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FORMATIVE TIME DETERMINATION IN NITROGEN-FILLED TUBE USING STATISTICAL METHODS

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Abstract: The formative time for different values of afterglow period with/without positive bias on the electrodes in nitrogen-filled tube has been investigated. The obtained values for average formative time delay which is determined as a difference between average total time delay of electrical breakdown and standard deviation are in accordance with those evaluated from Laue distribution. The good agreement of formative time values which are determined by these methods is observed in the case when the electrical breakdown is mostly initiated by secondary electrons from the cathode induced by positive ions remained from the previous discharge.

Key words: Nitrogen-field tube, statistical methods, formative time, Laue distribution.

1. Introduction

It is known that electrical breakdown in gases does not take place immediately upon applying a definite voltage to the tube, it is always delayed in time. The time interval which passes from application of voltage to the breakdown is called the time delay of electrical breakdown (t_d).

There are many definitions of the time delay. One of them is as follows: t_d is the time interval elapsed from the instant the applied voltage reaches the static breakdown voltage U_s to the moment when it starts to decrease due to the breakdown in the gas tube [1]. In this paper we use the following definition of the time delay: t_d is the time interval between the moment of

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applying of operating voltage $U_W (U_W > U_S)$ to the tube and the moment when the tube current reaches a detectable value.

Detailed experimental as well as theoretical investigations of the time delay in N_2, SF_6 and air is presented in the papers [2-4] using a tube with a pair of electrodes specially profiled (Bruce profile) to give a uniform electrical field.

Laue distribution of time delay in gases is presented in the papers [5-9] using a tube with spherical electrodes. It is shown that this distribution is valid for afterglow period (τ) from 5 ms to 24 h. The afterglow period is a constant interval between two successive measurements during which the voltage on the tube equals to zero.

The paper [10] has suggested the possibility of detection of metastable atoms at concentration as low as 10^4 cm^{-3} using the method of time delay measurements in gases. The sensitivity of this method is about 10^8 times better than that of optical ones [11].

A detailed investigation of time delay as a method for determination of long living metastable states in gases was given in some of our papers [12]-[24]. Also, in our recent papers [24], [25] it has been shown that time delay method can be used for ion detection from the secondary electron emission from the cathode surface.

2. Theory

Breakdown probability can be studied experimentally by measurements of the time delay. The time delay t_d consists of two parts, the statistical time delay (t_s) and formative time (t_f), the time delay being the sum of these ($t_d = t_s + t_f$) [26], [27]. The statistical time delay is the time between application of the operating voltage and the appearance of a free electron that initiates the breakdown. The formative time is the time required for the discharge to build up into a detectable current. Statistical time delay follows the distribution first applied by von Laue [28].

$$\frac{n}{N} = \exp(-WPt) \tag{1}$$

where n/N is the fraction of time delay greater than t, W is the rate of appearance of free electrons and P is the probability that an electron initiates the breakdown. The expression (1) is valid for $t_s >> t_f$. When $t_s \approx t_f$ the above expression can be written as [27]:

$$\frac{n}{N} = \exp[-(t - t_f)WP] \tag{2}$$

where $< t_s >= 1/WP$.

On the Laue diagram, $< t_f >$ is the value where the linear approximation of $ln(n/N)$ reaches the t_d-axis.

It is also shown [29] that statistical time delay distribution law can be written as

$$F(t) = 1 - \exp(-WPt) = 1 - \exp(-t/ < t_s >) \tag{3}$$

From this equation dispersion of statistical time delay can be determined as

$$\sigma^2 = \frac{1}{< t_s >} \int_0^{\infty} (t- < t_s >)^2 \exp(-t/ < t_s >) dt =< t_s >^2 \tag{4}$$

The standard deviation is $\pm < t_s >$. In this case formative time, being the difference of time delay and standard deviation, $< t_f >=< t_d > -\sigma$.

3. Experimental Details

The measurements of time delay were performed on a specially prepared tube whose shape is given in the paper [5]. The volume of the tube is about 500 cm^3. The electrodes are hemispherically ended rod/rod geometry, made of 99.98% purity copper and polished. The electrode diameter is 10 mm and a gap length is 0.5 mm.

Before the gas was admitted the tube was baked out at 350^o C and evacuated to a pressure of 10^{-7} mbar, in a process similar to that for production of X-ray and electron tubes. The bulb was made of a molybdenum glass. Matheson research grade nitrogen at a pressure of 6, 6 mbar was then admitted to the tube. Before the measurements, the cathode conditioning was done by cathode sputtering with glow discharge current of 0.5 mA. The operating voltage U_w was 30% higher with respect to the static breakdown voltage. Current flowing through the tube after the breakdown was 0.5 mA.

The measurements were carried out by electronic counter using the circuit shown in Fig. 1. As can be seen the time-base is generated by the timer 555 circuit in basic mono stable operation mode. After the push button PB is started, NE 555 reaches the quasi-stable state with high potential on pin 3. Transistor Q_1 conducts and voltage potential U_p (U_p is the positive bias on the electrodes) of electrodes is low and may be adjusted in the range from 0 to +90 V, continuously, with respect to the common pole of power supplies U_1 and U_2, but with the zero voltage across the tube electrodes. The

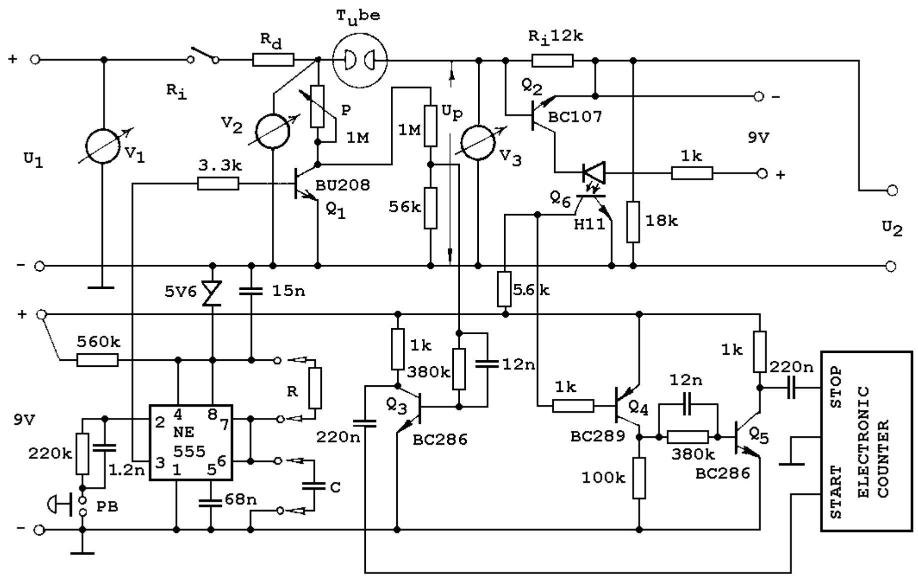
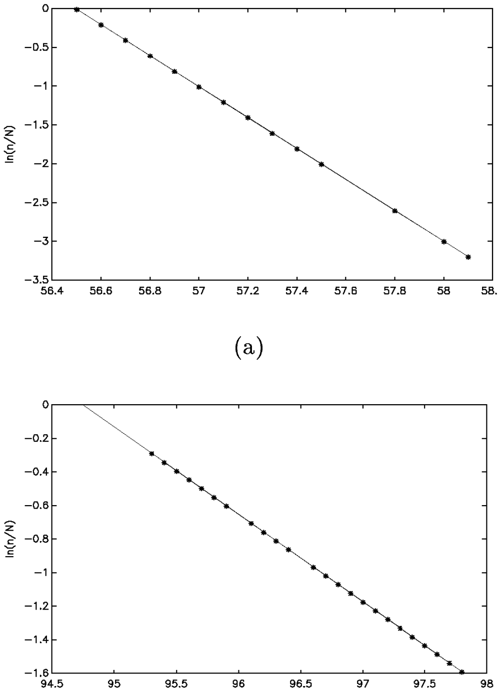


Fig. 1. Electrical circuit for time delay measurements.

potential was adjusted by potentiometer P supplied by the regulated power supply U_2 (voltages indicated by V_2 and V_3 are the same). After quasi-stable time $\tau_1 \approx 1.1RC$, NE 555 reaches the stable-state (voltage on pin 3 is low), transistor Q_1 is in off state, voltage on the left tube electrode is high. Circuit with transistor Q_3 generates a start impulse for an electronic counter. The tube current is then just a dark current. Voltage drop on the resistor R_i is low and transistor Q_2 is in off state. When the tube breaks down, transistor Q_2 is in on state, and circuit with opto-coupler Q_6, transistors Q_4 and Q_5 generates the stop impulse for the electronic counter.

4. Results and Discussion

Fig. 2(a) shows the Laue distribution for 100 t_d values observed on the tube when the positive bias on the electrodes is $U_p = 0$ V and afterglow period $\tau = 0.3$ ms. The (*) symbols represent the experimental values. The full curve is theoretical curve fitted by the least-squares method, using the polynomial form approximation. Fig. 2(b) shows the same distribution, but for the case when $U_p = 90$ V. The average formative time $< t_f >$ obtained from these distributions is 56.48 and 94.73 μs, respectively.



(a)

(b)

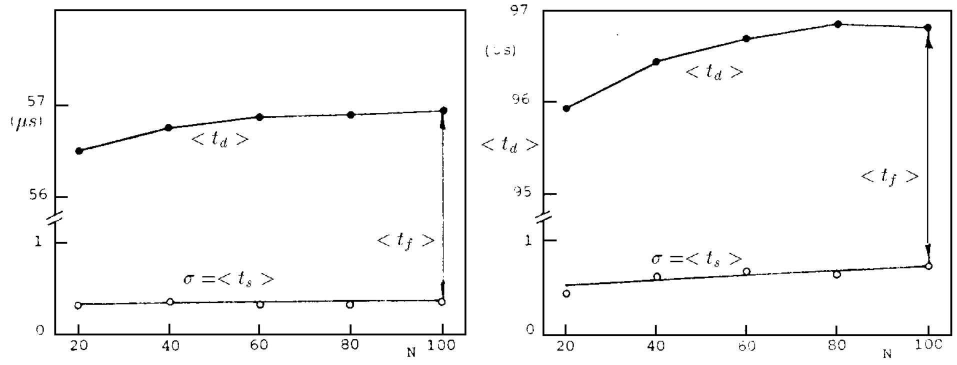
Fig. 2. The Laue distribution for $\tau = 0.3$ ms: (a) $U_p = 0$ V and (b) $U = 90$ V.

Fig. 3a illustrates the standard deviation $\sigma =< t_s >$ and average time delay $< t_d >$ as a function of number of t_d values N for the same group of data as for distribution in Fig. 2a. Fig. 3b shows the same dependence, but for the group of data t_d as for distribution in Fig. 2b. The values of $< t_f >$ obtained from these curves ($< t_f >=< t_d > -\sigma$) for $100 t_d$ values are 56.14 and 95.31 μs, respectively.

From Figs. 2 and 3 it can be seen that there is a good agreement of values of $< t_f >$ obtained from these two methods.

Fig. 4(a) illustrates the Laue distribution for 100 t_d values when $U_p = 0$ V and $\tau = 570$ ms. Fig. 4(b) shows the same distribution, but for the case when $U_p = 90$ V.

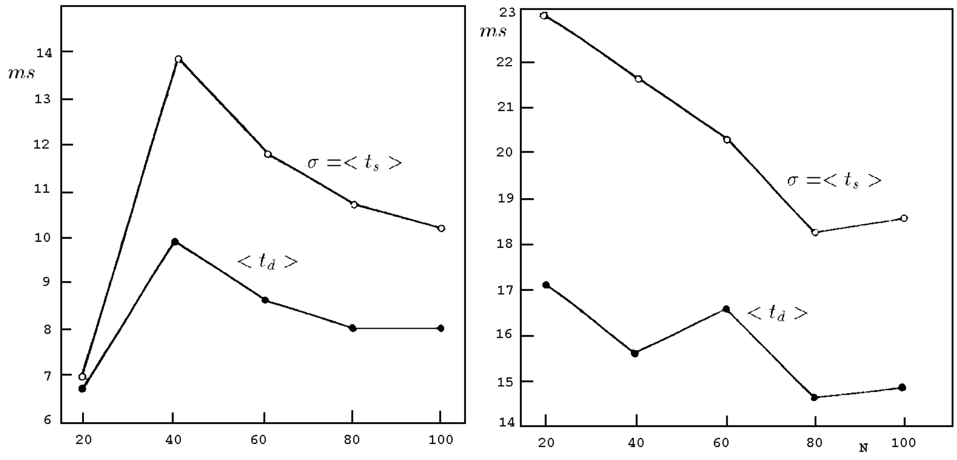
The curves of standard deviation and average time delay as a function of number of t_d value for the same group of data t_d as for distribution in Fig. 4(a), are shown in Fig. 5(a), while in Fig. 5(b) shown are the same



(a) (b)

Fig. 3. The standard deviation (σ) and average time delay ($< t_d >$) as a function of number of t_d values (N) for $\tau = 0.3$ ms: (a) $U_p = 0$ V and (b) $U_p = 90$ V.

dependence, but for the group of data t_d as for distribution in Fig. 4(b). From Figs. 4 and 5 it can be seen that average formative time $< t_f >$ cannot be determinate using these methods.



(a) (b)

Fig. 5. The standard deviation (σ) and average time delay ($< t_d >$) as a function of number of t_d values (N) for $\tau = 570$ ms: (a) $U_p = 0$ V and (b) $U_p = 90$ V.

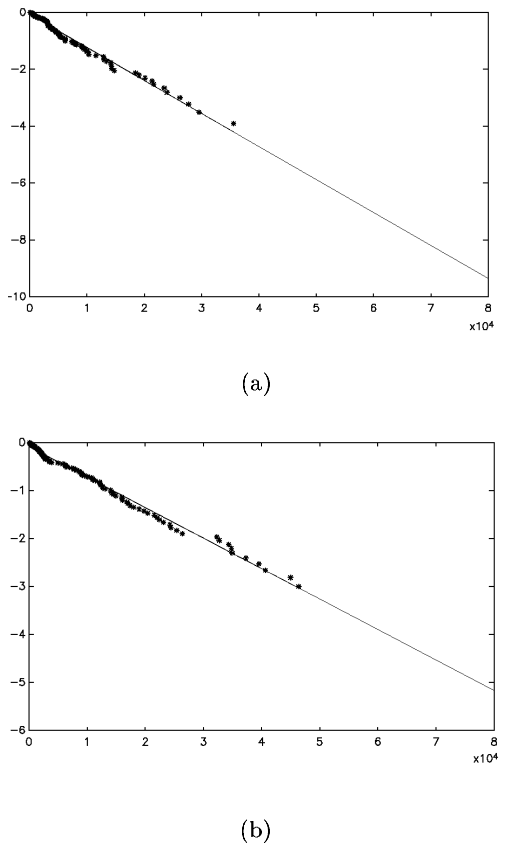


Fig. 4. The Laue distribution for $\tau = 570$ *ms:*
(a) $U_p = 0$ *V and (b)* $U_p = 90$ *V.*

The average time delay $< t_d >$ as a function of an afterglow period τ without and with positive bias on the electrode are presented in Fig. 6. Each point on the curves represents the mean values of a set of 100 measurements of t_d. From the figure it can be seen that rapid increase of $< t_d >$ occurs at $\tau \approx 200$ ms. On the basis of the curves behavior in Fig. 6 and results given in the papers [9,24,25] one can suppose that up to $\tau \simeq 200$ ms, the secondary electrons are ejected from the cathode by both positive ions and metastable states which remained from the previous discharge. After these values τ there are no positive ions and secondary emission electrons from the cathode are induced by metastable states. In that case the time delay increases rapidly because the probability of the breakdown taking place decreases.

From Fig. 6 it can be also seen that values of the $< t_d >$ are higher when the positive bias on the electrodes is applied for the same values of τ. It is concluded that positive bias on the electrodes removed the part of charges from inter electrode space during the afterglow period and time delay increases.

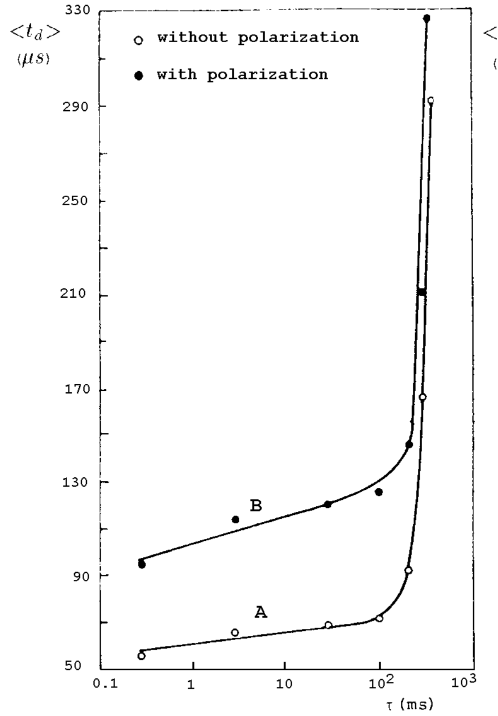


Fig. 6. The average time delay ($< t_d >$) as a function of afterglow period (τ): Curve A, obtained with $U_p = 0$ V and curve B, obtained with $U_p = 90$ V.

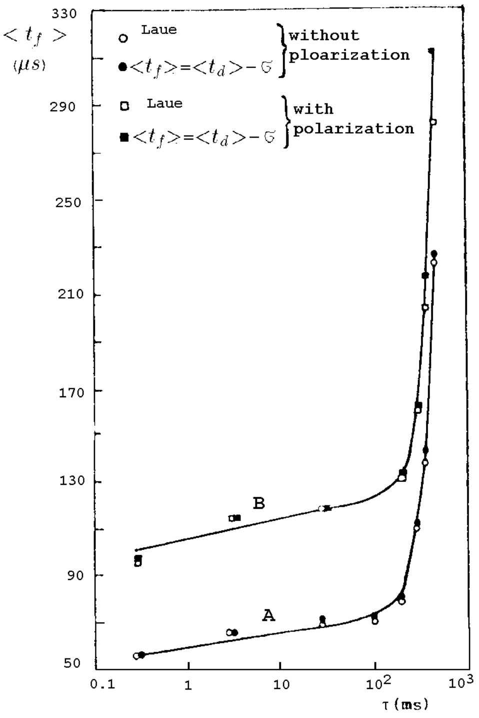


Fig. 7. The average formative time $< t_d >$ as a function of afterglow period (τ): Curve A, obtained with $U_p = 0$ V and curve B, obtained with $U_p = 90$ V.

The average formative time $< t_f >$ as a function of afterglow period *tau* without and with positive bias on the electrode are presented in Fig. 7. The values of $< t_f >$ for every value of τ are obtained from the Laue distribution and from the relation $< t_f > = < t_d > - \sigma$. It can be seen that there is a good agreement in the values of $< t_f >$ obtained by these methods when the breakdown is initiated by charges which remained from the previous discharge. The average formative time $< t_f >$, as an average time delay

$< t_d >$, depends on positive bias on the electrodes U_p. The values of $< t_f >$ are higher when $U_p = 90$ V than $U_p = 0$ V for the same values of τ.

5. Conclusion

The formative time as a difference between the average time delay of electrical breakdown and standard deviation, which is equal to average statistical time delay, has been determined. It is shown that this method can be used for determination of formative time when the dominant role in initiating the electrical breakdown have positive ions which remained from the previous discharge. The values of formative time which is determined by this method is in good agreement with values which are determined from the Laue distribution. When the metastable states play a dominant role in initiating the electrical breakdown, the formative time cannot be determined using these methods.

The formative time depends on the afterglow period. With increase of the afterglow period the charges in the inter electrode space diminish and the formative time increases. The formative time also depends on the positive bias of the electrodes. When positive bias is applied to the electrode the formative time is longer for the same afterglow period.

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