Influence of Fe doping concentration on SnO_2 thin layers

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***Abstract*—In this study, we report structural, morphological and optical properties of Fe-doped SnO_2 thin layers. Fe doping concentration has evaluated from 0 to 0.6 wt.%. XRD and SEM results revealed polycrystalline structure for Fe-doped SnO_2 thin layers. The optical transmittance of all thin layers displayed high transparency reach to 80% in visible region. The optical gap of these thin layers decreases from 3.87 to 3.58 eV. The crystalline sizes decrease from 35 to 30 nm. Electrical resistivity of thin layers increases from 1.2×10^{-2} to 6.8×10-2 Ω .cm.**

***Keywords*—** *$SnCl_2$, Spray pyrolysis, XRD, SEM, UV-Vis Spectroscopy , 4-point probe system.*

I. Introduction

Currently, transparent conductive oxides (TCOs) are witnessing a major revolution in several applications. The most important incentive to study TCOs is the transparency and electrical conductivity in the visible region, make them important for gas sensor, water treatment and flat panel display [1-3]. SnO_2 as TCO is obtainable materiel and simple to deposit as thin layers utilizing various process such as sol-gel[4], and spray pyrolysis[5]. The spray pyrolysis system probably the most appropriate process because of its modestly, easy to add doping materials [6].

The impurities such as antimony (Sb), fluorine (F), iron (Fe) , lithium (Li) and cobalt (Co) have been working to ameliorate tin oxide (SnO_2) properties [7-9]. Fe-doped SnO_2 has been shown to be the most interacting use due to its modestly and abundance.

In this paper, iron doped tin oxide (SnO_2: Fe) thin layers were placed by spray pyrolysis process. The aim of this work is to study the influence of Fe doping concentration on structure, optical and electrical properties of Fe-doped tin oxide thin layers.

II. Materials and Methods

A. *Thin films preparation*

Pure SnO_2 and Fe-doped SnO_2 thin layers were synthesized from a solution of tin dichloride ($SnCl_2$) and iron chloride ($FeCl_3$), respectively. The precursor concentration, was 0.5M. Iron doping was carried out by adding, appropriate amount of iron chloride ($FeCl_3$) solved in doubly distilled water. Fe doping concentration starting from 0 to 0.6 wt. %. The starting solution and blend solution were sprayed on heated glass substrates by spray pyrolysis process [10] .

III. Results and discussion

A. *Structural studies*

As seen in Fig.1, XRD spactra of pure SnO_2 and Fe-doped SnO_2 thin layers deposited by spry pyrolysis with different dopant. All the thin layers are polycrystalline structure, the most peaks agreement with the tetragonal SnO_2 (JCPDS No. 41-1445). There is no phase confirms that the iron was seen. From XRD results of SnO_2 thin layers one can observe that for Fe doped layers with 0.2, 0.4 and 0.6 wt.% the crystalline orientations were (*110*). while, for the pure SnO_2 thin layers, the crystalline orientations was (*211*). The texture coefficients TC(hkl) have been based on following formula [11]:

$$TC(hkl) = \frac{I(hkl)/I_0(hkl)}{N^{-1}\sum_n^N I(hkl)/I_0(hkl)} \qquad (1)$$

where TC(hkl) is the texture coefficient of the plane (hkl), I(hkl) is the measured intensity , I_0(hkl) is the standard intensity, N is the reflection number and n is the number of diffraction peaks. The preferred crystallographic orientation of all thin layers were along (*211*) plane.

The lattice parameter (a,b)and (c), for the tetragonal crystal were given from the following equation [12]:

$$\frac{1}{d_{hkl}^2} = \frac{h^2+k^2}{a^2} + \frac{l^2}{c^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where d_{hkl} is the distance between two adjacent parallel planes of the family hkl, (hkl) are the Miller indexes and (a,b) and (c) are the lattice parameters. The calculated and standard lattice parameters have been gathered in Table I .The lattice parameter (a) is decreased after iron doping concentration .

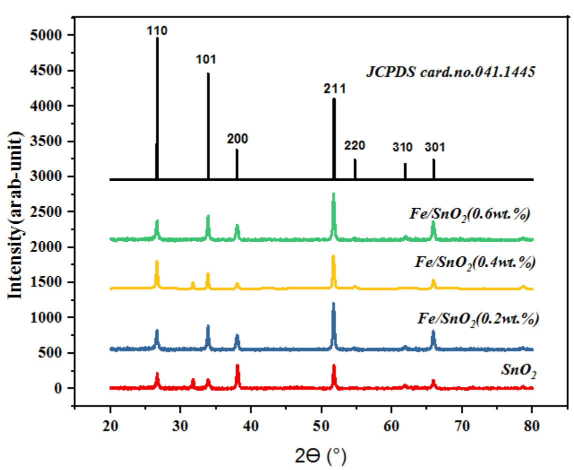

Fig. 1. *XRD patterns of various Fe doped SnO_2 layers .*

TABLE I. LATTICE PARAMETERS OF 0- 0.6 WT. % FE DOPED SnO_2.

Material	**Lattice parameters (A°)**	
	a	***c***
Pure SnO_2	4.73	3.17
Fe/ SnO_2 (0.2 wt. %)	4.72	3.28
Fe/ SnO_2 (0.4 wt. %)	4.72	3.28
Fe/ SnO_2 (0.6 wt.%)	4.71	3.20

The crystalline sizes of Fe-doped SnO_2 thin layers, were determined according to Scherrer's formula [13]:

$$D = \frac{0.9\lambda}{\beta\cos\theta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where D is the crystallite size, λ is wavelength (1.54056 A°) ,β is the full width at half-maximum (FWHM) and θ is the Bragg angle. The crystallite size (D) decreases from 35nm to 30 nm.

SEM microstructural analysis (Fig. 2) shows that the grain size of pure SnO_2 (a) thin layers is smaller than Fe doped SnO_2 thin layers (b).

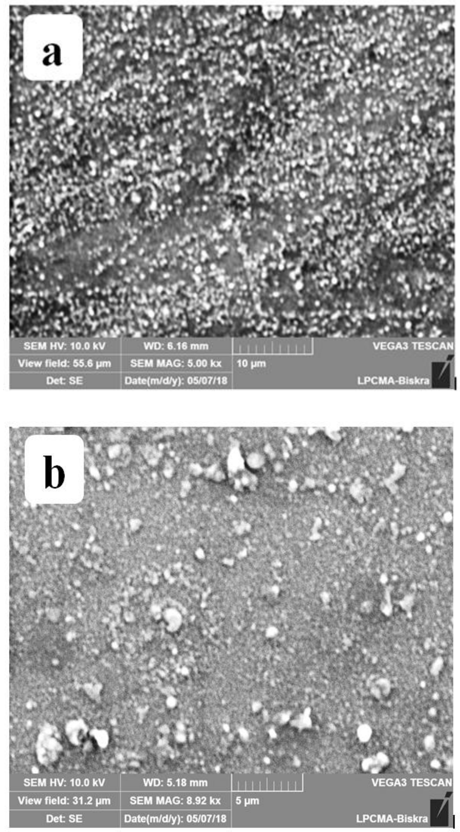

Fig. 2. *SEM images : a) pure SnO_2, b) Fe doped SnO_2 thin layers*

B. Optical studies

UV-VIS transmittance spectra of pure SnO_2 and Fe- doped SnO_2 thin layers with different dopant concentration as Fig.3 shows. The transmittance of pure thin layers reach to 80% in visible region. Fe-doped SnO_2 thin layers show a decrease in transmittance after doping with iron doping concentration. Fig.3 displays the optical band gap (E_g) Fe doped SnO_2 thin layers. The optical band gap (E_g) values were drawn from transmission spectra according to Tauc's relation [11]:

$$(\alpha h\upsilon)^2 = A(h\upsilon - E_g) \qquad (4)$$

where α is absorption coefficient, hν is the photon energy, A is a constant, E_g is the optical band gap. For E_g values were deduced from the transmission by extrapolating $(\alpha h\nu)^2 = 0$.The optical band gap values decreases from 3.87 to 3.58 eV as in Table II.

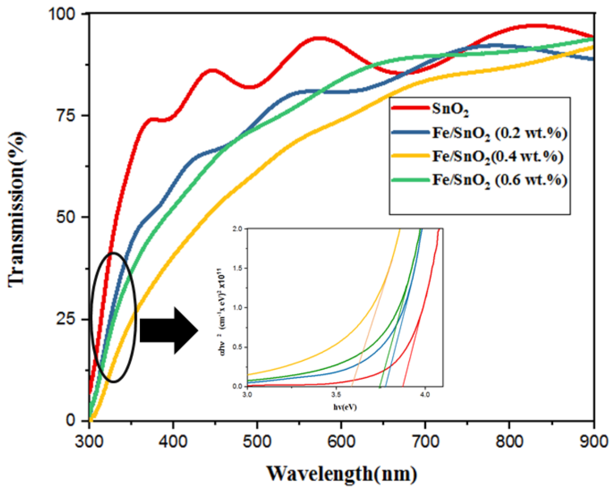

Fig. 3. *Band gap (E_g) for pure SnO_2 and Fe doped SnO_2 thin layers.*

TABLE II. THIN FILMS THICKNESS, TRANSMITTANCE, AND OPTICAL BAND GAP E_G VALUES FOR PURE SnO_2 FE DOPED SnO_2 THIN LAYERS.

Material	*Thickness t (nm)*	*Transmittance T (%)*	*Optical band gap E_g (eV)*
Pure SnO_2	211.29	81.20	3.87
Fe /SnO_2:(0.2 wt. %)	221.54	73.04	3.77
Fe /SnO_2:(0.4 wt. %)	216.94	62	3.58
Fe /SnO_2:(0.6 wt. %)	217	71.12	3.74

C. Electrical studies

The 4-point probe is preferable for sheet resistance (R_{sh}) measurement (Fig.4); in the linear 4-point probe method, the potential difference (V) is measured across the inner two and the current (I) is applied between the outer two leads.

To calculate sheet resistance (R_{sh}) depending on the following relation[14]:

$$R_{sh} = 4.532(\frac{V}{I}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

K=4.532 correction factor was applied for the sample (1 cm×1 cm). As seen in Table III , R_{sh} values of all thin layers increases with the increase in the doping concentrations.

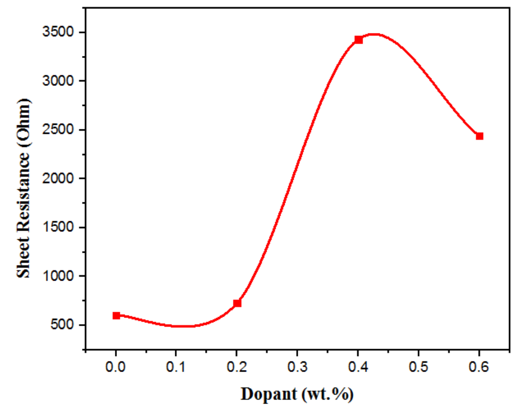

Fig. 4. *Electrical sheet resistance for pure SnO_2 and Fe doped SnO_2 thin layers.*

TABLE III. *VARIATION OF SHEET RESISTANCE (R_{SH}) AND RESISTIVITY VALUES OF FE DOPED SnO_2 THIN LAYERS..*

Material	R_{sh} (Ω)	*Resistivity(Ω cm)*
PureSnO_2	600	1.2×10^{-2}
Fe/ SnO_2 (0.2 wt.%)	700	1.4×10^{-2}
Fe/ SnO_2 (0.4 wt.%)	3400	6.8×10^{-2}
Fe/ SnO_2 (0.6 wt.%)	2445	4.9×10^{-2}

IV. CONCLUSION

Fe-doped SnO_2 thin layers with different dopant concentrations have investigated. Influence of dopant on the structural, morphological, optical and electrical properties of Fe-doped SnO_2 thin layers. XRD and SEM results revealed polycrystalline structure for Fe-doped SnO_2 thin layers. The optical transmittance of all thin layers displayed high transparency reach to 80% in visible region. The optical band gap of thin layers decreases from 3.87 to 3.58 eV. The crystalline sizes decrease from 35 to 30 nm. Electrical resistivity of thin layers increases from 1.2×10^{-2} to 6.8×10^{-2} Ω .cm.

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