Cumhuriyet Science Journal

e-ISSN: 2587-246X
ISSN: 2587-2680

Cumhuriyet Sci. J., 42(4) (2021) 916-923
http://dx.doi.org/10.17776/csj.974406

Characteristic of gap photodectored plasma cell

Duygu YİĞİT ÜNLÜ[1,*] ***Hatice Hilal KURT***[2]

[1]*Gazi University, Gazi University Institute of Naturel and Applied Science, Ankara/TURKEY*
[2]*Gazi University, Faculty of Science, Department of Physics, Ankara/TURKEY*

Abstract

In the study, it was experimentally investigated the Microelectronic Gas Discharge System (MGDS) with Gallium Phosphate (GaP) cathode. The system was operated in the dark and under different Infrared (IR) illumination intensities. The Current-Voltage Characteristic (CVC) was obtained for different IR illuminations under high-pressure conditions. IR illumination produced different electrical conductivities at high pressures. This reality shows that the system can operate more conveniently at high pressures for optoelectronic applications. It was determined that the system showed Negative Differential Resistance (NDR) and hysteresis behaviors when appropriate experimental parameters were set. It was seen that the pressure and distance between the electrodes has a significant factor in determining the hysteresis value. AVK, Discharge Light Emission (DLE), and hysteresis behaviors were investigated under different illumination intensities using a semiconductor plasma system. It has been observed that IR illumination creates different electrical conductivities at high pressures. This showed that the system can operate more conveniently at high pressures for optoelectronic applications. It has been observed that CVCs are more stable as the distance between the electrodes decreases. In this study, the IR sensitivity of GaP was tested for the first time. According to the experimental results, it was seen that GaP can be optically excited with IR light when the appropriate distance between the electrodes and the appropriate gas pressure was adjusted.

Article info

History:
Received:26.07.2021
Accepted:07.11.2021

Keywords:
Infrared GaP photodetector,
Microelectronic gas discharge system,
Current-voltage characteristic.

1. Introduction

In recent years, mycoplasma discharge systems have great interest due to their feasibility to environmental and industrial environments. Gas discharge plasmas are extensively utilized in technological applications such as light emission systems, plasma displays and display panels, laser technologies, fusion, atmospheric plasma units, surface coating and sterilization of biological units [1,2]. It is also used as a protective coating in the semiconductor industry, analytical chemistry, etching and deposition of thin films, environmental and biotechnological applications [3,4]. Convert to the IR signals into the visible region it is generally used the gas discharge devices with semiconductor electrodes [5,6]. In the case of gas discharge, any change in the electron property of the cathode may be undesirable and cause temporal and spatial instability in the functions of the system parameters [7].

In the discharge of the gases it is generally used Townsend and Glow discharges. Townsend discharge that can occur at low current value and also it is a weak discharge [8]. The space charge that produced by the Townsend discharge can affect and distort the electric field in the gas GaP [9,10,11]. Because of the Townsend discharge is a complex situation, gas discharge interval *d*, electrode shape, type of gas-filled and pressure *p* play an important role in the character of discharge [12]. However, it was occurred a strong discharge with high space-charge generation in the Glow discharge. In the glow discharge state, the positive space charge accumulates near the cathode. This accumulation is observed as a high luminous layer near the cathode [13].

In this study, MGDS with GaP cathode was investigated experimentally. The system was operated in the dark and under different IR illumination intensities. Firstly, CVCs were obtained for different IR illuminations in high-pressure situations. According to the CVC graphs, it was observed that IR illumination creates different electrical conductivities at high pressures. This reality showed that the system can

*Corresponding author. *e-mail address: dyunlu68@gmail.com.*

operate more conveniently at high pressures for optoelectronic applications. Then it was determined that the distance between the electrodes has an important outcome on the optical and electrical characteristic of the system. Three-dimensional CVC graphs were obtained as a function of pressure for different electrode distanced and cathode diameter D values. It was seen that CVCs were more stable as the distance between the electrodes decreased. In additionally, CVC graphs were obtained as a function of the distance between the electrodes at different p pressure values. Experimental data showed that currents of different magnitudes originate from different electrode spacing. Also, it was observed that maximum current values can be obtained at short distances between the electrodes and at low pressures. The pressure dependence of the recycle plots was investigated when the GaP photodetector was exposed to weak illumination intensity in the forward and feedback condition. In the study, it was observed that the hysteresis width (ΔV) changed depending on the pressure in the forward and feedback conditions, the hysteresis range narrowed with the increase in pressure.

2. Experimental Design

In Figure 1 showed that the setup of the MGDS [14]. The basic element of the discharge cell, GaP, was located at the cathode part of the cell. Total testing system; From right to left, the external light source consists of an optical lens for visible light emitted from the source, a silicon filter, a discharge cell, a CCD camera, a vacuum pump, a black box, and a digital manometer. In Figure 1(b) a detailed schematic diagram of the entire setup was shown with a sandwich-like structure. The gas discharge GaP was located between the two electrodes. One of them consists of a glass layer coated with SnO_2 and the other was composed of a semiconductor (such as GaP, GaAs). This range can be adjusted to different thicknesses from 45 μm to 323 μm. The DLE recorded with the CCD camera was transferred to a PC (Fig. 1(b)). A PC, some interface systems were used to measure the electrical property of the DLE. A Keithley 199 multimeter and a Stanford PS 325 high voltage power supply are used to measuring the electrical current flowing through the cell and the voltage across the cell. These measurements were digitized with software [14].

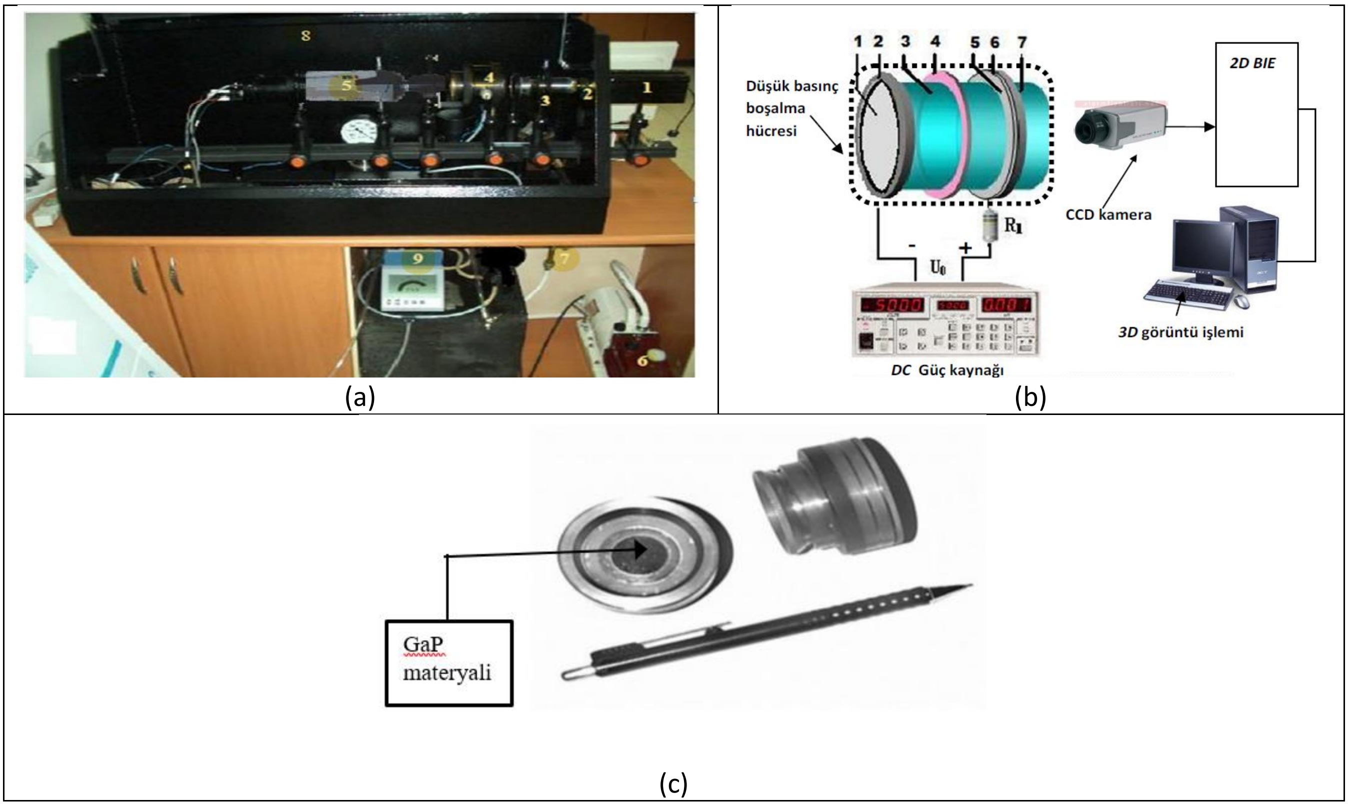
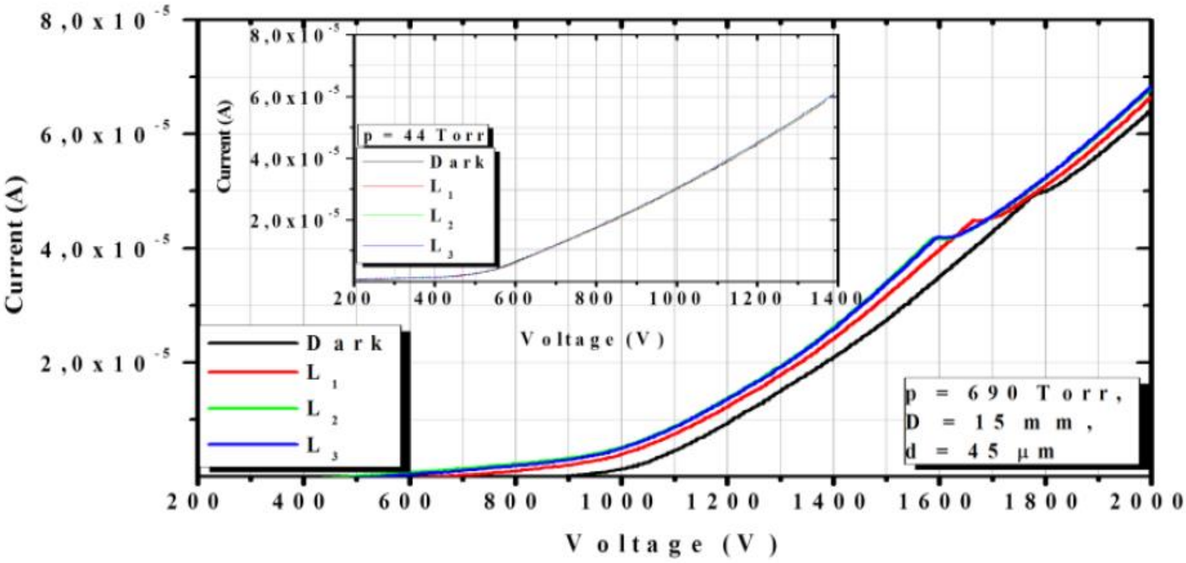


Figure 1. (a) MGDS: 1) Light source; 2) Optical lens; 3) Silicon filter 4) Gas ionization system; 5) CCD camera; 6) Vacuum pump; 7) Vacuum valve; 8) Experiment box and 9) Digital manometer; (b) Diagram of the sandwich-type ionization cell, measuring and recording system: 1) GaAs material; 2) Sample holder; 3) Microrelease spacing; 4) Insulating mica; 5) Transparent conductor SnO_2; 6) Glass disc, 7) Visible light beam. The dotted part is shown in (c). GaP material is located in the middle of the cell. The d distance between the electrodes is the micro distance between GaP and transparent SnO_2 [14].

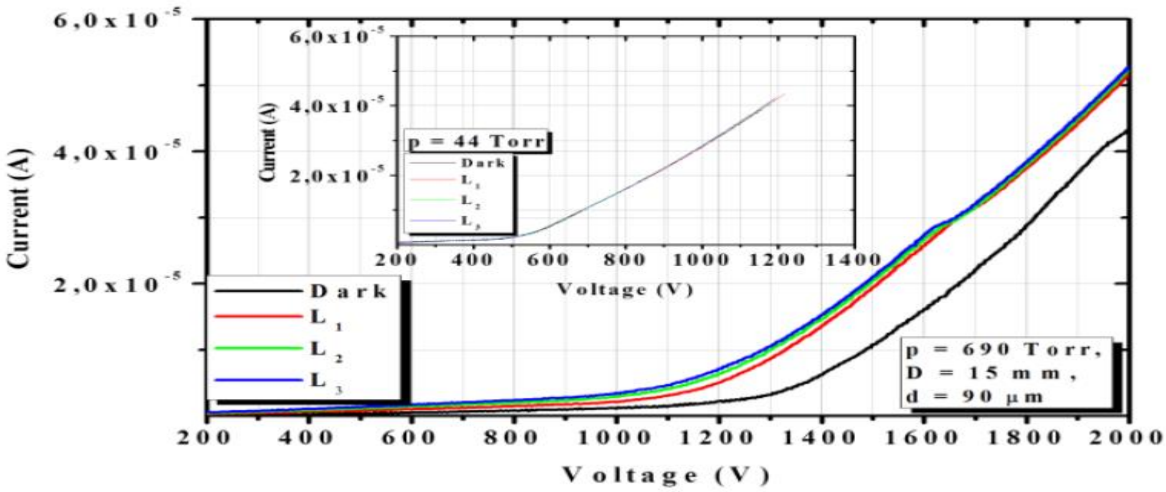
3. Results and Discussion

In the experimental studies, high resistance semiconductor GaP electrodes, which exhibit linear CVCs at different illumination intensities and are sensitive to IR light, were used in all voltage ranges. The spatial distribution of the current during gas discharge and the luminosity in the vacuum was proportional to the conductivity of the cell. Spatial dispersion leads to visualization of stability within a given parameter range. In plasma systems, optical and electrical prosperities of semiconductor electrodes were the significant importance they work as a control parameter and act as local resistors [15].

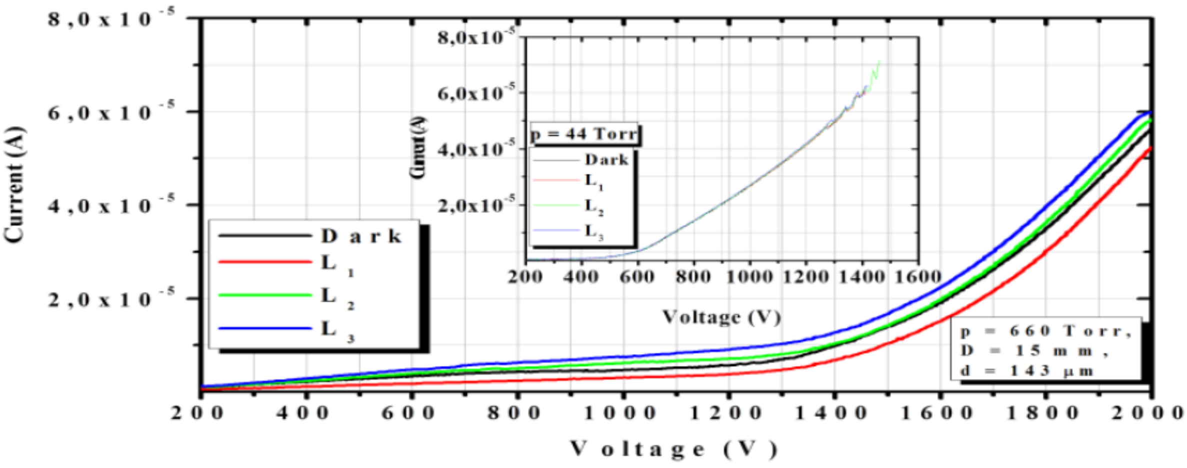
In Figure 2, CVCs were obtained for different IR illuminations under high-pressure conditions. IR illumination produced different electrical conductivities at high pressures. This reality shows that the system can operate more conveniently at high pressures for optoelectronic applications. When the IR light source was used in the system, the discharge current was varied through different illuminance intensities.



(a)



(b)



(c)

Figure 2. (a) Current-voltage graph for pressure of 690 torr, electrode diameter of 15 mm, and distance between electrodes of 45 µm. (b) Current-voltage graph for pressure of 690 torr, electrode diameter of 15 mm, and distance between electrodes of 90 µm. (c) Current-voltage graph for pressure of 660 torr, electrode diameter of 15 mm, and distance between electrodes of 143 µm.

The distance of the electrodes has an important result on the electrical and optical characteristics of the system. Figure 3 shows the CVCs measured between d = 240 µm and d = 445 µm as a function of pressure for different cathode diameter values D. It was seen that CVCs are more stable when set to d = 240 µm. Moreover, due to the plasma behavior inside the cell, the distance between the electrodes leads to differences in the discharge current. The difference in CVCs was due to the presence of electric field domains moving from the cathode to the anode. The pressure dependence of CVC at 240 µm is linear, while its behavior at 445 µm was non-linear.

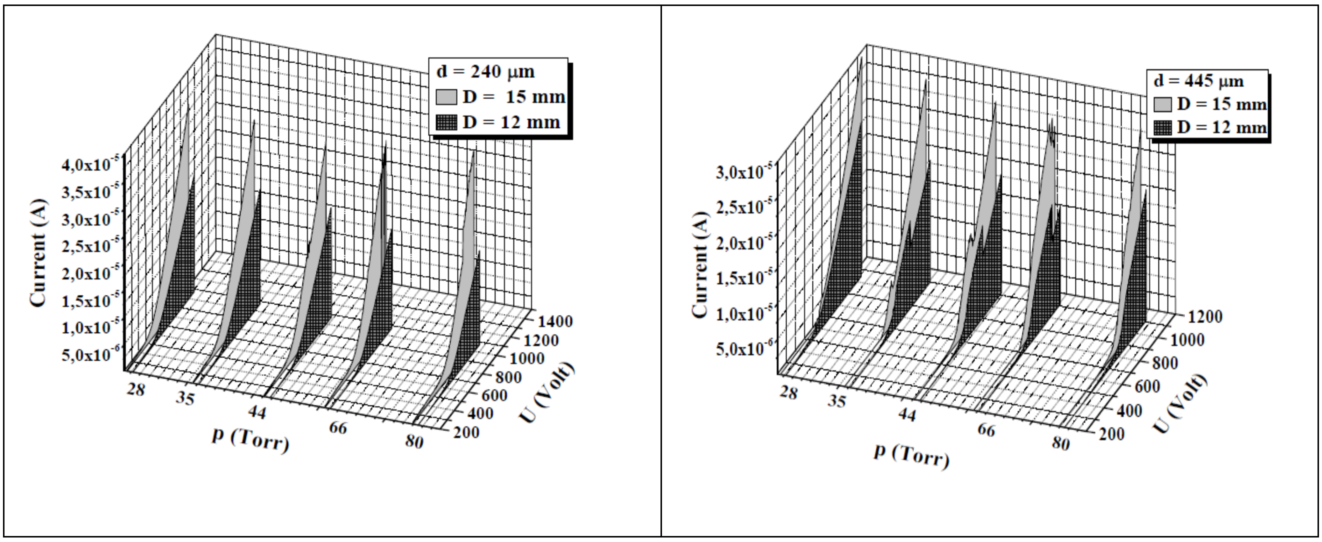


Figure 3. 3D CVC graph as a function of pressure for different d and D values.

It was known that GaP has high sensitivity in the wavelength range of 400-550 nm. Currently, almost all of the studies in the literature belong to the transmittance characteristics in the visible or UV region [1].

In this study, the IR sensitivity of GaP was tested for the first time. While no IR sensitivity was observed at a low-pressure value (p = 44 Torr), it was shown that GaP can be optically stimulated with IR light when the appropriate inter-electrode distance and the appropriate gas pressure (in the range of 660-690 Torr) are set. As can be seen in Figure 4, different conductivity values were obtained under different IR illumination at high pressures. On the other hand, there is a stable conductivity for low-pressure value. According to the obtained findings, the optical properties of GaP can be improved and the IR sensitivity of the material can be improved optically when the appropriate pressure value adjusted.

The relationship between current and distance between electrodes at three different pressure regimes is shown in Figure 4. Measurements were made for pressure values of 160, 200 and 360 Torr at distances between electrodes ranging from 50 µm to 525 µm. According to the results obtained; It has been seen that different magnitudes of currents will be obtained for different electrode distances. Accordingly, maximum current values were obtained at low pressures and short distances between electrodes.

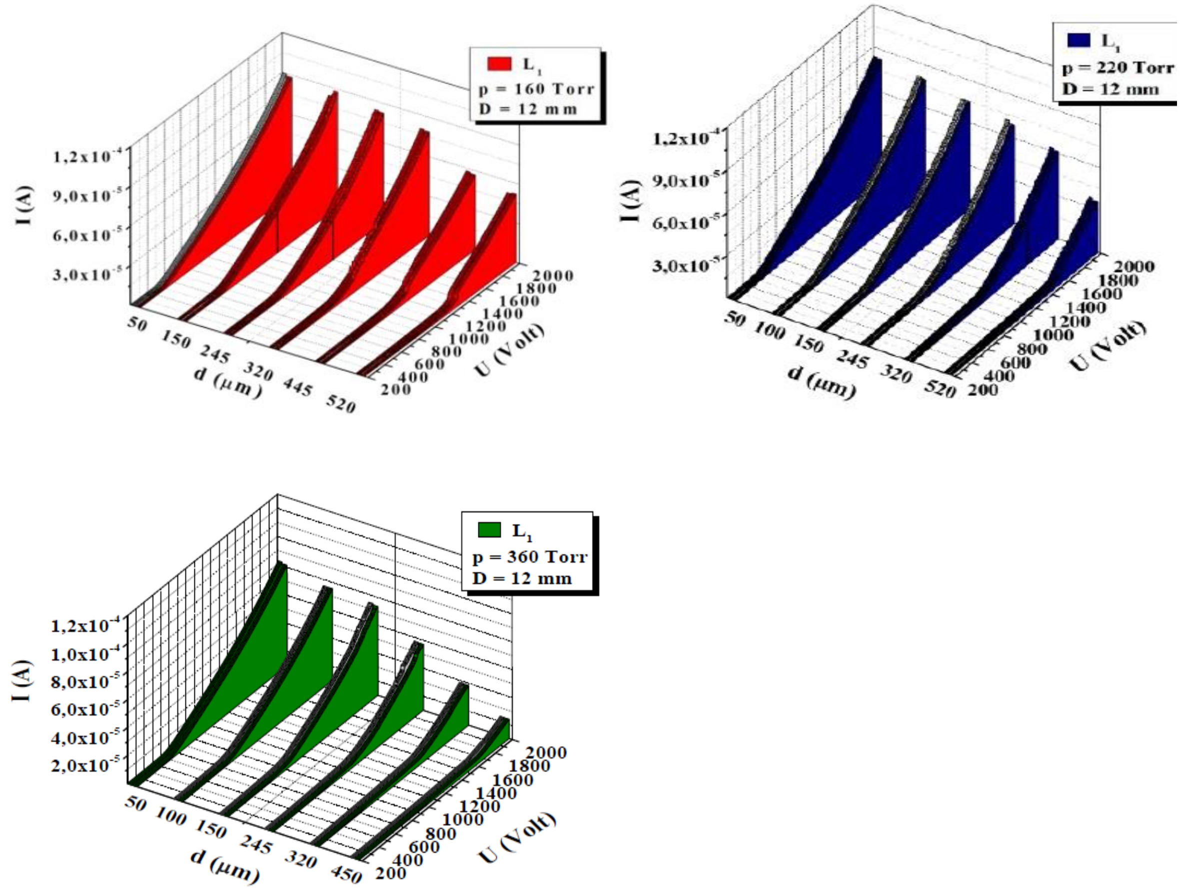


Figure 4. CVC graphs as a function of the d distance between the electrodes at different p pressure values.

Experimental results show that there were trap levels in GaP and these levels have different effects on current under forward and reverse voltage supply. In Figure 5 (a-d), the recycling (hysteresis) behavior of the electrodes depending on the gas saturation was investigated. Hysteresis was an indication of the bstable state of the system. Impurities and traps in the semiconductor affect the hysteresis state [16].

Figure 5 (a-d) CVC measurements applied to show the effect of pressure on hysteresis. It was observed that the function of the pressure in the forward and feedback conditions in the hysteresis width (ΔV) changes. The hysteresis range narrows with the increases in pressure. The pressure and the distance between the electrodes play a significant role in determining the true value of the hysteresis. Likewise, the radiation graphs inside the CVCs confirm the situation.

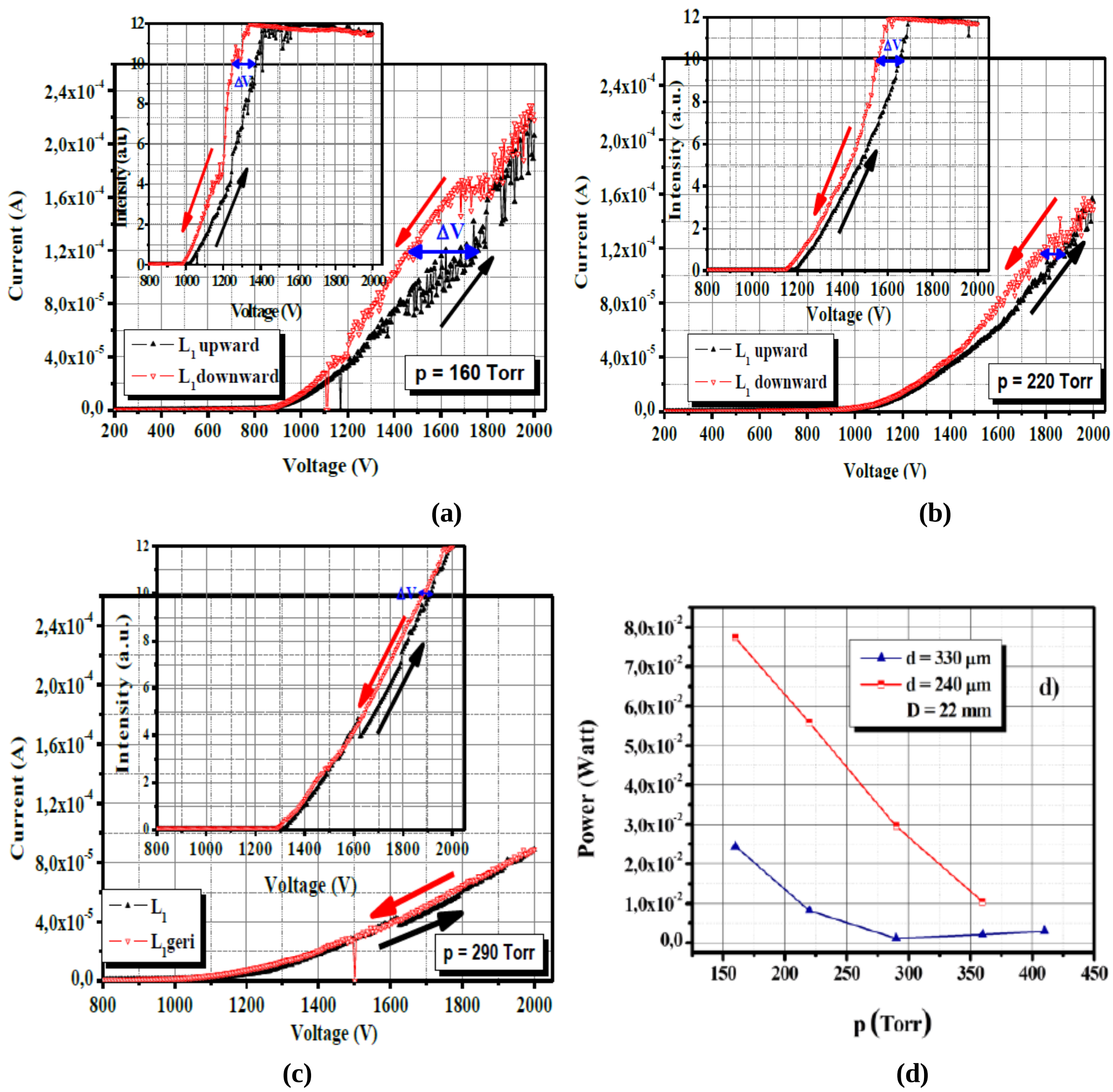


Figure 5. Pressure dependence of recycle graphs in forward and feedback condition when GaP photodetector is exposed to weak illumination; a) for p = 160 Torr; b) for p = 220 Torr; c) for p = 290 Torr; d) variation of force with pressure.

Figure 6 (a, b) shows the effect of the distance between the electrodes on the hysteresis. CVC measurements showed that the trapping centers in the GaP material changed the hysteresis width. This effect was significant evident when the thickness was reduced to a certain value. It was observed that the narrow electrode spacing supported the formation of hysteresis, whereas the wide electrode spacing prevented the hysteresis formation.

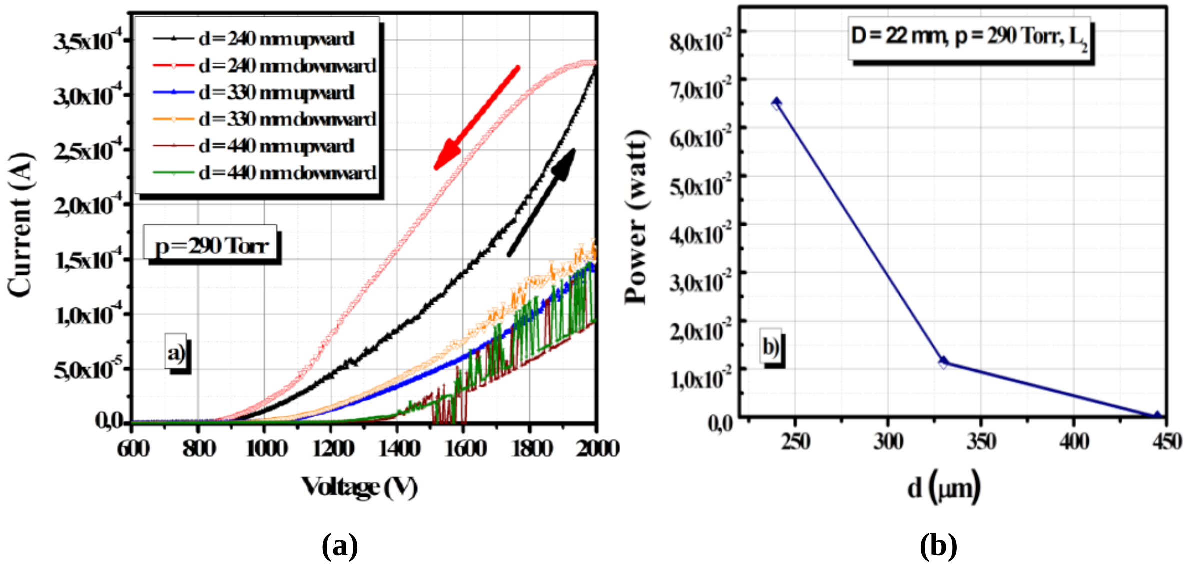


Figure 6. a) Recycle graphs at p= 2900 Torr for different electrode distances; b) Variation of the power according to the distance between the electrodes.

4. Conclusion

In the study, MGDS with GaP cathode was investigated experimentally. The system was operated in the dark and under different IR illumination intensities. The CVC was obtained for different IR illuminations under high-pressure conditions. IR illumination produced different electrical conductivities at high pressures. This reality shows that the system can operate more conveniently at high pressures for optoelectronic applications. It was detected for the first time for GaP that the system showed NDR and hysteresis behaviors when appropriate experimental parameters were set. It was seen that the pressure and the distance between the electrodes played a significant role in find out the hysteresis value. CVC, DLE, and hysteresis behaviors were investigated under different illumination intensities using a semiconductor plasma system. It was observed that IR illumination creates different electrical conductivities at high pressures. This showed that the system can operate more conveniently at high pressures for optoelectronic applications. It was also observed that CVCs were more stable as the distance between the electrodes decreases.

In this study, the IR sensitivity of GaP was tested for the first time in the experimental system. According to the experimental results, it was shown that GaP can be optically excited with IR light when the appropriate distance between the electrodes and the appropriate gas pressure was adjusted. When the experimental data were examined, it was seen that different current values would be obtained at different electrode distances. As a result of the comparison of the currents at different pressure values, it was seen that in the short distance between electrodes and at low pressure maximum current values can be obtained. Also, it was seen that GaP was important because it works at room temperature and has a wide application area in optoelectronic systems. IR photosensitive photodetectors were used in many applications. These photodetectors have some disadvantages, especially for remote IR regions, as they require a cooling unit. Despite its widespread use, the IR sensitivity of the GaP material has not been satisfactorily studied. It is thought that this study will help to better understand the electrical and optical characteristics of GaP material. In this sense, experiments were carried out to improve the performance of the system. GaP material has some advantages because it works at room temperature. For this purpose, a connection was established between flow and discharge characteristics at different pressure values. According to the experimental results, it can be said that GaP has technological importance as it can be used as an IR detector in IR image converters.

In this study, it was demonstrated by making both CVC and DLE measurements, unlike the studies of other independent authors, that the IR sensitivity of GaP electronic material is due to voltage-dependent electron trapping caused by inherent defects in the semiconductor n-type GaP material. In addition, the effects of various parameters on material characteristics (pressure, voltage, distance between electrodes, cathode diameter, and IR illumination intensity) were experimentally investigated. The change in electrical characteristics of GaP material has a significant effect in optoelectronic applications.

Acknowledgment

The paper produced from the master thesis of the first author under the supervision of Prof. Dr. Hatice Hilal Kurt.

Conflicts of Interest

No conflict of interest was stated by the authors.

References

[1] Portsel L. M., Lodygin A. N., Astrov, Y. A., Townsend-like discharge: the suppression of instabilities by a semiconductor electrode, *J. of Phys. D: Appl. Phys.*, 42 (23) (2009): 235208.

[2] Weltmann K. D., Kolb J. F., Holub M., Uhrlandt D., Šimek M., Ostrikov K., Becker K. (2019). The future for plasma science and technology, *Plas. Proc. and Poly.*, *16*(1), 1800118.

[3] Grill A., Cold plasma in materials fabrication, Vol. 151. IEEE Press, New York, 1994.

[4] Lieberman M. A., Lichtenberg A. J., Principles of plasma discharges and materials processing, *MRS Bullet.*, 30(12) (1994) 899-901.

[5] Lodygin A. N., Portsel L. M., Astrov, Y. A., DC Townsend Discharge in Nitrogen: Temperature-Dependent Phenomena, *Contr. to Plasma Phys.*, 52(8) (2012) 682-691.

[6] Salamov B. G., Kurt H. Y., Current instability in a planar gas discharge system with a large-diameter semiconductor cathode, *J. of Phys. D: Appl. Phys.*, 38(5) (2005) 682.

[7] Gurevich E. L., Kittel S., Hergenröder R., Astrov Y. A., Portsel L. M., Lodygin A. N., Ankudinov A. V., Modification of GaAs surface by low-current Townsend discharge, *J. of Phys. D: Appl. Phys.*, 43(27) (2010) 275302.

[8] Raizer Y. P., John E A., Gas discharge physics, Vol. 2. Berlin: Springer, 1997.

[9] Chen Z. G., Cheng L., Lu G. Q. M., Zou J., Sulfur-doped gallium phosphide nanowires and their optoelectronic properties, *Nanotechnology*, 21(37) (2010) 375701.

[10] Liu F., Song Y. J., Xing Q. R., Hu M. L., Li Y. F., Wang C. L., ... Wang C. Y., Broadband terahertz pulses generated by a compact femtosecond photonic crystal fiber amplifier, *IEEE Phot. Tech. Let.*, 22(11) (2010) 814-816.

[11] McIntosh D., Zhou Q., Lara F. J., Landers J., Campbell J. C., Flip-chip bonded GaP photodiodes for detection of 400-to 480-nm fluorescence, *IEEE Phot. Tech. Let.*, 23(13) (2011) 878-880.

[12] Zhuo L., Hai-Yun L., Xin-Xin W., Bo L. V., Zhi-Cheng G., Li-Ming W., Determination of ionization coefficient of atmospheric helium in dielectric barrier discharge, *Chinese Phys. Let.*, 25(6) (2008) 2136.

[13] Luo H., Liang Z., Lv B., Wang X., Guan Z., Wang L., Observation of the transition from a Townsend discharge to a glow discharge in helium at atmospheric pressure, *App. Phys. Let.*, 91(22) (2007) 221504.

[14] Kurt H. Y., Exploration of the Townsend regime by discharge light emission in a gas discharge device, *Chinese Phys. B,* 23(1) (2013) 015201.

[15] Kurt H. H., Tanrıverdi E., The Features of GaAs and GaP Semiconductor Cathodes in an Infrared Converter System., *J. of Elect. Mater*., 46(7) (2017) 4024-4033.

[16] Kurt H. H., Çetin S., Tanriverdi E., Yiğit D., Investigation of infrared GaAs photodetector instabilities, *Gazi Ün. Fen Bil. Der. Part C: Tas. ve Tek.*, 2(3) (2014) 281-288.