PECULARITIES OF PLASMA-CATHODE SURFACE INTERACTION AND ELECTRON-INDUCED EXCITATIONS IN SEMICONDUCTOR GAS DISCHARGE STRUCTURE

E. KOÇ[1], M.M. SHIRINOV[2] and B.G. SALAMOV[2,*]
[1]Department of Electrical and Electronics Engineering, Faculty of Engineering,
Istanbul Arel University, 34537 Istanbul, Turkey
[2]Institute of Physics, Ministry of Science and Education, AZ1073 Baku, Azerbaijan
**Corresponding author: baht1911@gmail.com*

The peculiarities of plasma-cathode surface interactions and electron-induced excitations were the focus of an experimental study in Ar plasma. In the present experiments, the *GaAs:Cr* cathode is utilized, which emits secondary electrons into the discharge during the plasma-cathode surface interaction. The gas discharge gap was set to 143 μm, the discharge diameter to 12 mm, and the pressure to a range of 44-760 Torr. This was done to explore the plasma-cathode surface interactions and electron-induced excitations. It was established that when the *GaAs:Cr* cathode was exposed to IR light, there was an increase in electron-impact ionization and excitations due to plasma-cathode surface interaction. Concurrently, observations were made about the development of electron-induced excitations in cold *Ar* microplasma under the conditions of increasing pressure. The results obtained from the plasma-cathode surface interactions and electron-induced excitations become significant for the development of the applications and technologies of cold-discharge plasmas.

Keywords: plasma-cathode surface interactions, discharge plasma, secondary electron emission, discharge emission, electron-induced excitations.
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1. INTRODUCTION

The plasma-cathode surface interaction is of significant application. This interaction is predominantly employed in applications and technologies such as discharge plasmas, thin films, plasma treatment, and surface cleaning [1-3]. As postulated in the relevant literature, interactions in the discharge plasma are known to occur in a dark region on the surface of the cathode or cathode sheath. These interactions can result in processes such as the emission of electrons from the cathode or surface modification. During the self-sustaining discharge, the discharge plasma interacts with the cathode surface, while electron-induced excitations and ionizations continuously develop within the discharge volume. It is evident that alterations in the intensity of optical emission are discernible at varying values of applied voltage and pressure. Electron-induced excitations have been the focus of significant research interest due to their applications in discharge emission, including excimer and light sources [4, 5]. It is therefore imperative that the behavior of surface interactions between plasma and cathode, in addition to electron-induced excitations, is thoroughly investigated for the purpose of optimizing discharge plasma applications.

In recent times, studies of plasma-cathode surface interactions and electron-induced excitations have become increasingly significant. The movement and direction of ions within the plasma-cathode surface region are of particular significance. The present study investigates the free collisions of the plasma-cathode surface region based on ions at low pressures [6]. The movement of ions within the plasma-cathode surface region is of significance. In this region, ions have been observed to return to the cathode [7]. The movement of excitation species and ions is a crucial factor in the characterization of this region. The electron-induced excitations in the vicinity of the cathode have been obtained [8]. The effects of temperature were expressed in the plasma-cathode surface region [9]. In this regard, the plasma-cathode surface region and electron-induced excitations provide significant knowledge with which to explore the properties of discharge plasmas.

A semiconductor gas discharge structure (*SGDS*) is employed to generate DC cold-discharge plasmas in the gas discharge system with a semiconductor cathode. The utilization of *SGDS* has been extensively documented in the domain of IR image converters, light sources, the imaging of electrical and structural defects of semiconductors, and certain lasers [10-13]. In this system, the semiconductor cathode assumes particular significance due to its role in current control through IR illumination and its capacity to regulate the stable state of discharge current within the discharge volume, attributable to its resistance to spatial distribution [3, 10, 13]. In *SGDS*, the characteristics of the plasma-cathode surface interactions and the electron-induced excitation processes occurring in the discharge volume have not yet been studied in order to reveal the characteristics of DC cold-discharge plasma. The plasma-cathode surface interactions and electron-induced excitation processes in the cold microdischarges are of significant importance when evaluating the characteristics of *SGDS*.

The objective of this study is to elucidate the plasma-cathode surface interactions and the behavior of electron-induced excitations of *SGDS*. The application of a voltage between the cathode and the anode resulted in the discharge plasma interacting with the cathode following the onset of the discharge. The discharge emission was thus obtained through the collisions of electrons and atoms at low and atmospheric pressures. It is demonstrated that, within the framework of *SGDS*, the electron-induced ionizations and excitations are subject to variation in response to the mean free path and pressure. The results obtained are in relation to technologies and applications of cold-discharge plasmas.

2. EXPERIMENTAL

Figure 1 shows experimentally the scheme of *SGDS*, which consists of the semiconductor cathode. The measurements were performed at room temperature.

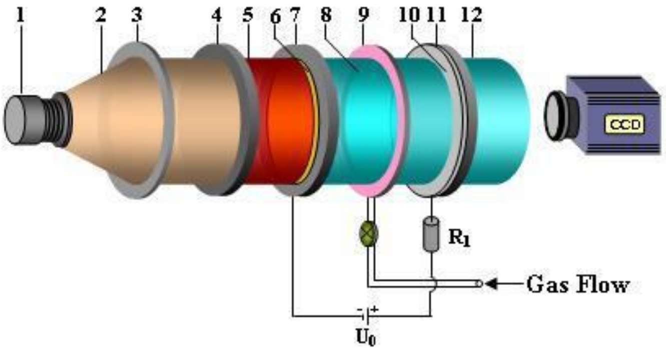

Fig. 1. Scheme of SGDS with GaAs semiconductor cathode: 1-light source, 2-incident light beam, 3-lens, 4-Si filter, 5-IR light beam, 6-semi-transparent Ni contact, 7-semiconductor cathode, 8-discharge gap, 9- insulating mica foil, 10-semitransparent conductive SnO_2 contact, 11-flat glass disk, 12-visible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

Semiconductor material (7) that is a semi-insulating n-type *GaAs:Cr* has a high resistivity of $\rho \cong 10^8\ \Omega\times$cm. GaAs:Cr is a direct semiconductor that has a bandgap of 1.43 eV at room temperature. Its thickness is 1 mm, and its diameter is 36 mm. A conductive SnO_2 (10) was covered on the anode. In the glass disk (11), the thickness is 2 mm, and the diameter is 36 mm. An insulator slab (9) has a circular spacer (8), and it was placed between the semiconductor cathode and the glass plate. The discharge gap d = 143 µm and the pressure p between 44 and 760 Torr were employed to reveal the properties of plasma-cathode surface interactions and electron-induced excitations. The diameter D of the effective electrode area in the discharge plasma was chosen in the range of 12 mm. The discharge gap between the anode and the semiconductor cathode was filled with *Ar* gas. The pressure in the gas discharge structure was changed by a needle valve between the discharge system and the mechanical pump. The values of discharge current were determined from current-voltage characteristics, and the values of discharge emission were obtained from intensity-voltage characteristics. In our experiments, the semiconductor photocathode *GaAs:Cr* is sensitive to the IR incident radiation. In DC cold microplasma, we studied the characteristics of plasma-cathode surface interactions and electron-induced excitations at low- and atmospheric pressures in *SGDS* with *GaAs:Cr* photocathodes in dark D and illuminations L_1 and L_3.

3. RESULTS AND DISCUSSION

To determine the plasma-cathode surface interaction in *SGDS*, the current-voltage characteristics without and with illumination in the discharge cell in Ar plasma with the GaAs photocathode are shown in Figure 2(a). After the onset of breakdown, the cold-discharge plasma establishes in the homogeneous electric field. The discharge current is the stable state when the discharge cell is illuminated. When the applied voltage is further increased, the potential drop between the GaAs photocathode and anode gradually forms. If any unstable current inhomogeneities occur, they are suppressed by the GaAs photocathode. We studied the characteristics of cold discharge up to the discharge current I value of approximately 1.2×10^{-4} A. Under these circumstances, it is observed that in the discharge volume, the current fluctuations occur in D before the onset of breakdown; however, in L_1 and L_3, the discharge current reaches high values when the GaAs photocathode is exposed to IR illumination. Due to the electron-induced ionizations generated by the discharge, some ions approach the near cathode. These ions enter the region of plasma-cathode surface interaction. These ions gain energy from the electric field. They reach the *GaAs* photocathode to form secondary electron emission. They collide with the cathode, and therefore, they lead to the secondary electron emissions liberated by the cathode surface. The photons, neutrals, and excitation species with long or short lifetimes interact with or collide with the cathode surface as well as the ions, and it results in the secondary electron emissions. The effect of these species on the plasma-cathode surface interaction was observed in the discharge volume at certain values of E/N (where E is the electric field and N is the number density of the gas) [9,14,15].

However, there are continuous effects of electron-induced ionizations on the plasma-cathode surface interaction during the discharge. The contributions of secondary electron emissions to discharge plasma are assumed to form outside the plasma-cathode surface interaction. Thus, in the discharge volume, the electron-induced ionizations are due to both the cathode with secondary electron emissions and the collisions to form the ionization of electrons and atoms in the plasma volume during the self-sustained discharge in *SGDS*. These result in the growth of the discharge current with the development of the electron-induced ionizations. When the intensity of IR illumination in the GaAs photocathode increases, the growth in the discharge current occurs. This growth can be explained by the increase of plasma-cathode surface interactions and the collisions to form the ionization of electrons and atoms in the plasma volume. In the discharge plasma, the plasma-cathode surface interactions are a dynamic process due to the formation of ions, photons, neutrals and excitation species with long or short lifetimes generated by the discharge plasma.

Figure 2(b) shows the intensity-voltage characteristics in *Ar* plasma with the *GaAs* photocathode under the different IR illuminations and *D*. We observed the uniform discharge emissions in *SGDS*. After 405 V in L_3 and 500 V in L_1, the discharge emission intensity gradually increases with the applied voltage. There isn't a discharge emission in *D* in Figure 2(b) because the discharge current wasn't remarkably observed in Figure 2(a). In L_1 and L_3, we obtained the growth in the discharge emission with the increase of plasma-cathode surface interaction. With the plasma-cathode surface interaction, the electrons liberated by the photocathode lead to the electron-impact ionizations and excitations in the discharge volume. The increases in the excitations provide the growth in the intensity of discharge emission. *UV/VUV* spectral lines of *Ar* become important for the secondary electron emissions liberated by the photocathode with the plasma-cathode surface interaction. *Ar* spectral lines distribute *UV/VUV* and IR regions in discharge plasma [14,16,17]. We can conclude that in the plasma-cathode surface interaction, UV/VUV photons provide the secondary electron emissions, and outside the plasma-cathode surface interaction, these secondary electrons may be important for the discharge emissions.

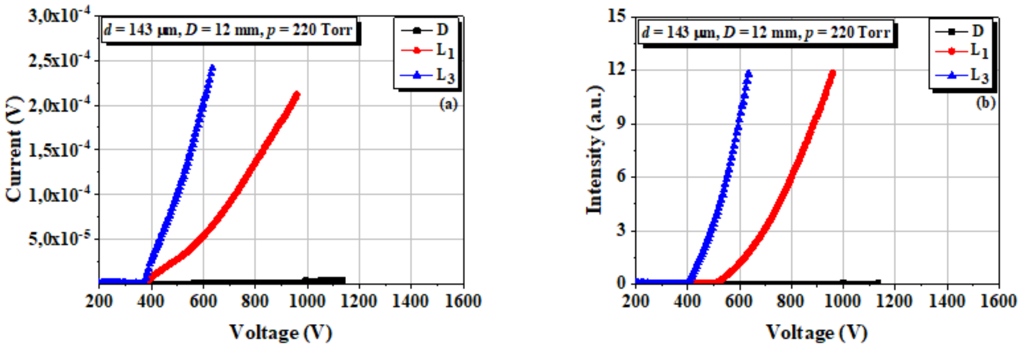

Fig. 2. (a) Current-voltage characteristics, and (b) Intensity-voltage characteristics in *Ar* plasma with *GaAs* photocathode.

In *SGDS*, to reveal the features of discharge emission in L_3, the intensity and pressure graph was shown in Figure 3(a). This graph was obtained in a constant discharge current at the value of $I = 1\times10^{-4}$ A. When the pressure increases, the discharge emission also increases. According to Figure 3(a), *Ar* excited species grow with increasing pressure. The decreases in the mean free path occur with the increase of pressure, and the energy that the electron gains from the electric field decreases. It results in collisions that occur with the lower energy of the atom and electron. Thus, the electron-induced excitations increase, and the intensity of optical emission in the discharge plasma reaches high values.

The behavior of discharge current in *SGDS* concerning pressure was obtained in Figure 3(b), which shows the current, voltage, and pressure graph. In this graph, the discharge emission intensity at the value of 5 a.u. is taken as the constant. When the pressure increased, the decreases in the discharge current were observed in *SGDS*. The electron-induced ionizations decrease with increasing pressure to reach a constant discharge emission. Due to the time lags required for the onset of discharge plasma, the discharge current remains at a low value, and it decreases when the pressure increases at a constant value of discharge emission. It leads to an increase in electron-induced excitations while the electron-induced ionizations occur.

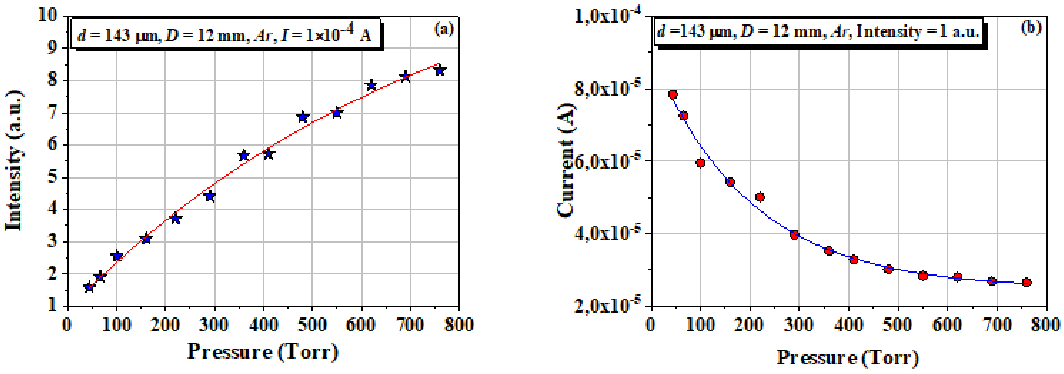

Fig. 3. (a) Intensity-pressure graph in L₁, and (b) Current-pressure graph in *Ar* plasma with *GaAs* photocathode in L_1.

The increase in the mean free path of low-pressure discharges gives rise to a significant number of electron-induced ionizations. Consequently, the discharge emission remains at low values at low pressures in *Ar* plasma [12]. The cathode exhibits a demonstrable dependency on low-pressure discharges. The effects were described in terms of interactions with the cathode of ions. However, the decreases in mean free path demonstrate the significance of electron-induced excitations at high pressures up to atmospheric pressure [12]. Consequently, this results in an increase in the intensity of discharge emission.

4. CONCLUSIONS

In *SGDS*, experimental investigation was conducted into plasma-cathode surface interactions and electron-induced excitations in *Ar* plasma. The present study was conducted in the stable state of discharge current generated in *SGDS*. It was established that when the *GaAs* photocathode was exposed to IR illumination, the discharge current increased due to plasma-cathode surface interactions. The increases in excitation thus provide the growth in intensity of discharge emission. In an argon plasma, electron-induced excitations developed when the pressure was increased. Consequently, it was established that the intensity of optical emission in *Ar* discharge plasma attains elevated values. It was observed that the electron-induced ionizations decreased with increasing pressure at a constant value of discharge emission intensity.

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[1] *B.G. Salamov, Y.O. Çiftçi and K. Çolakoğlu.* 2004 IEEE Trans. Plasma Sci. 32, 2093.

[2] *B.-O. Aronsson, J. Lausmaa and B. Kasemo.* 1997 J. Biomed. Mater. Res. 35,49.

[3] *E. Koç, B.G. Salamov, T.G. Mammadov, N.N. Lebedeva and V. I. Orbukh.* 2025 Phys. Status Solidi B 262, 2400364.

[4] *G.G. Lister, J. E. Lawler, W. P. Lapatovich and V. A. Godyak*. 2004 Rev. Mod. Phys. 76, 541.

[5] *M. Kaku, Y. Sato and S. Kubodera*. 2012 Appl. Phys. B 107, 85.

[6] *V. A. Lisovskiy, V. A. Derevianko and V.D. Yegorenkov*. 2014 Vacuum 103, 49.

[7] *M. S. Benilov*. 2010 J. Phys. D: Appl. Phys. 43, 175203.

[8] *C. Lazzaroni, P. Chabert, A. Rousseau and N. Sadeghi*. 2010 Eur. Phys. J. D 60, 555.

[9] *H.-P. Li and M. S. Benilov,* 2007 J. Phys. D: Appl. Phys. 40, 2010.

[10] *B. G. Salamov, B. G. Akinoğlu and N. N. Lebedeva.* 1999 J. Phys. D: Appl. Phys. 32, 2068.

[11] *B. G. Salamov*. 2004 Imaging Sci. J. 52, 225.

[12] *E. Koç, S. Karaköse and B.G. Salamov*. 2013 Phys. Status Solidi A 210, 1806.

[13] *B. G. Salamov*. 2004 J. Phys. D: Appl. Phys. 37, 2496.

[14] *A. V. Phelps and Z. Lj. Petrović*, 1999 Plasma Sources Sci. Technol. 8, R21.

[15] *D. Mariotti, J. A. McLaughlin and P. Maguire.* 2004 Plasma Sources Sci. Technol. 13, 207.

[16] *J. L. Zhang, S. J. Yu and T. C. Ma*. 2002 Vacuum 65, 327.

[17] *D. Staack, B. Farouk, A. Gutsol and A. Fridman*. 2008 Plasma Sources Sci. Technol. 17, 025013.

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