Studies on the Electrical and Optical Properties of Dip-coated Indium Tin Oxide Films

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Abstract

Glass substrates were coated with indium tin oxide (ITO) films using a homemade dip-coating unit, from a solution of indium chloride. The characterization of these films was done by X-ray diffraction, electrical resistivity measurement and optical transmission spectroscopy. Films deposited at optimum conditions exhibited a resistivity of $2.1\text{x}10^{-4}$ Ωm and a transmittance of 87 % at 550 nm.

Keywords: *Indium tin oxide films, Dip-coating, Sol-gel*

Introduction

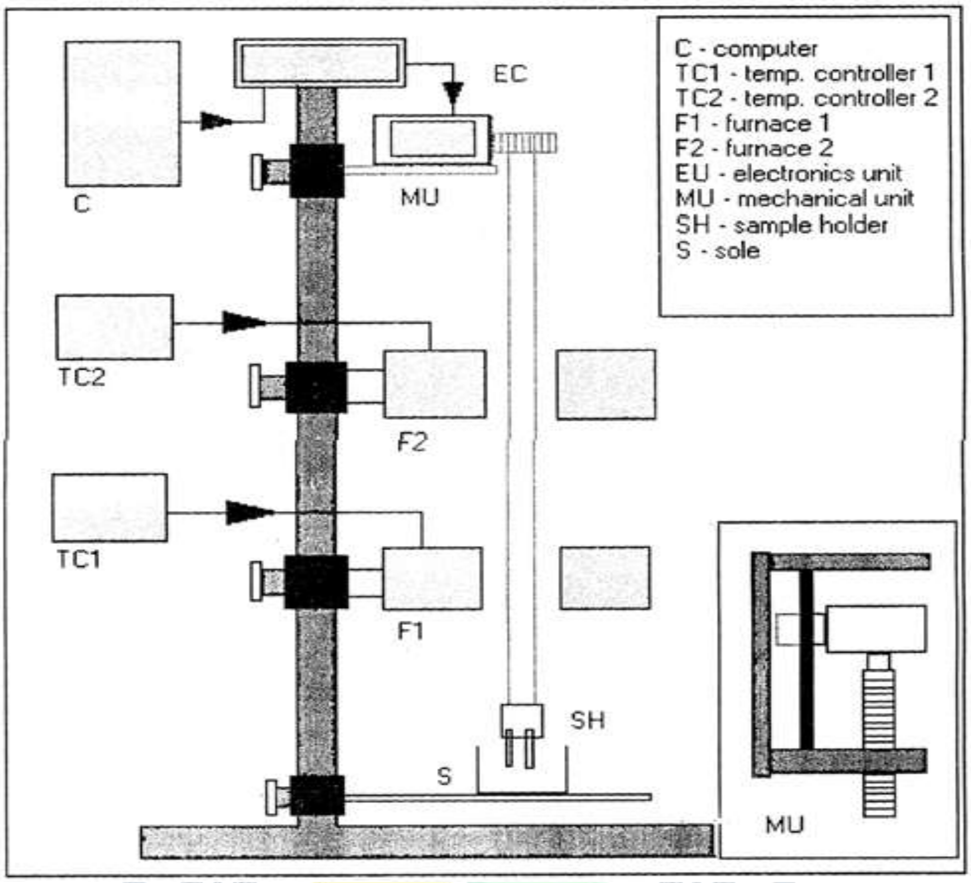
Sol-gel dip-coating method, a technique for thin film preparation, has gained considerable attention as it paves the way for the making of films on substrates of any shape with simple instrumentation. The cyclic steps for dip-coating involve dipping and withdrawing the substrate in and from the sol at a uniform velocity, drying the sample, annealing and repeating this cyclic process. For the deposition of films with reproducible and well- controlled characteristics through sol-gel method, it is extremely important to control precisely all the parameters (withdrawal velocity, drying temperature and time, number of dips, etc.) involved during each of the stages of processing. Because the wet coating process requires less capital and basic infrastructure, dip coating is an advantageous way to produce ITO thin films at a lower cost

The technological applications of Indium tin oxide (ITO) films involve solar cells, anti-static coatings, flat panel displays, electro-luminescent devices and sensors. ITO films were prepared by a sol-gel process using metal salts and organic solvents as raw materials. A homemade dip coating unit has been used for the coating process. The instrument is fine in the sense of programmability of parameters like dip velocity, withdrawal velocity, dip time, drying time, drying temperature, number of dips, etc. Films obtained have good electrical and optical properties. Optical, electrical and structural properties of the films were investigated. For the optimized films, variation in resistivity with temperature was studied.

Experimental Details

The dip coating unit is a completely home made one that uses a stepper motor, controlled through the parallel port of a personal computer. The motor is placed on a sliding platform and it rotates a threaded bolt over which two nichrome wires (0.2 mm diameter) hanging a tungsten sample holder are wound. The position of the holder in the horizontal plane remains unchanged during the process. The wires pass through two temperature controlled tubular furnaces, one for drying and the other for annealing the sample.

Anhydrous indium chloride (99.9% pure) was dissolved in acetyl acetone (99% pure). The solution was refluxed at 80ºC for about one hour. For doping, tin chloride was dissolved in ethanol and this solution was mixed with the refluxed solution at room temperature. The molar ratio of indium chloride to acetyl acetone was fixed as 1:8 in the present study. The ratio was experimentally determined for optimum film qualities.



Dip coating unit

The dip process was carried out in open atmosphere. The glass substrates were dipped into the solution for one minute with a dip velocity of 12 cm/minute. The withdrawal velocity was also the same. After each dip, the substrates were dried in the drying furnace at 260ºC for about 10 min. This process was repeated by changing wt% of tin addition. For a dip cycle of 10, the films were found to have desirable properties regarding thickness, resistivity, transmittance, etc. The films were then annealed at 500ºC for about one hour. Electrical properties of the films were studied using a four-point probe set-up and Hall probe method. Optical transmission studies in the 300-800 nm region were carried out using a spectrophotometer. The thickness of the film was measured using multiple beam interferometer technique. Crystal structures were analyzed using an X-ray diffractometer.

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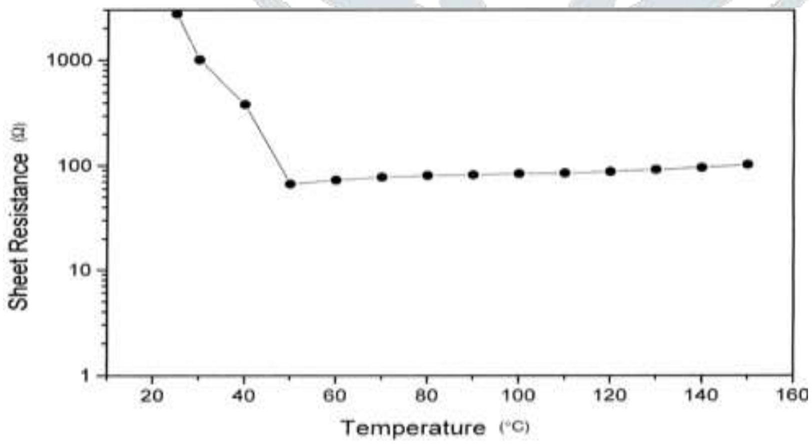
Electrical studies

Table Variation of sheet resistance, resistivity, transmittance and figure of merit of ITO films deposited on glass substrates with tin dopant concentration

Wt % of tin addition	Sheet resistance (kΩ)	Resistivity (Ωm)	Transmittance at 550 nm (%)	Figure of merit at 550 nm (Ω^{-1})
2.5	23.3	1.8×10^{-3}	75	2.41×10^{-3}
5	2.73	2.1×10^{-4}	87	9.09×10^{-2}
7.5	6.55	5.4×10^{-4}	81	1.9×10^{-3}
10	5.11	3.9×10^{-4}	43	4.7×10^{-5}
15	9.52	7.4×10^{-4}	34	2.7×10^{-6}

The variation of sheet resistance of ITO films with tin dopant concentration is shown in table. It was observed that the resistivity of tin doped ITO films depends strongly on tin dopant concentration. The resistivity of the films decreased with tin doping concentration up to 5 wt%. A minimum resistivity of $2.1\text{x}10^{-4}$ Ωm was obtained for 5 wt% tin doped films. Above 5 wt %, the resistivity increases with increasing tin dopant concentration. The replacement of indium ions by tin ions and their action as effective donors decreases resistivity. But when tin content increases not all tin ions can replace indium ions. A defect complex is formed when concentration of tin ions is very high. The high resistivity at high concentration of tin may also be due to the disorder produced in the lattice by the presence of interstitial dopant atoms and many grain boundaries due to small crystal grains. These two effects behave as barriers to electron movement inside the thin film.

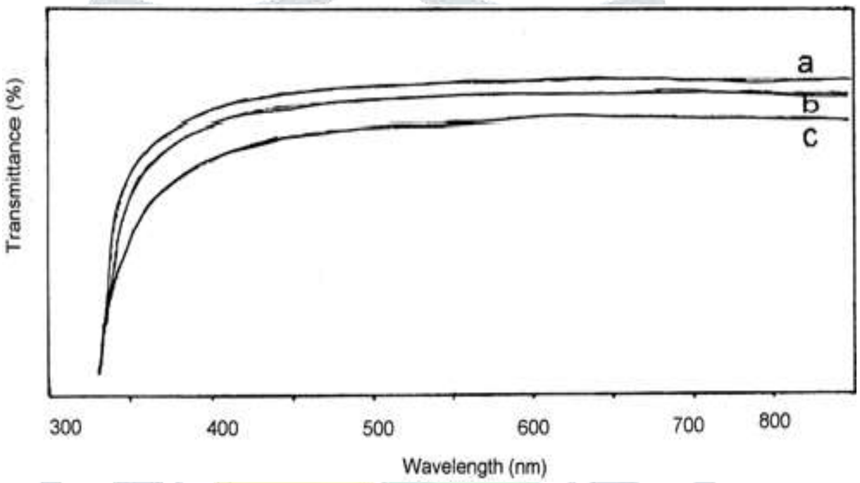


Variation of sheet resistance with temperature of the optimized ITO film

Figure shows the variation of sheet resistance with ambient temperature of ITO films deposited on glass substrates with 5 wt% tin doping. A negative temperature coefficient is observed up to about 60ºC. Then the resistance remains almost constant.

Optical studies

Optical transmission data is significant in evaluating the optical properties of ITO films. High visible transparency is required in applications for optoelectronic devices. Figure shows the optical transmission spectrum of ITO films deposited on glass substrates for different concentrations of tin doping. The variation in transmittance of the tin doped ITO films with tin dopant concentration is presented in Table. The high transmission of ITO films is due to wide band gap. It was observed that doping reduces optical transmission. This may be due to increased scattering of photons by crystal defects created by doping. A maximum transmittance of 87 % at 550 nm was obtained for 5 wt% tin doped films, which is sufficiently high for use as a transparent conductor.



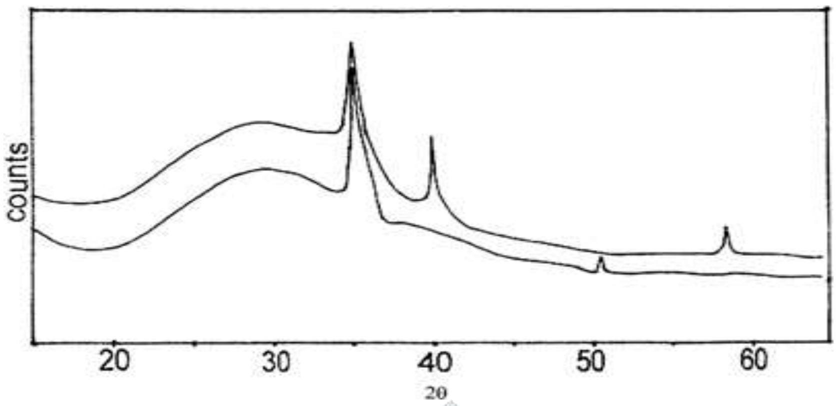
Transmission spectra of ITO films with tin dopant concentrations, (a) 5 wt% (b) 7.5 wt%, (c) 2.5 wt%

Figure of merit

The figure of merit of as-deposited ITO films was calculated using the relation T^{10}/R_S, where T is the transmittance and R_S is the sheet resistance. The figure of merit of as-deposited films for different tin wt % is shown in Table. A maximum figure of merit of was obtained for 5 wt % tin doped ITO films.

Structural properties

Figure shows the XRD spectrum of 5 wt% tin doped ITO films. The peaks in the spectrum correspond to the cubic structure of indium oxide films.



XRD spectra of ITO films with 5 wt % (top) and 7.5 wt % (bottom) tin dopant concentrations

Conclusions

Good quality ITO films have been deposited on glass substrates using an indigenously developed, programmable dip-coater. Films with 5 wt% tin dopant concentration were found to show maximum desirable properties. It has an optimum resistivity of 2.1×10^{-4} Ωm and transmittance of 87 % at 550 nm. The resistivity and transmittance of ITO films depend strongly on tin dopant concentration

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