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Structural and Optical Properties of Fluorine Doped Tin Oxide Thin Film Deposited by Home Built Spray Pyrolysis Unit

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Abstract: *Fluorine doped Tin Oxide (FTO) thin films were deposited on glass substrates by home built spray pyrolysis setup at (400 ± 5)ºC. The method was found to be very economic and functional. The deposited FTO films were highly transparent and had low resistivity. The structural investigation of as-prepared films was performed using X-ray diffraction. Our results showed that a deposited FTO film was of polycrystalline nature with preferential orientation along (211) planes. The direct band gap value was found to be 3.25eV for 10% FTO film. The sheet resistance of this film was measured to be 68 Ω/ square. The effect of fluorine doping concentration on its band gap was also studied in this report.*

Key Words: Spray Pyrolysis, FTO Film, Structural Property, Transmittance, Band Gap

1. INTRODUCTION

Transparent conducting oxide (TCO) thin films of Fluorine doped Tin Oxide (FTO) are finding wide ranges of optoelectronic device applicationsbecause of theirspecific electrical, structural and optical properties [1-2]. FTO generally exists as an n-type and wide band gap semiconductor with high transmittance in the visible region [2]. FTO has been recognized as a very promising material for a number of optoelectronic applications because of its stable nature at atmospheric conditions, mechanical hardness, chemical inertness, and high temperature durability. It has excellent electrical conductivity, greater mobility and good mechanical stability [1-3]. Due to these distinctive characteristics, it is used in solar cells as transparent and protective electrodes and in flat plate collectors as spectral selective windows for light to pass through to the active material where carrier generation occurs as an ohmic contact for carrier transport out of the photovoltaic [2, 3]. It is also used in gas detecting sensors, photo thermal converters, and for providing thermal insulation for houses [1-4]. Another advantage of FTO is that it iseasy to fabricate using low cost materials. The structure, surface morphology and electrical and optical properties of the FTO films strongly depend on the method of preparation and growth parameters. Thin films of FTO can be prepared by several deposition techniques such as dip coating[5], inkjet printing [6], magnetron sputtering [7], spray pyrolysis, etc [8-11]. We have prepared thin films of FTO by using a homemade spray pyrolysis setup.

2. EXPERIMENTAL

Thin films of FTO were deposited on glass substrates by using a homemade spray pyrolysis setup. At first, a precursor solution was prepared by dissolving 10g of stannous chloride in 25ml of distilled wateralong with a few drops of concentrated hydrochloric acid) with continuous stirring for 30 mins at (90 ± 5)ºC. For fluorine doping, 1g of ammonium fluoride (NH_4F) was dissolved in 25 ml of distilled water with continuous stirring for 10-15 min at (30 ± 5)ºC and then mixed with the stannous chloride precursor [10]. Finally, the mixture was stirred for an hour at room temperature and allowed to rest for 24 hrs to age it.

Before deposition of the film on the glass substrate, microscopic glass slides were ultrasonically cleaned by detergent thoroughly at first, then with acetone or ethanol to remove organic impurities, and, lastly, dried inside the hot oven. The above prepared solution was sprayed via the nozzle connected to the nebulizer. The distance between the nozzle and glass substrate was fixed at about 15 cm. Before spraying the precursor solution, the glass substrate was heated to (400 ± 5)ºC. The temperature of the substratewas controlled by a temperature controller attached to a heater. The spray rate (vol/min) and deposition time were controlled using apersonal computer. These sprayed samples were further annealed in air for 30 min at the same temperatureof deposition , (400 ± 5) ºC. They were subsequently cooled to room temperature. The structural and optical properties of as-deposited thin films of FTO were investigated by using X-ray diffraction and Ocean Optics, USB 2000, UV-Vis spectrophotometer [4].

3. RESULTS AND DISCUSSION

3.1 Structural Properties

The structural properties of as-prepared Fluorine doped Tin Oxide (FTO) thin films were studied using an X-ray diffraction (XRD) technique. The XRD experiment was done over the range of 20° - 80° at the Nepal Academy of Science and Technology (NAST), Khumaltar, Nepal. Figure 1 shows the X-ray diffraction pattern of 10% FTO film. This figure clearly shows the major peaks at 2q= 28.3661°, 35.6771°, 53.4952°, and 56.1869° which corresponding to orientation along (110), (200) , (211), and (220) planes respectively. The (hkl) indexing was done with reference to JCPDS card no. 41-1445[4]. The table 1 below shows the observed and standard d-spacings and corresponding (hkl) values. Crystallite size of as-prepared FTO was also calculated using Debye Sherrer's formula $D = \frac{0.9\lambda}{\beta \cos\theta}$ where λ, wavelength of x-ray used, β , the width of peak measured at full width half maximum (FWHM) measured in radian and θ, the bragg's angle. The average value of D was found to be about 12nm [12].

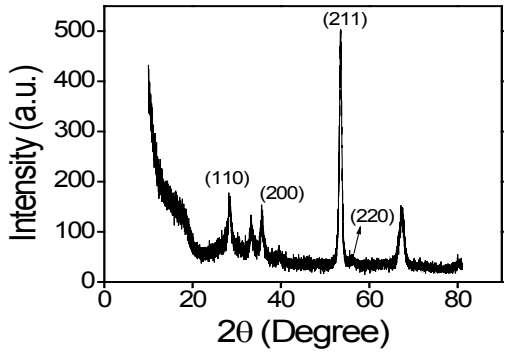

Figure 1: X-ray diffraction pattern of FTO thin film deposited on glass at (400 ± 5)°C by spray pyrolysis method

Table 2: 2θ value, (hkl), calculated and standard d-spacing values and crystallite size of 10% FTO film

S. N.	2q (Degree)	Calculated d-spacing (Å)	d-spacing from JCPDS (Å)	(hkl)	Grain size in (Å)
1	28.3661	3.1425	3.347	(110)	113.7234
2.	35.6771	2.5135	2.369	(200)	148.3530
3.	53.4952	1.7108	1.764	(211)	133.4901
4.	56.1869	1.6351	1.675	(220)	108.9224

3.2 Optical Measurements

Figure 2a and figure 3a show the transmittance versus wavelength scanned in the range of 350-900 nm of 10% and 8% FTO thin films respectively. These spectra were captured by an Ocean Optics,UV-Visible USB 2000 spectrophotometer, Singapore. The maximum transmittance was found to be 78% at 625nm for 10% FTO whereas it was 72% at 660 nm for 8% FTO. Corresponding $(\alpha h\nu)^2$ versus hν (eV) graphs were shown in figure 2b for 10% FTO film and figure 3b for 8% FTO film respectively. The band gaps of FTO films were calculated by extrapolating the linear portion of $(\alpha h\nu)^2$ into the hν axis [12, 13]. The measurements show that the direct band gap of about 3.25eV and 3.24eV for 10% and 8% FTO films. Hence our results showed that as the fluorine concentration increased, the transmittance increased by about 6% but there was no significant change in the band gap.

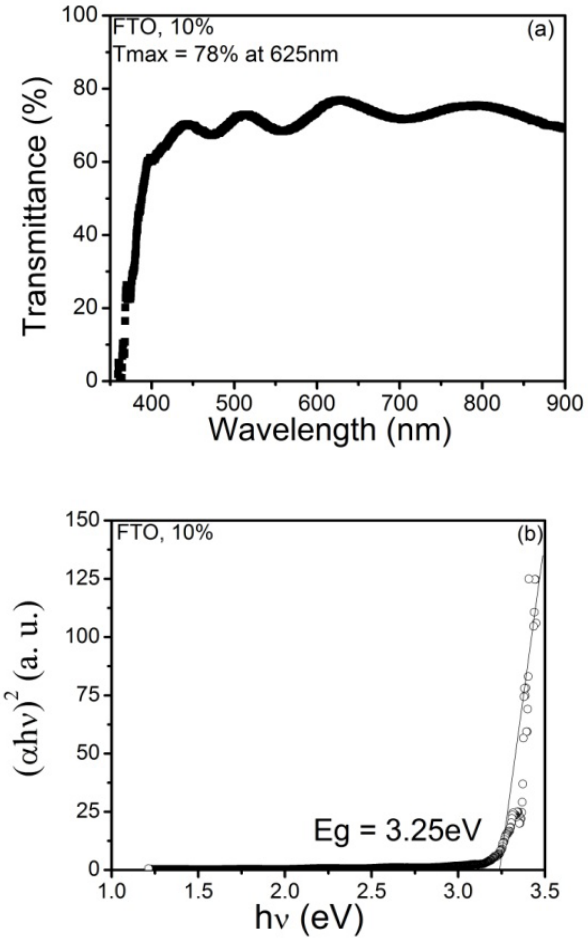

Figure 2: (a) The transmittance versus wavelength (b) corresponding to $(\alpha h\nu)^2$ versus hν of 10% FTO film

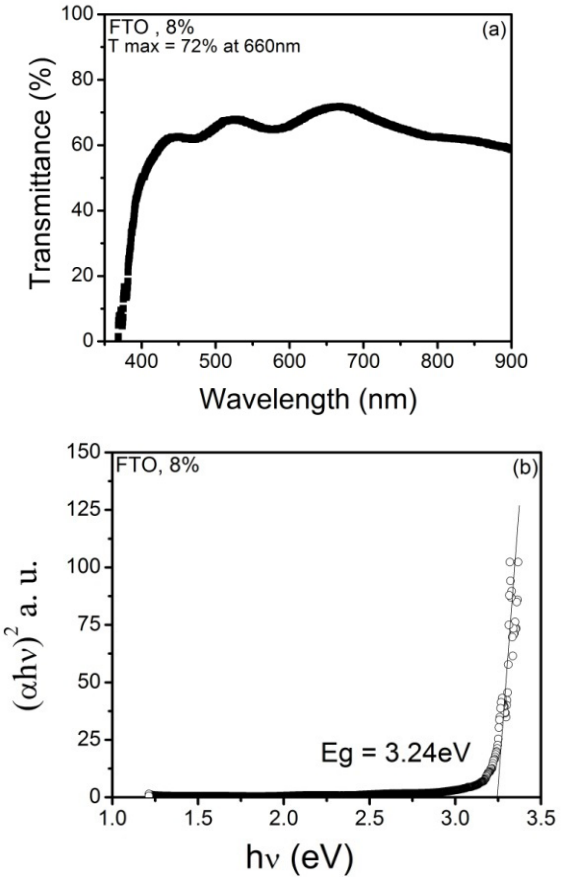

Figure 3: (a) The transmittance versus wavelength (b) corresponding to $(\alpha h\nu)^2$ versus hν of 8% FTO film

3.3 Electrical measurement

The sheet resistances of above prepared FTO thin films were studied using the four point probe technique [13, 14].
We observed that as the low volume of solution was sprayed into the glass substrate, the sheet resistance wasfound to be high due to only athin layer of FTO deposited. Our results showed the lowest sheet resistance of 68 ohm/square for 10% FTO film and 55ohm/square for 8% doped film.

4. CONCLUSIONS

Semiconducting thin films of Fluorine doped Tin Oxide (FTO) were successfully deposited on glass substrates using a homemade spray pyrolysis setup at (400 ± 5) ^{o}C. The method was found to be economic and suitable for research and development . The transmittance of 10% FTO film was found to be of 78% at 625 nm and sheet resistance 68 ohm/square. The direct band gap was found to be of 3.25 eV for 10 % FTO film. The X-ray analysis confirmed the polycrystalline nature of FTO film with preferential orientation along (211) planes.

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