Effect of rotational speed on structural and optical properties of spin coated SnO thin films

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Abstract. Tin monoxide films were synthesized by sol-gel process followed by spin coating at the spinning speeds from 1000 to 3000 rpm. X-ray diffraction profiles of the films exhibits amorphous nature. Surface morphological and elemental confirmation of SnO films were studied by scanning electron microscope and energy dispersive of X-ray spectroscopy. The optical transmittance of the films had an increment from 60 to 72% with the increase of spinning speed from 1000 to 3000 rpm. The band gap of SnO thin films varied from 2.96 to 3.52 eV with an increment in rotational speed due to Burstein-Moss (B-M) effect. The estimated particle size from the optical absorbance spectra using effective mass approximation method is decreased from 23.6 nm to 11.6 nm with an increment in the spin speed from 1000 to 3000 rpm.

1. Introduction
Tin (II) monoxide (SnO) had a potential significance because of p-type semiconducting nature and stabilization in structural and optoelectronic properties. It had a wide band gap ranging 2.5-3.4eV, which will be for most opto-electronic devices like diodes, transistors, complementary circuits, and gas sensitive materials etc. [1-3]. Though there are different process for the synthesis of SnO films [4-6]. The simple method is sol-gel spin coating with cost effective, and ability for uniformity films with good adherent, with a high surface area, small pore size, microstructural control of particles and uniformly distributed particles [7]. The main objective of this work is to study the structural, optical properties of SnO films grown by sol-gel spin coating (SGSC) process with varying rotational speeds from 1000 to 3000 rpm.

2. Experimental details
Tin oxide (SnO) precursor solution is prepared by using tin (II) chloride dihydrate (SnCl₂.2H₂O), 2-methoxyethanol (2-ME) as solvent, and monoethanolamine (MEA) as stabilizer to from a solution. The solution is stirred for 2 hours at the temperature 80 °C. After aging the synthesized solution for 48 hours, the resulting solution was spin-coated on glass substrates by varying rotational speed from 1000 to 3000 rpm for 45 s. The films were dried in an oven at 150°C for 15 min. This process will be continuously repeated up to 3 to 5 times in order to obtain a desired thickness of the films. The crystallinity and structure of SnO thin films were obtained from XRD data (Model: Bruker D-8 diffractometer) with the

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radiation of CuK$_\alpha$ having a wavelength $\lambda=0.154$ nm. Surface morphological and elemental analysis of SnO films were examined by FESEM combined with EDS. The absorption and transmission spectra of thin films were measured from the wavelength of 300 to 2500 nm by UV-Vis-NIR spectrophotometer (Model: Hitachi U-2900).

3. Results and discussion

XRD profiles of SnO films prepared by varying spinning speed from 1000 to 3000 rpm is illustrated in Fig. 1. From XRD, no extra peaks correspond to tin oxide is noticed indicating the amorphous nature. A broad hump in the spectra is because of amorphous nature. Similar behaviour in SnO films has been noticed in the previous research works [8, 9].

![Figure 1. XRD profiles of SnO films](image)

Gravimetric weight difference method is used to determine the film thickness by the equation [10]

$$t = \frac{m}{A \rho_b}$$  \hspace{1cm} (1)

where, ‘m’=film mass, A is the substrate area and $\rho_b$=density of the bulk material. In the thickness calculation, the density of the bulk material (SnO) was taken as 6.40 gm cm$^{-3}$ [11]. The thickness of the films prepared at 1000, 1500, 2000 and 3000 rpm were found to be 230, 210, 180 and 165 nm respectively. With the increase of rotational speed (rpm), the film thickness decreased because of increase in the centrifugal force of the solution acting on the glass substrate.

FESEM images of SnO films prepared at various rotational speeds are shown in Fig. 2(a)-(d). The surface morphology looks like featureless smooth surface, with lesser grain boundaries with the increment of rotational speed from 1000 to 3000 rpm, which can be attributed due to the amorphous state of the films. The surface is disordered with an irregular grain could lead to amorphous structure as seen in XRD studies. Generally, the SnO films prepared $<$400 °C forms amorphous nature with short-range and long-range disorder. Figure 3 shows the EDS of SnO films prepared at 2000 rpm. The strong peaks confirm the evidence of Sn and O elements in the energy dispersive spectrum. No other impurity peaks of the elements were present in the EDS spectra, which shows that the synthesized SnO thin films
were quite pure. The atomic wt% of the elements Sn and O is 43.3 and 56.7 respectively. In the EDS spectra, the element tin and oxygen peak are observed at 3.44 keV and 0.52 keV respectively.

![Figure 2. FESEM images of SnO films prepared at (a) 1000; b) 1500; (c) 2000; and (d) 3000 rpm.](image)

![Figure 3. EDS of SnO thin film prepared at 2000 rpm](image)

Figure 4 illustrates the absorbance spectra of SnO films grown by changing rotational speeds from 1000 to 3000 rpm. The spectra show low absorbance in the visible and near infrared regions, while the optical absorbance is higher ultra violet region. In the IR region, the absorbance decreases and the films
became transparent. The decrement in the absorbance of the films with an increment in the wavelength is due to high energy absorption. In absorbance spectra, the absorption edge shifts towards the shorter region of wavelength with an increasing in the spin speed from 1000 to 3000 rpm. The average optical transmittance of SnO thin films is illustrated in Fig. 5, which is between 60-72%. The increment in the transmittance with an increment of rotational speed because of reduction in the film thickness and reduction of light scattering. The transmittance spectra of about 70% was obtained for 3000 rpm at the visible wavelength region. The increase in transmittance explains the reduction of light scattering because of lower film thickness.

The absorption coefficient (α) of the films were calculated from the relation [12]

$$\alpha = \frac{A}{t}$$

where A = optical absorbance and t = film thickness. The films exhibit α > 10⁴ cm⁻¹ which is consistent with the optical absorption behaviour indicating the visible light produce electron-hole pairs which can be used as absorber layer for solar cells.

The absorption coefficient (α) and optical band gap (E_g) is related with the relation [13]

$$(\alpha h\nu)^n = B \left(h \nu - E_g\right)$$

where B =constant, hν = photon energy and E_g = optical band gap. For n = 2, 2/3, 1/2 and 1/3 the transition corresponds to direct allowed, direct forbidden, indirect allowed and indirect forbidden [8, 9]. Figure 5 exhibits the Tauc’s plot of (αhν)² versus hν for SnO thin films exhibits a sharp absorption edge indicating the high quality of the film. The band gap (E_g) of the SnO films are varied from 2.36 to 3.08 eV with an increment in rotational speed due to the effect of Burstein-Moss (B-M).

The related equation for energy band gap widening ΔE_g and optical carrier concentration(n_{opt}) is [14]

$$\Delta E_g = \left(\frac{\hbar^2}{8m^*}\right)\left(\frac{3n_{opt}}{\pi}\right)^{1/3}$$

The band gap widening increases the n_{opt} of SnO films. The optical carrier concentration of SnO thin films is obtained from the equation (4) and it increased from 1.18×10¹⁹ to 1.53×10²⁰ cm⁻³. The n_{opt} of SnO thin films increased with an increment of rotational speeds from 1000 to 3000 rpm. The increase of n_{opt} may also be attributed to decrement rate release of free carriers from trap centres in thicker films. Since the thicker films are less defective, the scattering of carriers by defects will be also less.
The particle size is calculated from effective mass approximation method using the relation [15]

\[ E_g = E_{gb} + \left( \frac{k^2 \pi^2}{2m^* R^2} \right) \]  

(5)

where \( E_g \) and \( E_{gb} \) are the band gap values of SnO and bulk SnO semiconductor (\( E_{gb} = 2.4 \) eV), \( m^* = 0.27m_e \) = effective mass of the electron and \( R \) is the particle radius. The particle size obtained from the absorbance spectra decreased from 23.6 to 11.6 nm with an increase of rotational/spinning speed from 1000 to 3000 rpm. The optical parameters of SnO films prepared at different rotational speeds are reported in Table 1.

| S.No | Rotational speed (rpm) | Optical band gap, \( E_g \) (eV) | Particle radius, \( R \) (nm) | Optical carrier concentration, \( n_{opt} \) (\( \text{cm}^{-3} \)) |
|------|------------------------|-------------------------------|----------------------------|-------------------------------|
| 1    | 1000                   | 2.36                          | 23.6                       | 1.18 \times 10^{19}           |
| 2    | 1500                   | 2.97                          | 13                         | 1.12 \times 10^{20}           |
| 3    | 2000                   | 3.02                          | 12.3                       | 1.30 \times 10^{20}           |
| 4    | 3000                   | 3.08                          | 11.6                       | 1.53 \times 10^{20}           |

Conclusions
SnO films were synthesized by sol-gel spin coating (SGSC) process at the spin speeds 1000, 1500, 2000 and 3000 rpm. The decrement of film thickness from 230 to 165 nm with an increment of rotational speed from 1000 to 3000 rpm. XRD patterns of SnO films confirms the amorphous nature. The surface morphology of SnO films shows very smooth, homogeneous and irregular grains. The average transmittance of SnO films decreases with an increment of rotations speed due to the decrease of film thickness. The band gap of SnO films increased from 2.36 to 3.08 eV due to Burstein-Moss (BM) with an increase of rotational speed. The optical carrier concentration of SnO thin films increased from 1.18\times10^{19} to 1.53\times10^{20} cm\(^{-3}\) with an increase of spinning speed from 1000 to 3000 rpm. From these results we conclude that SnO films can be utilized for novel opto-electronic devices.

References
[1] Jesus A. Caraveo-Frescas, Pradipta K. Nayak, Hala A. Al-Jawhari, Danilo B. Granator, Udo Schwingenschlogl and Husam N. Alshareef 2013 ACS Nano 7 5160
[2] In-Tak Cho, Myeonghun U, Sang-Hun Song, Jong-Ho Lee and Hyuck-In Kwon 2014
Semicond. Sci. Technol. 29 045001

[3] Kachirayil J.Saji, Venkata Subbaiah Y, Kun Tian and Ashutosh Tiwari 2016 Thin Solid Films 605 193

[4] Ahmed Yousef Mohamed, Seung Jun Lee, Younjin Jang, Jun Shik Kim, Cheol Seong Hwang and Deok-Yong Cho 2020 J Phys. Condens. Matter. 32 065502

[5] Ebitha Eqbal and E.I.Anila 2018 Physica B Condens Matter. 528 60

[6] Sima Rezalou, Tuba Öznülüer and Ümit Demir 2018 Appl. Surf. Sci. 448 510

[7] Aegerter MA, Almeida R, Soutar A, Tadanaga K, Yang H and Watanabe T 2008 J. Sol. Gel. Sci. Tech. 47 203

[8] Po-Ching Hsu, Shiao-Po Tsai, Ching-Hsiang Chang, Chao-Jui Hsu, Wei-Chung Chen, Hsing-Hung Hsieh and Chung-Chih Wu 2015 Thin Solid Films 585 50

[9] Zhong-guo Li, Ling-yan Liang, Hong-tao Cao and Ying-lin 2017 J Phys Conf Ser. 844 012017

[10] Sakhare RD, Khuspe GD, Navale ST, Mulik RN, Chougule MA, Pawar RC, Lee CS, Shashwati Sen and Patil VB 2013 J Alloy Compd. 563 300

[11] Matthias Batzill and Ulrike Diebold 2005 Prog. Surf. Sci. 79 47

[12] Ibrahim R. Agool, Evan T. Salem and Marwa A. Hasan 2011 Int. J Mod. Phys. B 25 1081.

[13] Rajesh Kumar B and Subba Rao T 2013 Appl. Surf. Sci. 265 169

[14] Rajesh Kumar B and Subba Rao T 2015 Materials Today: Proceedings 2 1502

[15] Devjyoti Lilhare, Sandhya Pillai and Ayush Khare 2018 J Electron. Mater. 47 6532