# SEMICONDUCTOR GAS DISCHARGE ELECTRONIC DEVICES: STABILITY AND CURRENT BEHAVIOUR

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Müxtəlif elektrodlar arası məsafələrdə *d* (45-530 mkm), atmosfer təziqinə qədərki müxtəlif təzyiq *p* intervallarında (28-620 Torr) və müxtəlif katod keçiriciliyində yarımkeçirici elektrodlu qazboşaldıcı sistemin VAX tədqiq olunmuşdur. Müxtəlif parametrlərin elektrik düşgüsünə və müstəvi qazboşaldıcı sistemin cərəyanının rəksinə təsiri müəyyən edilmişdir. Göstərilmişdir ki, istənilən eksperimental şəraitdə katodun diametrinin *D* böyüməsi ilə cərəyanın sıxlığı $U>U_B$ gərginlik intervalında böyüyür. Eyni zamanda, böyük *D* üçün cərəyanın rəqs diapozonun genişlənməsi müşahidə olunur.

Исследованы ВАХ газоразрядной системы с полупроводниковым электродом при различных межэлектродных расстояниях *d* (45-530 мкм), диапазонах давлений газа *p* вплоть до атмосферного (28 - 620 Тор) и проводимости катода. Выявлено влияние различных параметров на электрический пробой и колебания тока в плоской газоразрядной системе. Показано, что при всех экспериментальных условиях с увеличением диаметра катода *D* плотность тока в интервале напряжений $U > U_B$ растет. Одновременно, для больших *D* наблюдается протяженная область колебаний тока.

The current-voltage characteristics of the gas discharge system with a semiconductor cathode have been studied in in the wide pressure range up to atmospheric pressure *p* (28 - 620 Torr), interelectrode distances *d* (45 - 530 μm) and different conductivities of the cathode. The influence of different parameters on electrical breakdown and current oscillations in a planar gas discharge system are studied. We show that for all experimental conditions the current density increases over the entire range of voltages $U > U_B$ as the effective diameters *D* increases. At the same time, for large *D* an expanded range of current oscillations is observed.

## 1. INTRODUCTİON

During the past decades a large interest has been manifested in the study of electronic micro-discharge devices [1,2]. Compared to high-power discharge systems (e.g., arc discharge devices), micro-discharge devices are characterized by a small characteristic dimension of the discharge volume, by a low density of charge carriers in the discharge gap, and, as a consequence, by a relatively low electrical power dissipated in a device. The electrode dimensions, especially the electrode gap width *d* in the micrometre range, are small enough to generate sufficiently high electric field strengths to ignite atmospheric pressure glow discharges while being driven by dc voltages [3,4]. As is known [5,6], the dc Townsend-discharge breakdown curves are described by the Paschen law $U_B = f(pd)$; i.e., the breakdown voltage $U_B$ is a function of the product of the gas pressure *p* and distance between the electrodes *d*. However, in some experimental studies it was revealed that, at equal values of the product *pd*, the breakdown voltage for a long discharge gap with flat electrodes is appreciably higher than for a short gap [7,8]. In this work, we have studied experimentally the breakdown in a dc electric field in a planar gas discharge system with various interelectrode distances *d* and different effective diameters *D* of the electrode areas of the semiconductor cathode in darkness and upon illumination. The current of the discharge is controlled by a spatially homogeneous infrared light that increases the specific conductivity of the semiconductor plate *σ*. Formation of discharge glow is eventually initiated by the avalanche process of multiplication of free electrons in the gas at strong electric field and leads to increase current. The loss of stability of the homogeneous state is due to the appearance of the negative differential resistance (*NDR*) of gas discharge domain when current exceeds critical value.

## 2. Experimental

Scheme of the gas discharge system with a semiconductor cathode is shown in Fig.1. The total current *I* through the discharge cell and the voltage drop *V* between the electrodes is recorded simultaneously. The diameter of the high-resistivity ($\rho \sim 10^8$ Ωcm) *GaAs* cathode is 36 mm and its thickness is 1 mm [9]. On the illuminated side of the *GaAs*, a transparent conducting vacuum-evaporated *Au*-layer is coated. The anode is a disc of glass (with 30 mm diameter and 2 mm thickness) coated with a thin layer of a transparent conductor $SnO_2$. The inner surface of the semiconductor cathode was separated from a flat anode by an insulating mica sheet with a circular aperture at its centre. The typical effective diameters of the active electrode areas *D* (i.e. gas discharge gap or diameters of the circular through aperture in the insulator) are 5, 9, 12, 18, 22 mm. Variation of the thickness of the insulator made it possible to vary the size of the inter-electrode air gap *d* between 45 and 530 μm.

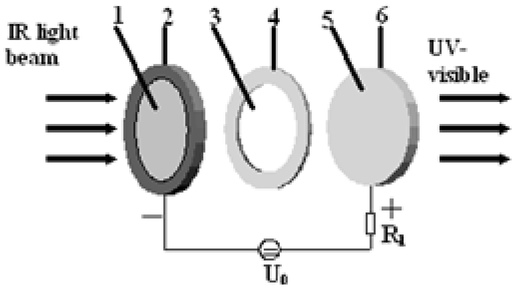

*Fig. 1.* Scheme of the gas discharge cell: 1- semitransparent *Au* contact; 2 – semiconductor *GaAs* cathode; 3 – gas discharge gap; 4 – mica foil; 5 – semitrasparent conductive $SnO_2$ contact; 6 – flat glass disc.

The paramater *pd*, is important for the description of the Townsend discharge breakdown curves. Intensity of the light incident on the cathode was changed by filters. In the *IR* region the photoconductivity in *GaAs* is attributed to *Cr* impurities. The internal photoeffect mechanism in semiconductors is responsible for the broad range of the system sensitivity in the *IR* spectral range [10]. The discharge gap of the cell is filled with atmospheric room air and the measurements are carried out at room temperature. The breakdown voltage $U_B$ was measured accurate to ± 3V and 5V.

## 3. RESULTS AND DISCUSSION

Figure 2 shows the *CVC* of the gas discharge cell in parallel-plane geometry with different conductivity $\sigma$ of the semiconductor cathode, which was varied by its uniform illumination through the semi-transparent *Au*-contact. The *CVC* allow us to determine the cell parameters: 1) breakdown voltage $U_B$; 2) variation of conductivity σ (or resistivity ρ) of the semiconducting cathode at different illumination intensities *L* (*i.e.* change of $\sigma = \partial J/\partial U$, or $\rho = \partial U/\partial J$ where *J* is the current density). Figure 2 also shows that the *CVC* is very close to linear if $U > U_B$. As demonstrated in Fig.2, the potential drop across the discharge gap in this range was nearly constant and the electric field increased only at the semiconductor cathode [11]. It is important to note that even for the maximal value of feeding voltage $U_0$ applied to the electrodes, the current density of the non-illuminated cathode is quite low and does not exceed a few microamperes per centimetre square.

We clearly demonstrate the effect of the voltage amplitude and gas pressure on the dynamics of transient processes in the system. Many investigations [9,12,13] confirm that Paschen's curves $U_B = f\,(pd)$ really have minima. $U_B$ min depends on gas type and cathode material, as well as on their purity. Following dynamic method normally used in our work will be considered here [14,15]. In this method, the voltage is applied to the cell and the cell is moved towards the breakdown status. After that, $U_0$ is swiched and on during each second, increasing the $U_0$ value simultaneously.

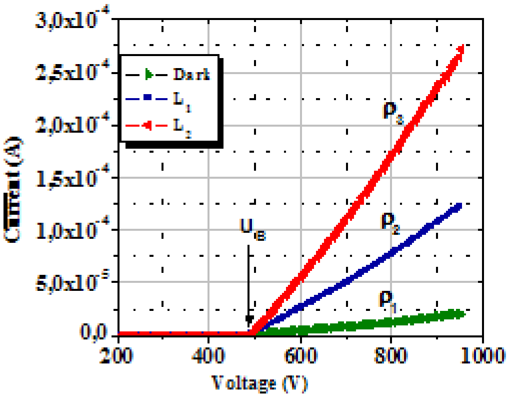

*Fig. 2. CVC* of a planar discharge cell in darkness and under a weak and a strong illumination intensities of light $L_1$ and $L_2$, respectively. The curves $\rho_1$-$\rho_3$ represent the *CVC* for three resistivities of the GaAs cathode for $p$ = 28 Torr, $D$ = 22 mm, $d$ = 445 µm.

The minimum voltage value for which the electrical breakdown still appears can be considered as $U_B$. It should be noted that breakdown voltage depends on the rate of the increase of the $U_0$ (see Fig.3).

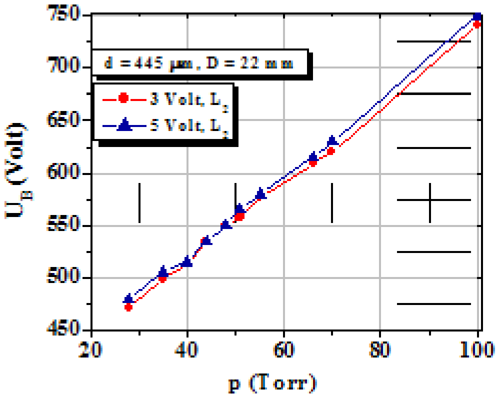

*Fig. 3.* Dependence of the breakdown voltage $U_B$ on the rate of the increase of the applied voltage $U_0$: for increment 3V and 5V.

Due to linear ramp, *k* is in fact the ratio between the voltage step and the time interval between successive steps. The voltage step was 3 V and 5 V while the time interval was varied from 0.01 to 1 s, and, consequnetly, the obtained values of *k* were from 100 $Vs^{-1}$ to 1 $Vs^{-1}$. Dependence of the $U_B$ on the k for air-filled cell at different pressures (28 -500 Torr) are shown in figure 3. The $U_B$ value depends on the *k* values. Larger *k* values give higher $U_B$ value. This can be observed by comparing the results in figures 3. It can be concluded that value of $U_B$ will be more precise if *k* values are lower.

Figure 4 shows the breakdown curve of the gas discharge cell in parallel-plane geometry for different diameters *D*. It is seen from Fig.4 that by increasing the effective *D* the minimum of the Paschen curves are shifted to the region lower breakdown voltages $U_B$. At the same time, the value of $U_B$ can be changed by increasing the conductivity of the cathode and the conductivity can be adjusted by the illumination intensity [16,17] . $U_B$ depends on the rate of the increase in the applied voltage $U_0$ and on the contact materials on the cathode surface, cathode material [18,19] and on the presence of IR illumination intensity. Thus the $U_B$ is lower when the cell is illuminated by *IR* light.

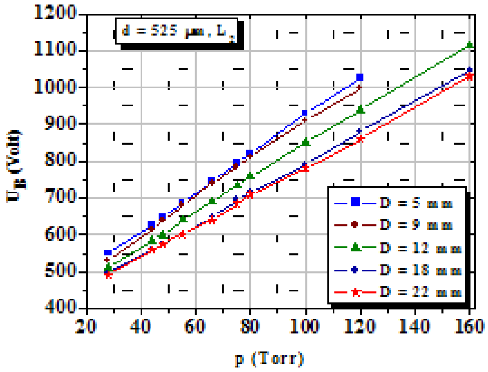

*Fig. 4.* Measured breakdown curves of the Townsend discharge in an air for GaAs semiconductor cathode under strong illumination intensities of light $L_2$ for different diameters *D* of the electrode areas. The interelectrode gap $d$ = 525 $\mu$m.

The latter is in accordance with an earlier result that showed additional ionization in interelectrode space decreases $U_B$ [20]. In the planar dc-driven gas discharge devices with a small active volume, the role of the space charge of the ions in a discharge process is diminished, and the transport of ionized particles in the gap is mainly controlled by the electric field, determined by surface charges on electrodes (see [5]). Breakdown current behaviour has been observed to ocur early when the application of voltage to the electrodes and the establishment of a self-sustained discharge has a strong stochastic character [21,22]. The breakdown is characterized by the rapid gas transition from a very poor electrical conductor with the resistivity of ≈ $10^{14}$ Ωm to a relatively good conductor with a resistivity that is many orders of magnitude lower (the resistivity depends on particular conditions and is typically about $10^3$ Ωm in glow discharge) [23]. Figure 5 shows the complicated physical processes occurring in semiconductor discharge gap. These are the nonlinear autocatalytic process of multiplication of charge carriers and capacitive and resistive processes [24].

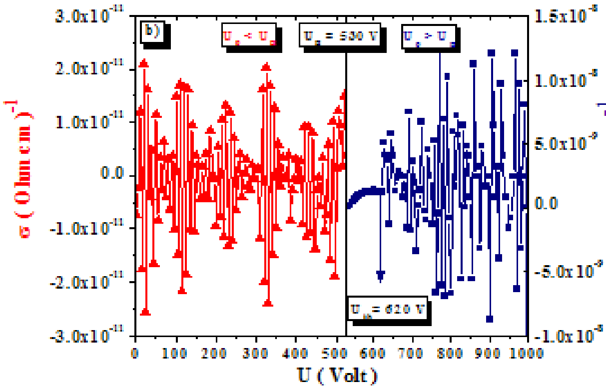

*Fig. 5.* Dependence of conductivity $\sigma$ on the feeding voltage for different pressure $p$ in a planar semiconductor gas discharge cell. The effective diameter of the electrode area $D$ = 22 mm. The interelectrode distance $d$ = 525 μm and gas pressure $p = 44$ Torr

For different pressures, the characteristics of the gas discharge conductivity as function of applied voltage changes drastically. At the same time, we believe that the local inhomogenities of the semiconductor play an important role in order to produce such an effect for certain voltages. The explicit form for conductivity is as given:

$$\frac{\Delta I}{\Delta V} = \frac{I_{n+1} - I_n}{V_{n+1} - V_n} \tag{1}$$

and

$$\sigma = \frac{\Delta I}{\Delta V}\frac{d}{S} \tag{2}$$

in which $d$ is the thickness and $S$ is the active area of the the gas discharge gap, respectively. Such fluctuations result from a spatially random distribution of charged defects. The frequency and amplitude of the current oscillation depends on feeding voltage $U_0$, the voltage increment of the power supply and the illumination intensity [8,9]. Figure 5 also presents the data on the breakdown voltage $U_B$, threshold voltage $U_{th}$ for the onset of oscillations, and the maximum voltage $U_0$ at which current oscillations are observed. The oscillations exist at $pd$ lying on both sides from the minimum of the Paschen curve. At the same time, the amplitude of current oscillation in a device with fixed geometrical parameters is mainly determined by the current density: it increases monotonically with current density. These observations, together with the data of the present work, show the existence of the oscillatory instability in the range of control parameters. The experimental data, together with theoretical considerations of the problem of stability of the system [26], suggest that it is the non-linearity of the gas-discharge (which is of the $S$ type) that is responsible for the effect. To clarify the mechanism of the observed phenomena, a theoretical analysis of the dynamics of an extended system that consists of the gas-discharge gap and the semiconductor cathode, which are characterized by nonlinearities in the *CVC*s, is required.

## 4. CONCLUSIONS

In this study, Townsend and glow-discharge initiation in air in a planar gas discharge system with a semiconductor cathode was investigated experimentally for variable interelectrode gaps and effective diameters of the cathode areas $D$. It is shown that when driven with a stationary voltage, it generates current instabilities with different amplitudes of oscillation. We suppose that the peculiarities of the current passage are attributed to the formation of non-equilibrium unstable current structures in the gas depending on the $d$, effective $D$ parameters and emission properties of the semiconductor electrode surface.

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