CHARACTERISTICS OF SECONDARY ELECTRON EMISSIONS IN COLD PLASMAS WITH NANOPOROUS ZEOLITE CATHODE

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This study investigates the characteristics of cold-discharge plasmas with the natural nanoporous zeolite cathode taking into account the secondary electron emission processes. The zeolite cathode in the continuing and in the onset of discharge gives the important contributions the discharge due to its nanopores. Paschen curves from 8 Torr to high pressure discharge up to atmospheric pressures are scrutinized to reveal the processes of the onset of discharge. We discussed the secondary electron emissions liberated by the nanoporous zeolite material into the discharge space in the relatively low electric fields in the discharge gap. The homogeneous microdischarge is evaluated with the processes of the nanoporous zeolite cathode and discharge. The coefficients of secondary electron emission liberated by the nanoporous zeolite were obtained at the discharge gap of 250 μm in air medium.

Keywords: secondary electron emissions, breakdown, nanoporous, microdischarge.

1. INTRODUCTION

The great attention is given to generate cold-microdischarge plasmas that have a homogeneous and low-energy consumption when the secondary electron emission (SEE or γ) process in the cathode surface is considered. The interaction of mainly ion or photon with the cathode results in the SEE emitted by the cathode. These SEEs affect the microdischarge characteristics in relation to the alteration in the discharge current. The SEEs are one of focal points in the development of microdischarges applications. The microdischarges have extensively used in the various applications including the light sources, microreactors, and the plasma display panels [1-3].

Recent studies show that the determination of the effect of SEE on the discharge has a subject of wide interest importantly with respect to the low or high pressure, and the cathode type due to alterations in the discharge current. The discharge formations including mainly the ions, UV-VUV photons, metastables, and heavy-particle ionizations become important in the generation of SEE with the planar cathodes [4-6]. For the generation of SEEs in the discharge volume, it is concentrated to these discharge formations that are developed with the processes of collision-induced ionization and excitation depending on the E/N value. The emission properties of the different planar cathodes change with respect to the E/N values [5]. But there are differences in the number of the SEEs emitted by the planar cathodes depending on the discharge formations. Also, the penetrating and transport, and emission processes are related to the ion energy under the bombardment mechanism or discharges [7,8]. The developments that depend on the SEE give an important way to affect the discharge properties.

The zeolite gas discharge system (ZGDS) that consists of nanoporous zeolite cathode and discharge volume is used to generate the cold microdischarges [12]. In ZGDS, zeolite, which consists of the numerous porous structures in its surface, is an aluminosilicate crystal including mainly cation and anion in its volume, and it has the channels and cages [13]. These properties make unique it the application areas like mainly microelectronics, energy storage devices, and a plasma light source [9-13]. When the zeolite cathode is used in the plasma generation, its conduction mechanism based on SEE affects the plasma characteristics. In the low electric fields, SEEs are still an unknown process in the pores. ZGDS is of the ability of producing a homogeneous microplasma distribution at the low or high pressures.

The study aims to reveal the characteristics of cold-discharge microplasma including secondary electrons emitted by the nanoporous zeolite in ZGDS in the relatively low electric fields for the first time to our knowledge. ZGDS has enabled the generation of a microdischarge distribution with the contribution of the volume processes and the electron emission from zeolite. The discharge formations including the ions or photon gave SEEs in the discharge space under the low electric fields. With the emissions in the nanoporous zeolite cathode and the discharge collision-induced ionization and excitation processes, ZGDS formed the homogeneous discharge space distribution at the relatively low or high current values, and to reveal the SEE process and the discharge homogeneous it presented the important opportunity.

2. EXPERIMENTAL

Figure 1 shows the experimental setup of ZGDS. Measurements were performed in air medium on zeolite cathode (2), which has a type of clinoptilolite. The nanoporous zeolite cathode was a plate having a diameter *D* (3) of 22 mm and a thickness of 2 mm. The external surface (1) of the zeolite was covered with a Cu layer that was approximately 40-nm thick. The anode was the glass disk (6) coated with a semitransparent conductive SnO_2 layer (5). A discharge gap *d* of 250 μm was preferred to provide relatively low electric field. Before air was filled the ZGDS, the discharge cell was evacuated up to $p = 1\times10^{-6}$ Torr. A needle valve between the discharge cell and the mechanical pump was used to change the pressure value of ZGDS. The Cu and the SnO_2 electrodes were connected to an external circuit that consists of a DC voltage source and a series resistor R_1. DC voltage source works up to 2500 V. R_1 measuring the current in the circuit has 10 kV. A mica (4) that has a spacer with a circular space is placed between the zeolite and the glass plates. The photomultiplier head measured the gas discharge light emission (7) occurring in the discharge volume. The current–voltage graphs and the intensity–voltage graphs to obtain the gas discharge light emission formed in ZGDS were registered by varying the voltage with a rate of 5 V/s from 8 Torr to high pressure discharge up to atmospheric pressures. In our calculation, after we found α that is defined as the number of ionization events with an electron per unit length, we obtained γ. The experimental coefficients were selected as $A=42.37\times10^{-21}$ m^2 and B = 1031.07 Td at 273 K in air medium [4]. γ presents the number of electrons escaping from the cathode per ion. All measurements in ZGDS were performed at room temperature.

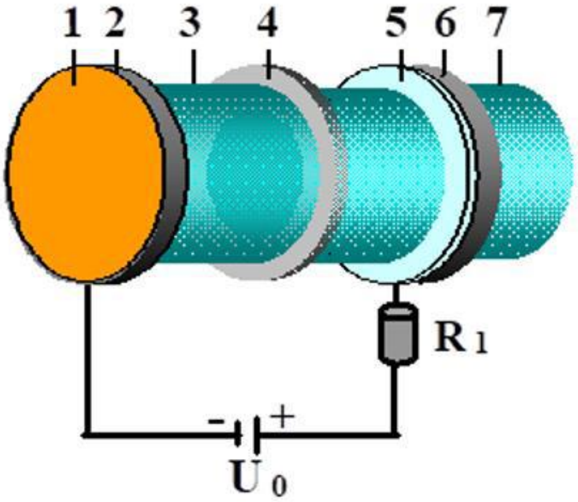

Fig. 1. The experimental setup of ZGDS. 1-metallic Cu contact. 2-Zeolite cathode. 3-diameter D of discharge gap. 4-mica. 5-semi-transparent conductive SnO_2 contact. 6-glass disc. 7-UV-visible light beam.

3. RESULTS AND DISCUSSION

To reveal the discharge characteristics of ZGDS we investigated the cold microdischarge at the different pressures at the discharge gap of 250 μm in the ranges of $E/N \leq 2300$ Td. Figure 1 (a) shows the Paschen curve in air medium generated by the ZGDS. The breakdown curves in Figure 1 (a) consist of the left and right-hand branch. We obtained the minimum value of breakdown, which corresponds the breakdown voltage $V_B = 405$ V at 18 Torr in Figure 1 (a). We can express that to explain Paschen curve in Figure 1(a) the evaluation of processes of cathode SEE and discharge space becomes important.

Figure 2(b) shows the graph of γ and E/N. We obtained that γ_i is 0.00514 when E/N=2210.13 Td, and γ_i is 0.00298 when E/N=1753.52 Td. Thus, at the high values of E/N, the cathode emissions reach the higher values. It is important that in the discharge space there are dominantly electron-induced collisions that result in the atoms to ionize at the high values of E/N. An electron in the discharge space gains enough energy to ionize the atom. At the high values of E/N, there are dominantly the ion-induced secondary electrons γ_i in the discharge volume. Thus, we express that these ionize atoms collide the cathode surface. After they penetrate into the cathode, the secondary electrons that gain enough energy can reach the discharge space. These ionized atoms can move into nanopores, and they penetrate into the cathode with higher energy. In this case, the secondary electrons with the higher energy can emit into the discharge volume. With this discussion, we conclude that because the nanopores in the zeolite have the high electric field, they affect the onset voltage of microdischarge with the energetic secondaries. Under these conditions, the zeolite nanopore cathode in ZGDS behaviors like the emission source at the high values of E/N. The typical situation of SEE includes the effectiveness of cathode emissions in the low-pressure discharges [4].

The zeolite cathode of ZGDS used in the generation of microplasma is of critical importance because it has special nanopores on its surface in the continuing and the onset of discharge. The special nanopores on its surface give contributions through the interactions of surface and plasma. The cathodes used in the discharge plasma give markedly contributions that include mainly SEE and the homogeneous of the discharge. Thus, both surface and nanopores of zeolite play a key role to change discharge current. It is important to express that the pores resided in the surface constitute the high electric fields when it is applied a voltage difference between the cathode and anode. The nanopores due to high electric fields are responsible for giving the energetic electrons into microdischarge as well as the surface.

The energy of ions in the discharge volume is vital in the formation of internal-SEEs. The energy transferring the cathode atoms with the ion-transport become the important in the liberation and the formation of SEE into discharge volume when the internal-SEEs have the enough energy to reach the surface [7,8]. The nanoporous zeolite gives important contributions for the ion-transport and SEEs when they move in the high electric fields inside the pores. The nanoporous zeolite may affect the ion-transport and penetrating processes into cathode.

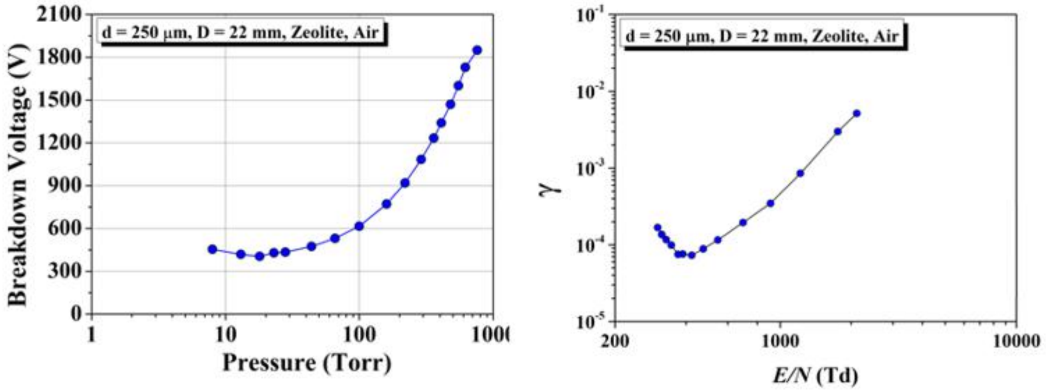

Fig. 2. (a) Paschen curve obtained in air medium in ZGDS. (b) γ and E/N graph in ZGDS.

At the low values of E/N in Figure 2(b), the electron-induced excitations in ZGDS become an important process in discharge space. These excitations lead to the generation of the photons in discharge volume, and the photon- induced secondary electrons γ_{ph} are emitted by the zeolite cathode. The electron-induced excitations dominantly result in the photoelectric process developing in discharge space. UV-VUV photons generated by gas in discharge volume are responsible for the electron emission from the zeolite cathode, and the spectrum characteristics of N_2 and O_2 in air give the important contributions in the liberation of the electron by cathode in discharge medium [4,5]. However, since the particle number and the collision frequency in discharge space increase, ionization per particle falls, and in this case the breakdown shifts at the higher electric field values in ZGDS.

Figure 3 shows the current-voltage (I-V) graphs at different pressures in ZGDS. We can express that the microdischarges in ZGDS are obtained as homogeneous plasmas in wide range of pressure. We may express that the current instabilities including mainly the spatiotemporal inhomogeneities, and hysteresis formations [14-16] weren't observed in the discharge space for the microplasma generated in ZGDS. The space-time distribution of the microdischarge is maintained as the homogeneous at low-current discharge, and if the discharge current reaches the higher values, the stability in the microdischarge still remains unalterable.

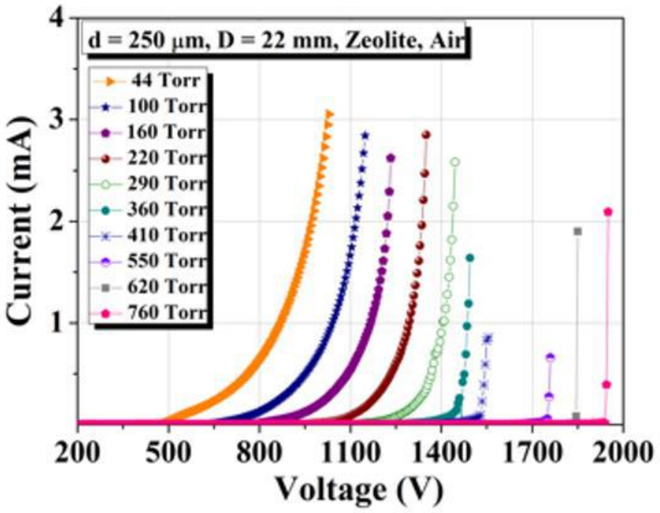

Fig. 3. I-V graphs obtained at the different pressures in ZGDS.

4. CONCLUSION

At the low electric fields, the discharge properties in ZGDS were studied with the SEE processes and in the homogeneous microplasma. The zeolite cathode gives important contributions because there are high electric fields occurring in its nanopores. In the zeolite cathode including the high electric fields in the nanopores, it was obtained that, with the contribution of pores, SEE is at the high values because the cathode nanopores-ion interactions at the low pressures are important; however, SEE increases because the photoelectric process develops at the high pressure up to atmospheric pressures in ZGDS. In the homogeneous microdischarges, the low-pressure discharge of ZGDS depends on the nanoporous zeolite cathode, and the discharge current develops fastly in comparison of the high pressure discharge up to atmospheric pressures. The results obtained in the zeolite cathode with the pore become important to appreciate the discharge characteristics in the microplasma devices.

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