Investigating Optical Properties of ITO Thin Film Grown by RF Sputtering

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Abstract

Indium tin oxide (ITO) thin films of different thickness were successfully grown on the corning glass substrate using radio frequency magnetron sputtering technique. All the sample were undergone heat treatment at temperature of 600 ºC for 4 hours inside a furnace. The measurement of the thickness have been performed using surface profiler and optical properties have been studied using UV-VIS spectroscopy in wavelength regime 200-2500 nm for determination of energy band gap. Energy band gap was calculated based on the optical transmittance and photon energy and being measured in range of 2.76 eV – 3.54 eV while the transmittance was approximately 90 %.

Keywords: ITO, RF Sputtering, Transmittance, Energy Band Gap

1. Introduction

Indium tin oxide, ITO or the other synonym tin-doped indium oxide is a mixture of 90% indium oxide, In_2O_3 and 10% tin dioxide, SnO_2 [1] by weight percentage. It has slightly yellow to grey colour in powder form and almost colourless when being deposited onto the substrate as a thin film [2]. Nowadays, many companies and industries used indium tin oxide in the form of thin film as a gas sensing monitoring system in order to maintain the exposure of the toxic gasses in the surrounding environment. Indium tin oxide has been adapted in many industries in the world due to its cost effectiveness. Furthermore, indium tin oxide is a very stable compound and has long term usage [3]. It also has fast response time and high sensitivity towards toxic gasses [4].

Indium tin oxide thin film has high optical transmittance in the visible region that gives high conductivity [5]. Because of the transparent properties of indium tin oxide, it yields low resistivity [6] and give good conductivity due to its addition and increment of carrier concentration [7]. Tin-doped indium oxide has many other industrial applications such as, liquid crystal display [8], development in television and computer screen. Besides, it also has been used in anti-static coating [9], solar cell [10], heat mirror [11], light emitting diode [12], flat panel display [13] and electroluminescent devices [14].

Nowadays, many techniques and methods are used to deposit metal oxide thin film on the substrate such as thermal heat evaporation [15], pulse laser beam exposure [16], chemical vapor deposition [17], electron beam thermal evaporation [18], spray pyrolysis [19] and radio frequency magnetron sputtering [20]. This research work has focused on the uses of radio frequency magnetron sputtering method to deposit ITO thin film.

2. Experimental

The thin film layer of indium tin oxide was grown by radio frequency sputtering deposition technique because the adhesion of the sensing layer and the substrate is strong and most preferable among others [21]. Pellet of indium tin oxide which is 90/10 ratio percentage have been supplied by Kurj. J. Lesker with purity 99.99%. The substrate materials to be used for metal oxide semiconductor thin film deposition must be strong enough to accommodate the high temperature and pressure force because the substrate will also serve as a mechanical support for the thin film. In addition, it also must not be reactive to any element that is in terms of its physical and chemical force reaction. So, the corning glass is chosen as a medium due to its high melting point at about 800°C, long term stability and free of chemical reaction that might change its properties. The corning glass is cut into three segments and the dimension of each segment is 2.5 cm x 2.5 cm as shown in Figure 1.

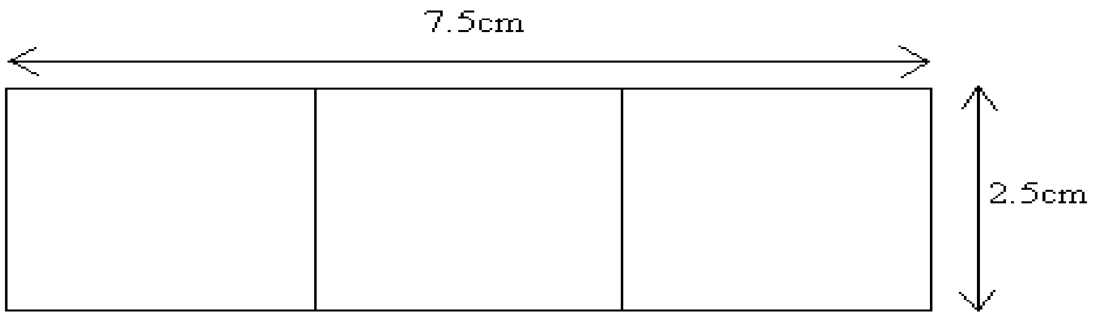


Figure 1 Dimension of cut segment

After the cutting process, the substrate is cleaned to ensure that it is free from dirt, dust or fingerprints and any element that can affect the film deposition. The cut segment is immersed in the chromic acid and then the substrate is put in the (Branson 3210) Ultrasonic Bath Cleaner for 40 minutes. The substrate is rinsed with deionized water and then another 40 minutes is treated in ultrasonic bath into the isopropanol.

The substrate is then dried using the compressed air gun. The cleaned substrate is put inside the sputtering chamber under applied pressure 10^{-3} mbar for deposition of thin film. The thin film is deposited with layer of aluminum electrode to investigate electrical properties of deposited thin films.

3. Results and Discussions

The deposition of indium tin oxide thin films are prepared for 6 different deposition time and heat treatment at 600 ºC for 4 hours inside the furnace. The thickness of deposited thin films are measured using surface profiler machine.

Table 1 Deposition time and thickness

Deposition Time (minutes)	Thickness (x10^{-9} m)
15	132
30	172
45	227
60	283
75	347
90	424

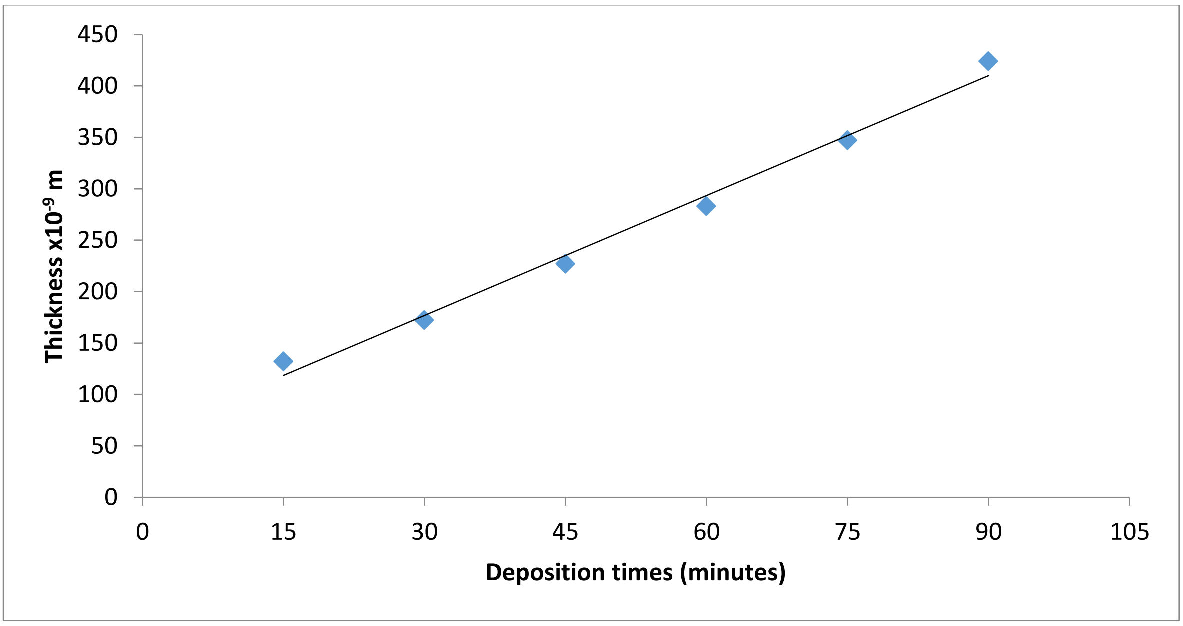
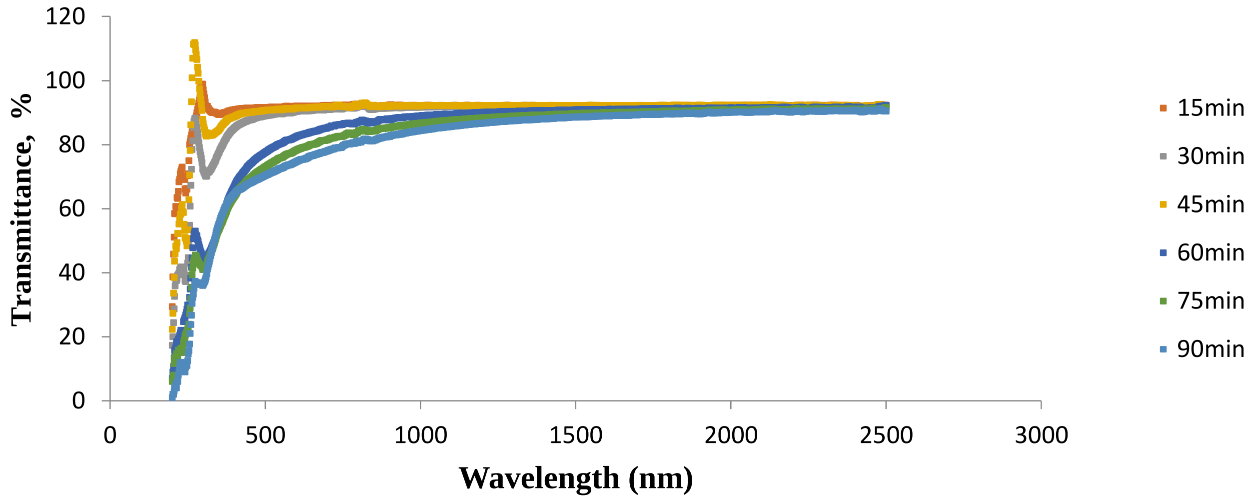


Figure 2 Graph of thickness against deposition times

From table 1 and figure 2, it can be seen that, the thickness of the samples is increased with increase in deposition time. This is due to the growth of the atom to the surface of the film.

a.



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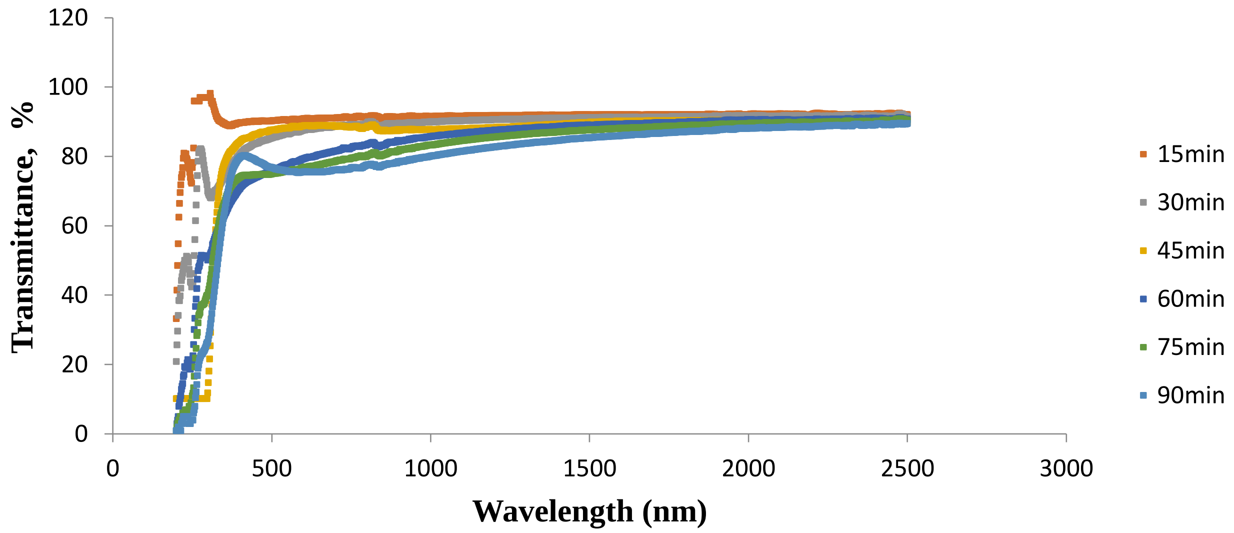

Figure 3 (a) Transmittance spectrum for as-deposited indium tin oxide thin film (b) Transmittance spectrum for anneal indium tin oxide thin film at 600°C for 4 hours.

Figures 3 (a) and (b) shows the change in transmittance spectrum of indium tin oxide thin film of different thicknesses before and after heat treatment respectively. The average transmittance for both graphs is about 88-90% in visible region. From the graph, 15 minutes deposition time sample has shown the highest transmittance spectrum around 92-93%. It can be inferred that, as the thin film thickness increases, the transmittance decreases. This situation happens when the thin film thickness is increased and the grain size of the sample also increases. It caused the incident light is likely collide the atoms within the thin film. On the other hand, thicker thin film allows less light transmission as compared to thin film with less thickness [22].

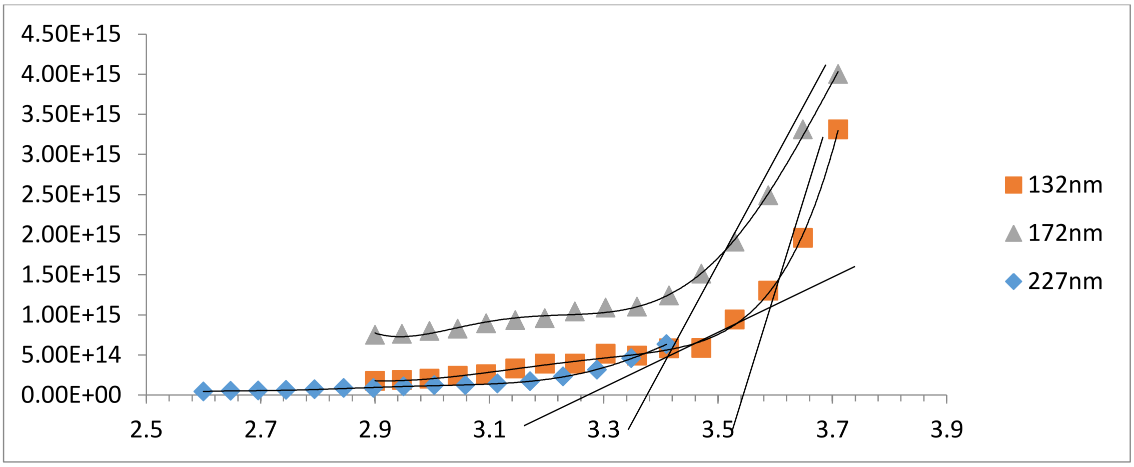

Figure 4 Graph of $(\alpha h\upsilon)^2$ versus photon energy (hυ) for as-deposited ITO at thickness 132nm, 172nm and 227nm.

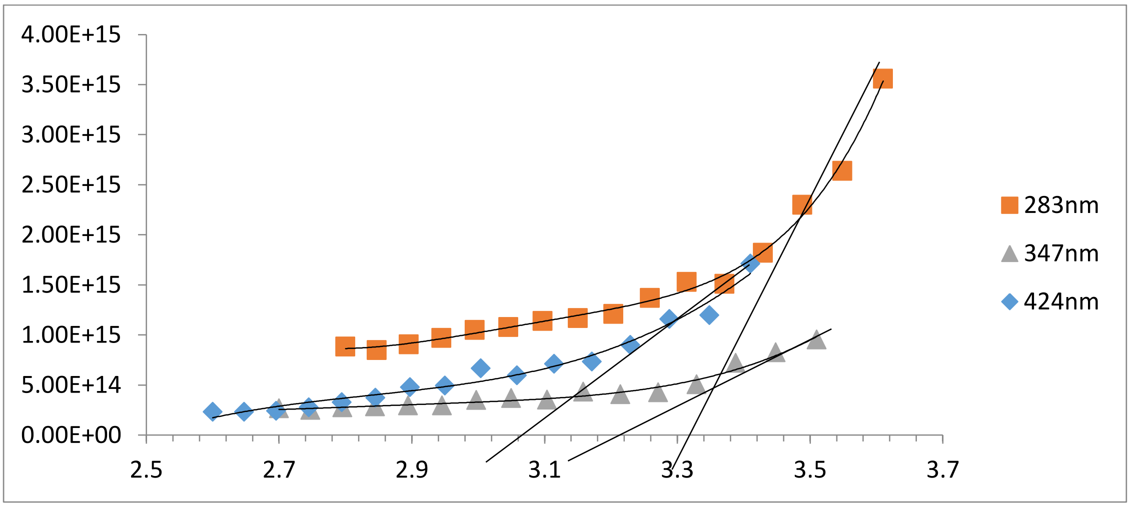

Figure 5 Graph of $(\alpha h\upsilon)^2$ versus photon energy (hυ) for as deposited ITO at thickness 283nm, 347nm and 424nm.

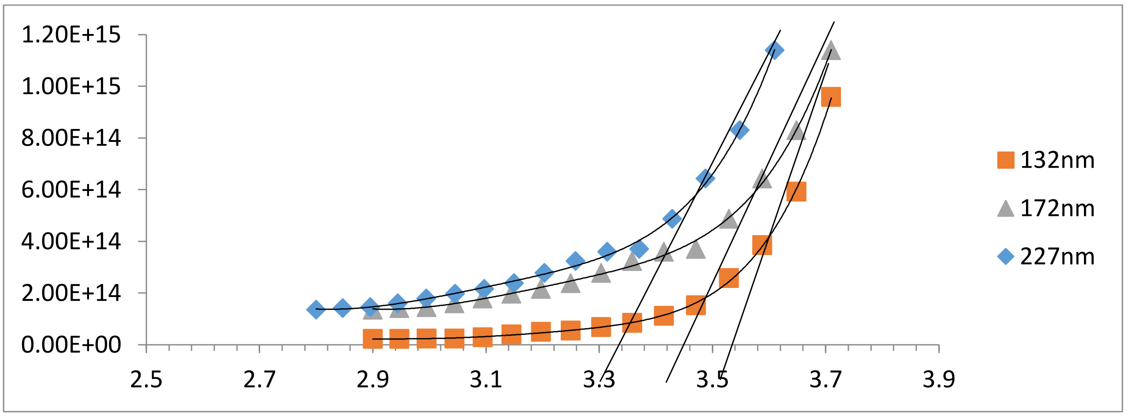

Figure 6 Graph of $(\alpha h\upsilon)^2$ versus photon energy (hυ) for annealing ITO at thickness 132nm, 172nm and 424nm.

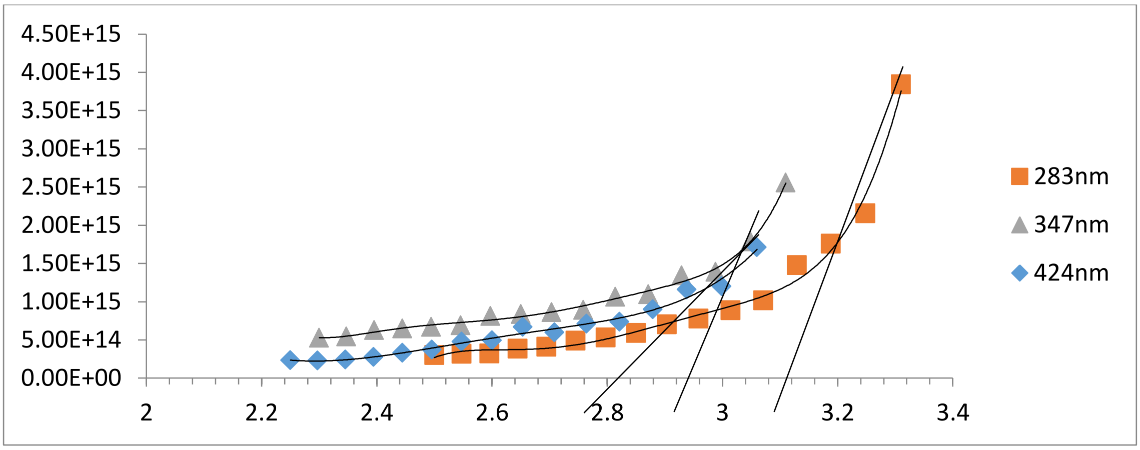

Figure 7 Graph of $(\alpha h\upsilon)^2$ versus photon energy (hυ) for annealing ITO at thickness 283nm, 347nm and 424nm.

Band gap energy is a separation between the valence band and the conduction band [23]. To ensure there is a current flow between the gap, electron must be excited from the valence to the conduction band. The excitation of the electron depends on the energy band gap band. Smaller band gap is easier for electron to jump or excite as compared to larger gap. The width between two bands determines whether the material is metal, semiconductor or insulator. Metal have an overlapping gap between valence and conduction band. As a result, electron does not need any energy in order to excite and flow. On the other hand, insulators are materials that have very large band gap energy and no electron can flow or excite between the bands. For semiconductor, it is a material between metal and insulator. The energy band gap can be measured by extrapolating the linear line tangent to the curve of $(\alpha h\upsilon)^2$of direct band gap versus the photon energy (hυ) until intercept at x-axis as shown in Figure 4 - Figure 7. Figure 4 and Figure 5 show, band gap profile for as-deposited indium tin oxide thin film while Figure 6 and Figure 7 are for indium tin oxide that undergoes annealing process. From the energy band gap graph versus indium tin oxide thin film thickness analysis shows that, both as-deposited and annealed samples, decrease exponentially with thickness, which may be due to the quantum size effect that usually occurs in semiconductor materials when the thickness is reduced or smaller than the average distance between the colliding atoms. When the thickness of the thin film is lesser or thin, the energy band gap is bigger due to the quantum effect [24].

Table 2 Energy band gap for as-deposited and heat treatment indium tin oxide

Thickness ($\times 10^{-9}$m)	**As-Deposited (eV)**	**Heat Treatment (eV)**
132	3.54	3.51
172	3.34	3.42
227	3.18	3.30
283	3.30	3.08
347	3.14	2.92
424	3.02	2.76

Furthermore, Table 2, figure 8 and figure 9 shows that, when the thin film undergoes annealing process, the energy band gap slightly decreases from as-deposited sample. When the sample is heated, it might change the structure of the semiconductor from amorphous to crystalline phases. Energy band gap for crystalline semiconductor is smaller than the amorphous semiconductor. This is due to the lack of long range order in amorphous where the configuration of amorphous atom is not rigid and not symmetrical while crystallize structure show more rigid and the atom more repetitive form. [25].

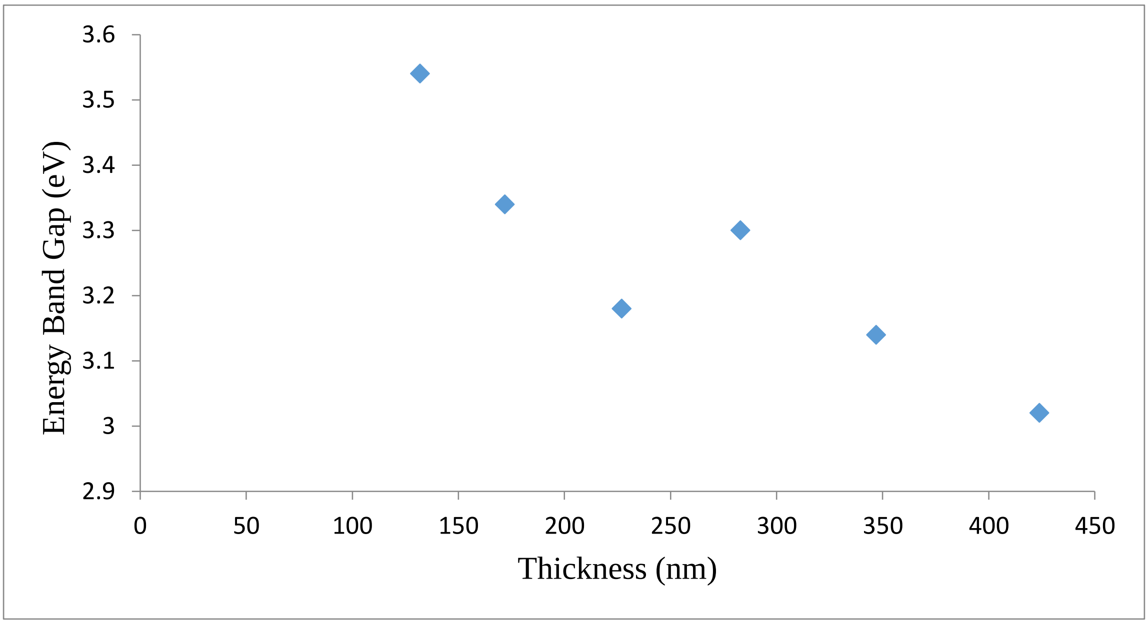

Figure 8 Energy band gap versus indium thin oxide thickness for as-deposited sample.

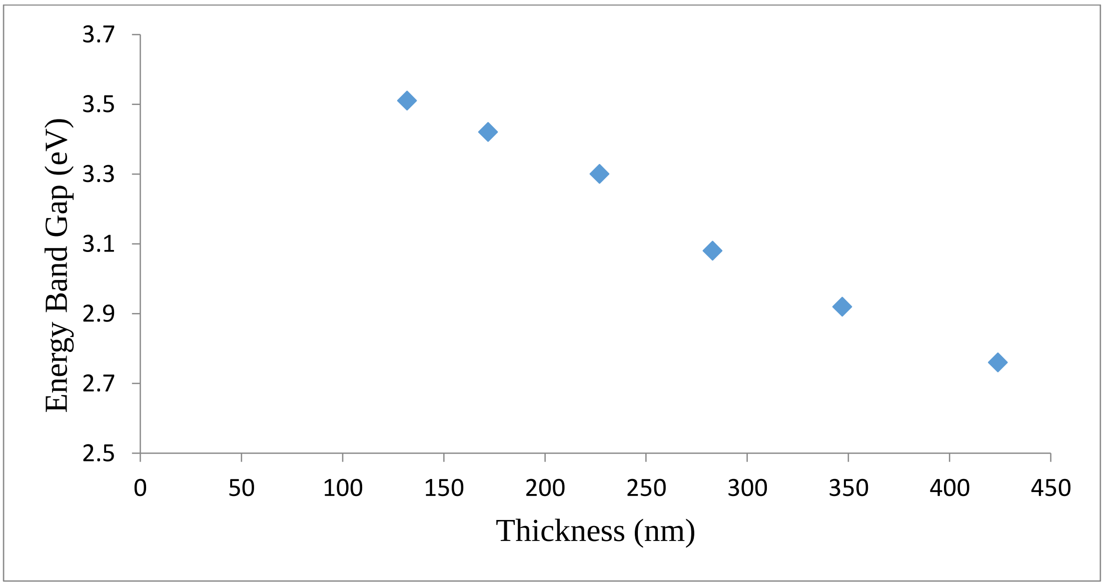

Figure 9 Energy band gap versus indium thin oxide thickness for annealing sample.

4. Conclusion

Indium tin oxide thin films have successfully been deposited on corning glass by using radio frequency magnetron sputtering technique. The optical properties of the deposited films are measured and characterized for as-deposited and annealed samples at 600°C for 4 hours. From the results, the average value of the transmittance about 88-90% is recorded. Film with thickness 132 nm for deposition time 15 minutes shows the highest transmittance. The annealed samples has shown slightly lower values of band gap as compared to the as-deposited samples. It is observed that, when the thickness of film is increased, the energy band gap is decreased.

5. Acknowledgments

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