [15–18]. τ is the time interval between the operating voltage turn-off in the previous breakdown and turn-on in the following breakdown.

The aim of this article is to determine the static breakdown voltage in the case of combined Townsend's and vacuum breakdown mechanism. Based on the experimental data of electrical breakdown time delay vs. relaxation time, the influence of neutral active particles in air, UV and gamma radiation on the electrical breakdown initiation will be considered. The distributions of experimental data of electrical breakdown time delay for different afterglow periods are also a subject of this article.

2. Experiment

2.1. Gas-filled tube

The breakdown voltage and electrical breakdown time delay measurements were performed on the tube with one fixed and one movable electrode, so that the electrode gap could be varied between 0.1 and 3 mm by a permanent magnet from the outside (the shape of the tube is given in [19]). The tube bulb was made of borosilicate glass (8245 Schott technical glass) with volume $V = 1$ l. The electrodes were spherical, 10 mm in diameter, made of iron. Qualitative energy dispersive spectroscopy (EDS) analysis of the electrode surface showed that it contains oxygen which indicates the existence of iron oxide. The mechanical vacuum pump decreased the pressure in the tube to 0.7 mbar and, after that, the tube was sealed. The analysis of air in the tube was not made. Before the measurements, the cathode surface was conditioned by performing several thousand breakdowns for about 1 h in order to disperse the gas monolayer remaining on the cathode surface after manufacturing and polishing.

2.2. Sources used in tube irradiation

As a source of UV radiation a commercial mercury lamp was used. The lines shown in Fig. 1 have been obtained by this lamp.

The instrument used in spectroscopic analysis was Avantes spectrometer Avaspec-3648 which has a useable range of 200–850 nm. The spectrometer has a diffraction grating with 600 lines/mm and the slit size is 10 μm making the lowest resolution between two near lines 0.32 nm. As can be seen, the most intense lines in the spectrum are wavelengths 546.1, 435.1 and 253.4 nm. The other lines in the wavelength range from 313 to 579.1 nm have a lower intensity. A piece of borosilicate glass was placed between the mercury lamp and the spectrometer in order to ascertain which wavelengths could pass through the gas-filled tube walls and how

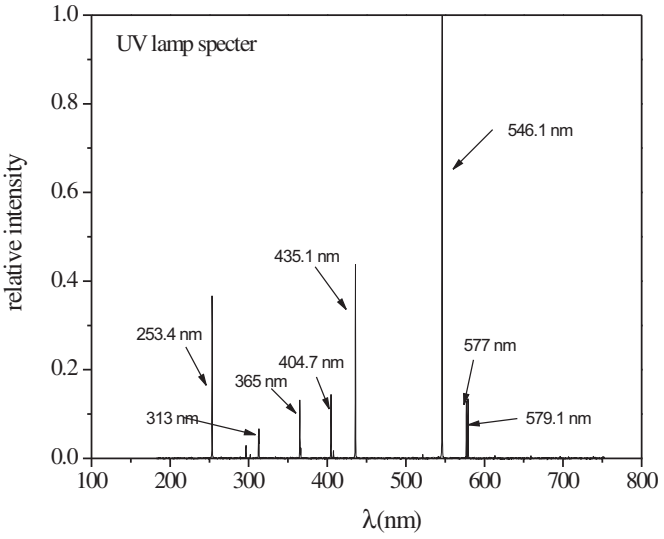

Fig. 1. Strongest observed lines in the emission spectrum of the UV lamp.

is light intensity affected in this process. This emission spectrum is shown in Fig. 2 and it can be seen that wavelengths larger than 313 nm can pass through the glass walls. When taking light intensity into consideration, the glass partially absorbs the light of 313 nm only, while its completely transparent for larger wavelengths.

Gamma radiation source was radium $^{226}_{88}$Ra with activity of $A = 12$ Bq. The diameter of radioactive source is 6 mm and radiation was perpendicular to the electrode gap. The exposed dose rate D_e of gamma radiation was calculated according to $D_e = A\Gamma/r^2$, where $\Gamma = 1.7 \cdot 10^{-18}$ Cm^2 kg^{-1} [20] is the gamma constant and r is the distance between the source and the inter-electrode gap. During the measurement, r was 10 cm which corresponds to exposed dose rate $D_e = 7.7 \cdot 10^{-12}$ Ckg^{-1} s^{-1}.

2.3. Measurement systems

2.3.1. System for measurement of breakdown voltage

The system for measurement and data acquisition of the breakdown voltage consists of a serial connection between Keithley

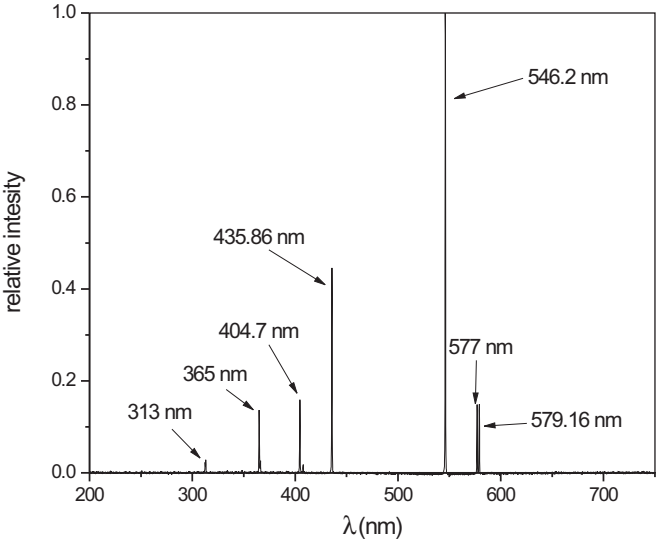

Fig. 2. Strongest observed lines in the emission spectrum of UV lamp which pass through the molybdenum glass.

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