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# Characterization of Morphological and Optical Properties of $MgO:SnO_2$ Nanostructure Thin Films

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**Abstract**

The study focuses on investigating the morphological and optical properties of $MgO:SnO_2$ nanostructure films using the precipitation method for nanoparticle synthesis and the chemical spray technique for thin film preparation on glass substrates with different concentrations of $MgO_{1-x}$: SnO2 $_x$ (x=0.2,0.3,0.4,0.5). Morphological, and optical, properties of these films have been investigated,The main focus of the study is to analyze the morphological properties of the $MgO:SnO_2$ nanostructure films, This includes studying the nanostructured morphology of the films. The optical properties of the MgO: SnO2 films have been investigated as a function of MgO and the bandgap energy was estimated to be in the range of (3.5- 3.1) eV, The refractive index and extinction coefficient of the films were also determined, and the results indicated that the films had good transparency in the visible region.

**Keywords:** $MgO:SnO_2$ films, chemical spray , Nanostructure, Morphological , Optical properties.

## توصيف الخصائص السطحية والبصرية للأغشية الرقيقة $MgO:SnO_2$ نانوية التركيب

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**الخلاصة**

تركز الدراسة على دراسة الخصائص السطحية والبصرية لأغشية $MgO: SnO_2$ النانوية باستخدام طريقة الترسيب لتحضير الجسيمات النانوية بتقنية الرش الكيميائي لتحضير الأغشية الرقيقة على ركائز زجاجية بتركيزات مختلفة من $MgO_{1-x}$: $SnO2_x$ x=0.2،0.3،0.4،(0.5)تم التحقيق من الخصائص السطحية والبصرية لهذه الأفلام ، والتركيز

الرئيسي للدراسة هو تحليل الخصائص السطحية لأغشية $MgO: SnO_2$ النانوية ، وهذا يشمل دراسة التشكل النانوي للأفلام. تم فحص الخصائص البصرية لأغشية $MgO: SnO_2$ كدالة لـ MgO وقدرت طاقة فجوة الحزمة لتكون في نطاق ev(-3.7 3.1) ، كما تم تحديد معامل الانكسار ومعامل الخمود للأغشية ، وأظهرت النتائج أن الأفلام تتمتع بشفافية جيدة في المنطقة المرئية.

**الكلمات المفتاحية :** أغشية $MgO: SnO_2$ ، الرش الكيميائي ، التركيب النانوي ، الخصائص السطحية، الخصائص البصرية.

## Introduction

The precipitation method is a well-established technique for synthesizing nanoparticles with controlled composition and morphology. By carefully manipulating reaction conditions, such as temperature, pH, and precursor concentrations [1,2], it becomes possible to obtain homogeneous nanoparticles with desired properties. In our research, we employed the precipitation method to synthesize $MgO:SnO_2$ nanoparticles with tailored compositions[3,4] . Chemical spray deposition offers advantages such as simplicity, scalability, and uniformity in the fabrication of thin films. By atomizing a solution containing the nanoparticles onto a substrate, a thin film is formed as the solvent evaporates, resulting in a nanostructured film morphology [5,6]. The nanostructured morphology of the films, typically comprising interconnected nanoparticles or nanocrystallites, influences their surface area and porosity [7,8], The resulting high surface area can be advantageous for applications such as gas sensing and catalysis. Understanding the morphological features of these films is essential for tailoring their properties to specific applications [9,10].

Optical properties play a crucial role in determining the material's interaction with light. We analyze the transparency of the films in the visible light range, which is crucial for optically transparent electrode applications like solar cells and displays [11,12]. Additionally, we investigate the optical bandgap of the films, as the incorporation of SnO2 into the MgO matrix can modify this parameter, the optical bandgap defines the energy range of light that can be absorbed or emitted by the material. We also explore the optical absorption properties, which may be enhanced due to the presence of nanoparticles and their surface Plasmon resonances [13,14].

By studying the morphological and optical properties of $MgO:SnO_2$ nanostructure films synthesized via the precipitation method and prepared as thin films using chemical spray deposition, we aim to contribute to the understanding of these materials' potential for various applications. The obtained knowledge can pave the way for the development of novel nanomaterials with tailored properties and open up new avenues for their utilization in emerging technologies.

**Experimental Part**

**1.** Preparation of $MgO_{(1-x)}$: $SnO2_{(x)}$ Nanoparticles:

Weigh the desired amounts of Magnesium chloride and tin (IV) chloride separately.

a) Dissolve each chloride in deionized water.
b) Slowly add the Magnesium chloride solution to the tin chloride solution while stirring continuously with a magnetic stirrer.
c) Add Ammonium hydroxide solution to the mixture until the pH reaches approximately (pH=9).
d) Continue stirring the mixture for 2-3 hours to ensure complete precipitation of the nanoparticles.
e) The resulting mixture will turn white, and a precipitate of $_{MgO1-x}$: $SnO_{2\ (x)}$ nanoparticles will form.
f) The collected precipitates are then dried, typically using an oven at (200°C) for 6 h, to remove any remaining moisture.
g) The dried precipitates are subjected to thermal treatment, usually in the furnace at (800°C) for 4 h.

**2.** Preparation of MgO, $SnO_2$, and $MgO:SnO_2$ Thin Films:

a) Clean glass substrates sequentially with acetone, ethanol, and deionized water.

b) Prepare a solution of the $MgO_{(1-x)}$: $SnO_{2(x)}$ nanoparticles by dissolving them in ethylene glycol with a mass ratio of 0.1:10 at room temperature.

c) Ensure that the concentration of MgO, $SnO_2$, and $MgO:SnO_2$ in the solution is 0.1 g.

d) Deposit the MgO, $SnO_2$, and MgO:$SnO_2$ thin films onto the cleaned glass substrates using the spray pyrolysis method at room temperature.

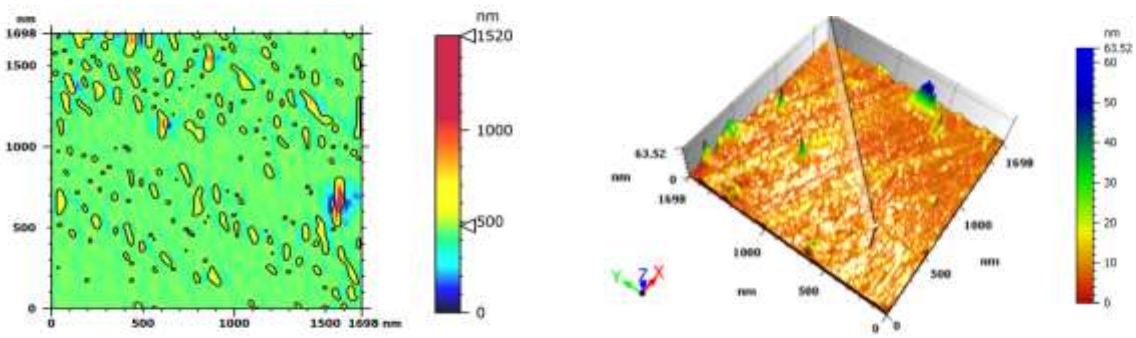
e) Place the films on a hot plate set at 90 °C in the air for 5 minutes to remove organic contaminations.

## Results and Discussion

Fig.(1-a) AFM characterization is an outstanding analytical technique for the study of different surface morphology and texture of the thin flm. A changes in the AFM topographical images of MgO thin film demonstrates three-dimensional films AFM micrographs. The study of the images reveals that have strengthened both the surface pores and nodules, and that the roughness of the substratum is due to the height of the lumps on the surface [15]. Fig(1-b) shows the AFM images of the surface of grown and annealed SnO2 thin film, AFM images reveal that the prepared $SnO_2$ thin films have highly rough and porous surface morphology, The asgrown $SnO_2$ thin films show sharp grain edges which become nano-sized and are advantageous for gas sensing applications due to high surface to volume ratio [16]. Fig(1-c) shows the AFM images for the sample $MgO_{(0.5)}$:$SnO_{2\,(0.5)}$ shows a hilly topology with large size which is formed of the segregation of the nanoparticles leading to high roughness (59.96 nm). The roughness of the films reduces with the increases than it is in the pure, as shown in table(1).

**Table 1:** AFM parameters for MgO:$SnO_2$ thin films

| Samples by Chemical Spry | Roughness Average Sa (nm) | RMS (nm) | Particles Size (nm) | Surface Skewness (RsK) (nm) | Surface Kurtosis (Rku) (nm) | Maximum Height Sz(nm) |
|---|---|---|---|---|---|---|
| **MgO** | 384.4 | 498.9 | 55.30 | 0.0530 | 2.831 | 3167 |
| **SnO2** | 35.42 | 47.91 | 90.38 | 1.266 | 5.570 | 349.7 |
| **MgO:SnO2** | 1.347 | 2.655 | 138.3 | 8.878 | 115.2 | 76.40 |



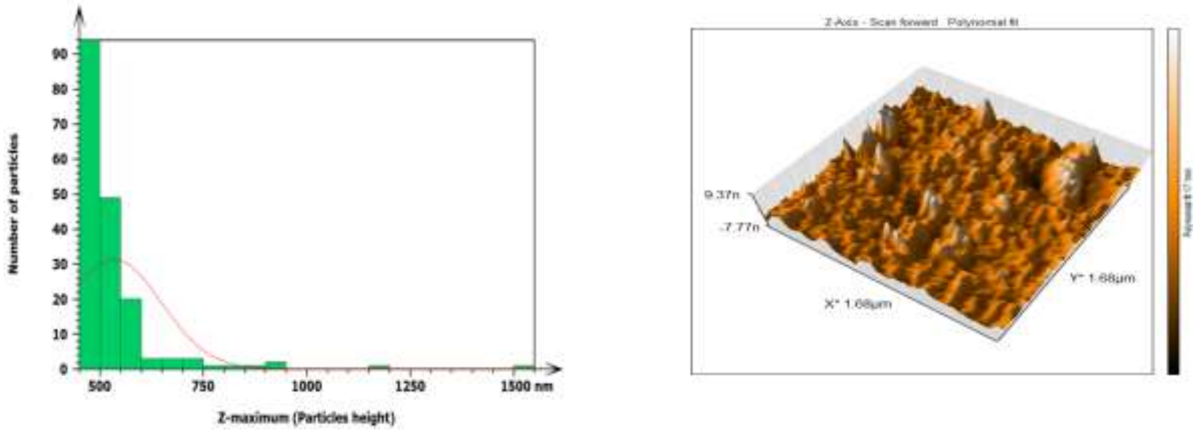



**Figure (1-a):**MgO thin flims by Chemical Spray.

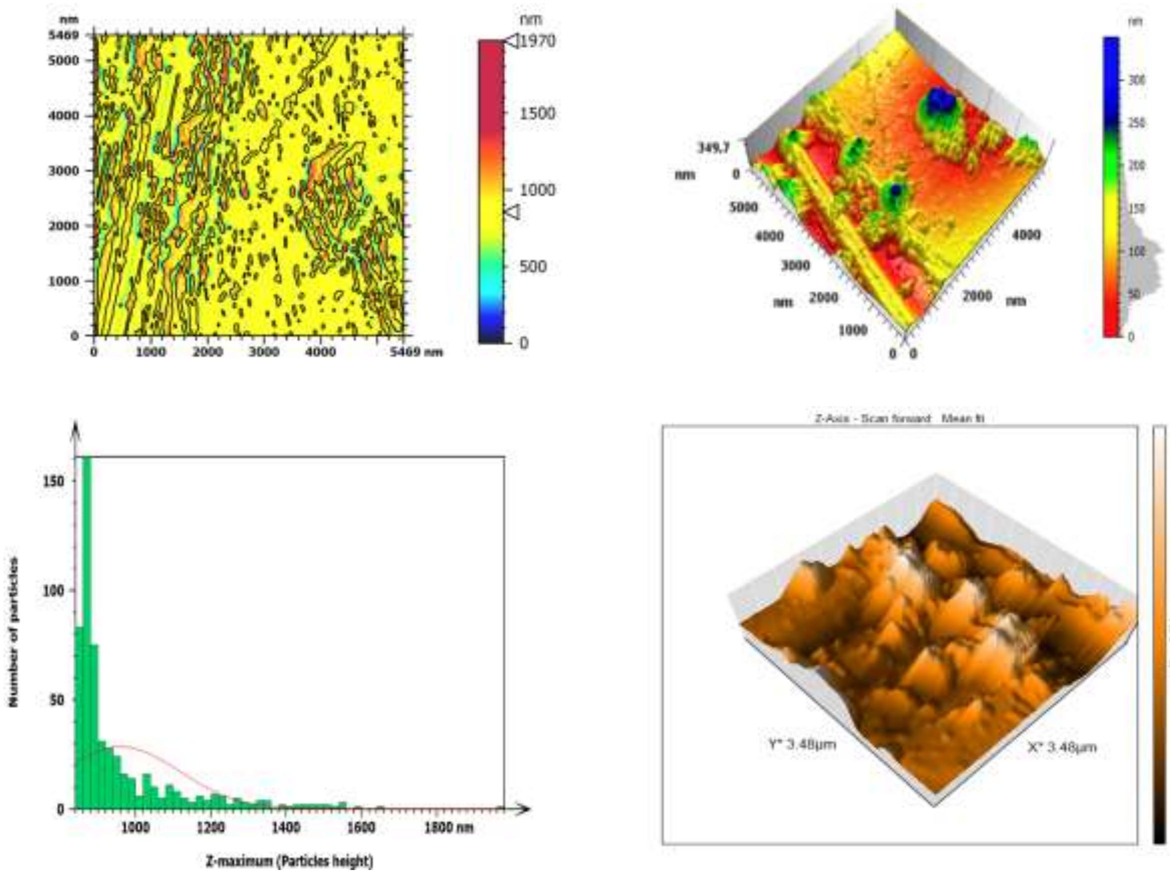



**Figure (1-b):** $SnO_2$ by Chemical Spray

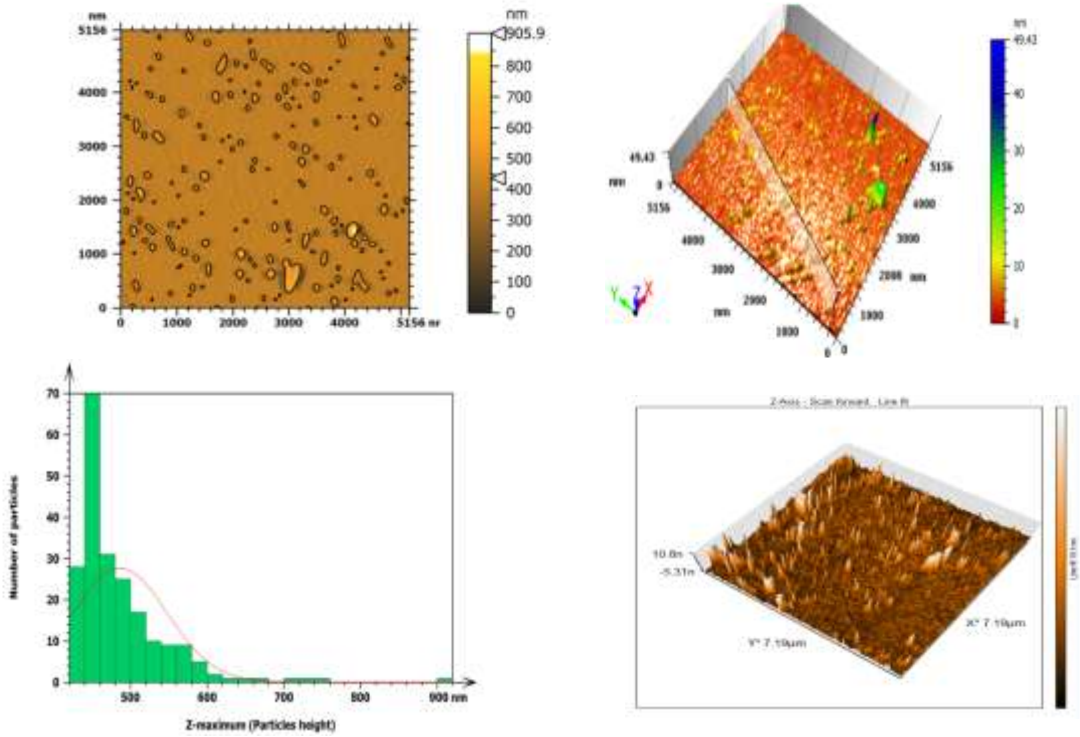



**Figure (1-c):** $MgO:SnO_2$ by Chemical Spray.

For the use of opto-electronic device applications, the adaptation of the optical band gap and the absorption behavior of the film have played a crucial role. The optical transmission spectra of pure MgO and $MgO:SnO_2$ films in the range of 200–1200 nm are illustrated in Fig. 2. All the films present a sharp absorption edge around about 300 nm. It can be observed that the transmittance of the films decreased with increasing the MgO. The maximum transmission of the pure MgO film was around 65%, whereas the $MgO:SnO_2$ films show a mean transmittance above 75%. Similar change of transmission with concentration [17].

Reflectance of the surface of a material (thin film) is the fraction of incident light that is reflected at an interface [18]. Fig. 2. shows the spectral reflectance curve as a function of wavelength. Reflectance is calculated from absorptance and transmittance by using eq. (1). We observed that reflectance have high value which decreasing with wavelength increasing for all films [18].

$$R=1-(A+T) \qquad (1)$$

When R is reflectance, A is absorbance and T is transmittance

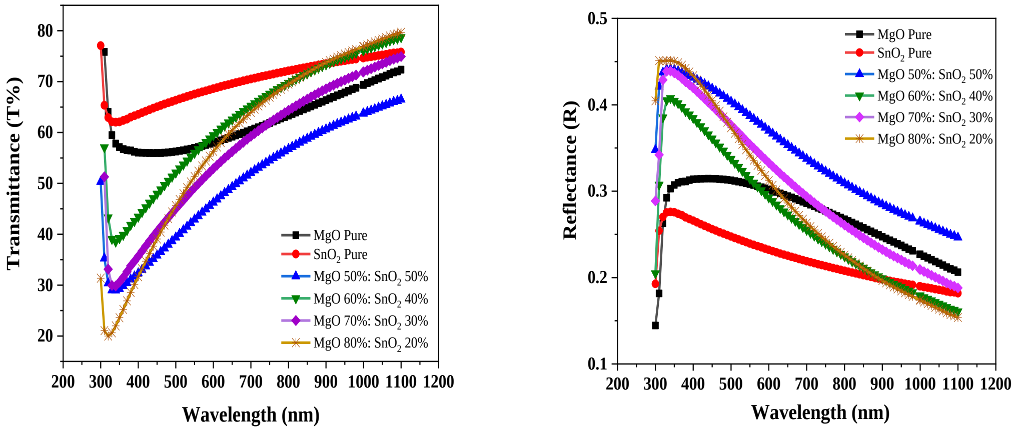



**Figure 2:** T% and R for MgO: $SnO_2$ films

The optical absorption coefficients (α) of these films were determined from the transmittance spectra using the Lambert equation The absorbance spectrum of MgO:$SnO_2$ used to calculate the Absorption coefficient (α) by applied the following equation (2)[19,20]:

$$\alpha = 2.303\,\frac{A}{t} \qquad (2)$$

Where (A) is the absorbance and (t) is film thickness Fig. (3) declare that the increases of MgO concentration lead to increasing the absorption coefficient (α) due to the formation localized levels within the energy gap ,This works is to reduce the energy gap values which leads to bias absorption edge towards longer photon energy.

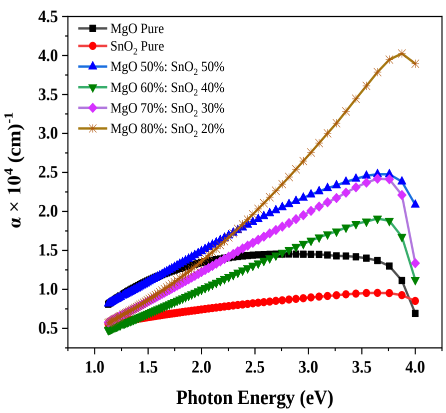


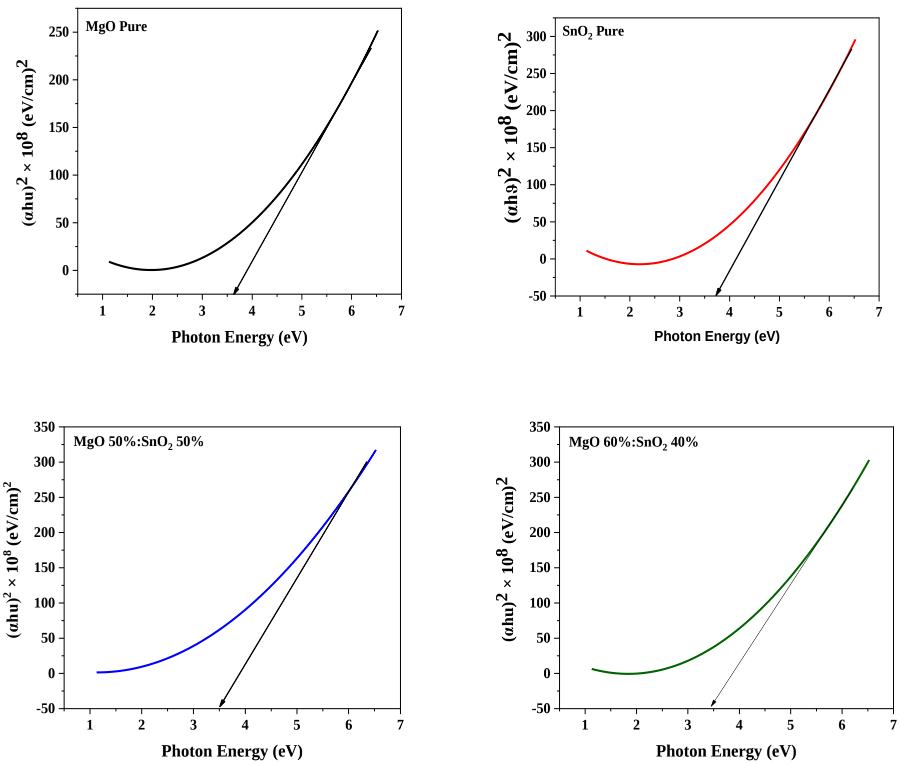

**Figure 3:** The absorption coefficient for MgO:$SnO_2$ films.

The direct optical band gap for are prepared films is calculated from the Beer Lambert law relation [21,22]

$$\alpha h\vartheta = C(h\vartheta - E_g)^{1/2} \qquad (3)$$

Where, $h\vartheta$ is the photon energy, Eg is the energy band gap and absorption coefficient ($\alpha$). Allowed direct transition, forbidden direct transition respectively, The pure and MgO: $SnO_2$ films have a direct band gap as calculated from following relation (3)

The calculated band gap values of pure MgO (3.6), $SnO_2$ (3.8) and MgO:$SnO_2$ films are( 3.5, 3.4, 3.3and 3.1 ev). It is noted that the energy band-gap value is decreasing with increasing MgO content can be explained by the difference in ionic radius between Mg and Sn (0.067 nm of $Mg^2$ and 0.071 nm of $Sn^4$) and the electronegativity which leads to create the new defects introduced when Mg was substituted into $SnO_2$. On the other hand this effect was probably due to the occupation of MgO atoms into the interstitial sites in $SnO_2$ lattice [23].



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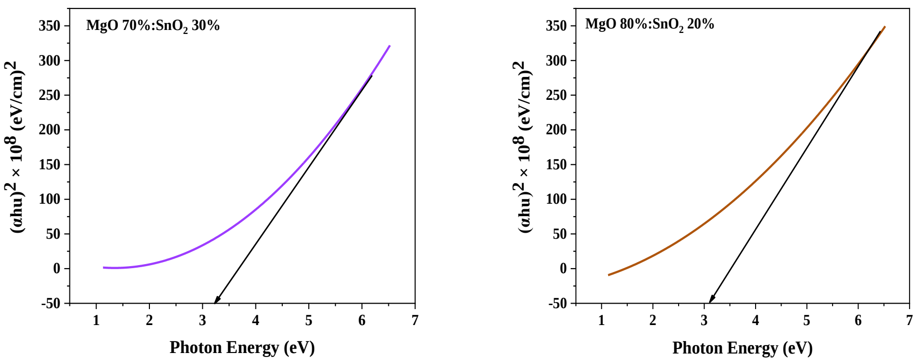


**Figure 4:** Eg for MgO: $SnO_2$ films

Fig. 5 that the refractive index values had increased from (1.8-2.1))ev as the photon energy from ( 1.2 to 3.7 ) ev and then decreased to 2.1-2.9 for 3.9 ev . However, the rate of increase upto 3.7 ev and then decrease for 3.9 appears to be dependent on the used relations. Since refractive index is strongly related with band gap energy.

Extinction coefficient of $SnO_2$ thin films refers to a measure of absorption of light in a medium, which defines how strongly this $SnO_2$ compound absorbs light of given wavelength. The extinction coefficient (k) of $SnO_2$ thin films is determined from the following relation (4)[24]:

$$k_o = \frac{\alpha\lambda}{4\pi} \qquad (4)$$

Where α and λ are the absorption coefficient and wavelength of incident beam respectively.

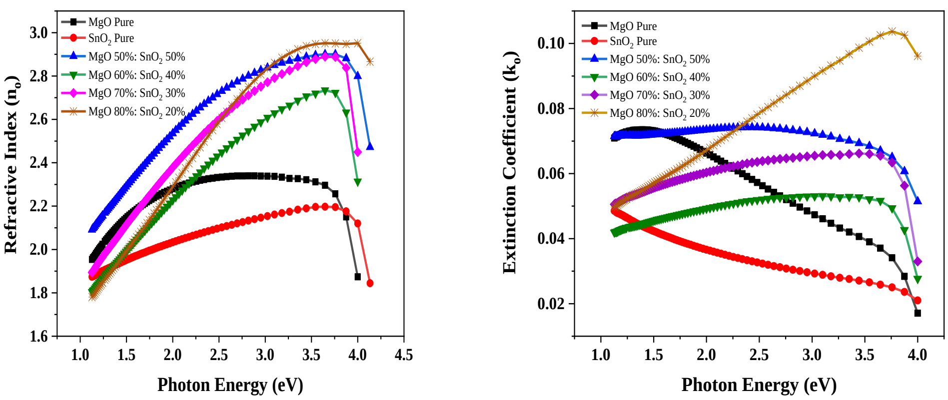


**Figure 5:** $n_o$ and $k_o$ for MgO: $SnO_2$ films

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Fig.(6) shows that real dielectric constant and the imaginary dielectric constant as a function of hv , In the horizontal and vertical position there are similarity of the behavior of the refractive index with a real dielectric constant as for the section of the imaginary dielectric constant , the difference in the curves between the horizontal and vertical modes due The difference in absorption coefficient values [25,26] .

$$\varepsilon_r = n_\circ^2 - k_\circ^2 \quad (5)$$

$$\varepsilon_i = 2n_\circ k_\circ \quad (6)$$

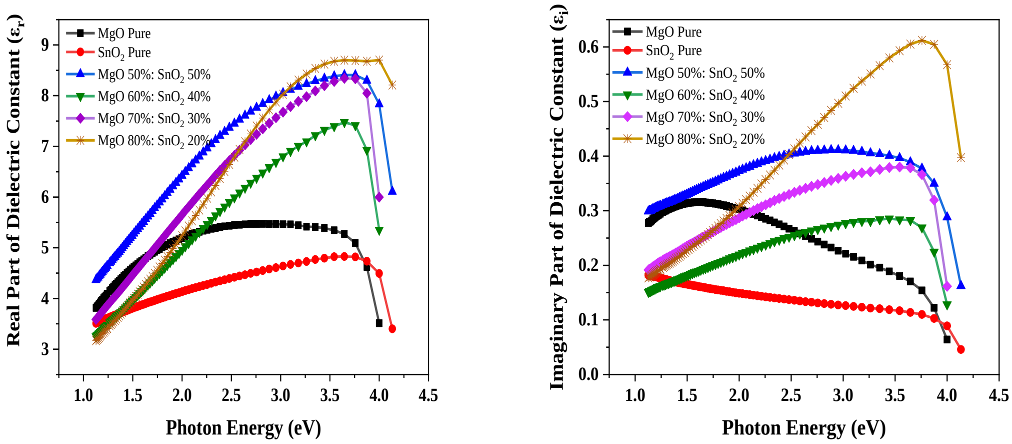


**Figure 6:** $\varepsilon_r$ and $\varepsilon_i$ for MgO: $SnO_2$ films

## Conclusions

Nanoparticles of MgO:SnO2 have been successfully synthesized by chemical precipitation method, then MgO:SnO2 films have been successfully prepared on glass substrate at temperatures (90°C) using the spray pyrolysis technique. The process parameters were optimized to have good quality crystalline films. (AFM) studies confirmed the uniformity and well grown crystalline morphology of the (MgO, SnO2, MgO:SnO2) films prepared at the optimum temperature. The grain size of the thin films calculated from (AFM) in the range of (36.16, 94.94, 107.3) nm, respectively. Then UV analyses have aided in investigating the optical properties, and the bandgap energies for pure MgO, pure SnO2 and MgO:SnO2 were found to be 3.5 - 3.1 eV, respectively.

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