Journal of Engineering and Applied Sciences

MEDWELL PUBLICATIONS SINCE 2000

Impact of Dielectric Barrier Discharge (DBD) Plasma on the Optical Properties of Thin Films

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Key words: Dielectric Barrier Discharge (DBD) plasma, optical properties, Cadmium Oxide CdO thin film, thermal chemical spraying, extinction, refraction

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Page No.: 1937-1942
Volume: 15, Issue 8, 2020
ISSN: 1816-949x
Journal of Engineering and Applied Sciences

Abstract: In this study, a Dielectric Barrier Discharge DBD plasma system used to affect the pure thin Cadmium Oxide (CdO) films. This system produces non-thermal plasma at atmospheric pressure using frequency (500 kHz) and a voltage between (100-1500 kV). Thin films of cadmium oxide have prepared on clean glass stands at 350°C by thermal chemical spraying and cadmium acetate ($Cd(CH_3COO)2.2H_2O$) was used as a source material of Cd with concentration about (0.1 M) dissolving in 50 mL re-distilled water. The Ultraviolet (UV) spectrum of films using optical absorption calculations which were taken in spectral area between (350-1100 nm), the transmittance and reflectance for films in the Ultraviolet-Visible area (UV-VIS) and effect of exposure to plasma on absorbance, transmittance, absorption coefficient, energy gap, extinction coefficient, refractive index, real and imaginary dielectric constant and optical conductivity have studied in this study. The results showed that both of the transmittance and the energy gap decreases when exposure time for plasma increases while absorption and absorption coefficient, refraction, extinction coefficient, real and imaginary dielectric constant and optical conductivity increase when exposure time for plasma increases.

INTRODUCTION

Plasma concept: The term "plasma" uses to describe partially or completely ionized gas containing electrons, ions and neutrals. Although, there is always a slight degree of ionization in every gas an exact definition of plasma is "a quasi-neutral gas that contains charged and neutral particles and exhibits collective behavior" (Jefferson *et al*., 2008). The quasi-neutrality refers to the characteristic which the positive and negative space charges would equal in the plasma, so that, the plasma generally is considered electrically neutral. If the local concentration of charge appears, the electrostatic forces that created by the space charge would restore the neutrality of charge. The collective behavior for plasma is a result of Coulomb forces which are long-ranged and cause remote regions to interact with one another. These characteristics are important in distinguishing a plasma state from a neutral gas and other ionized gases (Jefferson *et al*., 2008).

An important characteristic of plasma that is a chemically reactive medium consists of a large number of different species such as electrons, positive and negative ions, free radicals, gas atoms and molecules in the ground or any higher state of any form of thus, it is an energetic chemical environment which combines particles and radiations of a diverse nature (Clementi *et al*., 1976).

There are many ways to produce non-thermal plasma including the way to Dielectric Barrier Discharge (DBD), corona discharge, atmospheric pressure plasma jet, plasma needle. The important advantage of the method of dielectric barrier discharge is the possibility of producing cold plasma in an economical and reliable way this feature has led to its use in many important industrial applications Including environmental medical, bacterial cleansing, surface treatment, ozone generation (Liu *et al*., 2004).

During plasma processing in these applications there is a mutual effect between the plasma particles (electrons, ions, free radicals) and the surface of the treated material (Brandenburg, 2018).

Cadmium Oxide CdO: The Cadmium Oxide (CdO) films consider a semiconductor where it shows in nature in two ways (Two combinations). Both of crystalline and random are crystalline in structure and characterizes with a brown or red color while its structural structure is random and colorless (Ali *et al*., 2015). The classification of compound in semiconductors is negative (n-type) because of the gapes for oxygen that resulted from the molecular incompatibility of components (Ohrin, 1991). The nature of its crystalline structure characterizes with a crystalline cube (cubic) centralized faces cadmium oxide belongs to the group (II-IV) of the periodic table. It has a gap of an energy that its values are between (2.21-2.95 eV) at room temperature (300°k) (Chen, 1984). It uses as a thin film for manufacturing optical diodes, optical transistors, photovoltaic cells, the crystal displays thin film transistors, light emitting diodes, infrared detectors, anti-reflective and reflective coatings (Nehra *et al*., 2008).

MATERIALS AND METHODS

Experimental work

Preparation of thin films using thermal chemical spraying: Pellucid and conductive CdO thin films were deposited on clean glass stands by using thermal chemical spraying. Cadmium acetate ($Cd(CH_3COO)2.2H_2O$) was used as a source material of Cd with concentration about (0.1 M) dissolving in 50 mL re-distilled water, the microscope glass substrate after subjected to the cleaning process were placed on hot plate until it reaches 350°C. The optimum deposition parameters such as spray time (5 sec), substrate spray nozzle distance (29 cm), spray interval (55 sec) and carrier gas pressure (compressed air 105 Nm^{-2}).

Dielectric barrier discharge system: Dielectric barrier discharge system consists of two cylindrical electrodes of copper that has 50 mm diameter for each electrode where the electrodes are surrounded by 10 mm of Teflon. Two cylindrical electrodes are placed on stand where they can move up and down and can control at distance (d) between them. The upper electrode supplies by alternating power supply and the other electrode connects to Earth terminal. One or both of electrodes covered with dielectric. Figure 1 shows a diagram of this system while Fig. 2 shows a photograph for it.

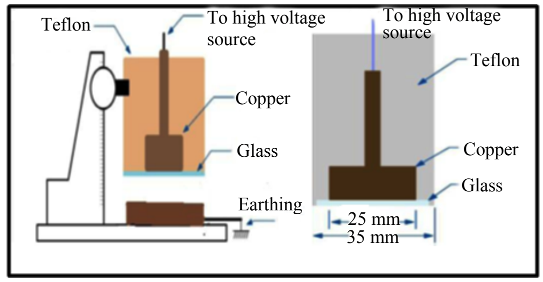

Fig. 1: Diagram of the system DBD


Fig. 2: Photograph of the system DBD

RESULTS AND DISCUSSION

Transmittance: Figure 3 shows the spectrum of transmittance is as a function of wavelength for Cadmium Oxide (CdO) film before and after exposure to a non-thermal plasma of with times of 0, 5, 15, 25 min. It has been shown that the spectrum of transmittance changes and decreases gradually when the time of exposure to a non-thermal plasma increases where the cause of this decreasing of spectrum of transmittance belongs to increasing of absorption after exposure to a non-thermal plasma.

Absorptance: Figure 4 shows the spectrum of absorptance is as a function of wavelength for Cadmium Oxide (CdO) film before and after exposure to a non-thermal plasma of with times of 0, 5, 15, 25 min. It has been shown that the spectrum of absorptance increases gradually when the time of exposure to a non-thermal plasma increases where the cause of this increasing of spectrum of absorptance belongs to decreasing of transmittance.

Reflectance: Reflectance can be calculated from the spectrum of Transmittance (T) and the spectrum Absorptance (A) according to conservation of energy using the following equation (Chopra, 1969):

$$R+T+A = 1 \quad (1)$$

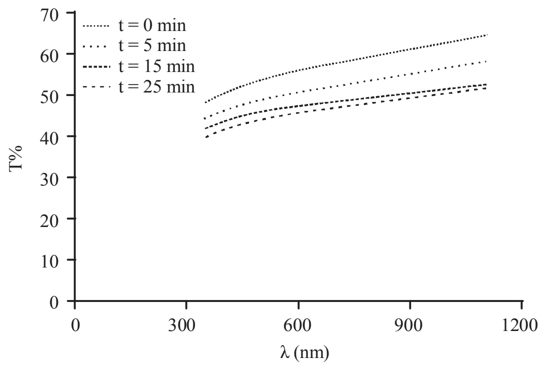

Fig. 3: The spectrum of transmittance is as a function of wavelength for cadmium oxide film before and after exposure to a non-thermal plasma of with different times

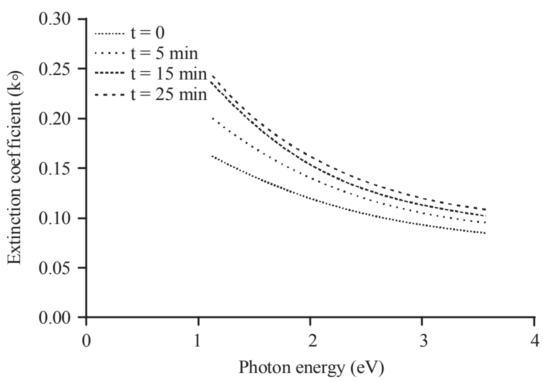

Fig. 4: The spectrum of absorptance is as a function of wavelength for cadmium oxide film before and after exposure to a non-thermal plasma of with different times

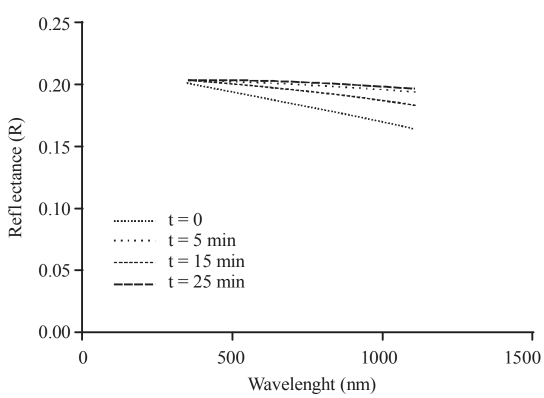

Fig. 5: The spectrum of reflectance is as a function of wavelength for cadmium oxide film before and after exposure to a non-thermal plasma of with different times

Reflectance: Reflectance can be calculated from the spectrum of Transmittance (T) and the spectrum

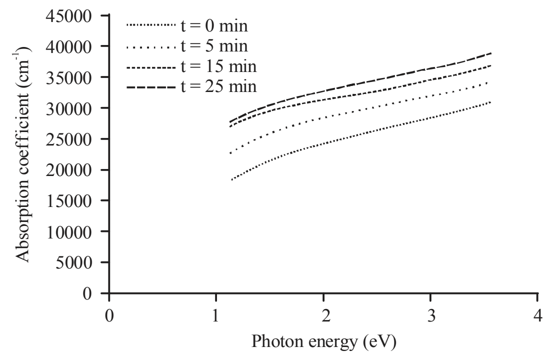

Fig. 6: Coefficient of absorptance as a function of photon energy for cadmium oxide film before and after exposure to a non-thermal plasma of with different times

Absorptance (A) according to conservation of energy using the following equation (Chopra, 1969):

$$R+T+A = 1 \tag{1}$$

Where:
R = Reflectance
T = Transmittance
A = Absorptance

Figure 5 shows the spectrum of reflectance is as a function of wavelength for Cadmium Oxide (CdO) film before and after exposure to a non-thermal plasma of with times of 0, 5, 15, 25 min. It has been shown that the spectrum of reflectance increases gradually when the time of exposure to a non-thermal plasma increases where the reflectance depends on nature of surface of thin film.

Optical constants

Absorptance coefficient: Absorptance coefficient can be calculated by Lambert equation as following (Tauc, 1972):

$$\alpha = \frac{2.303A}{t} \tag{2}$$

Where:
α = Absorptance coefficient
A = Absorptance
t = Thickness of thin film

Figure 6 shows the curve of coefficient of absorptance is directly proportional to photon energy for Cadmium Oxide (CdO) film before and after exposure to a non-thermal plasma of with times of 0, 5, 15, 25 min. It has been shown that the coefficient of absorptance increases gradually when the photon energy increases this means that it has a high values, thus, it may be an indication to occur direct electron transitions between conduction and valance bands. In addition, it has been shown that coefficient of absorptance increases gradually when the time of exposure to a non-thermal plasma increases.

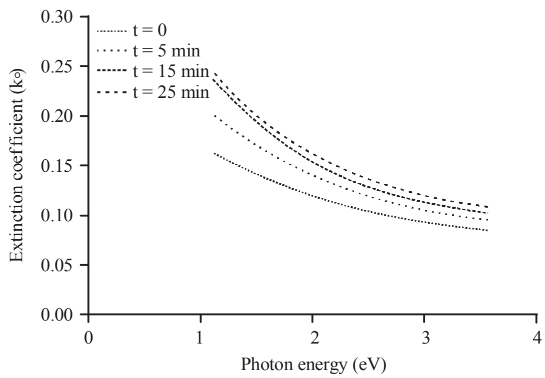

Fig. 7: Extinction coefficient is as a function of photon energy for cadmium oxide film before and after exposure to a non-thermal plasma of with different times

Extinction coefficient: Extinction coefficient can be calculated by the following equation (Nnabuchi, 2006):

$$K_\circ = \frac{\alpha\lambda}{4\pi} \quad (3)$$

Where:
$K_\circ$ = Extinction coefficient
α = Absorptance coefficient
λ = The wavelenght of the Fallen photons

Figure 7 shows the extinction coefficient is as a function of wavelength for Cadmium Oxide (CdO) film before and after exposure to a non-thermal plasma of with times of (0, 5, 15, 25 min). It has been shown that the values of extinction coefficient decrease gradually when the photon energy increases and when the time of exposure to a non-thermal plasma increases, the extinction coefficient will increase where the reason belongs to increasing of absorptance.

Refractive index: Refractive index can be calculated by the following equation (Nadeem and Ahmed, 2000):

$$R = \frac{(n-1)^2}{(n+1)^2} \quad (4)$$

The above equation can be re-arranged as the following:

$$n = \frac{1+\sqrt{R}}{1-\sqrt{R}} \quad (5)$$

Where:
R = Refractive index

Figure 8 shows the refractive index is as a function of wavelength for Cadmium Oxide (CdO) film before and after exposure to a non-thermal plasma of with times of 0,

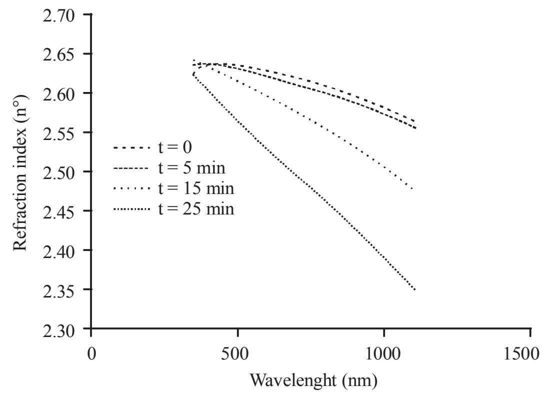

Fig. 8: Refractive index is as a function of wavelength for cadmium oxide film before and after exposure to a non-thermal plasma of with different times

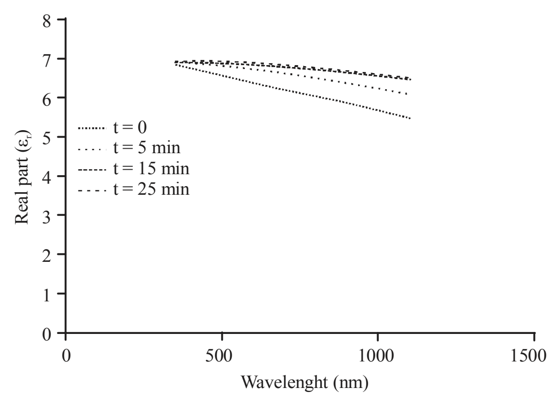

Fig. 9: Real part of dielectric constant is as a function of wavelength for cadmium oxide film before and after exposure to a non-thermal plasma of with different times

5, 15, 25 min. It has been shown that the nature of curve for refractive index like approximately to nature of reflectance curve because of the relation between reflectance and refractive index as shown in above equation. This is mean that there is inverse relationship between values of refractive index and the wavelength of the fallen photon where the value of refractive index decrease gradually when the wavelength of fallen photon increases. In addition, when the time of exposure to a non-thermal plasma increases, the refractive index will increase where the reason belongs to increasing of reflectance after exposure to a non-thermal plasma.

Dielectric constant: The real and imaginary part of dielectric constant can be calculated by the following equation (Moss *et al*., 1973):

$$\varepsilon = \varepsilon_r + i\varepsilon_i,\ \varepsilon_r = n_\circ^2 - k_\circ^2,\ \varepsilon_i = 2nk \quad (6)$$

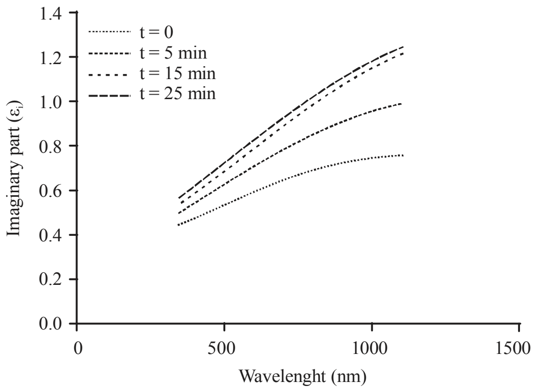

Fig. 10: Imaginary part of dielectric constant is as a function of wavelength for cadmium oxide film before and after exposure to a non-thermal plasma of with different times

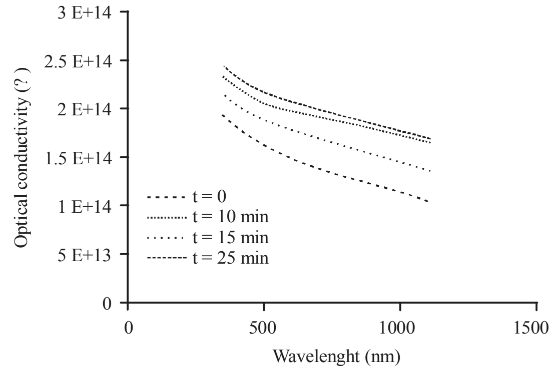

Fig. 11: The optical conductivity is as a function of wavelength for cadmium oxide film before and after exposure to a non-thermal plasma of with different times

Where:

ε_r : Real part of dielectric constant

ε_i : Imaginary part of dielectric constant

Figure 9 shows the real part of dielectric constant is as a function of wavelength for Cadmium Oxide (CdO) film before and after exposure to a non-thermal plasma of with times of (0, 5, 15, 25 min). It has been shown that the nature of curves for real part of dielectric constant like approximately to nature of refractive curves because of the relation between real part of dielectric constant and refractive index as shown in above equation. This similarity belongs to depending of real part of dielectric constant on values of $(n_\circ)^2$ are more than its depending on values of $(k_\circ)^2$ because the values of (k°) are low compared to the values of (n°) where the extinction coefficient will be weak, especially, after squaring. In addition, it has been shown that the values of real part of dielectric constant increase gradually when the time of exposure to a non-thermal plasma increases according to values of refractive index and extinction coefficient.

While Fig. 10 shows the imaginary part of dielectric constant is as a function of wavelength for Cadmium Oxide (CdO) film before and after exposure to a non-thermal plasma of with times of (0, 5, 15, 25 min). It has been shown that the values of increase gradually when the time of exposure to a non-thermal plasma increases because of the refractive index and extinction coefficient.

Optical conductivity: Optical conductivity can be calculated by the following equation (Igwe and Ugwu, 2010):

$$\sigma = \alpha n c \varepsilon_\circ \text{ or } \sigma = \frac{\alpha n c}{4\pi} \tag{7}$$

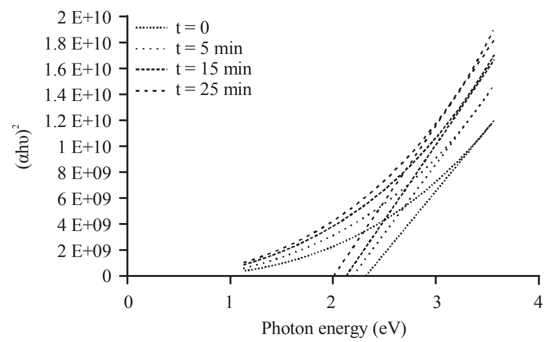

Fig. 12: The optical energy gap is as a function of photon energy for cadmium oxide film before and after exposure to a non-thermal plasma of with different times

Where:

σ = Optical conductivity

c = Speed of light

Figure 11 shows the optical conductivity is as a function of wavelength for Cadmium Oxide (CdO) film before and after exposure to a non-thermal plasma of with times of 0, 5, 15, 25 min. It has been shown that the optical conductivity increase gradually when the time of exposure to a non-thermal plasma increases because of depending on values of absorptance coefficient.

Optical energy gap: The coefficient of absorption can be calculated according to the Tauc's relation as follows (Nnabuchi, 2006):

$$\alpha h\upsilon = B\left(h\upsilon\text{-}Eg\right)^m \tag{8}$$

Where:

B = Constant; its value varies depending on the transitions

E_g = The energy gap

h_υ = The photon energy

m = Constant that has value 1/2 for direct allowed transmission for semiconductors (Barote, 2013)

By plotting $(\alpha h\upsilon)^2$ against photon energy h_υ when extending the straight part of the resulting curve to cut the hυ axis at point $(\alpha h\upsilon)^2$ equal zero, the intersection point represents the Energy gap (E_g).

Figure 12 shows the optical energy gap is as a function of photon energy for Cadmium Oxide (CdO) film before and after exposure to a non-thermal plasma of with times of 0, 5, 15, 25 min. It has been shown that the optical energy gap decrease gradually when the time of exposure to a non-thermal plasma increases where value of energy gap equal to 2.3 eV before exposure to a non-thermal plasma. While, after exposure to a non-thermal plasma, the value of energy gap equal to 2.2, 2.12, 2 eV with times of 5, 15, 25 min, respectively.

CONCLUSION

Exposure to a non-thermal plasma for Cadmium Oxide (CdO) film leads to decreasing of value of both of energy gap and transmittance when the time of exposure to a non-thermal plasma increases for different times. While the values of absorptance, reflectance, absorptance coefficient, extinction coefficient, refractive index, real and imaginary part of dielectric constant and optical conductivity increase when the time of exposure to a non-thermal plasma increases for different times.

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