Investigation On The Optical, Electrical And Structural Properties Of ITO On Glass Substrate

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Abstract: This thesis paper is mainly focus firstly deposited ITO thin films on glass substrate as good transparent conducting electrode as low resistivity and high optical transmittance. Indium tin oxide (ITO) thin films have been deposited on glass substrate to be used as transparent conducting electrode.ITO has been deposited by using electron beam evaporation (E-beam) method. The surface morphology of ITO films was investigated by AFM and also studies the electrical and optical properties of these films. The effect of annealing of the ITO was also investigated. It was found that the conductivity of ITO film was proportional to the annealing temperature and time below 600°C. The surface morphology of ITO films for different annealed temperature has been also investigated by AFM and it was found that surface roughness of ITO film increase with annealing temperature.

Index Terms: ITO thin film, E-beam evaporation, AFM, Annealing, Surface roughness, film thickness, Transmittance..

Introduction

Transparent conducting oxide (TCO) films have been widely used for a variety of optoelectronics applications such as, light emitting diode (LEDs),flat panel displays (FPD) storage-type cathode ray tubes, solar cells, gas sensors, photo catalysts light emitting diode (LEDs) and surface layers in electroluminescent etc. Among the existing TCOs, Indium tin oxide (ITO) is one of the most frequently used material because of its unique characteristics such as low resistivity, high optical transmittance over the visible wavelength region, excellent adhesion to substrates and chemical stability. ITO is an n-type wide band gap (3.3-4.3 ev) Semiconductor which shows high transmittance in the visible and near-IR regions of the spectrum [1]. ITO is a transparent conductive oxide, intensively used in optoelectronic devices within thin film coatings. This conducting oxide exhibits interesting optical and electronic properties [4-9]: high optical transmittance over 90% from visible to near IR wavelength. The use of transparent conducting electrodes at the front of the cell is essential to allow light to travel to the active material. ITO has been used almost exclusively as the transparent conductor [2].

2 EXPERIMENTAL:

Thin films are thin material layers ranging from fractions of nanometer to several micrometers in thickness [1]. There are various techniques for depositing thin film depending on the type of materials and thickness of layer to be deposited. In this thesis work Electron beam evaporation technique was used to deposit ITO.

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In this research, Edwards E-306 vacuum coating unit was used for depositing ITO, film specimens for all the experimental investigations (e.g. electrical and optical) have been prepared by e-beam technique using Edwards E-306 vacuum coating unit. The unit consists of a deposition chamber, a pumping system and electrical sources. The deposition chamber is cylindrical and has a mechanically polished interior. A stainless steel substrate holder to hold four substrates is situated just above the source. A mechanical shutter operated from outside the chamber isolates the source from the substrate for desired times. A tungsten filament (W) is used for the electron beam. The accessory is comprised of six hearth turret with rotary drive. The source turret is rotated, raised and lowered by an external control mechanism. The deposition chamber is evacuated with oil diffusion pump, which is controlled by an automatic evacuation system. The coating unit is provided with Edwards, EBS power supply unit having high tension (HT) 0-6 kV and low tension (LT) 0-500 mA In order to study the various properties of thin films, specific shape and size of the films are necessary. The commonly used methods of patterning thin films are:

(i) Physical masking,
(ii) Photoresist,
(iii) Inverse photoresist, and
(iv) Inverse metal masking,

In present work, physical masking has been used by author. There are suitably shaped apertures through which deposition is made to have desired pattern of the films. The film uniformity strongly depends on the dimension of mask. Hence, the mask should be as thin as possible. The effect of mask dimension on the uniformity of film thickness is very important and should be taken into account. This problem can be properly solved by preparing mask using opaque sheet. The various types of mask used in the present work are given below. The commercially available ITO powder (99.99% pure) obtained from **Inframat Advanced Materials, USA (Catalog #49N-5090B and Lot #IAM20226NITO)**, was used as the evaporation source material. At first a suitable mask and Source turret (with source-hearth contained ITO powder) is adjusted and then shutter is placed between the substrate holder and source hearth to protect the substrate from unwanted deposition. Then the HT and LT regulators on the EBS power supply unit are ensured in the zero position. After switching ON the power supply the LT control of this supply unit is then increased slowly in order to degas the filament and evaporated, it is kept at about 60% on the LT control, and it is continued to degas the filament until the system pressure is reached a steady level and then LT control is reduced to zero. Then HT control of the EBS power supply is increased to HT voltage of 2 kV indicates on the meter and then the LT control is slowly increased until an emission current of 30 mA indicates on the meter. The HT voltage drops slightly. The source turret is slowly raised and hearth height is adjusted as the previous relevant steps to obtain the best film conduction. The shutter is then removed to allow deposition onto the substrate through the mask windows. When the deposition of film is completed then the shutter is replaced at the proper time. The EBS power supply is switched OFF properly. The high vacuum valve is then closed. The vacuum chamber and the fabricated devices are allowed to cool down for about 20 min before air is admitted. This adopted technique may reduce the probability of oxidation. The films are then taken out and stored them into desiccators for various measurements. During the deposition of ITO, two films are prepared in a single run. The characteristics of thin films deposited by e-beam technique depend on a number of process variables or deposition parameters. The various quantities such as source to substrate height, deposition rate, beam current, chamber pressure, quality of substrate, substrate temperature, size of atomized particles etc. affect the film properties. The optimum values of deposition variables for ITO thin films are found as follows

- **(a)** Source to substrate height dSS =9 cm,
- **(b)** Deposition rate = 1.094 $nms^{-1.}$
- **(c)** Beam current =30 mA,
- **(d)** Chamber pressure = 2.5×10^{-5}mbar
- **(e)** Voltage =2 kv

After the deposition, the samples were annealed in a thermal annealing furnace (carbolite CWF 12/13) in air at 200°C, 400°C and 600°C for 10 min. But 600°C show good result than other temperature. All the samples were annealed at 600°C for 10 minutes. After annealing they were left to be cooled naturally to the room temperature before being used. After annealing the surface morphology of the ITO films were measured by AFM. The roughness of ITO film has been investigated by AFM data and took positive steps to reduced surface roughness

3. Result & Discussion

3.1 Determination of ITO film thickness

The thickness of ITO films on glass substrate was measured by interference fringe method. If h is the fringe displacement and d is the fringe spacing then the film thickness t is given by,

$$t = (h/d) \times (\lambda/2)\ m$$

Where λ=589 nm is the wavelength of the monochromatic light.

Table -1: Data for determination the thickness of ITO film on the glass substrate.

Fringe displacement [mm]				Fringe spacing [mm]			Thickness [nm]
Sample	h1	h2	h=h2-h1	d1	d2	d=d2-d1	t
01	101.47	100.97	0.51	104.41	100.96	3.51	42
02	95.3	89.17	6.13	83.7	97.34	13.64	133
03	81.5	82.1	0.6	81.0	82.1	1.1	177
04	96.5	100.2	3.7	91.2	96.3	5.1	214

3.2 Structural study of ITO on glass substrate

The surface morphology for different annealed temperature of ITO films was studied by AFM. Fig 1.1 (a), (b), (c), (d) shows the 3D-AFM image of the ITO/glass samples those were annealed at different temperatures but their deposition time same 100 sec. The roughness of these films has been investigated by AFM. Roughness of these films increased with increasing annealing time .The roughness has been found rms roughness = 1.639 nm and average roughness=1.334 for as deposited film. The roughness has been reduced by annealing the film and finally we got some good result. The as deposited film roughness has been reduced by annealing at 600° C for 10 minutes in the order of rms roughness=0.719 nm and average roughness=0.55 nm. Fig 1.1(e) show how roughness varied with annealing treatment.

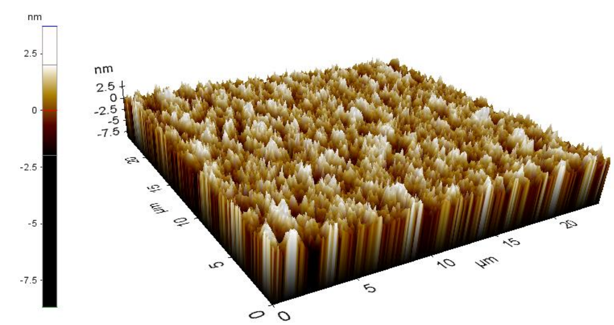

Figure 1.1(a) Surface morphology of as deposited ITO film.

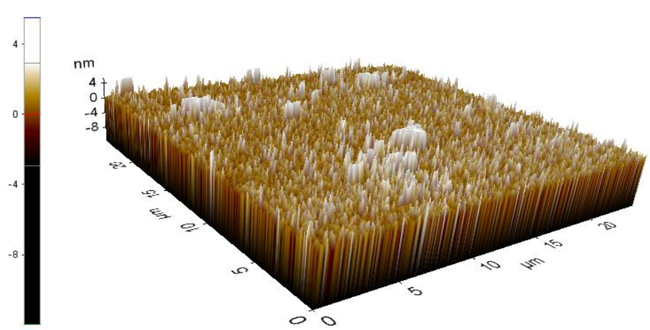

Figure 1.1 (b) Surface morphology of ITO film anneal at 500°C for 10 minutes.

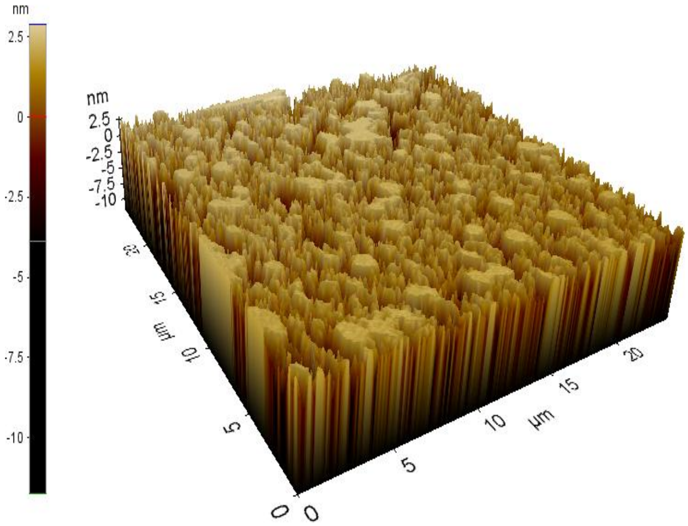

Figure 1.1 (c) Surface morphology of ITO anneal at 400°C for 10 minutes

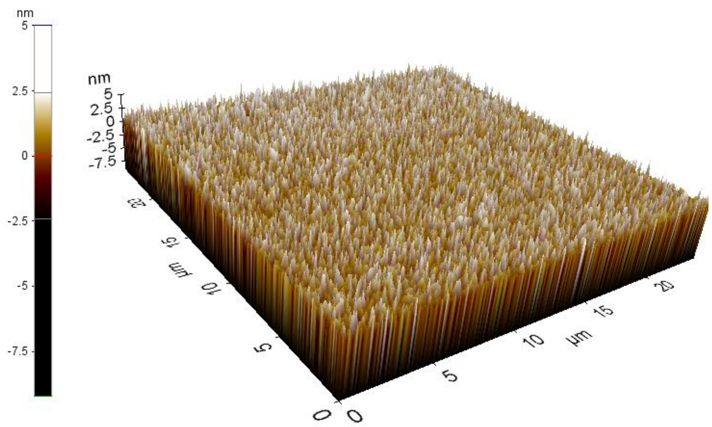

Figure 1.1 (d) Surface morphology of ITO anneal at 600°C for 10 minutes.

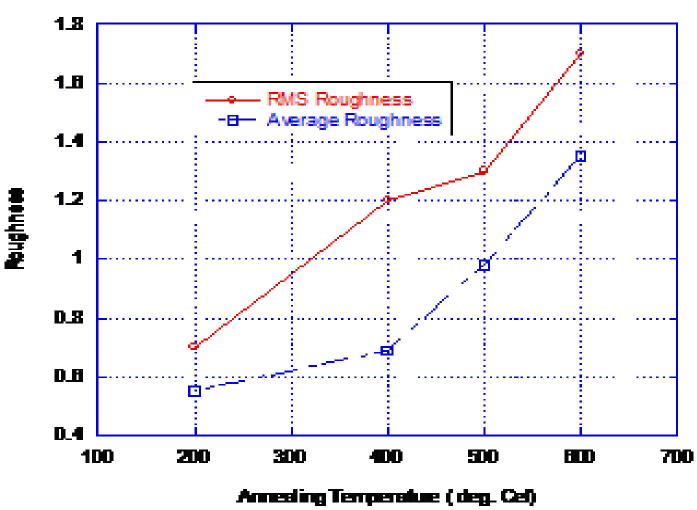

Figure 1.1 (e) Variation of films roughnesses with annealing.

3.3 Study the transmittance of ITO films

The optical spectra of transmittance, T (%) have been measured at wavelength range from 300nm to 800 nm by using UV-Visible spectrophotometer (UV-1650PC).fig 2 represent the variation of transmittance with respect to the wavelength for ITO/glass samples those were annealed at different temperature but their deposition time same .From figure 6.2 it is clear that transmittance increased with the thickness of ITO. From fig 2 shows the measured transmittance of ITO film over the wavelength range 300nm to 800 nm. We obtained transmittance over 90% for the ITO film thickness of 214 nm.

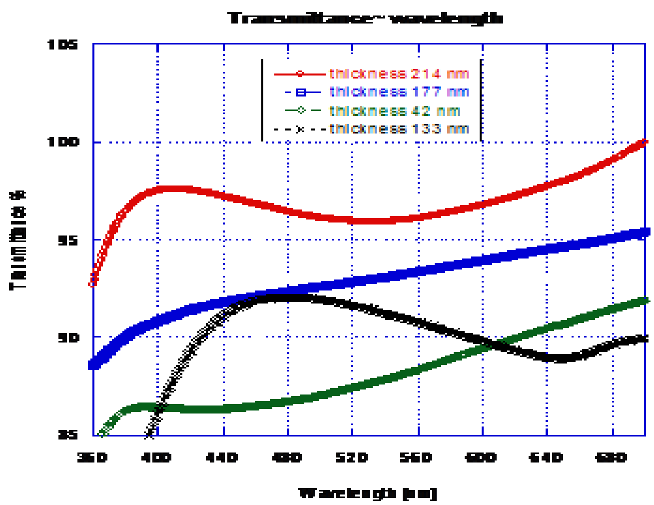

Figure 2 Variation of transmittance with wavelength for different annealed temperature.

3.4 Study the resistivity of the ITO films

The resistivity of ITO films depends on film thickness. Fig 3 shows the variation of resistivity with thickness for ITO films those were annealed at 600°C for 10 minutes .From fig .3 we observed that resistivity of ITO films decrease with the increase of films thickness.

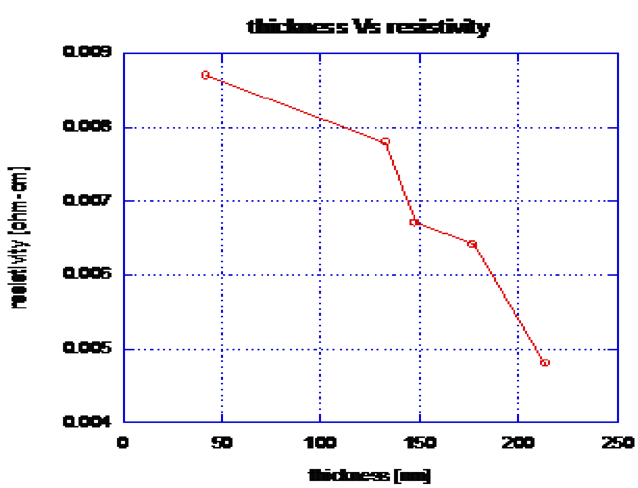

Figure 3 Variation of Resistivity with film Thickness

DISCUSSION:

In this thesis various characterizations of ITO films deposited by electron beam evaporator showed its possible use as a transparent conductive electrode. The surface roughness of ITO film has been measured by AFM. The roughness of ITO films was reduced by annealing the films (figure 1). The transmittance of ITO films depends on thickness (figure 2.) The transmittance above 90% was obtained for ITO film thickness of 214 nm. The resistivity of ITO films decreased with the increase thickness of ITO (figure 3) that supports the previous study of Shabbir [3].

CONCLUSION:

In conclusion work, we have performed AFM technique to investigate surface roughness of deposited ITO on glass substrate. The experimental result shows that surface roughness increase with annealing temperature as shown in figure 1.1(e). ITO films deposited at room temperature are found to be in well crystalline structure. Subsequent annealing enhances the crystallinity and which results in growth in crystallite size. The as-deposited ITO films showed poor electrical conductivity and optical transparency. But these parameters improved with the annealing temperature. When the films were annealed at 600^0C for 10 minutes it exhibited good electrical conductivity and high optical transparency. The resulting increase in transparency over 85 % in the visible light range for the film annealed at 600°C and decreases the resistivity of the films due to annealing at 600°C. The evolution of electro-optical parameters in this study is related to the improvement in structural characteristics of the films. Eventually, it is realized that the thermal annealing temperature plays a vital role in optimizing the structural and optoelectronic properties of electron beam evaporated ITO films.

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