

RESEARCH PAPER

## Optical Properties of Radio Frequency- Sputtered CdSe Thin Films for Photoelectric Applications

Iman A. Mohammed Ali <sup>1</sup>, Khamael Ibrahim Abdulwahid <sup>2</sup>, Mohammed K. Khalaf <sup>3\*</sup>

<sup>1</sup> Ministry of Higher Education and Scientific Research, Baghdad, Iraq

<sup>2</sup> Department of Physics, College of Science, University of Misan, Maysan, Iraq

<sup>3</sup> Ministry of Higher Education and Scientific Research, Science and Technology, Baghdad, Iraq

### ARTICLE INFO

#### Article History:

Received 11 July 2022

Accepted 14 September 2022

Published 01 October 2022

#### Keywords:

Cadmium Selenide

Optical Properties

RF Sputtering

Thin Films

### ABSTRACT

Nanocrystalline Cadmium Selenide (CdSe) films were deposited on glass substrates by Radio frequency sputtering technique with different power of argon plasma. The influence of acquired thickness of sputtered films on optical characteristics was investigated. The influence of preparation conditions on thin film thickness was identified, is highly influenced by the argon discharge plasma's sputtering power. UV-Visible transmittance spectra indicated the optical characteristics, and the bandgap energy was calculated. The films were discovered to have a direct allowed transition after optical absorption investigations. The direct bandgap energy was found to decrease as sputtering power increases along with film thickness. The slight decrease has been attributed to the increasing diffusion impurities which occupy interstitial sites between selenium atoms. The dielectric constants, extinction coefficient, and refractive index generally increased with increase in films thickness due to increased density of the deposited films as a result of sputtering power increasing. The results showed good optical properties of the films deposited at 100 °C using the RF sputtering technique which is suitable to use as an active layer in thin-film-based photoelectric cells.

### How to cite this article

Ali I M, Abdulwahid K I, Khalaf M K. Optical Properties of Radio Frequency- Sputtered CdSe Thin Films for Photoelectric Applications. J Nanostruct, 2022; 12(4):914-920. DOI: 10.22052/JNS.2022.04.013

### INTRODUCTION

The fascination with metal chalcogenide semiconductor nanoparticles stems from the fact that their optical characteristics are markedly different from those of bulk material, i.e., Their absorption and luminescence spectra are influenced by their size. Cadmium Selenide nanocrystals with nano heterostructures show promise as optic and optoelectronic devices [1, 2], solar batteries [3, 4], and fluorescent markers in biophysical processes [5, 6]. Chemical techniques of template synthesis or controlled precipitation

in solution employing surfactants as stabilizers are used to make Cadmium Selenide nanocrystals in the majority of situations [5]. However, such synthesis processes may not necessarily allow for high nanoparticle concentrations, which are frequently required in thin-film optical composites. The fundamental absorption edge of polycrystalline or crystalline semi-conductor is the regions in which the electrons are transferred from the valence band to the conduction band (excited) by absorbing the incident photons". These photons should have an energy equal to

\* Corresponding Author Email: [Mohammedkhkh@yahoo.com](mailto:Mohammedkhkh@yahoo.com)



or higher than the semiconductor’s energy gap. The absorption edge becomes wide”) for unideal, polycrystalline and amorphous semiconductor because the allowed localized levels are found in energy gap. The width of these localized levels can be calculated using Urbach Rule [7]:

$$\alpha = \alpha_0 e^{(h\nu/\Delta E)} \tag{1}$$

, where  $\alpha$  is the coefficient of absorption in (1/cm), The photon energy is denoted by the letter  $h\nu$ , and  $\Delta E$  is the energy gap’s breadth of localized levels. The energy divide values of Cadmium Selenide depend on many parameters, such as sputtering power, vacuum pressure, density of impurities, substrate temperature, and annealing temperature [8]. Usually Cadmium Selenide thin films have been prepared using physical and chemical methods such as thermal evaporation, chemical path deposition, sputtering, electron beam evaporation, spray pyrolysis, electro-deposition, photoelectron chemical, SILAR and photochemical deposition [9, 10]. Among all the techniques of deposition, RF sputtering is one of the greatest compositions. The physical characteristics of Cadmium Selenide films are regulated by process factors such as the partial pressure of argon, the sputtering power, and the sputtering rate duration, as well as deposition processes. In this work, RF magnetron sputtering was used to create Cadmium Selenide thin films on a glass substrate, and the effect of sputtering power and corresponding film thickness on optical characteristics was examined.

**MATERIALS AND METHODS**

Cadmium Selenide powder with a purity of 99.99% was squeezed in a mold by a hydraulic piston to produce a disk with a diameter of 5 cm and a thickness of 3 mm, sintered at 500 °C for 4 hours, and placed as a sputtering target in a magnetron gun. A stainless steel chamber with a compact sputtering Coater System (CRC-600;

Torr International Services LLC) was employed. The films were deposited from Cadmium Selenide target using a radio frequency (RF) magnetron sputtering source with Ar gas with rotational substrate controller at 100 °C. The sputtering chamber was throttled and the sputtering gas pressure was  $2 \times 10^{-2}$  mbar after it was evacuated to less than  $5 \times 10^{-5}$  mbar. The RF power supplied at (50-125) W and deposition time for 1 hour. The films were deposited on substrates made of glass with diameters of (4×1.5×0.15) cm with optical transmission of >95 percent. The substrates were cleaned by using ultrasonic in ethanol 96%, then by 15 minutes in distilled water, then left to dry at room temperature. The spectrophotometer (UV-VIS-2601, Biotech Engineering Management CO.LTD) was used to measure the optical spectrum of absorption and transmission.

**RESULT AND DISCUSSION**

*Sputtered Films Thickness*

In Table 1, the thickness of R.F sputtered The thickness of thin Cadmium Selenide films was measured. using the optical interferometer method. Thin Cadmium Selenide films have different thicknesses. is presented as a function of sputtering power. Present results are in agreement with published work [14, 15, 16]. Poor sputtering power is likely to result in a low deposition rate because to the less energetic argon over the target species. In the current work, this had an impact on the sluggish nucleation and development of a few tiny grains on the surface. The number of Cadmium Selenide atoms created from the target by sputtering rose as RF power increased, and the chance of the Cadmium Selenide atoms arriving on the substrate without collisions increased, resulting in the maximum deposition rate.

*Spectrums of Absorbance (A), Reflectance (R), and Transmittance (T)*

Fig. 1 shows that, absorbance, transmittance, and reflectance of light spectrums respectively of

Table 1. The thickness of RF sputtered CdSe thin films.

| sample | Sputtering power(Watt) | Thickness(nm) |
|--------|------------------------|---------------|
| S1     | 50                     | 185.3 nm      |
| S2     | 75                     | 205.2nm       |
| S3     | 100                    | 209.7nm       |
| S4     | 125                    | 232.5nm       |



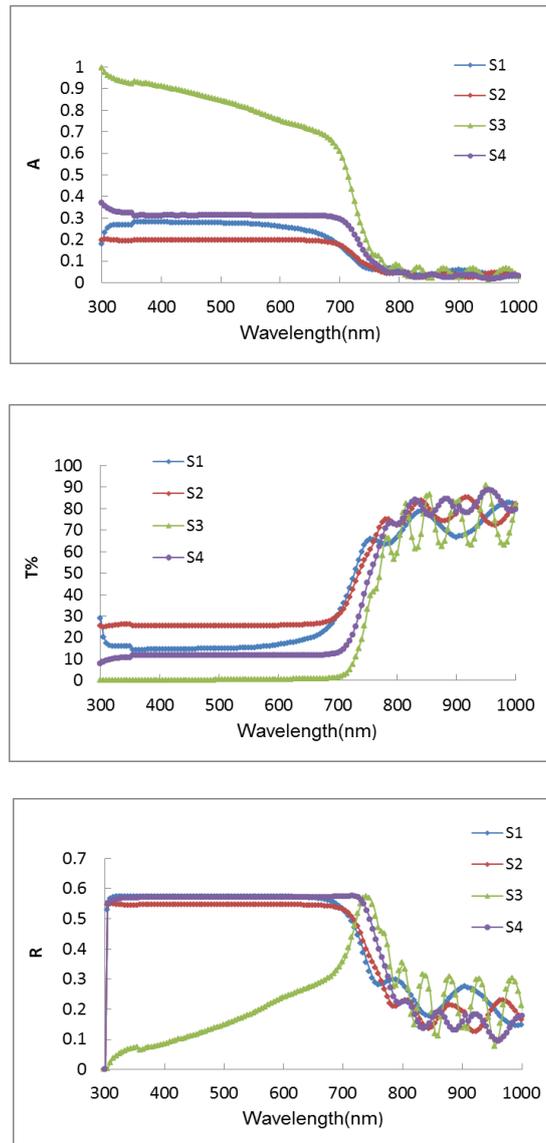


Fig. 1. The optical absorbance, transmittance and reflectance spectrums respectively of deposited CdSe films with different thickness using different sputtering power.

deposited films with different thicknesses, which are prepared at various sputtering power (50, 75,100 and 125) W At normal temperature, the wavelength range is 300-1100 nm. The Absorption (A) and transmission (T) is used to compute reflectance (T) Energy communication is governed by the rule of entropy. [14].

$$T = (1-R)^2 \cdot e^{-\alpha t} \quad (2)$$

, where t is the deposited layer thickness and

absorption coefficient ( $\alpha$ ). The figures show In the UV range (300–400 nm), the films absorb a lot of light, and, the optical absorbance, transmittance, and reflectance in the visible region increase and decrease respectively with an increase of film thickness. This impact might be explained by an increase in cadmium and oxygen atom diffusion into the bandgap as localized levels. [12]. The figures show that the absorbance increases, transmittance, and reflectance decrease respectively The photon falling on the prepared

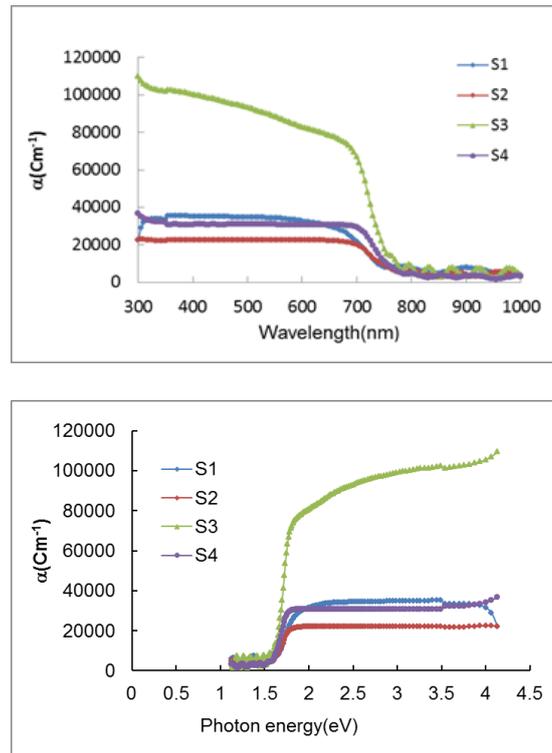


Fig. 2. Absorption Coefficient ( $\alpha$ ) against wavelength (photon energy) deposited CdSe films with different thickness using different sputtering power.

film's surface will be absorbed by the crystals inside a single grain in a series of operations as the thickness of the prepared film increases, and as a result, its capacity to reflect or permeabilize without being absorbed by the complex atoms' electrons will be restricted, particularly as the thickness of the prepared film increases. As the number of crystals in it grows, so does the thickness, resulting in total absorption and a rise in the absorption coefficient. What has been said thus far corresponds to the findings of investigations. [10]. The Cadmium Selenide thin films deposited on the glass substrate showed a transmittance of ~60-80 % in the range 700-1000 nm and are found to decrease as sputtering power increases along with the film thickness which shows the improvement in crystallinity.

#### Optical Band Gap and Absorption Coefficient

The Absorption Coefficient is the ratio of decreasing radiation intensity as it passes through a substance using the following equation. [16, 17]:

$$\alpha = 1/t \ln 1/T \quad (3)$$

It is clear from Fig. 2, that the region of absorption occurs at ( $\lambda = 300 - 750$  nm). The absorption coefficient takes higher values ( $> 10^4$   $\text{cm}^{-1}$ ), originating from valence band electrical transitions and impurities, as well as energy band transitions. With rising wavelengths, these values quickly decrease. The fluctuation in absorption coefficient with wavelengths becomes minor in the spectrum area (700-800 nm), and the values of all Cadmium Selenide films are fairly near at the cut-off wavelength.

The increase in absorption coefficients with the increasing the film thickness which is related to sputtering power is clear and reduced nearly at the region of the cut-off wavelength range. This increment is related to the Cd and Se atoms in the crystal structure of Cadmium Selenide films, which occupy an impurity energy level and increase the absorption of the photons. Utilize the fundamental absorption, which corresponds to the transition

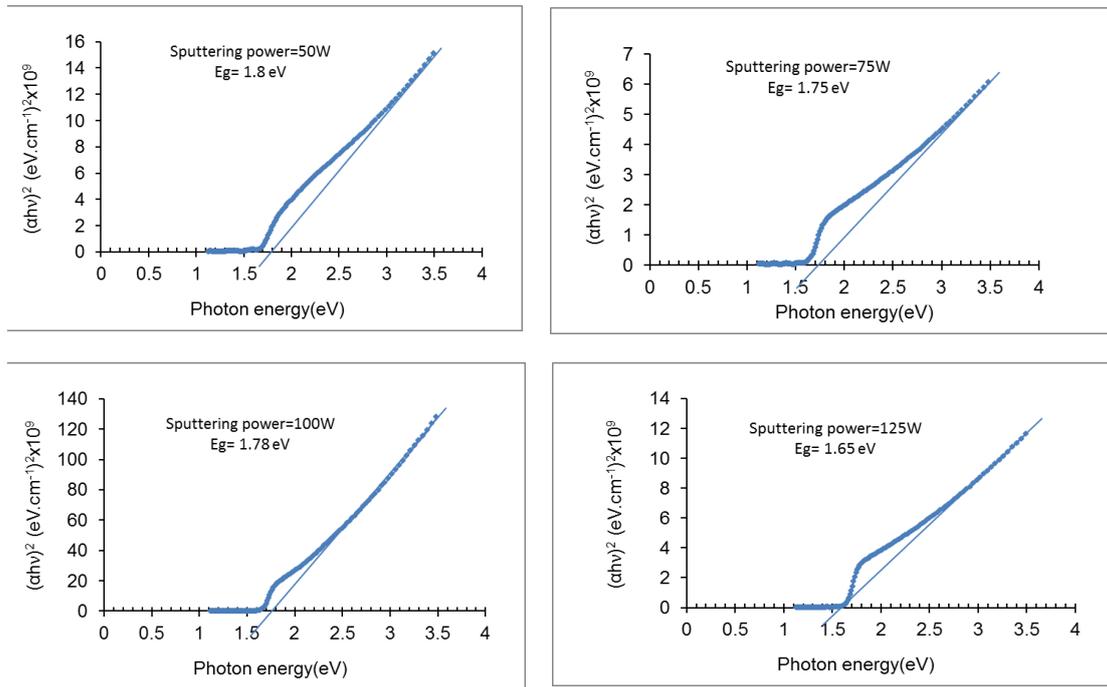


Fig. 3. The variation of  $(\alpha h\nu)^2$  with photon energy of CdSe thin films deposited with different thickness using different sputtering power.

from the valance band to the conduction band, to calculate a material's bandgap. The connection between and the incident photon energy ( $h\nu$ ) is as follows [16, 17]:

$$\alpha h\nu = A_0 (\hbar\nu - E_g)^r \quad (4)$$

, where  $A_0$  is a constant,  $E_g$  is the material's bandgap, and  $r$  is a variable depending on the kind of transition. The authorized direct, allowed indirect, banned direct, and indirect transitions are prohibited are represented by the parameters  $1/2, 2, 3/2,$  and  $3,$  respectively. The direct energy gap of produced films was calculated using a plot of the absorption coefficient as a function of photon energy Fig. 3. Extrapolating the straight-line section of the  $(\hbar\nu)^{1/r}$  versus  $h$  plot with  $r=1/2$  yields the value of  $E_g$ . In Fig. 3, the plot of  $(\hbar\nu)^2$  vs.  $h$  is displayed. The direct badgap energy value was discovered to be (1.8, 1.75, 1.75, 1.62) eV for Cadmium Selenide thin films deposited using sputtering power of a range of 50, 75,100 and 125 W respectively. The direct bandgap energy was found to decrease as sputtering power increases along with film thickness [18]. The crystallite size-dependent features of the bandgap energy are

responsible for these variations. Cadmium and oxygen diffusion occupy interstitial critical sites between Cadmium Selenide lattices, resulting in a modest decrease in direct bandgap. As a result of this process, new localized states of impurities emerge, causing the optical bandgap to shrink.

The refractive index and extinction coefficient follow the same pattern as the transmittance and absorbance spectra. Fig. 4 shows that it is found that, at ( $\lambda = 750-1000$  nm) for different sputtering power (increasing the thicknesses) causes increasing of refractive index values. This behavior may be due to an increase in packing density because of increases in the degree of crystallization. The values of refractive index become relatively lower at wavelength about ( $1 \mu\text{m}$ ), where films are transparent and the reflectance of Cadmium Selenide films estimated are very low. The refractive index of deposited Cadmium Selenide films ranges between these values, as seen in this diagram.  $\sim 2$  and  $3,$  The extinction coefficient, on the other hand, fluctuates between  $5 \times 10^{-2}$  and  $\sim 1$  at the wavelength of  $\lambda = 750-1000$  nm. Refractive index values in the present work are in agreement with the values that have been published (2.73–2.76) [19]. The high refractive index value makes

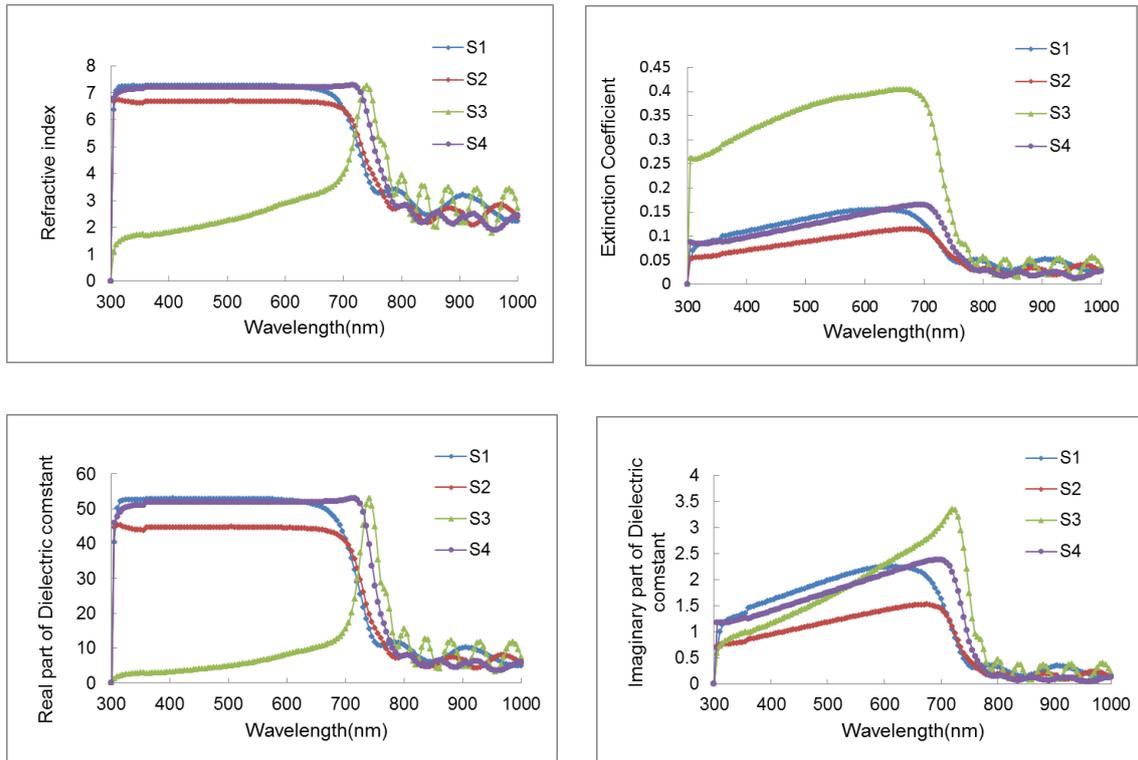


Fig.4. Extinction coefficient, refractive index, and real and imaginary parts of the dielectric constant's behavior of CdSe thin films deposited with different thickness using different sputtering power.

these films a good material for photovoltaic NIR photodiode application.

This coefficient relies on the absorption coefficient, for that, its behavior can be resembling absorption coefficient [20,21]. The behavior explanation of extinction coefficient with the sputtering power and related films thickness can be related in terms of induced impurities i.e for high absorption coefficients it is possible the films would contain enough impurities to give rise to a high extinction coefficient. Between the valence and conduction bands, the density of local levels generated by impurity atoms in the faulty material functions as a ladder for the transfer of electrons absorbing photons with energy less than the value of the  $op$ , as shown in the figure. This is owing to the density of the local levels generated by impurity atoms between the valence and conduction bands in the faulty material, since these levels function as a ladder for the transfer of electrons absorbing photons [21].

The tangible and intangible elements of the deposited dielectric constants Cadmium Selenide

films for different sputtering power are calculated by using the following equations [8, 14].

$$\epsilon_1 = n^2 - k^2 \quad (5)$$

$$\epsilon_2 = n^2 \cdot k^2 \quad (6)$$

The dependence of  $\epsilon_1$  and  $\epsilon_2$  on wavelength is shown in Fig. 4, and it is concluded, that the variations of  $\epsilon_1$  and  $\epsilon_2$ , Because the smaller values of  $k^2$  in contrast to  $n^2$ , the imaginary component of the dielectric constant 2 is mostly dependent on the  $k$  values, which are connected to fluctuations in absorption coefficient. Due to the intense interaction between the highly energy photons and the charge carriers of the material, the values of the actual dielectric increase significantly

#### ONCLUSION

Sputtered Cadmium Selenide thin films were effectively obtained. The optical characteristics of Cadmium Selenide films are impacted by film thickness, which is linked to the sputtering

power, according to spectrum examination of transmittance and absorbance at (300-1100) nm for the produced films. The ideal preparation conditions for producing Cadmium Selenide thin films may be inferred. is sputtering power of 100Watt with the thickness of ~ 210nm .These sputtered films recorded the greatest absorbance, the direct bandgap was confirmed and found to be around 1.7eV. This was the permeability with the lowest value. With this value of thickness in the manufacture buffer layers of solar cells and in the production of contemporary electronic devices, such as photodiodes (an optical signal detector in a communications system) that operate in the visible-near infrared range of the electromagnetic spectrum.

#### CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

#### REFERENCE

1. Chopade P, Jagtap S, Gosavi S. Material properties and potential applications of CdSe semiconductor nanocrystals. *Nanoscale Compound Semiconductors and their Optoelectronics Applications*: Elsevier; 2022. p. 105-153.
2. Fonash S, Van de Voorde M. *Engineering, Medicine and Science at the Nano-Scale*. Wiley-VCH Verlag GmbH & Co. KGaA; 2018.
3. Salaromoli H, Maleki E, Shariatinia Z, Ranjbar M. CdS/CdSe quantum dots co-sensitized solar cells with Cu<sub>2</sub>S counter electrode prepared by SILAR, spray pyrolysis and Zn-Cu alloy methods. *J Photochem Photobiol A: Chem*. 2013;271:56-64.
4. Chung NTK, Nguyen PT, Tung HT, Phuc DH. Quantum Dot Sensitized Solar Cell: Photoanodes, Counter Electrodes, and Electrolytes. *Molecules*. 2021;26(9):2638.
5. Madhavi J, Prasad V. ZnS and ZnS/CdS core-shell Nano particles: Synthesis, properties and Perspectives. *Surfaces and Interfaces*. 2020;21:100757.
6. Díaz-González M, de la Escosura-Muñiz A, Fernandez-Argüelles MT, Alonso FJG, Costa-Fernandez JM. Quantum Dot bioconjugates for diagnostic applications. *Topics in Current Chemistry Collections*: Springer International Publishing; 2020. p. 133-176.
7. Oluwatosin Abegunde O, Titilayo Akinlabi E, Philip Oladijo O, Akinlabi S, Uchenna Ude A. Overview of thin film deposition techniques. *AIMS Materials Science*. 2019;6(2):174-199.
8. Wooten F. INTRODUCTION. *Optical Properties of Solids*: Elsevier; 1972. p. 1-14.
9. Abdul-Ameer Al-Rehamey HJ. Structural, electrical and optical properties of CdS thin films and the effect of annealing on photoconductivity. *Iraqi Journal of Physics*. 2019;12(25):138-147.
10. Agool IR, Mohammed HM, Abd Al Hussan SM. Synthesis, Characterization and Optoelectronic Properties of Solar Cells Device for Vacuum Thermally Evaporated Pure and Gallium Doped CdSe Thin Films. *IOP Conference Series: Earth and Environmental Science*. 2021;790(1):012086.
11. Khalaf MK, Mazhir SN, Mahdi MS, Taha SK, Bououdina M. Influence of RF sputtering power on surface properties and biocompatibility of 316L stainless steel alloy by deposition of TiO<sub>2</sub> thin films. *Materials Research Express*. 2018;6(3):035401.
12. Salman, et al. Plasma Spectroscopy Diagnostics of V2O5 at a Variable of Operating Power and Pressure With Radio Frequency Magnetron Sputtering. *Baghdad Science Journal*. 2019;16(1):0209.
13. Khalaf MK, Hassan NK, Khudiar AI, Salman IK. Photoconductivities of Nanocrystalline Vanadium Pentoxide Thin Film Grown by Plasma RF Magnetron Sputtering at Different Conditions of Deposition. *Physics of the Solid State*. 2020;62(1):74-82.
14. Thin Film Processes - Artifacts on Surface Phenomena and Technological Facets. *InTech*; 2017.
15. Khudiar AI, Khalaf MK, Ofui AM. Improvement of the sensing characterizations of ZnO nanostructure by using thermal annealing prepared through R. F. magnetron sputtering technique. *Opt Mater*. 2021;114:110885.
16. Khalaf MK, Abed Al-Kader DS, Salh JM. Effect of thickness and type of substrate on optical properties of chromium oxide thin film prepared by sputtering magnetron. *IOP Conference Series: Materials Science and Engineering*. 2021;1105(1):012065.
17. Zanatta AR. Revisiting the optical bandgap of semiconductors and the proposal of a unified methodology to its determination. *Sci Rep*. 2019;9(1).
18. Hussain S, Iqbal M, Khan AA, Khan MN, Mehboob G, Ajmal S, et al. Fabrication of Nanostructured Cadmium Selenide Thin Films for Optoelectronics Applications. *Frontiers in Chemistry*. 2021;9.
19. Akaltun Y, Yıldırım MA, Ateş A, Yıldırım M. The relationship between refractive index-energy gap and the film thickness effect on the characteristic parameters of CdSe thin films. *Opt Commun*. 2011;284(9):2307-2311.
20. Khalaf MK, al-kader Dsa, salh JM. Annealing Effect on Structural and Optical Properties of Cr<sub>2</sub>O<sub>3</sub> Thin Films Prepared by R.F Magnetron Sputtering. *IOP Conference Series: Materials Science and Engineering*. 2021;1105(1):012064.
21. Khalaf M, Mohammed Ali I, Dathan MJ, Hamil M. Effect of O<sub>2</sub>, N<sub>2</sub>, Ar, and Ar/O<sub>2</sub> Plasma Treatment on Optical Properties of Polyaniline Films. *Egyptian Journal of Chemistry*. 2021;0(0):0-0.