THE POSSIBILITY FOR GAMMA AND UV RADIATION DETECTION BASED ON ELECTRICAL BREAKDOWN TIME DELAY MEASUREMENT IN KRYPTON AND XENON FILLED DIODES

by

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The paper presents results of electrical breakdown time delay mean value $\bar{t}_d$ as a function of relaxation time τ (memory curve) for krypton and xenon-filled diodes at 270 Pa pressure. Memory curves were obtained for the cases without radiation as well as in the presence of gamma and UV radiation. It was shown that significant influence of UV radiation to $\bar{t}_d$ can be observed for τ 100 ms, as well as gamma radiation for τ 10^3 ms. Laue's distribution was also investigated for electrical breakdown time delay data sets t_d, obtained for τ 150 ms, without radiation as well as in the presence of gamma and UV radiation. It was shown that for all these data sets Laue's distribution stands, except for the case when krypton-filled tube was subjected to UV radiation. On the basis of the obtained results, the throughout analysis was performed with the aim to investigate possible application of these diodes as sensors of gamma and UV radiation.

Key words: electrical breakdown time delay, gamma radiation sensor, UV radiation sensor, memory curve

INTRODUCTION

Krypton and xenon low temperature plasmas have wide application in technology and electronics. For example, glow discharge in krypton and xenon mixtures with NaCl, KCl, and CsCl vapors are used as a source of non-coherent UV radiation [1, 2]. Krypton and xenon discharge is used for lighting purposes in mercury-free fluorescent lamps [3, 4]. Xenon at low pressure is also used for excitation of phosphorus in optoelectronic devices [5]. Krypton is used in flash-lights for high-speed pictures, in incandescent lamps it leads to life time increase in Tungsten filaments and for counters for detection of low energy X-ray [6]. These gases are also used for coating materials sputtering in plasma display panels [7] as well as components in gas-filled surge arresters mixtures [8, 9].

The most commonly used method for generation and sustaining of low temperature plasma in noble gases is the application of electrical field to the gas-filled diodes electrodes. Neutral gas in inter-electrode space contains a few electrons and ions formed under impact of cosmic rays and natural radioactivity with gas. Electric field accelerates these free charge carriers, what further leads to generation of additional charge particles in collision with gas atoms. This can lead to the charged particles avalanche, when balance between charge carrier creation and loss appear, so the steady-state plasma develops. In order to form such plasma, it is necessary to elapse a certain period of time often referred as electrical breakdown time delay t_d. The time t_d is a sum of two components [10]: the statistical time delay, t_s, defined as the time interval elapsed from the instance of voltage pulse application until the occurrence of the electron, which further initiates the discharge and formation time, t_f, after which steady-state plasma develops.

During the discharge in pure noble gases, beside electrons and positive ions, metastable atoms, and resonance excited states are also formed. The presence of positive ions and metastable states in post discharge regime (afterglow period) can induce secondary electron emission from the gas-filled diode cathode (SEE), which leads to initiation of next breakdown when the voltage is reconnected to electrodes. The presence of these particles in post discharge regime can be very efficiently followed using the time delay method [11-13]. This method is based on the analysis of $\bar{t}_d$ $f(\tau)$ dependence, known as the memory curve. The $\bar{t}_d$ is the mean value of electrical breakdown time delay and τ is the interval between two successive voltage pulses applications on the gas-filled diode electrodes (τ is often referred as an afterglow period or relaxation time). Us-

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ing this method, it is also possible to detect the presence of gamma and UV radiation, which leads to the increase in electron yield in inter-electrode space [6].

The aim of the paper is to investigate the possibility for application of krypton and xenon-filled diodes as sensors of gamma and UV radiation, using experimental data of electrical breakdown time delay as a function of relaxation time (memory curve). This dependence enables the determination of relaxation time value for which these diodes are most sensitive to gamma and UV radiation.

EXPERIMENTAL DETAILS

The electrical breakdown time delay t_d measurements were performed on two geometrically identical spherical diodes. Diodes bulbs were made of 8245 Schott technical glass with volume V 87 cm^3, fig. 1. Two cylindrical iron electrodes with 1 cm diameter with hemispherical peaks were placed inside the diode with 1 mm gap. Electrodes were made of technically pure iron and quantitative energy dispersive spectroscopy (EDS) analysis of the electrode surface has shown that it contained oxygen which further indicates the existence of iron oxide. The presence of iron oxide leads to the decrease in electrode material work function relative to pure iron. Prior krypton and xenon were admitted in the diodes, they were backed out at 350 °C and pumped down to 0.1 Pa pressure. After that, one of the diodes was filled with krypton, while the other one was filled with xenon at 270 Pa pressure and sealed out. Krypton purity was 99.998 % with impurities: argon <0.0001 %, carbon dioxide <0.0001 %, carbon monoxide < 0.0001 %, helium <0.0001 %, hydrogen <0.0001 %, methane <0.0001 %, nitrogen <0.001 %, oxygen <0.0002 %, water <0.0004 % and xenon < 0.001 %. Xenon purity was 99.995 % with impurities: water <0.0002 %, oxygen <0.0001 %, nitrogen <0.0004 %, methane <0.00005 %, krypton <0.0003 %, hydrogen <0.0001 %, carbon monoxide <0.0003 %, carbon dioxide <0.0003 % and argon <0.0005 %.

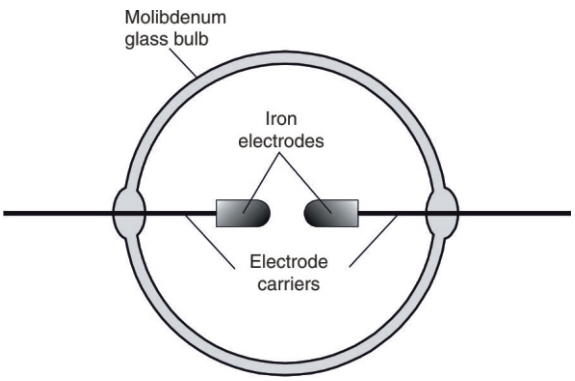

Figure 1. Gas-filled diodes cross-section

The $^{226}_{88}$Ra was used as a source of gamma radiation with the activity of A = 12 kBq. The diameter of the radioactive source was 6 mm and the beam of the source was directed perpendicular to the inter-electrode space. The exposed dose rate is calculated according to the expression $\dot{D}e = A_\gamma \Gamma r^2$, where Γ = 1.7 10^{-18} cm^{2}kg^{-1} is the gamma constant [14] and r is the distance between the source and the inter-electrode gap. During the experiment, the distance between the source and the inter-electrode gap was maintained constant and the air kerma rate for this conditions was $\dot{D}e$ = 652.4 nGy/h. Gamma radiation leads to the increase in electron yield through Compton's effect by interaction between photons and diodes, glass and electrodes. The diodes irradiation was performed perpendicular to the inter-electrode gap.

As a source of UV radiation photo optic lamp Hg100 Quicksilber/Mercury, made in Germany, was used. The diodes irradiation was performed perpendicular to the inter-electrode gap. The lamp was designed to be used as a high quality monochromatic light source. Its emission spectrum was measured using Avantec spectrometer 3648 with a range from 200 to 850 nm [15]. The spectrometer has a diffractive grating with 600 lines per mm and slit size of 10 m, making the lowest detectable resolution between two near lines 0.32 nm. Based on the previous experimental results [16], the transparency of 8245 Schott technical glass, for wavelengths smaller than 300 nm, was zero. In the interval from 300 to 400 nm transparency increases and for λ nm , it is 90 %. As it can be seen from fig. 2, there is wavelength λ nm (3.96 eV energy) whose transparency is 30 % and λ nm (3.38 eV energy) which has transparency of 90 %. These wavelengths probably could be responsible for electron release from the cathode through photoelectric effect due to the fact that iron electrodes contain oxide which decreases work function. The value of pure iron work-function reported in literature varies from 3.5 eV [17] up to 4.3 eV [18]. Since the electrodes contain impurities, which decrease the work-function value, it can

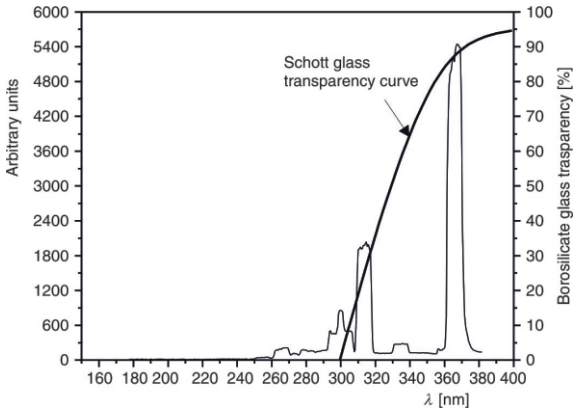

Figure 2. Emission spectrum of Hg100 queck-silber mercury lamp, made in Germany

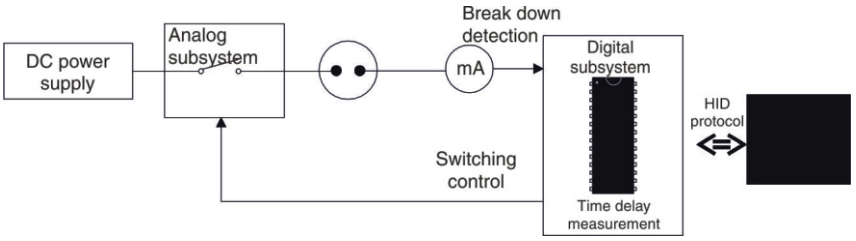

Figure 3. Block diagram of electrical system for electrical breakdown delay time measurements

be assumed that the mentioned wavelengths can lead to the release of electrons through the photo-effect.

Block diagram of the system for electrical breakdown time delay measurement and data acquisition is presented in fig. 3. System consists of two integral parts, analog and digital. Major function of analog part is to provide voltage $U_w > U_s$ (U_s is the static breakdown voltage) switching on the diode. The core of a digital part is Microchips PIC18F2550 microcontroller, responsible for three important tasks: directing start and stop signals which provide voltage switching on the diode, electrical breakdown detection and electrical breakdown time delay measurements. Detailed description of the system is given in [19]. Improved version of the system, used in this paper, provides the applied voltage rise time of 20 ns and it is about four orders of magnitude shorter than measured t_d values. On the basis of these data, it can be concluded that the applied voltage rise time does not make significant influence on t_d. The modified version of the system enables t_d measurements for minimal value of relaxation time of $\tau = 1$ s, while the previous system [19] provided the measurements for minimal value of relaxation time $\tau = 1$ ms.

RESULTS AND DISCUSSION

Electrical breakdown time delay t_d is a statistical property. Because of that, in order to form a memory curve, it is necessary to perform a large number of measurements for every single value of relaxation time τ and determine mean value $\bar{t}_d$. Figures 4 and 5

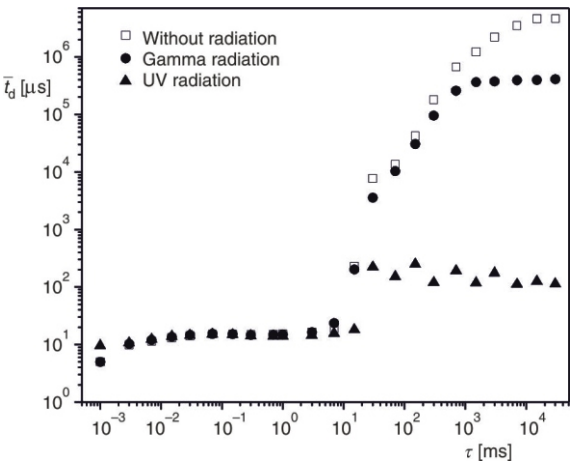

Figure 4. Memory curves for krypton-filled diode without radiation and in the presence of gamma and UV radiation

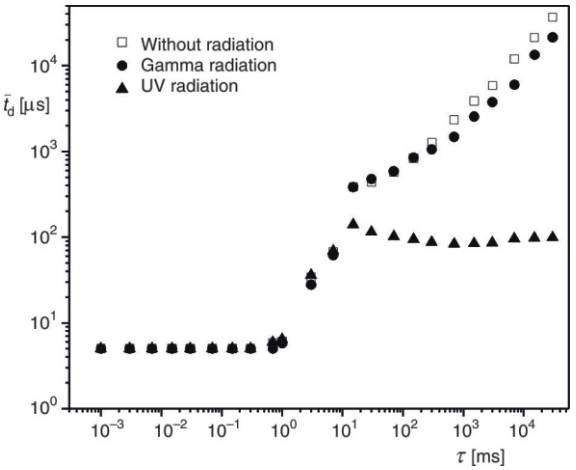

Figure 5. Memory curves for xenon-filled diode without radiation and in the presence of gamma and UV radiation

present memory curves for krypton and xenon-filled diodes, measured for the case when diodes were not subjected to any type of radiation as well as for the case of gamma and UV radiation. Memory curves were obtained for applied voltage $U_w = 1.5U_s$ (U_s is the static breakdown voltage). It can be seen from the figures that for small τ values (for krypton-filled tube up to τ ms and for xenon-filled tube up to τ ms) the value of $\bar{t}_d$ const. Our earlier investigations for krypton-filled diode [6] and for xenon-filled diode [20] have shown that such behavior is a consequence of positive ions presence, formed during previous breakdown and discharge. It can also be seen that for such small τ values gamma and UV radiation doesn't influence to $\bar{t}_d$. For τ values up to several milliseconds, these diodes cannot be used for detection of gamma and UV radiation.

Rapid increase in $\bar{t}_d$ with the increase in τ, figs. 4 and 5, is a consequence of full recombination of positive ions, so that the breakdown initiation is a consequence of SEE induced by electrically neutral active particles, formed also during breakdown and discharge in the gas. Earlier investigations [6, 20] have shown that these particles originate from gas impurities, most probably N_2 molecules whose dissociation during breakdown leads to the creation of nitrogen atoms in the ground state N(^{4}S). These atoms, in collision with the cathode, can induce SEE process. The recombination time of N(^{4}S) is considerably longer than positive ions recombination time. In this memory curve, areas of gamma and UV radiation lead to signif-

icant decrease in $\bar{t}_d$. On the basis of memory curves behavior in figs. 4 and 5, it can be concluded that diodes can be used as sensors of UV radiation for relaxation times $\tau > 10^2$ ms as well as gamma radiation sensors for $\tau > 10^2$ ms.

On the basis of earlier investigations [6, 20] it was concluded that for τ values, when rapid increase in $\bar{t}_d$ occurs, figs. 4 and 5, electrical breakdown time delay is a consequence of statistical time delay, t_s. Namely, in the area of $\bar{t}_d$ rapid increase with the increase in τ, standard deviation is in the same order of magnitude as $\bar{t}_d$. On the other hand, $\bar{t}_s$ ($\bar{t}_s$ is the mean value of statistical time delay), so it can be concluded that $\bar{t}_d$ $\bar{t}_s$. Such conclusion can be proved using Laue's distribution, which can be expressed as $n(t)/N$ exp[$(t$ $t_s)/\bar{t}_s$] [21], where $n(t)$ is the number of t_s values larger than t, N is the total number of measured t_d data. Laue's distribution is often presented as linear dependence between $\ln[n(t)/N]$ and t known as Lauegram.

Figures 6 and 7 present $\ln[n(t)/N] = f(t)$ dependence for krypton and xenon-filled diode, respectively. For both diodes a total of 100 t_d measurements were performed for τ ms, for the cases when there was no radiation and when the diodes were subjected to gamma and UV radiation. It can be seen from the figures that td data can be very well described by linear fit, *i. e.* Laue's distribution stands when diodes were not subjected to radiation as well as when they were subjected to gamma radiation. For the case of UV radiation Laue's distribution stand for xenon-filled diode, while for krypton-filled diode it exhibits behavior only similar to Laue's distribution for values which fulfill the condition that $t_s >> t_f$ *i. e.* t_d t_f.

CONCLUSION

The possibility of krypton and xenon-filled diode application as sensors of gamma and UV radiation was analyzed on the basis of electrical breakdown time delay experimental data. It was shown that these diodes are sensitive to above mentioned types of radiations for relaxation times longer than positive ions recombination time, when statistical time delay is longer than formative time. Using these sensors, it is possible to detect low doses of gamma radiation as well as UV radiation with wavelengths longer than 300 nm. In order to make valid conclusions regarding the introduction of these sensors in commercial applications, it is necessary to perform additional investigations. In the case of gamma radiation, it is necessary to investigate, in more details, the dose range in which these diodes could be successfully applied. For diodes application as sensors for UV radiation, additional investigations should be performed with different bulb glass in order to increase the wavelength interval which could be detected. In addition, it should be investigated the impact

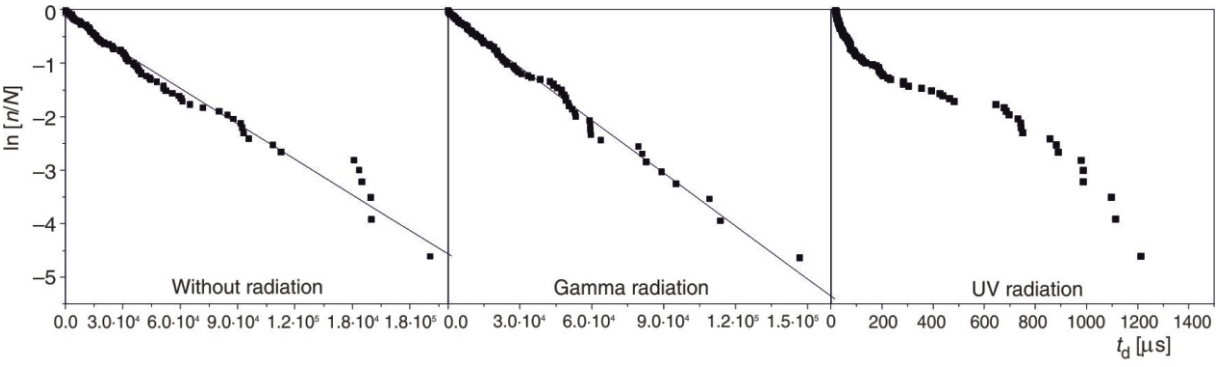

Figure 6. Lauegram for krypton-filled tube diode without radiation and in presence of gamma and UV radiation

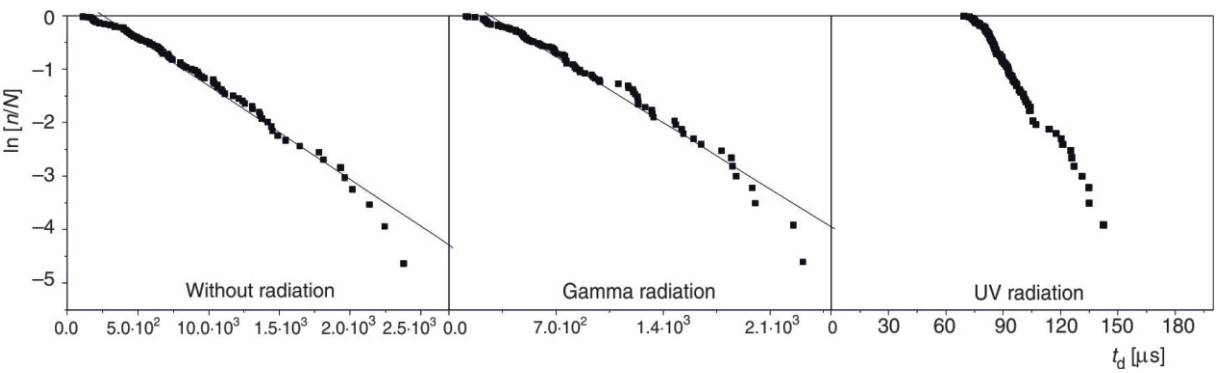

Figure 7. Lauegram for xenon-filled tube diode without radiation and in presence of gamma and UV radiation

of cathode material with small work-function in order to increase diodes sensitivity to UV radiation.

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AUTHORS' CONTRIBUTIONS

The idea for the study was put forward by M. M. Pejović. The activation and measurements were carried out by M. M. Pejović and E. N. Živanović. The discussion and interpretation of the results was carried out by M. M. Pejović, E. N. Živanović, and Č. I. Belić. The figures were prepared by E. N. Živanović and M. M. Pejović.

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МОГУЋНОСТ ДЕТЕКЦИЈЕ ГАМА И УВ ЗРАЧЕЊА ЗАСНОВАНЕ НА ВРЕМЕНУ КАШЊЕЊА ЕЛЕКТРИЧНОГ ПРОБОЈА У ДИОДАМА ПУЊЕНИМ КРИПТОНОМ И КСЕНОНОМ

Рад приказује резултате средње вредности времена кашњења електричног пробоја, $\bar{t}_d$, у функцији времена релаксације τ (меморијска крива) за диоде пуњене криптоном и ксеноном, на притиску од 270 Pa. Меморијске криве су снимане за случај када диоде нису озрачене као и за случајеве када су биле озрачиване гама и УВ зрачењем. Показано је да утицај наведених зрачења на $\bar{t}_d$ може бити примећен за $t > 100$ ms. Лауеове расподеле су такође разматране за сетове података времена кашњења електричног пробоја t_d, који су добијени за $t = 150$ ms, без утицаја зрачења као и у присуству гама и УВ зрачења. Показано је да Лауеова расподела важи за све сетове података сем у случају када је диода пуњена криптоном изложена УВ зрачењу. На основу добијених резултата извршена је опширна анализа са циљем да се испита потенцијална примена наведених диода као сензора гама и УВ зрачења.

Кључне речи: време кашњења електричног пробоја, сензор гама зрачења, сензор УВ зрачења, меморијска крива