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Structural and Morphological Investigations of Indium Trioxide Deposited using PLD at Different Pulsed Laser Energies

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ABSTRACT

In this paper, studied the effect of changing the laser energy on the properties of the prepared indium oxide thin (In_2O_3) which was deposited by pulsed laser deposition in silicon bases. Due to unique properties of indium oxide (In_2O_3), the most important is the high electrical conductivity, and the continuous development of sensor material, which in turn leads to an improvement in sensitivity of the gas, which greatly affects the properties of the gas sensor. 2w1The pulsed laser deposition method was used to prepare In_2O_3 films (nanoparticles) using (Nd: YAG) laser with a wavelength of 1064 nm. The sample was characterized by using x-ray diffraction (XRD). The morphological properties indicate polycrystalline nature and microscope picture Electron scanning showed the formation of spherical nanoparticles with change in optical properties occurring while increasing laser energy and the examination of atomic force microscopy (AFM) showed that the films prepared by pulsed laser deposition technique have smaller number of grain size and homogeneously distributed, which indicates to the crystalline nature of the film.

Keywords: In_2O_3; Nanostructure; sensors; characteristics

1. INTRODUCTION

Metal-doped oxides known as transparent conductive oxides (TCOs) are utilized in electronic components such as photovoltaic cells and flat panel displays (including inorganic devices and dye-sensitive solar cells) [1-3].

The objective of the ongoing research aims to enhance the electrical and optical characteristics of some TCOs. Indium zinc oxide (IZO), ITO, and other materials are being examined by researchers (indium tin oxide), and they are improving these materials by changing the parameters inside the volatile sedimentation machine [4-8]. Researchers may create various concentrations of carrier and sheet resistance inside the gadget by altering specific parameters [9-13]. Carrier concentrations impact the sample's short-circuit current [14, 15]. The researchers adequately changed the settings and discovered combinations that enhance the short-circuit current [16-17].

TCOs, or transparent conducting oxides, have a semiconducting application like solar cells and liquid crystal displays; high optical transparency that is significant in the visible range with outstanding electrical characteristics is crucial [18-22]. In_2O_3 and a few other oxide semiconductors CdO, ZnO, and SnO are significant for the implementation of numerous devices and crucial research [23-26]. They have excellent electrical conductivity, excellent substrate obedience, high brilliant transmittance, hardness, and chemical subsidence. Numerous investigations have been done as a result of these features [27-30].

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In_2O_3 has a broad optical band gap and excellent electro-optical characteristics in the visible spectrum, making it one of the most significant TCO materials [31-35]. This composite's band gap has made it widely employed in a variety of applications, including optoelectronic devices, organic/polymer light-emitting diodes, electrical switches and memories [36-40], grating materials, electrochromic devices, ultrasensitive gas sensors, etc. [41-43]. In_2O_3 acquires a variety of morphologies as its size is shrunk to the nanoscale, including wires/belts, cubes, octahedrons, and bamboos [44-46]. The properties of In_2O_3 nanostructures are powerfully related to their morphologies [47-49].

The notable point for In_2O_3 nanomaterial is the parasitic blue-green release, which is ascribed to oxygen vacancies that persuade deep donor defect levels inside the band-gap of In_2O_3 nanostructures [50-55]. Vacuum evaporation, pulsed laser deposition, sputtering, the sol-gel process, and a number of chemical techniques have all been used to create In_2O_3 films [56-60]. The basic investigation of In_2O_3 thin films' electrical, physical, and optical properties [61-65] reflects the significance of these materials from a technical perspective [66-68]. There is a lot of interest in the development and comprehension of the optical characteristics of indium oxide (In_2O_3) thin films due to the practical need for novel materials as well as the application of electrical and optical devices [69-73].

In this study, different energies have been used and thin films were prepared by pulsed laser method the primary objectives of this work were to optimize the IO thin films deposition and to Study the structural, and morphological properties of the obtained films, and study the effect of these properties with deposition parameters, such as power and working pressure, etc.

2. EXPEREMENTAL

Undoped wide-gap, n-type Indium Oxide material were used for fabricating In_2O_3 thin films by the pulsed laser deposition technique on the silicon substrate, this method produce high-quality films of a variety of materials and is simple in operation as only a few parameters need to be controlled to grow multilayer structures, which could be evaluated for possible applications. And as shown in Figure 1 (a) shows the schematic diagram of the PLD system used in this study. Nd: YAG laser with wavelength (λ= 1.064 nm) and frequency (3 Hz).

The laser parameters were correctly indicated for each flow energy of 800 mJ, 700 mJ, and 600 mJ, a converging lens was used to focus the laser beam on the rotating target, with 300 pulses, an undoped indium oxide target was provided from china. The target was fixed at a 45 angle of incidence; the temperature was maintained within the range of 300 ^{0}C. All films were produced with background oxygen pressure of 100 mbar. The background oxygen stimulates equivalent film formation as oxide deposition. It also argues for decreasing conductivity. Even though at lower pressures the presence of oxygen favors a highly textured columnar growth with smooth surface, at elevated pressures it gives rise to more defective structures with more localized electronic transport.

The observed behavior can be belonging to variations in the plume of ejected material and in surface diffusion caused by changes in oxygen pressure in the PLD process. Figure 1(b) shows samples were deposited onto a silicon substrate using this process. A hotplate heated the substrate layer at temperature (300^{0}C). The processes were performed in less than 10 minutes. The film thickness was measured by a stylus profile meter, and it was found to be about (71- 243) nm. The deposited samples of Nano indium tri-oxide film have been examined and tested using XRD and AFM showing the crystal structure and the topographic properties. The next part of the findings and discussions analyzes each result.

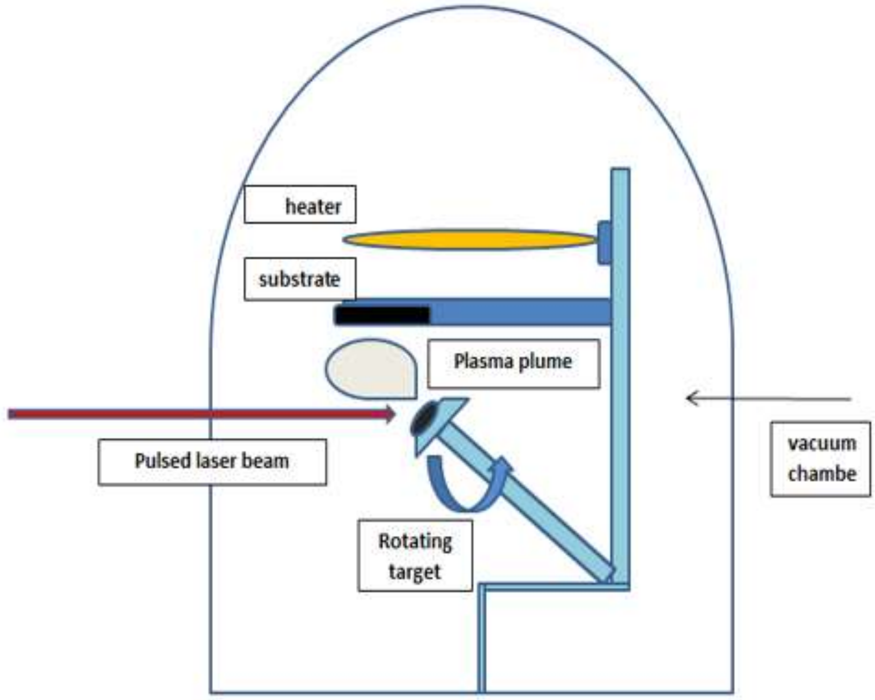

Figure 1. Pulsed laser deposition technique.

3. RESULTS AND DISCUSSIONS

3.1 Structural Properties

The XRD patterns of the prepared samples were shown in Figure 2. The XRD characteristic phase for the prepared thin layer of In_2O_3 showed diffraction peaks at 2θ: 30.82°, 35.52°, 51.44°, and 60.79°, which corresponded to (222), (400), (440), and (622) respectively cubic crystal of In_2O_3. The samples show the crystalline size was increased by increasing the participation energy from 600 to 1000mJ with the size increased from 13.92nm to 20. 97nm (Table 1). Due to an increase in structural crystallization, the peak's intensity and sharpness start to rise as the ablation energy is raised from 600 to 800 mJ. The results showed an increase in the intensity of the peaks and this increase is due to an increase in the crystallization rate with an increase in the energy of the pulsed descent laser, which works to remove a larger amount of nanocrystals and thus increases the deposit of the laser-absorbed nanocrystals on the quartz substrates, thus the distribution is more regular and more crystallized.

Table 1 The crystalline size determined by Scherrer equation

Sample	Crystalline size (nm)
600	13.92
700	13.98
800	14.43

The XRD In_2O_3 nanoparticles created on quartz substrate at various energies are shown in Figure 2. (600, 700, and 800mj). The conventional cubic structures of the indium oxide crystal are matched with the diffraction peaks in the XRD pattern.

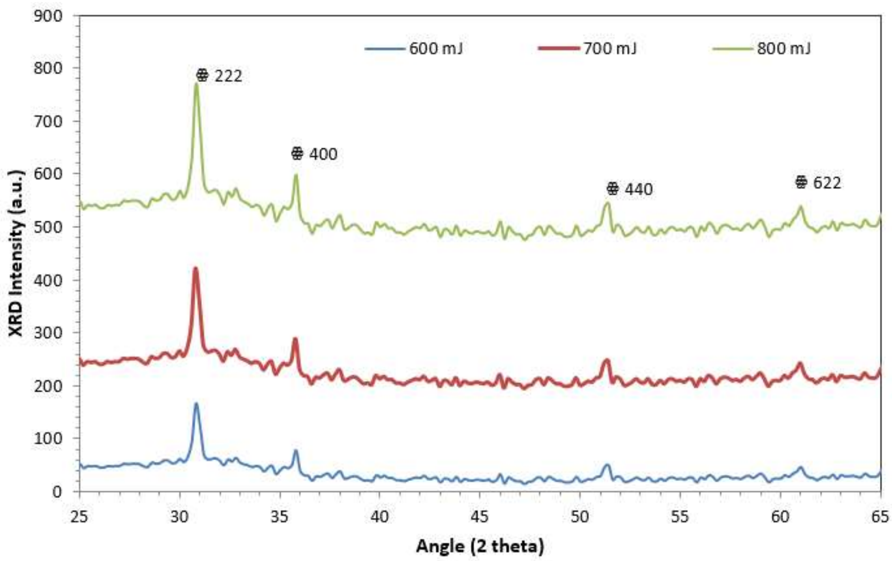

Figure 2. XRD pattern of In_2O_3 deposited at different pulsed energies.

Table 2 XRD parameters of the In_2O_3 thin films at different energies (600, 700, 800 mJ)

λ	2theta	theta	β=FWHM (deg)	theta rad	sinθ	2sinθ	d	d^2	h	k	l	a(A)
600	30.8	15.4	0.4	0.269	0.266	0.531	1129.705	1276232.76	2	2	2	3913.41
600	35.8	17.9	0.2	0.312	0.3074	0.615	976.0649	952702.65	4	0	0	3904.25
600	51.4	25.7	0.4	0.448	0.4337	0.867	691.7877	478570.16	4	4	0	3913.34
600	61.1	30.55	0.4	0.533	0.5083	1.016	590.2142	348352.74	6	2	2	3915.03
700	30.8	15.4	0.4	0.269	0.2656	0.531	1317.989	1737094.59	2	2	2	4565.64
700	35.8	17.9	0.8	0.312	0.3074	0.615	1138.742	1296734.16	4	0	0	4554.96
700	51.4	25.7	0.4	0.449	0.4337	0.8679	807.086	651387.1565	4	4	0	4565.56
700	61.2	30.6	0.4	0.534	0.5090	1.0180	687.567	472748.1658	6	2	2	4560.80
800	30.8	15.4	0.4	0.269	0.2656	0.5311	1506.273	2268858.24	2	2	2	5217.88
800	35.8	17.9	0.7	0.312	0.3074	0.6147	1301.419	1693693.597	4	0	0	5205.67
800	51.4	25.7	0.4	0.449	0.4337	0.8673	922.384	850791.3881	4	4	0	5217.78
800	61.5	30.75	0.4	0.537	0.5113	1.0226	782.3302	612040.4736	6	2	2	5189.39

3.2 Morphological Properties

AFM analysis makes it easy to characterize the morphology and compare the roughness of various In_2O_3 thin films. The three-dimensional surface morphology of the In_2O_3 thin films deposited at energies of 800 mJ, 700 mJ, and 600 mJ, respectively, is shown in Figures 3(a)–3(c). The RMS values of the thin films that were deposited were listed in Table 2. At 600 mJ, the surface roughness of the In_2O_3 film was approximately 8.597 nm with a granular structure (Figure 3(a)). At 700 mJ In_2O_3 thin film grain sizes are uniformly distributed along the film surface. In contrast, the high-energy thin films 800 mJ displayed a more homogenous structure with the highest RMS value range of around 28.49 nm (Figure 3(c)). Increasing up to 1000 mJ we noticed that the structure become more organized and homogeneous and more granules. AFM research revealed that In_2O_3 thin films deposited at high power energy had a more uniform structure and rougher surface compared to In_2O_3 films formed at low energy. The results showed a more uniform and more homogeneous distribution of the nanoparticles by increasing the energy of the pulsed deposition laser, and this increase is due to the increase in the crystallization rate with the increase in the energy of the pulsed deposition laser, which works to remove a larger amount of nanocrystals and thus increases the deposit of the laser-absorbed nanocrystals on the quartz substrates and thus the distribution more regular and more crystallized.

Table 3 RMS surface roughness of the deposited thin film at different energies (600, 700, 800 mJ)

Sample No.	Energy (mJ)	Average roughness sa(nm)	RMS
1	600	6.915 nm	8.597 nm
2	700	23.22 nm	32.87 nm
3	800	28.49 nm	35.34 nm

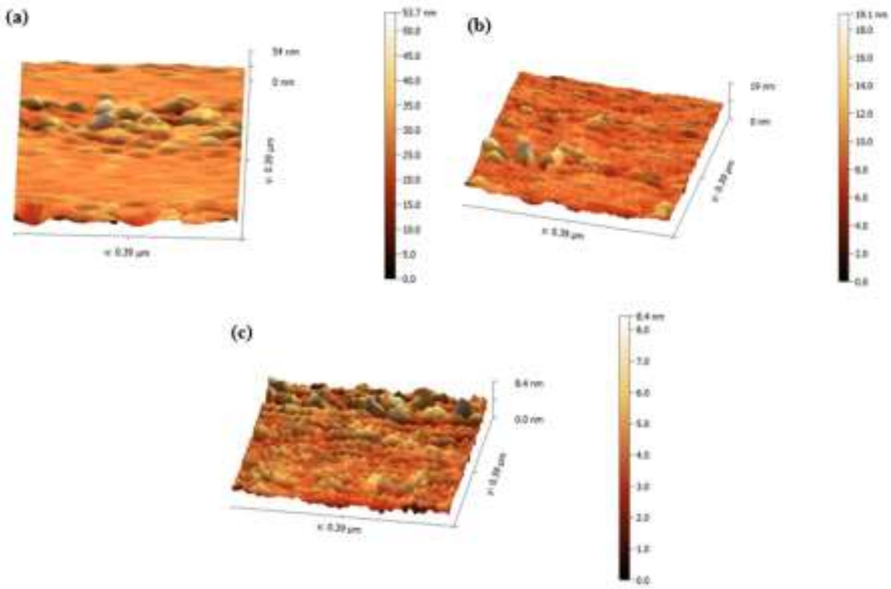

Figure 3. AFM images for pure In_2O_3 thin film at different energies (600, 700, 800 mJ).

4. CONCLUSION

This paper presents the synthesis of indium oxide thin films (In_2O_3) nanostructure with five different energies using the pulsed laser deposition technique. In_2O_3 deposited on the silicon substrate analysed using XRD, and AFM tests. Through the results of the X-ray diffraction examination, it was found that the membrane is polycrystalline. The results of X-ray diffraction showed that the higher the energy of the incident laser has increased granule size. Through the results of atomic force microscopy (AFM), It was found that the higher the laser power, the higher the volume ratio granular.

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