Studying The Effects Of Annealing Temperatures On Nio P-Type MSM Photodetector Prepared Using Physical Vapor Deposition (PVD).

Abdulrahman Rashid Hammood[1*], N.K. Hassan[2], Abdul Kareem Dahash Ali[3]

[1*]University of Tikrit, Iraq, Email: abdulrahmman002@gmail.com
[2]University of Tikrit, Iraq, Email: [b]nadimkh4@tu.edu.iq
[3]University of Tikrit, Iraq

***Corresponding Author:** Abdulrahman Rashid Hammood
[*]University of Tikrit, Iraq, Email: abdulrahmman002@gmail.com

Abstract.
Using the physical vapor deposition (PVD) technique, nickel oxide (NiO) thin films were applied to glass substrates and annealed for two hours at various annealing temperatures (280°C, 320°C, and 360°C). On the structural, optical, and electrical characteristics of the NiO thin films, the effect of the annealing temperatures was studied. According to X-ray diffraction, a cubic structure with a strong (2 2 0) preferred orientation persisted through various thermal treatments. and that the crystallite size increased as the annealing temperature increased., The absorption peak increased with increasing annealing temperatures to become 0.84 with a small shift towards the shorter wavelength, according to the optical absorption spectra, which were shown to be a result of the process. Absorbance. the band gap of about 3.61 eV at 280ºC and 320ºC has 3.63 eV. For 360ºC annealed films, the optical band gap continues to decrease close to 3.67 eV. As a result of our study, we were able to demonstrate that the surface-to-volume ratio has a significant impact on the photo response characteristics of the photodetectors. Low sensitivity and lengthy rise times were caused by the annealing temperatures, which also decreased photodetection performance.

Keywords: nickel oxide, annealing times, physical vapor deposition, thin film, thermal vacuum evaporation.

Introduction

Due to the rapid advancement of optoelectronic technology, a variety of photonic sensors have been extensively researched to monitor the environment and improve quality of life. Particularly, such equipment was widely employed in UV photodetectors, aircraft, fire sensing, bio-imaging, and pollution monitoring.[1, 2]. The wide band gap and great stability of transition metal oxide semiconductors (WO3, TiO2, SnO2, and ZnO) make them suitable UV photodetectors[3]. The challenge of putting the shallow acceptors in the valence band prevented many researchers from studying the p-type semiconductor-based photodetectors (VB) [4,5] However, the exceptional durability, low cost, and high sensing capacity of NiO-based films have increased their significance. [6]. Additionally, NiO is a transparent p-type semiconductor with a wide band gap (3.3–4.0 eV) that resonates with the UV–A spectrum's cutoff wavelength.[6, 7]. Basically, stoichiometric NiO outperforms high resistivity at room temperature, posing severe limitations on charge carrier formation and delivery. [8]. As a result, there are several ways to decrease the resistance, including studying how the particle size affects the detector's performance by reducing the gap and modifying the annealing temperature.

We compared the UV photodetector performance of NiO films that were deposited at various annealing temperatures, including 280 C, 320 C, and 360 C for two hours. By using X-ray photoelectron spectroscopy, the surface chemistry of NiO films was investigated (XRD).

Experimental:

NiO films were deposited at low pressure (2x10-5 mbar) by a physical vapor deposition device as shown in (Fig.1) onto the glass substrates using pure Ni targets. Ni films were oxidation and annealed at different temperatures to obtain NiO thin films. The M-S-M structure was fabricated by patterning the Al metal electrodes using a hard mask. The photo-active area and electrode area were maintained as 25 mm2 and 5 mm2, respectively.

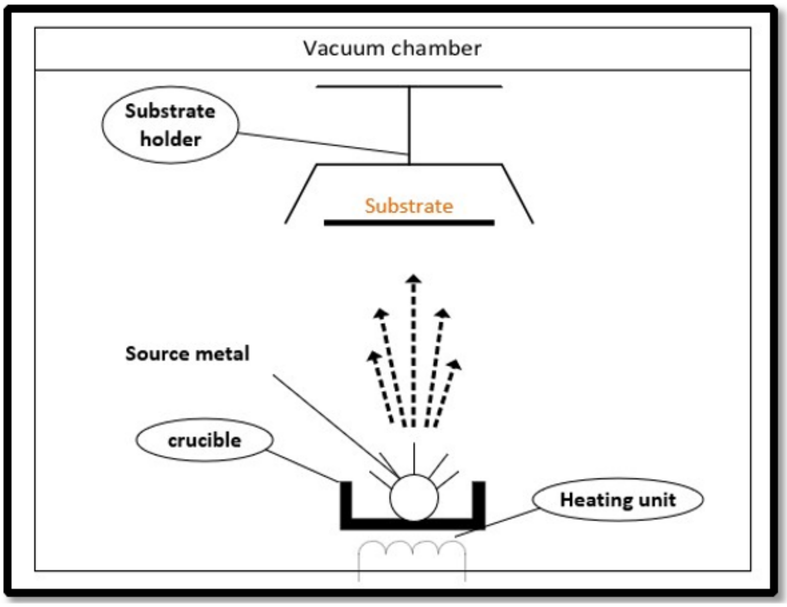

Figure 1: Schematic illustration of physical vapor deposition-PVD-process

Results and Discussions

Structure and morphology of the CuO/NiO films. (fig.1) shows the Results from X-ray diffraction for a (pure) NiO thin film that was annealed at 280 °C,320°C and 360°Cfor two hours revealing that it had five primary peaks with diffraction angles of 37.684, 43.8307, 63.2077, 75.3729, and 79.0575 that are associated with the (111), (200), (220), (311), and (222) planes. with cubic polycrystalline structures. By studying these curves, it is possible to identify the sharp peaks that arise when beams of these rays are shed at various angles on the membrane and pass through a number of levels (220, 200, 111, 311, 222) so they can overlap constructively when a Bragg's condition is present. The results were found to be consistent when compared to the international card numbering system (00-001-1239JCPOS), and we observe the prevalent trend (220). The results showed that the intensity of the peak (220) increases with the increase in annealing, (as the increase in the height of some peaks is evidence of an increase in crystallization of the material and a decrease in crystalline defects, which gives the atoms of the material potential energy to rearrange themselves in the lattice.

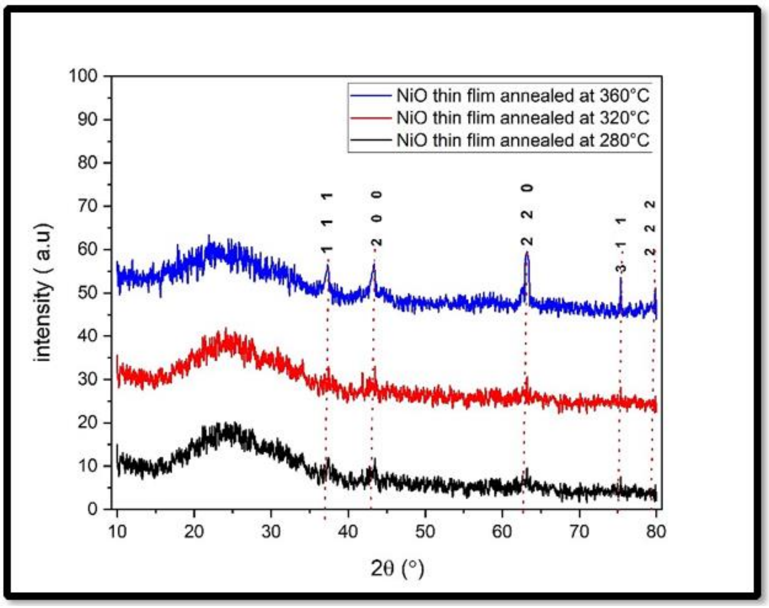

Figure 2: XRD spectra of NiO thin film annealed at 280 °C, 320 °C, and 360 °C for 2 hours

SEM was used to analyze the films' morphology at a 10 keV operating voltage (Fig. 3), which displays typical SEM images of NiO nanocomposite thin films produced on glass substrates at various annealing temperatures. The results showed that the NiO thin layer has a fine nanoparticle structure and is susceptible to aggregate because of the uniformity of the surfaces, high surface energy, and surface tension of the nanoparticles. It is dispersed equally across all substrates. As shown in (Fig.3 a, b, and c), the NiO films' grain size increases with increasing annealing temperatures, and continuous grain distribution indicates that the grains adhere adequately to the produced films' surface.

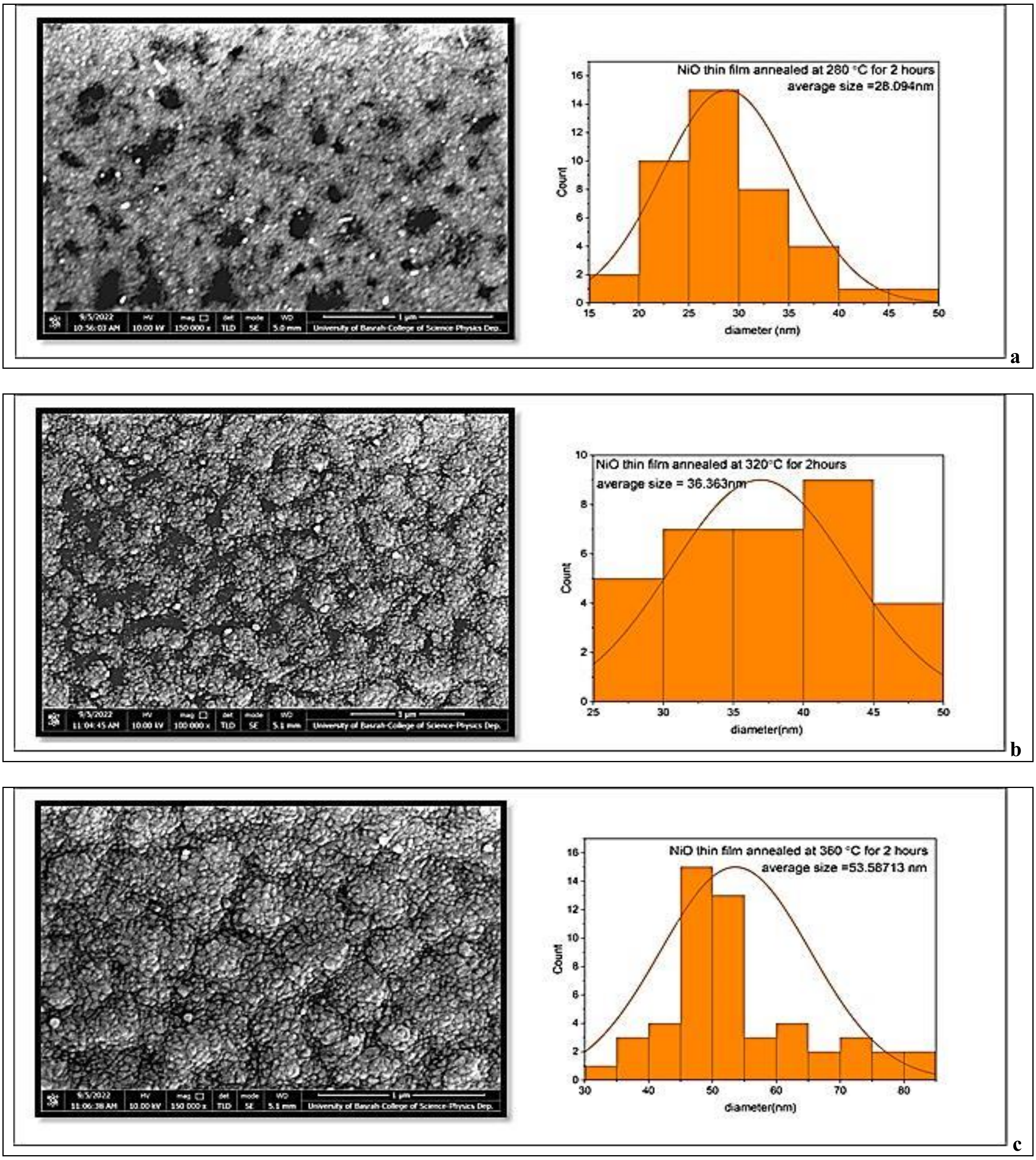

Figure 3: illustrates the surface morphology of NiO thin film annealed at different temperatures for 2 hours a- annealed at 280 °C , b- annealed at 320 °C,and c- annealed at 360 °C

Optical properties: A shimadzu UV-1800 instrument was used to measure the optical transmission of annealed thin films in the UV-VIS spectrum (300 - 1100 nm). For NiO films, the direct band gap structure or direct transition semiconductors are related to the optical band gap (Eg).[9]

$$\alpha = (h\upsilon - Eg)\ 1/2 \qquad (1)$$

h is Plank's constant and υ is the frequency of the incident photon.

The absorbance spectra for NiO thin films with different annealing temperatures for two hours of time (300nm and 1100nm) were recorded and compared as demonstrated in (Fig.4). when the film is annealed at 280 °C The absorbance is approximately (0.33) at wavelength 301 nm, and after annealing at 320°C, the absorbance is approximately (0.37) at wavelength 300.4 nm and at 360°C is (0.84) at wavelength 300.4 nm. It was observed that after the effect of adsorption, Absorption decreased due to increased grain size and reduced surface roughness. It is clear from the spectrum that absorption begins to decrease at a wavelength of about 350 nm sharply with increasing wavelength and increasing distances between atoms, making the surface more absorbent of the light incident on it.

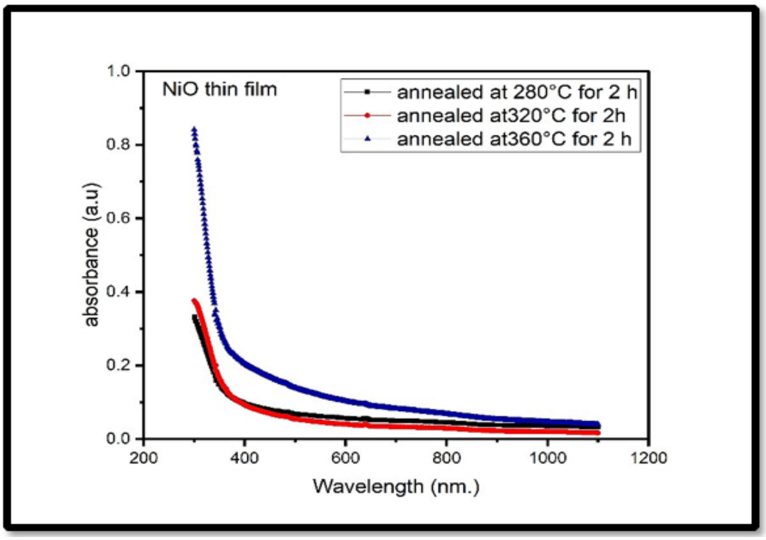

Figure 4: shows the relationship between absorbance as a function of the wavelength of NiO films annealed at 280°C,320°C, and 360°C for 2 hours

The optical energy gap can be calculated by equation (1). The optical band gap for NiO thin films annealed at various temperatures has been calculated from the magnitude of the intercept of the straight line at α= 0. About 3.61 eV is the band gap of the films when they are annealed at 280°C, while 3.63 eV is the band gap at 320°C. The optical band gap keeps rising for 360°C annealed films, approaching 3.67 eV. The outcome is provided in (Fig.5).

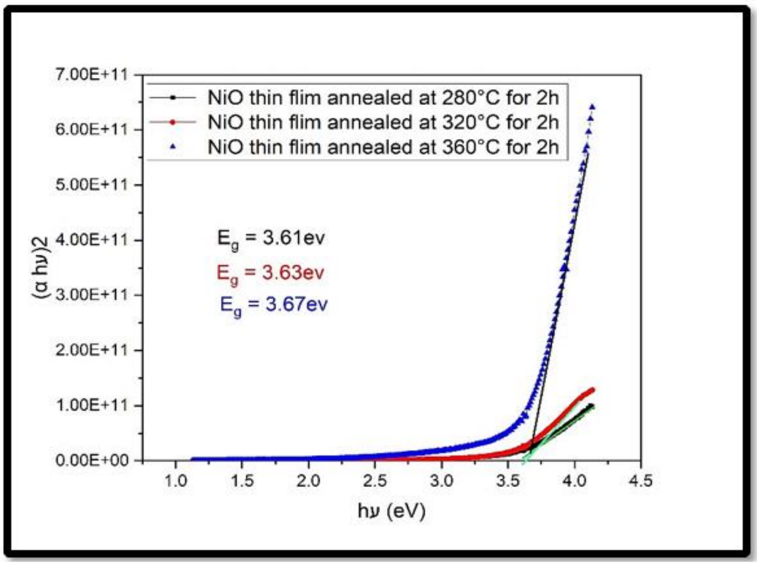

Figure 5: Tauc plots of the NiO thin film annealing at different temperatures

Electrical properties. **Electrical properties.** In order to determine the ideality factor and Schottky barrier height when creating MSM, the following thermionic emission theory equations may be employed.[10],[11]

$$I = I_{s_0}\left(e^{\frac{-qV}{\beta k_B T}} - 1\right) \qquad (2)$$

where I_{s0} is the saturation current given by:

$$I_{s_0} = AA^{*}T^{2}\, e^{\frac{-q\varphi_B}{k_B T}} \qquad (3)$$

where kB is the Boltzmann constant, φB is the barrier height, q is the charge of an electron, T is the absolute temperature, A* is the effective Richardson constant, A is the Schottky contact area, and β is the ideality factor. by rearrangement, which is obtained (Equation 3)

$$\beta = \frac{q}{k_B T}\left[\frac{V_F}{\ln\frac{I_F}{I_{s_0}}}\right] \qquad (4)$$

where V_F is the forward bias voltage, I_F andI_{S0} are the forward bias current.

Following two hours of annealing at various temperatures with Al electrodes, the relationship between the voltage applied and the current flowing through the NiO MSM detector is shown in (Fig. 6). With a bias voltage of 5 volts applied, the voltage measurements were performed. Based on the correlation between current and voltages, it is determined that the current of NiO MSM detectors is (2.50, 2, and 1.7 nA., respectively) at the different annealing temperatures in the forward bias. Because the structural properties of the thin film have improved and the energy gap has widened, the current is lower in NiO thin films than it was after the annealing temperatures were raised. Due to the enormous energy required for electrons to traverse the energy gap.

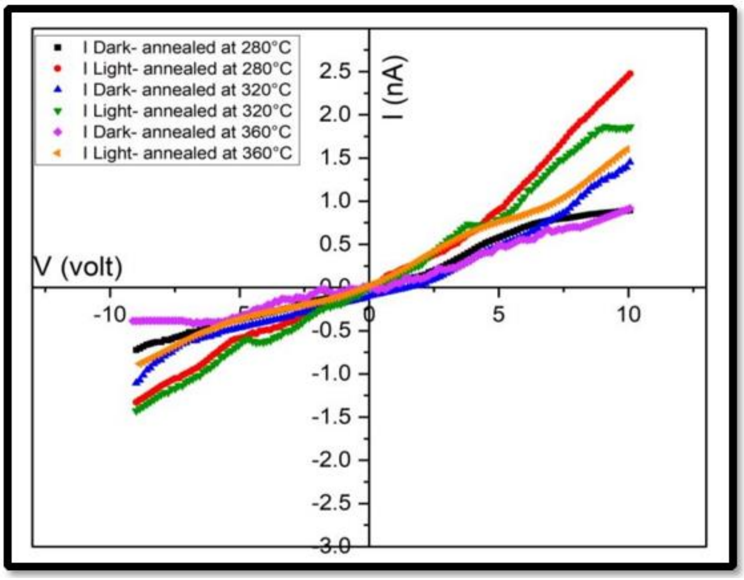

Figure 6: The Current – Voltage comparison between Dark and Light of NiO thin film deposed glass substrate annealed different annealing for 2 hours

The repeatability of the NiO MSM device was investigated by measuring the dynamic responsivity time through illumination sensors to chop light at 5 V. (Fig. 7). MSM's response was favorable due to the materials' large photoactive surface areas, excellent quality, and absence of flaws.. [12], [13]]. The voltage increased while the saturation current increased as a result of the expanding photocurrent. The MSM device was more sensitive at 5 V for the thin film that was annealed at 280°C for 2 hours. While the PD was lighted, the applied electric field generated photo-induced charges. The conductivity of the device was significantly boosted by the photocurrent and bias current.[13]. As responsivity (Rλ), quantum efficiency (η(λ)), noise equivalent power (NEP), and specific detectivity (D*) are measured at various temperatures, other electrical parameters of the photodetector made from annealed NiO are investigated. as demonstrated in (table .1)

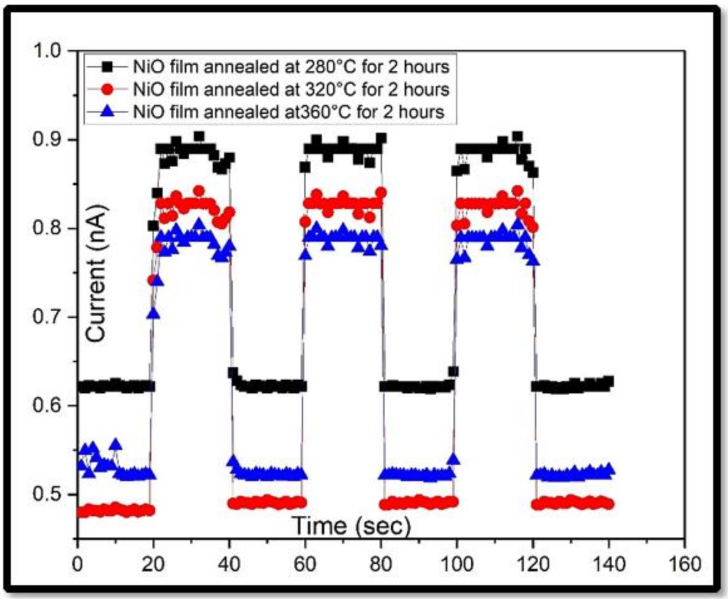

Figure 7: The repetitive switching of the light for the NiO photodiode devices at V= 5 V

Table 1: Results of photodetectors for NiO thin films illumination at 450 nm.

Sample Thin film	annealing conditions		Rλ(μA/W)	η(λ)%	NEPx10^{-10}(W)	D*x10+8 (cm.Hz$^{1/2}$.W-1)
	annealing time (hour)	Annealing temperatures(C)°				
NiO	2	280	1.233	0.000347	6.92	3.63
	2	320	1.32585	0.00037364	7.1	3.47
	2	360	1.17	0.000331	7.29	3.36

Conclusions.

On a glass substrate, nanocrystalline NiO thin films were successfully deposited employing more efficient, less difficult, and more affordable PVD procedure. The generated films stick to the substrate with a consistent structure. The XRD results show that crystallite size increases with increasing annealing temperatures. According to the morphological findings, the grains are well spaced over the substrate, and the films have a high homogeneity layer with diameters of (28.094, 36.363, and 53.587) nm. Additionally, during annealing times of (280ºC, 320ºC, and 360ºC), respectively, it was discovered that the optical energy gap decreased as annealing temperatures increased (Eg= 3.61, 3.63, and 3.67) eV. Due to their great transparency, these films are excellent for nano-optoelectronic applications, particularly in solar cells as a window or antireflection.

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