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Impact of Deposition Temperature on Indium Trioxide's Structural and Optical Properties

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ABSTRACT

This study examined how altering the deposition temperature affected the characteristics of the indium oxide thin (In2O3) films that were produced. using silicon bases and the pulsed laser deposition (PLD) technique. In2O3 films (nanoparticles) were prepared by the PLD method utilizing a 1064 nm wavelength (Nd:YAG) laser. Atomic force microscopy, UV-visible spectroscopy, Field Emission Scanning Electron Microscopy (FE-SEM), and x-ray diffraction (XRD) were used to describe the sample. The films' polycrystalline structure was demonstrated by the X-ray diffraction pattern data. image of a microscope Atomic force microscopy (AFM) analysis showed that the films made using the PLD process had a homogenous surface, and UV-visible spectroscopy revealed that spherical nanoparticles with altered optical characteristics emerge when the temperature of deposition changes. The produced films' absorbance, transmittance, and energy gap spectra, which were examined in relation to their optical characteristics, were 3.91 eV at 300 C.

Keywords: *Indium Trioxides, Nanostructure, Laser fluencies, PLD, FESEM*

1. INTRODUCTION

Materials made of semiconductor metal oxide (SMO) make good choices for a variety of electrical devices [1-3]. Their exceptional stability, homogeneity, great transparency, and superior electrical performance have garnered significant attention [4, 5]. studied a great deal. Because of these important features, a wide variety of manufacturing processes are now available that use SMO [6, 7]. For semiconductor gas sensors, the genesis of semiconductivity in metal oxides was investigated for the most significant oxides, such as SnO2, In2O3, ITO, ZnO, Cr2O3, CuO, and others [8-12]. Their distinct set of functional characteristics—most notably electrical conductivity, transparency throughout a broad spectrum, and strong surface reactivity—place them in the category of transparent conductive oxides [13-16].

Indium oxide, or In2O3, has recently caught the interest of scientists. In optoelectronic applications, it is a crucial transparent conducting material [17-19]. The material is popularly known as Indium Tin Oxide (ITO) [20, 21], The quintessential Transparent Conducting Oxide (TCO), when doped with SnO2 [22-24]. Because of its intriguing physical and chemical properties, In2O3 finds extensive use in a variety of technical applications, such as transparent films for organic light-emitting diodes (OLEDS) and organic photovoltaic cells (OPVC). It is also employed in chemical gas sensing and heterogeneous catalysis. There is ongoing debate over even fundamental material properties as the fundamental band gap [25-28].

An n-type semiconductor is In2O3 [29, 30]. The strong non-stoichiometry seen in highly reducing circumstances is also explained by the intrinsic donor faults that give rise to the n-type conduction. Up until now, In2O3's high carrier concentration made it a very good conductor even in the absence of external dopants. Due to its high stability, strong conductivity, and an energy level that is suitable for water splitting, In2O3 may be used in photoelectrochemical (PEC) applications [31-36].

This study used a variety of substrate temperatures and the pulsed laser approach to create thin films. Optimizing In2O3 thin film deposition and examining the resulting films' structural, optical, and morphological characteristics as well as the relationship between these characteristics and deposition parameters like power and working pressure were the main goals of this work.

2. EXPERIMENTAL

As seen in Figure 1, which displays the PLD method utilized in this investigation, In2O3 thin films were created on a silicon substrate using the PLD approach. Nd:YAG laser with frequency (3 Hz) and wavelength (λ = 1.064 nm). The parameters were displayed accurately. For every 200, 250, 300, 350, and 400 degrees Celsius, China supplied an undoped indium oxide target with 300 pulses. The laser intensity was 800 Mj, and the target was set at a 45-degree angle. Every movie was made with a background oxygen pressure of 100 mbar. This technique was used to deposit samples onto silicon substrate, as seen in Figure 1. Figure 2 displayed the PLD system's schmtic diagram. The substrate layer was heated to 300 C using a hotplate. The procedures took less than ten minutes to complete. Using a stylus profile meter, the film thickness was determined to be between 71 and 243 nm. The sample of indium oxide thin film nanoparticles (in2O3) was examined using the FESEM, AFM, U-visible, and XRD tests. The results and debates section that follows provides an analysis of every result.

Figure 1. PLD system.

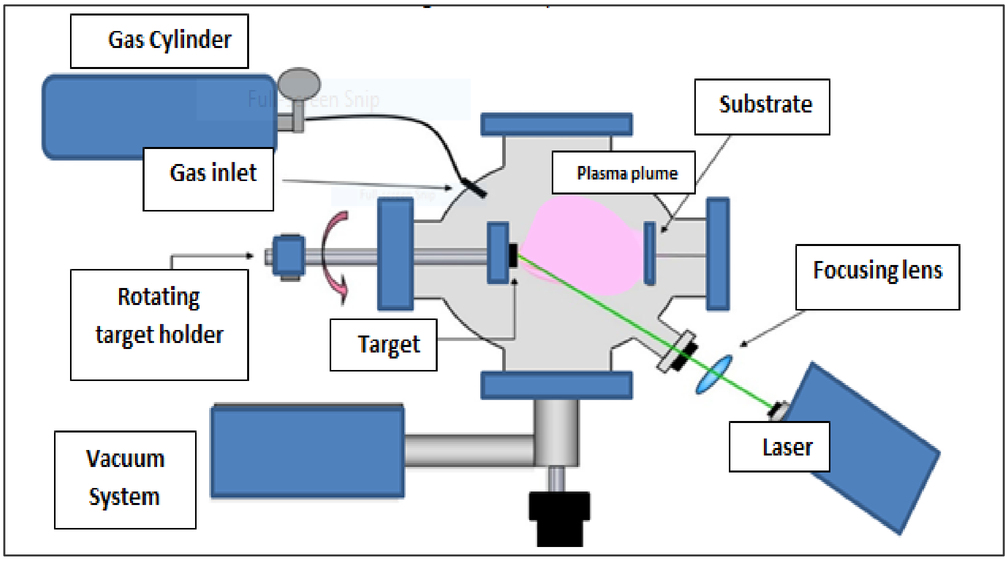


Figure 2. The schematic diagram of PLD system.

3. RESULTS AND DISCUSSION

3.1. Structural Properties

Figure 3 displayed XRD of the produced thin layer of In2O3 samples. The diffraction peaks at 2θ of 30.82°, 35.52°, 51.44°, and 60.79°, reflected from (222), (400), (440), and (622) planes of cubic crystals of In2O3, respectively [37-39]. It is clear that the heights of the main peaks of the indium(III) oxide nanostructures increase with the increase in the temperature of the pulsed laser deposition substrate, this increase is attributed to the enhanced cohesion process of the nanocrystals that were ablated using the laser. Therefore, the crystallization process will be enhanced and improved with an increase in the temperature of the deposition substrate. The samples demonstrate that raising the temperature from 200 to 400º C increased the crystalline size [40-43]. A high degree of improvement in the structural properties was also observed, such as the improvement in crystal size, and all XRD data are shown in Table 1.

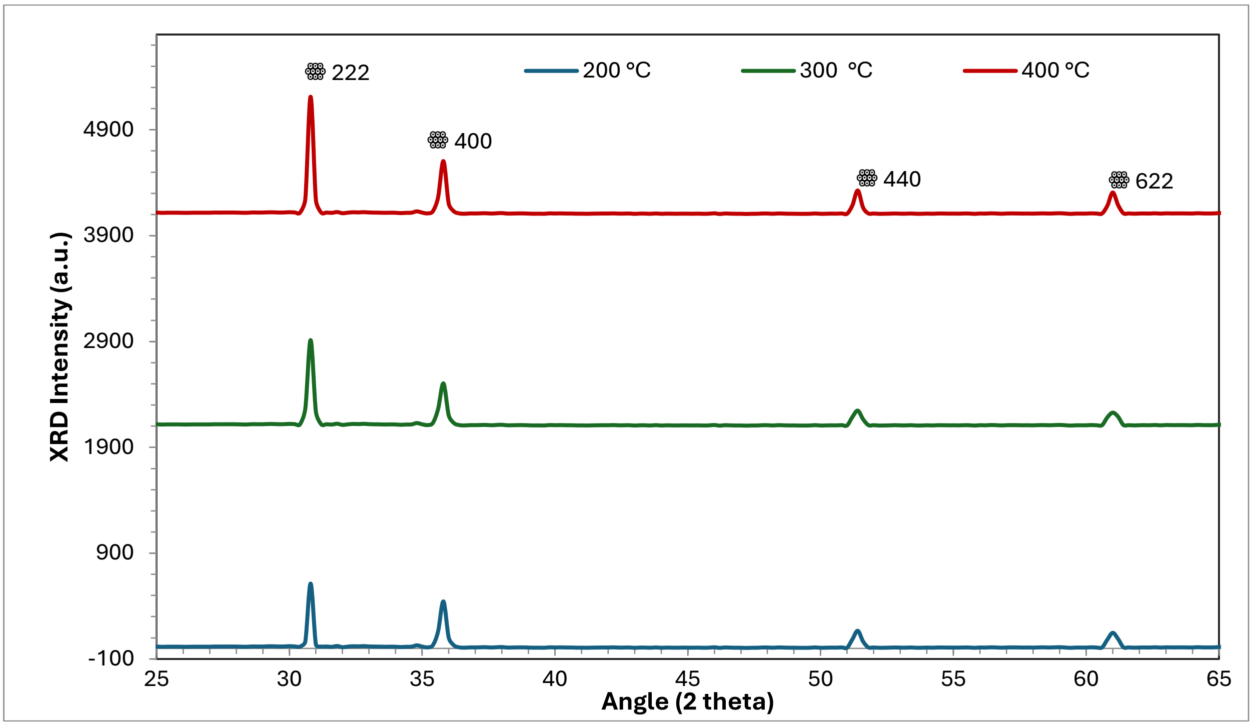


Figure 3. XRD spectra at deposition temperature (200-250-300-350-400C).

Table 1 In2O3 thin-film XRD characteristics at various temperatures (200–250–300–350–400C)

T	2theta	β=FWHM(deg)	D (nm)=0.9λ/βcosθ	$d_{spacing}$=λ/2sinθ	h	k	l	a(A)
200	30.8	0.4	21.52	0.28	2	2	2	0.969
200	35.8	0.22	37.97098	0.24	4	0	0	0.96
200	51.4	0.2	23.03	0.17	4	4	0	0.96
200	61.1	0.3	24.10	0.14	6	2	2	0.96
300	30.8	0.3	22	0.28	2	2	2	0.96
300	35.8	0.4	12.27	0.24	4	0	0	0.96
300	51.4	0.36	22.5	0.17	4	4	0	0.96
300	61.5	0.41	27	0.98	6	2	2	0.96
400	30.8	0.2	22.5	0.28	2	2	2	0.96
400	35.8	0.23	45	0.24	4	0	0	0.96
400	51.4	0.28	45	0.17	4	4	0	0.96
400	61.1	0.28	32.95	0.14	6	2	2	0.96

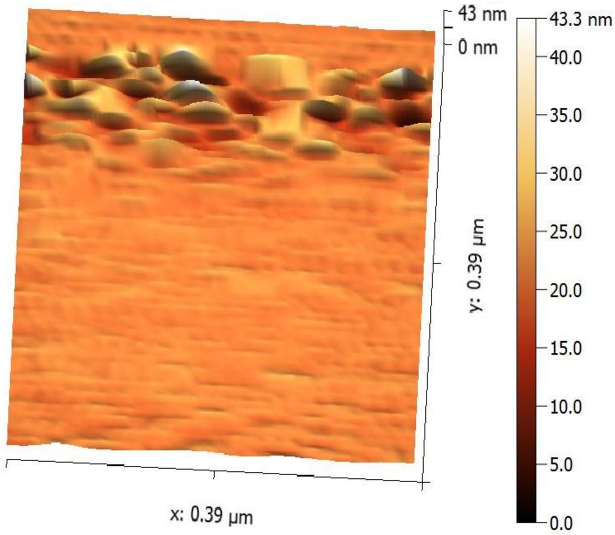
3.2. Morphological Properties

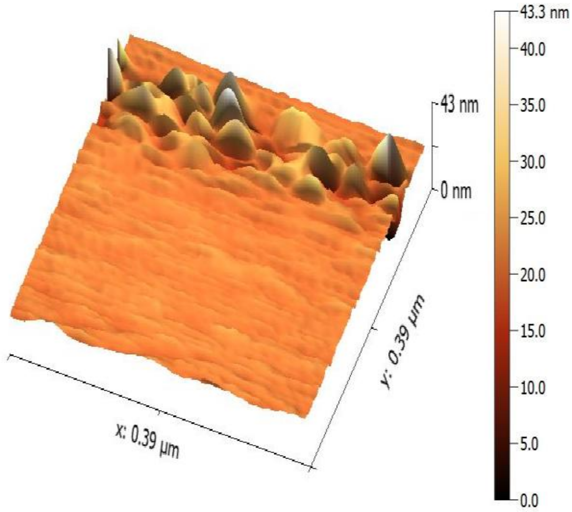
3.2.1. AFM Results

In order to study the topography of the surfaces of the prepared thin films and the extent to which a change in the deposition temperature affects them,(with the ability to image and analyze these surfaces and give very accurate important information about the values of the square root of a square, Roughness Average-Ra).

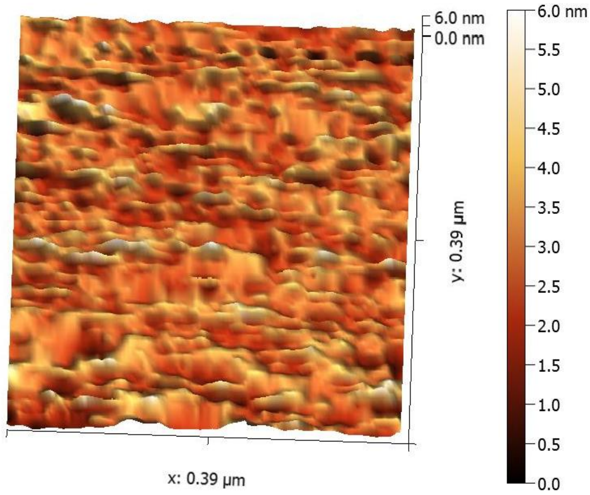
Two-dimensional atomic force microscope images show In2O3 samples prepared on Silicon floors at different deposition temperatures. The result of changing the temperature on the dimensions and geometric shape of the prepared samples most clearly manifested in the images of a microscope Atomic forces in Figure 4 [44, 45]. The images also show a increase in the RMS and Ra values of the prepared thin films by increasing the deposition temperature. Values of (RMS) and (Ra) for prepared samples are listed in Table 2 [46, 47].

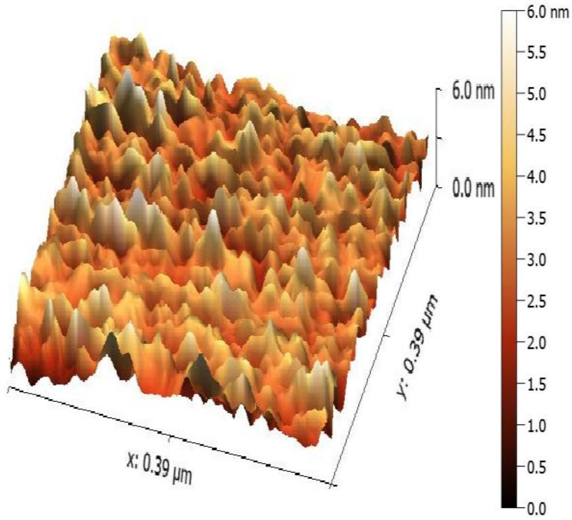
Figure 4 illustrates how additional grains form as the substrate temperature rises. As the substrate temperature increases, an improvement in grain size can be seen. This finding is consistent with XRD data showing that particle size rises as substrate temperature rises [48-50].



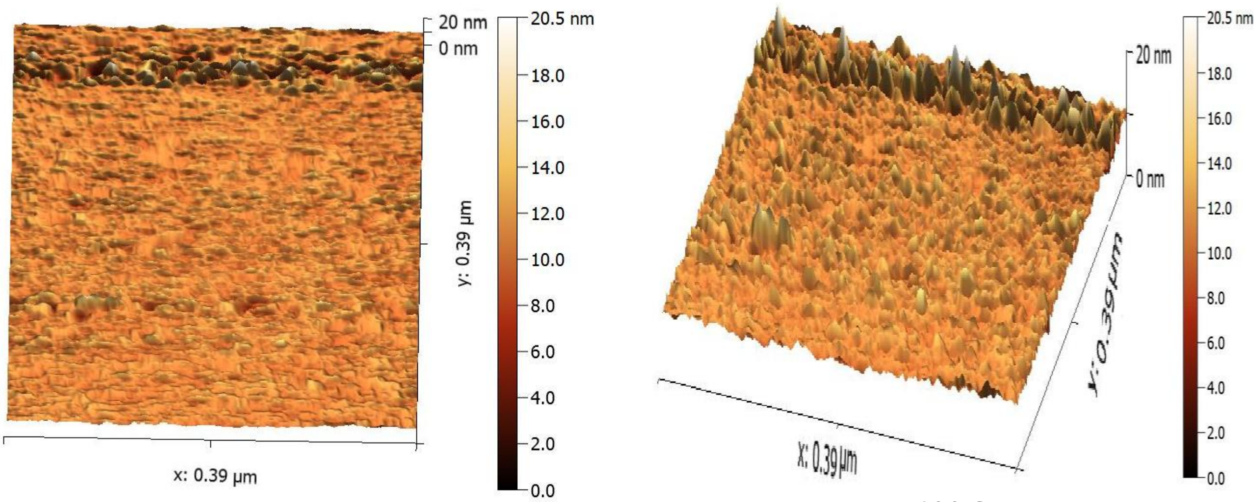


200 200 C





300 C



400 C

Figure 4. Pure In2O3 thin-film AFM pictures at various temperatures (200, 300, and 400 C).

Table 2 Values of (RMS) and (Ra) for prepared samples

Sample No.	Temperature (C)	Average roughness (nm)	RMS (nm)	Grain size (nm)
1	200	21.73	2.15	93.99
2	300	3.37	4.64	39.71
3	400	11.50	1.36	111.27

3.3. Optical Properties

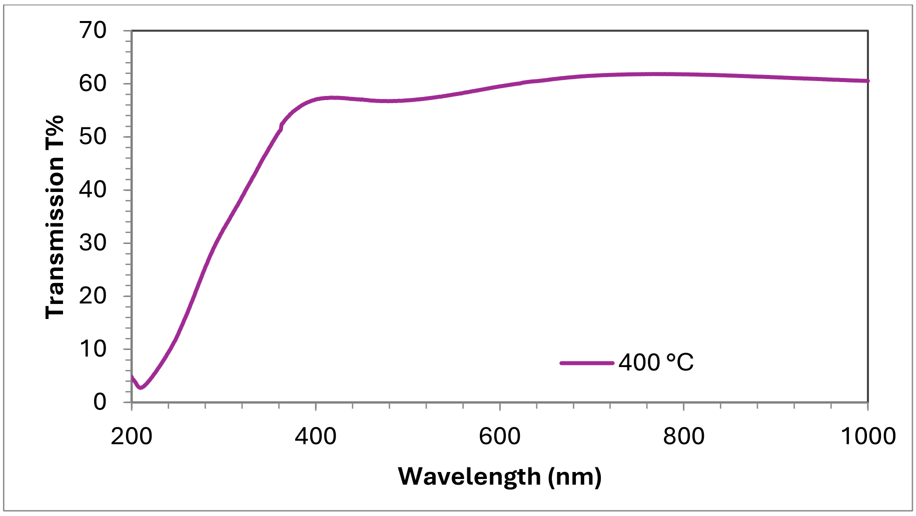
The optical absorbance and transmittance spectra for In2O3 thin films made utilizing a pulsed laser deposition process at optimum substrate temperatures 400 degrees Celsius) are displayed in Figs. 5(a) and 5(b). In this instance, it was discovered that In2O3 thin films had a pronounced absorption edge at wavelengths over 350 nm and were transparent, which is higher than 80%, in the visible range (400–800). As seen in Fig. 6(b), the Nano-thin films have very low absorption in the visible and near-infrared (NIR) region, beginning at 400 nm to 800 nm, but considerable absorption in the UV range [51-54].

The Tauc relation [55-58] has been used to calculate the band gap (Eg);

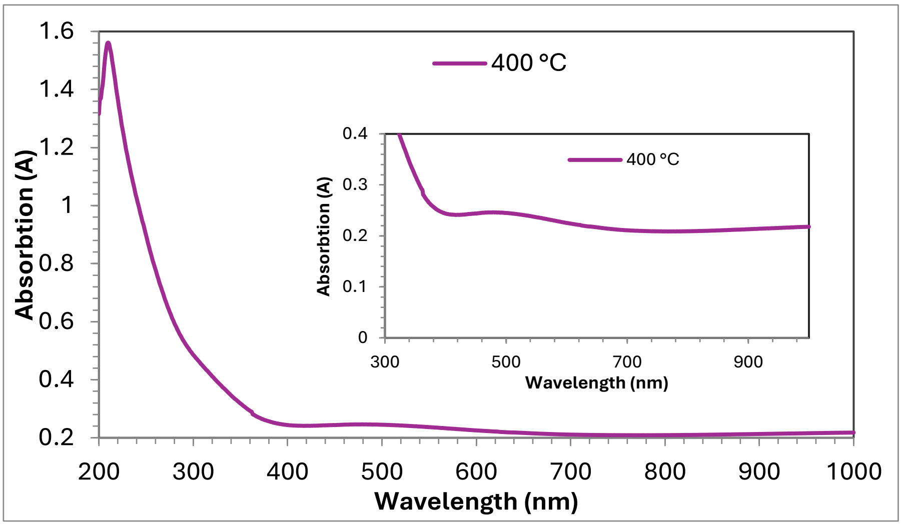
$(\alpha h\nu)m = A\ h\nu - Eg$

The energy band gap values at optimum deposition temperatures are tabulated in Table 3, where hv is the photon energy, A is a constant, Eg is the band gap energy, and m have values 1/2, 3/ 2, 2, and 3 depending on the type of electronic transition causing the absorption.

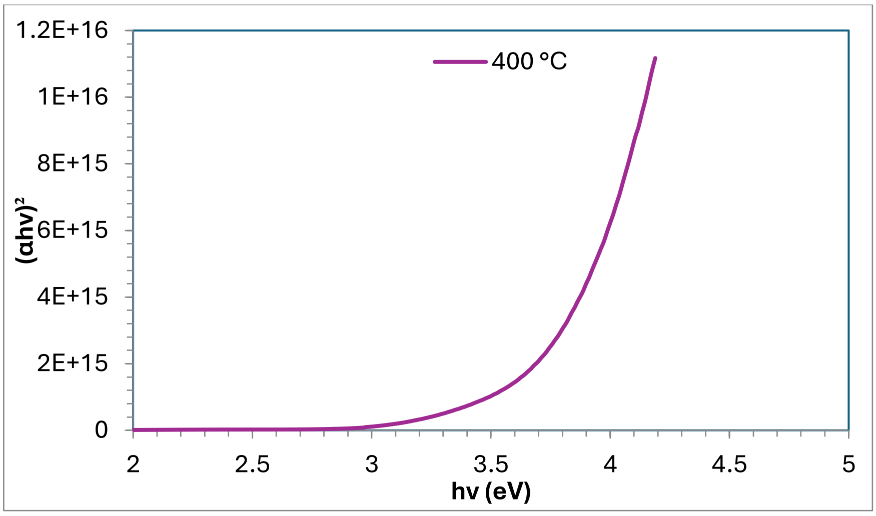
To determine the samples' band gap, Figure 5.c plots (αhv)2 against photon energy (hν). Plotting the linear part of the plot against the photon energy axis yields the absorption edge, which indicates that the sample has a direct band gap. The In2O3 nanostructure is discovered to have a straight band gap in the 3.53–3.91 eV region [59-63].



(a)



(b)



(c)

Figure 5. a) In2O3 Transmittance at optimum deposition temperature (,400 C)., b) In2O3 Absorbance at optimum deposition temperature (400 C). c) In2O3 Energy band gap at optimum deposition temperature.

Table 3 In2O3 nanostructure Energy band gap at different deposition temperature

Sample no.	Temperature °C	Energy band gap (eV)
5	400	3.68

4. CONCLUSION

In conclusion, the PLD approach successfully created an In2O3 nanostructured thin film. Indium oxide thin film (In2O3) nanostructure fabrication at five distinct temperatures is presented in this article. XRD, AFM, FESEM, and U-visible investigations were used to examine the In2O3 that was placed on the silicon substrate. The XRD spectrum demonstrates the crystalline cubic structure of the In2O3 nanospheres. At 400 °C, the In2O3 thin films crystallized the best. According to AFM analysis, the average grain size is between 40 and 190 nm. The UV-Vis spectrum (3.91 eV) was used to compute the assessed optical band gap energy. In2O3 nanoparticles are a good material for synthesis gas sensors and optoelectronic device applications because of their strong band gap value.

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