EFFECTIVE ROLE OF VOLUMETRIC COLLISIONS IN BREAKDOWN AT ATMOSPHERIC PRESSURE IN SEMICONDUCTOR GAS DISCHARGE SYSTEM

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The effects of collision processes in discharge volume in breakdown were investigated in the range of *E*/*p* (100-600 V/cm×Torr). We obtained the breakdown curve for argon micro-plasma in a semiconductor gas discharge system consisting of GaAs cathodes to the contributions of the collision processes in discharge volume when the gas discharge gap (*d*) is45μm. The secondary electron emission liberated by the semiconductor cathode was found as a result of interaction with the cathode of ions and photons occurring in plasma space. Under electric fields, the collision processes in discharge volume provide the rapid growth of electron multiplication required for avalanches. At high pressures up to atmospheric pressure, our investigations show that the value of secondary electron emissions for semiconductor cathode gradually grows. In these conditions, micro-plasma was obtained with a homogeneous formation. For plasma light sources and gas discharge lasers, our results become important to reveal the volumetric processes of micro-discharge electronic devices at high pressures up to atmospheric pressure.

Keywords: cathode surface–plasma interactions, electrical breakdown, secondary electron emission, semiconductor cathodes.
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INTRODUCTION

Atmospheric-pressure dc cold micro-discharges that arestable and the low-current are one of the most common plasma types. It is due to the advantages. They contain the wealthy species in the plasma volume. It isn't observed the damages to the environment. However, the important disadvantage in atmospheric-pressure cold micro-discharges is the high energy required for the discharge formation and the self-sustained discharge. The effect of the cathode on the discharge is weak, which means that the volumetric processes gain importance. This disadvantage leads to the difficulties such as cost in the cold micro-plasma applications. Also, it can be the transitions from a stable state to an unstable state for the micro-discharges in the plasma volume. Micro-discharges have been prevalently utilized in the various technologies of light sources, microreactors, and plasma display panels [1-3].

Recently, to detect the characteristic properties of the atmospheric-pressure cold micro-discharges the studies were widespread. In such a type of discharge, it is mainly encountered with intense collisions in discharge volume, thermal effects, under the small mean free path, and the developments in the collision frequency. The discharge volume occurring in volumetric collisions covers the intense electron density and photon. The existence of plasma species gives the markedly various spectra lines with the collisions in the discharge volume [4-8]. Particularly, a photoionization process in the discharge volume becomes important in the development of the discharge plasma. It plays a critical role in the evaluation of volume processes for the discharge formations and the self-sustained discharge sat high pressures up to atmospheric pressure.

A gas discharge system that consists of a semiconductor cathode is a semiconductor gas discharge system (SGDS) employed in the production of atmospheric-pressured cold micro-discharges. In SGDS, the semiconductor cathode makes an important contribution to the micro-plasma via secondary electron emission (SEE), and at the same time, it can be the ability to extinguish the formations of nonhomogeneous current in the discharge space due to its spatial distribution [9-12]. In SGDS, the volumetric collision processes occurring in discharge volumes far haven't been investigated for the atmospheric pressure dc cold micro-discharges. It becomes important the evaluate volumetric collision processes for the cold micro-discharges revealed in the discharge volume of SGDS.

We aim to present the effective processes of volume ionization playing a role in atmospheric-pressure dc cold discharges with the semiconductor cathode at the breakdown instant. SGDS was applied the enough high electric fields to generate collisions in discharge space. SGDS generated a uniform micro-plasma with numerous collisions in discharge space, and the collision processes including mainly collision-induced excitations and collision-induced ionization, and photoionization were obtained with the inelastic collisions. It depends on the energy given between the cathode and anode the discharge formation and the self-sustained discharge with these collisions. We consider that the volumetric collision processes will become important in developing micro-discharge applications and technologies.

EXPERIMENTAL

The experimental scheme of SGDS with the semiconductor cathode is shown in Figure 1.

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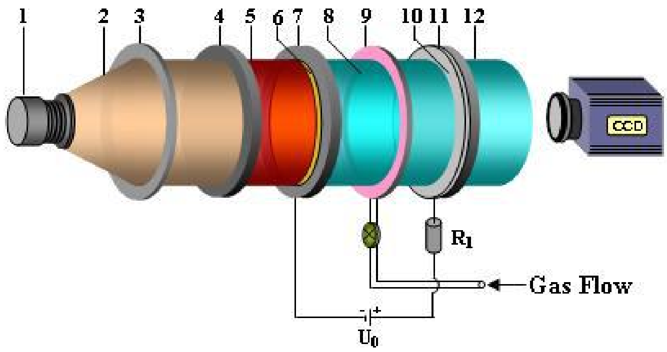

Fig. 1. Scheme of SGDS with GaAs semiconductor cathode: 1 - light source, 2 - incident light beam, 3 - lens, 4 - Si filter, 5 - IR light beam, 6 - semi-transparent Ni contact, 7 - semiconductor cathode, 8 - discharge gap, 9 - insulating mica foil, 10 - semitransparent conductive SnO_2 contact, 11 - flat glass disk, 12 - visible light beam.

Semiconductor material (7) consists of semi-insulating n-type GaAs:Cr with high resistivity ($\rho \cong 10^8$ Ω×cm), and it is a direct semiconductor that has a bandgap of 1.43 eV at room temperature. The thickness and the diameter are 1 and 36 mm, respectively. The anode was covered with a conductive SnO_2 (10), and it had a glass disk (11) with a 2 mm thickness and a 36 mm diameter. An insulator slab (9) between the semiconductor cathode and the glass plate has a spacer with a circular aperture (8). The discharge gap d = 45 µm and the pressure p between 550 and 760 Torr were used to obtain the right-hand branch of the breakdown curve. The discharge gap between the glass plate and the semiconductor cathode plate was filled with argon gas. The gas pressure of the discharge system was changed by a needle valve between the discharge chamber and the mechanical pump. The values of breakdown voltage U_B were determined from current-voltage characteristics. The experiments were carried out at room temperature. In this study, when the semiconductor cathode absorbs the incident radiation L_3, we investigate the volumetric processes in the atmospheric-pressure dc cold discharges in SGDS with GaAs cathode.

RESULTS AND DISCUSSION

The breakdown curve of SGDS with the GaAs cathode is presented in Figure 2at high pressures up to atmospheric pressure. When the pressure is increased, the voltage values required for the onset of discharge plasma also increase. We obtained the breakdown voltages U_B = 315 V at 550 Torr, and U_B = 345 V at 760 Torr at d = 45 μm in L_3. With the increasing pressure, the collisions of more gas atoms placed in the discharge space lead to the onset of discharge plasma at higher voltage values. To express this increase, the volumetric collisions of atoms, species, and electrons in the plasma space are taken into account when the applied potential and the pressure increase. In discharge plasma, with increasing electric field, the volumetric collisions continuously develop, while GaAs cathode markedly emits SEEs in discharge space.

At high pressures up to atmospheric pressure, Figure 3 shows γ levels released by the GaAs cathode at the onset of discharge plasma. The secondary electron emission coefficient (γ) for the electrons emitted from the cathode gradually increases with the increasing pressure in the ranges of E/p between 100 V/cm×Torr and 150 V/cm×Torr. It was found as $\gamma = 7.26\times10^{-4}$ at 550 Torr, and $\gamma = 1\times10^{-3}$ at 760 Torr. In the plasma space, the electron gainsless energy from the electric field when E/p decreases**.** At the reduced values of E/p, the electron-induced excitations become important, and this case reveals the presence of formation in discharge volume due to photons. VUV-UV photons and the resonant emissions are dominant processes, and the increasing number of metastable species are important in these ranges of E/p but it is observed the decreases in the ionizations [7,8]. For these ranges of E/p, the photoionization mechanism makes an important contribution to ionizing the atoms in the discharge space. Photons formed in the discharge volume have enough energy to ionize the atoms. The collision-induced excitations and ionizations continuously develop in the discharge volume with the increasing electric field. This consideration indicates the importance of volumetric collisions in the discharge space at high pressures up to atmospheric pressure. The onset of discharge plasma depends on the volumetric collisions while SEEs emitted from the cathode increase at the reduced values of E/p. The formation of SEEs in these ranges of E/p originated from the photon-induced SEEs. But, when the pressure increases, the photon-induced SEEs liberated by the cathode also increase.

With the increasing pressure, the increase in the number of collisions is significant to initiate the discharge plasma. The increase of applied voltage leads to the increase in the number of collisions in this volume, and therefore the discharge plasma is required for the high voltages. The results obtained from Figure 2 show that the voltages of breakdown curves shift to the high values. It is about the high electric field at 45μm at high pressures up to atmospheric pressure for micro-discharges. In these conditions, the onset of plasma and the self-sustained plasma are required for enough high electric fields. This case results in a time lag in the breakdown curve when the pressure increases. At high pressures up to atmospheric pressure, collision-induced excitation becomes important while collision-induced ionization gives their products in the discharge volume. We conclude that the collision processes occurring in the micro-plasma volume present unique effects in the onset of discharge plasma. Therefore, the plasma space at the high pressures up to atmospheric pressure is occupied by the intensely collision-induced excitation and ionization processes.

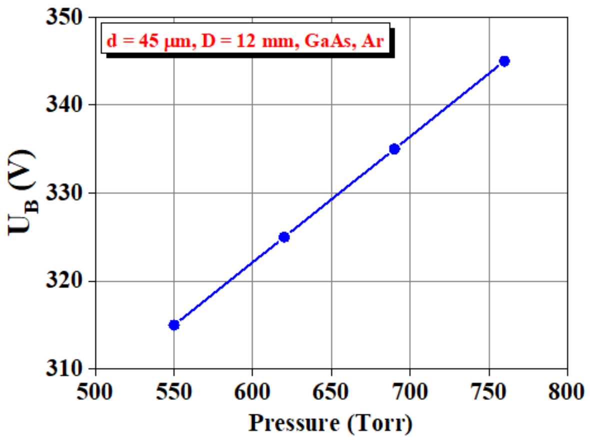

Fig. 2. Breakdown curve in Ar medium in SGDS at high pressures up to atmospheric pressure.

To form the microplasma, the photoionization occurring in the discharge space gives a unique contribution with an ionizing effect on the gas atoms under the inelastic collisions when the number of gas atoms increases. Photoionization becomes important in the electron multiplication required for avalanches in SGDS. On the cathode, due to the photons occurring in the discharge volume, the photoelectron mechanism is valid, and the photons contribute to the electron emission from the cathode; however, in the plasma volume, there are increases in the amount of space charge. Also, the different plasma regimes can be observed with the processes of collision-induced excitation and ionization when the electron density increases. The results obtained in [14,15] show the critical role of the volumetric processes occurring in the formation of discharge plasma and self-sustained plasma. It can result in disorders in the spatial–time distribution of microplasma.

In the atmospheric-pressure DC discharge of SGDS, the collision-induced excitation and ionization processes become important to generate the current in discharge space. The current-voltage characteristics to express the state of the atmospheric-pressure DC discharge of SGDS under the collision-induced excitation and ionization processes are shown in Figure 4. The formation and maintenance of low-current discharge are directly about the numerous collision-induced excitation and ionization processes obtained in discharge space. For the breakdown, it needs to have a high electric field under these conditions. With the increasing electric field, many collisions in discharge space develop. From this point, the volumetric collision processes in discharge space are characteristic of microplasma at high pressures up to atmospheric pressure, and therefore discharge volume presents a main effect for microplasma. There is an important dependency on the discharge volume of microplasma at high pressures up to atmospheric pressure [8].

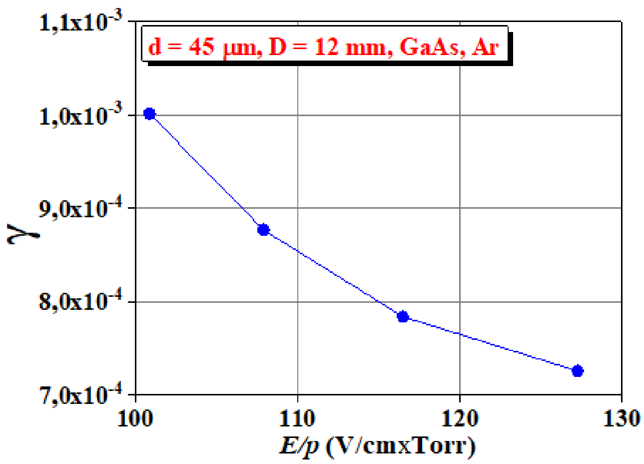

Fig. 3. Secondary electron emission and E/p graph obtained in SGDS in L_3.

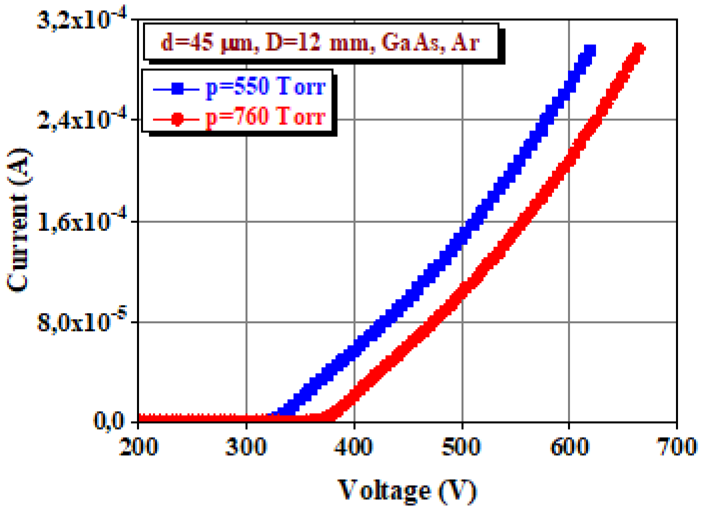

Fig. 4. Current-voltage characteristics obtained at high pressures up to atmospheric pressure in SGDS in L_3.

After the breakdown, the growth in the discharge current develops step by step when the applied voltage increases. The homogeneous spatial-time distribution is established in the conditions of low-current micro-discharge after the breakdown. The discharge current is sustained by the main volumetric collision processes and also SEEs liberated by cathode through discharge space. When the accumulation of space charge in discharge volume becomes important, deviations in the stability of discharge space can be observed [16]. With the important development of volumetric collision processes, the homogeneity of spatial-time distribution begins the losses, and it results in the oscillations or abrupt decrease of discharge current. It becomes important the govern volumetric collision processes to obtain the stable discharge in microplasma applications.

CONCLUSIONS

We investigated the effect of volumetric collisions in breakdown in argon environment in atmospheric-pressure dc microdischarge in SGDS with GaAs cathode. At high pressures up to atmospheric pressure, the amount of SEE released by the cathode reaches high values at the reduced values of *E*/*p*. It was observed that the breakdown voltages shift to the higher applied voltage values when the amount of SEE is at higher values. At the reduced values of *E*/*p*, the formation of discharge plasma is about photoionization structure in the effects of collision-induced excitation and ionization. When the volumetric collision processes in discharge plasma are taken into account, we consider that the efficiency of microplasma applications will develop at high pressures up to atmospheric pressure.

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