Kingdom of Saudi Arabia
Imam Mohammad Ibn Saud Islamic University
College of Sciences – Department of Physics

Optical and morphological properties of Indium Tin oxide (ITO) thin films

A graduation project submitted to the Department of Physics in partial fulfillment of the requirements for the degree of Bachelor of Science in Physics

Belih Nasser Belih Al Fahadi

Supervisor:

Dr. Ahmed AL-Kaoud (IMSIU)

IMAMU – Riyadh -KSA

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Transparent Conductive Oxide (TCO)
Indium Tin Oxide (ITO)
Scanning Electron Microscopy (SEM)
Atomic Force Microscopy (AFM)
Energy-dispersive X-ray spectroscopy (EDX)

Acknowledgment شكر وتقدير

بسم الله الرحمن الرحيم

الى جميع من كان لهم دور في مسيرتي الاكاديمية

اود أن أعبر عن عميق امتناني وشكري لجميع من ساهم في وصولي إلى هذا الإنجاز العظيم، وهو حصولي على درجة البكالوريوس. لقد كانت رحلة مليئة بالتحديات، لكن بفضل الله ثم دعمكم المستمر، استطعت تخطي كل الصعاب وتحقيق هذا الحلم.

أشكر الدكاترة الكرام الذين كانوا مصدر إلهام لي، وقدموا لي العلم والمعرفة، وعلّمني كل منهم دروسًا لا تقدر بثمن والشكر موصل لمشرف البحث الدكتور احمد القعود على دعمه خلال هذا البحث وشكرا الى الدكتور نذير مصطفى والدكتور محمد عبدالرافع على جهودهم التعاونية اثناء جمع البيانات.

كما أود أن أقدم شكرًا خاصًا لأسرتي الحبيبة على دعمهم اللامحدود، وتشجيعهم المتواصل الذي كان له الأثر الأكبر في تحفيزي للوصول إلى هذا الهدف.

إنني اليوم أعيش لحظة فخر واعتزاز، وأعدكم أنني سأبذل قصارى جهدي للمساهمة في خدمة مجتمعي ووطننا الغالي بما تعلمته.

والحمد لله رب العالمين

Abstract

Indium Tin Oxide (ITO) thin films are crucial in various technological fields due to their combination of optical transparency and electrical conductivity. Their optical properties, including high transparency in the visible spectrum and tunable reflectance, make them ideal for use as transparent electrodes and in display technologies. The morphological properties, such as grain size, surface roughness, and thickness, play a significant role in determining their performance in different applications. Understanding and controlling these properties is a key to optimizing ITO films for specific uses, including energy-efficient devices, sensors, and displays.

الملخص

تعد الاغشية الرقيقة من أكسيد الانديوم والقصدير ذات أهمية كبيرة في مختلف المجالات التكنولوجية نظرا للجمع بين الشفافية البصرية والتوصيلية الكهربائية تجعل خصائصها البصرية, بما في ذلك الشفافية العالية في الطيف المرئي والانعكاس المنضبط , مثالية للاستخدام في الأقطاب الشفافة وتقنيات العرض, تلعب الخصائص التركيبية مثل حجم الحبيبات وخشونة السطح والسمك دور حاسما في تحديد أدائها في التطبيقات المختلفة. كما يعد فهم هذه الخصائص والسيطرة عليها امرا أساسيا لتحسين أداء الاغشية الرقيقة للاستخدامات محددة بما في ذلك الأجهزة الموفرة للطاقة وأجهزة الاستشعار والشاشات.

Introduction

Indium tin oxide (ITO) has a unique set of properties, such as high ultraviolet absorption, high reflectance infrared, good processing performance, good mechanical strength and abrasion resistance, and a wide band gap (3.5–4.2 eV). ITO also possesses great photo electrolytic properties that include electrical conductivity of 10^3–10^4 Ω^{-1} cm^{-1} and transparency of 80 to 95% in the visible range [1]. Based on the above-mentioned exceptional intrinsic properties, this material is widely used in the manufacture of flat panel display, solar cells, light emitting diodes (LEDs), microwave and radio frequency shielding devices, touch switches, architectural glass, and other fields [2]. However, the efficiency of relevant electronic devices has been limited by the large electrical resistivity of the transparent electrodes. Thus, it is important to keep the transparency high for ITO films without a noticeable drop, while decreasing their resistivity [3].

The physical properties of ITO films such as morphology and microstructure, also the electrical and optical properties depend on the preparation method and experimental conditions of films. Also, the crystallinity, surface roughness, impurity levels and band gap of the synthesized thin films may be affected by various growth conditions [4], [5], [6]. ITO Thin films can be obtained using different processes such as chemical vapor deposition (CVD), and physical vapor deposition (PVD) among them sputtering and pulsed laser deposition (PLD) [1-5].

In this project, we characterized commercial transparent conducting ITO thin films prepared by sputtering deposition technique on glass substrates. The optical properties, such as transmission, reflectance and absorption were measured. Also the optical band gap, morphology, and chemical composition of the ITO films were investigated. Our aim was to assess the possibility to use the films as anodes in optoelectronic devices such as organic light emitting diodes and even organic solar cells.

Chapter 1

Literature review

1.1 Transparent conductive oxide (TCO)

All the optically transparent and electrically conducting oxides (TCO) are binary or ternary compounds, containing one or two metallic elements. Their resistivity could be as low as 10^{-4} Ω.cm, and their extinction coefficient k in the optical visible range could be lower than 0.0001, owing to their wide optical band gap that could be greater than 3.6 eV. This remarkable combination of conductivity and transparency is usually impossible in intrinsic stoichiometric oxides; however, it is achieved by producing them with a non-stoichiometric composition or by introducing appropriate dopants.

1.2 Indium Tin Oxide (ITO)

Indium tin oxide (ITO) is a transparent and conductive ceramic material made by mixing indium oxide (In_2O_3) and tin oxide (SnO_2) [4]. Typically, ITO contains about 90% indium oxide and 10% tin oxide by weight. However, the exact composition may vary depending on the application. The material is widely known for its high optical transparency, electrical conductivity, and ease of deposition as a thin film.

ITO is used primarily in the electronics and optics industries. Its main applications include touch screens, liquid crystal displays (LCDs), organic light-emitting diodes (OLEDs), and solar panels. Additionally, it is employed in anti-reflective coatings and as a thin-film resistor [5]. Oxygen content in ITO depends on the stoichiometry during fabrication, as oxygen vacancies significantly affect its electrical properties. Its unique combination of transparency and conductivity makes it suitable for modern technology.

1.3 Physical Vapor Deposition (PVD)

1.3.1 Sputtering

Magnetron sputtering is a dominant technique for the production of thin films because a large quantity of thin films can be produced at relatively high purity and low cost.

This entails ejecting material from a source called a "target" onto a "substrate" like a silicon wafer shown in figure 1.1

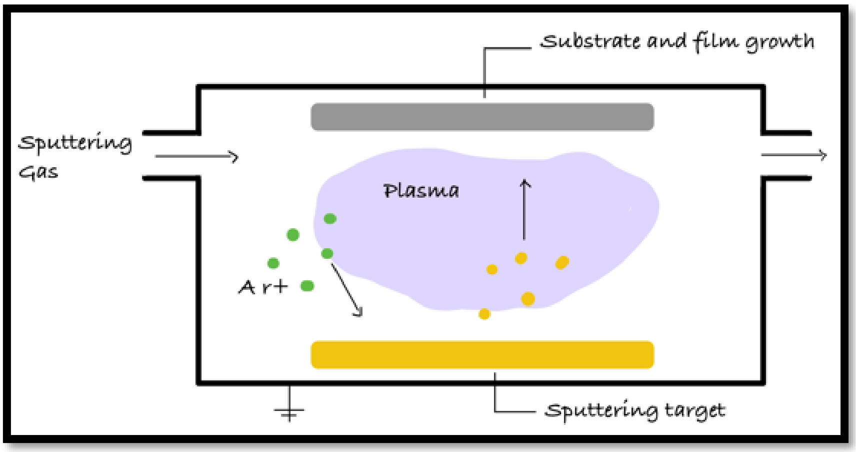

Figure 1.1: A schematic of a sputtering process system

Magnetron sputtering is a process of collision between incident particles and targets. Since high-speed sputtering is performed at low pressure, the ionization rate of the gas must be increased effectively. The incident particle undergoes a complex dispersion process in the target, collides with the target atom, and transmits part of the momentum to the target atom, which in turn collides with other target atoms to form a cascade process. During this cascade, certain target atoms near the surface gain sufficient momentum for outward motion and are spewed out of the target. Magnetron sputtering increases the plasma density by introducing a magnetic field on the surface of the target cathode and using the magnetic field constraints on the charged particles to increase the sputtering rate. Magnetron sputtering includes many types, such as direct current (DC) magnetron sputtering for conducting films and radio frequency (RF) for semiconducting and insulating films [3].

1.4 Pulsed laser deposition (PLD)

The experimental set-up for PLD experiment is based on two main equipment: a laser system and a vacuum chamber. The used laser systems were a Nd:YAG laser and an ARF excimer laser. The targets and collector substrate are mounted in the chamber in a vertical position, at variable distance. The angle of incidence of the laser beam was set at 45°. The substrates were fixed on a heating system. During deposition, the targets were rotated and the laser beam was translated on surface of the targets. The film deposition was performed in a dynamic ambient background gas (O_2, N_2, etc.) and the flow rates of gases were precisely controlled through a mass flow controller shown in Figure 1.2.

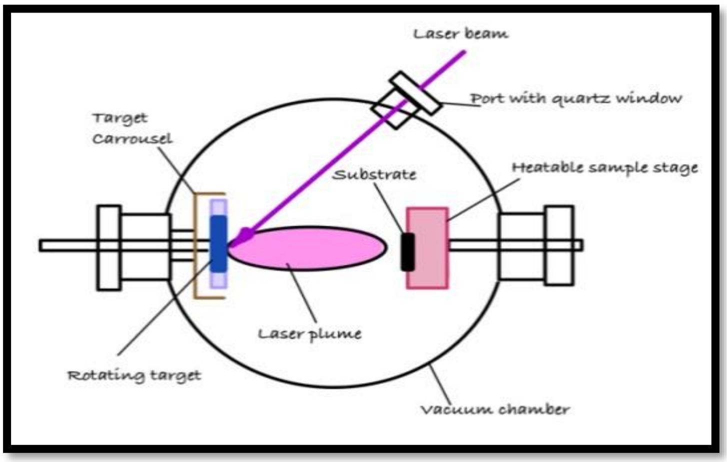

Figure 1.2: A schematic of a Pulsed laser deposition

Chapter 2

Experimental details

2.1 Commercial ITO

Commercial ITO thin films deposited on polished soda-lime glass substrates by a sputtering process were purchased from [MTL, USA]. The 150 nm thick films (ITO) were deposited on glass substrates (0.7 mm thick) and 1"×1" size were used for the deposition of the oxide films.

Optical properties such as transmission reflectance and absorption were measured using a UV-3600 i plus UV-Vis spectrophotometer. The surface morphology was examined by scanning electron microscopy (SEM).

Energy-dispersive x-ray (EDX) was performed to find the chemical composition of ITO film.

2.2 Scanning Electron Microscopy (SEM)

The surface morphology of ITO samples was investigated using Scanning Electron Microscopy (SEM) JEOL JSM-7600F. As shown in figure 2.1.

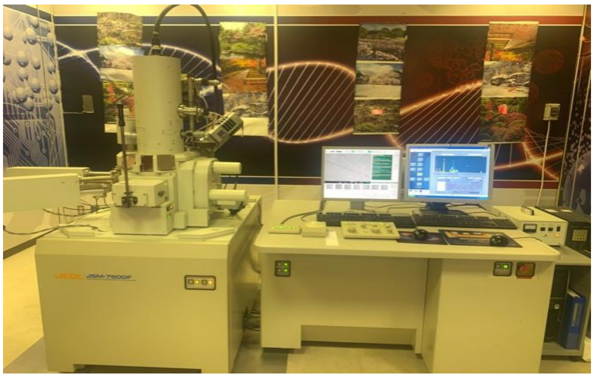

Figure 2.1: Scanning Electron Microscopy (SEM) used

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2.3 Atomic Force Microscopy (AFM)

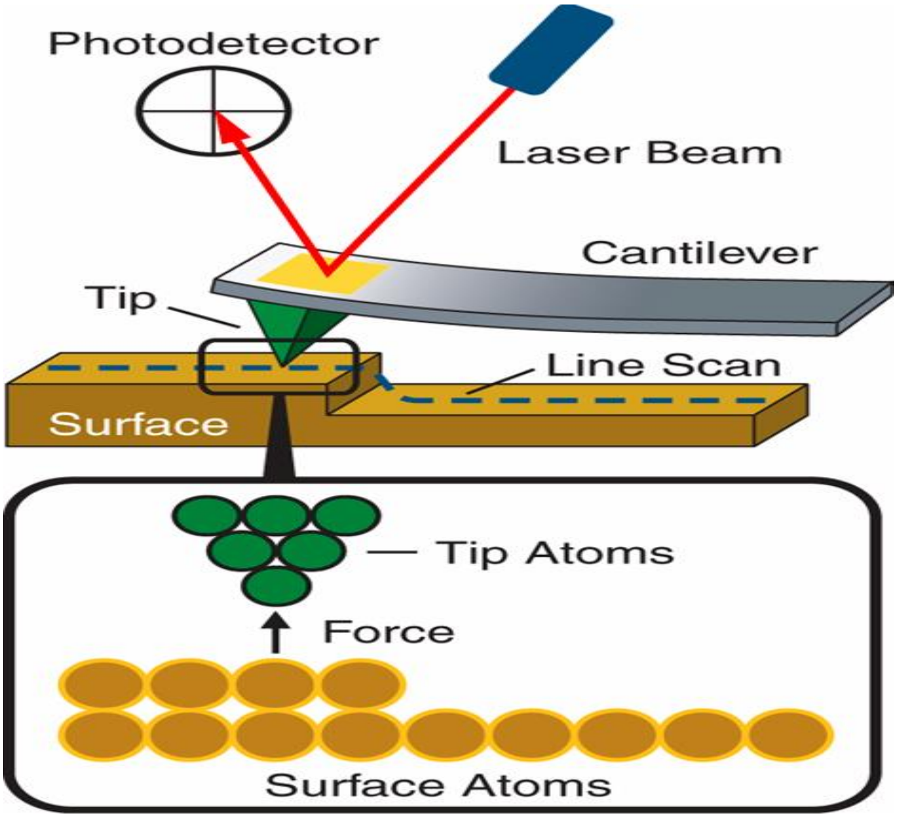


Figure 2.2: Schematic diagram of Atomic Force Microscopy (AFM) used.

Atomic force microscopy (AFM) was used to evaluate the morphology and surface roughness of the ITO films. The instrument type is an (AFM) Multi-Mode8-Bruker. Figure. 2.2 shows a schematic diagram of the Atomic Force Microscopy.

2.4 UV-visible spectrophotometer

The optical properties such as transmission, reflectance and absorption of the oxide films deposited on glass substrates were measured using a Perkin Elmer Lambda 950 UV-VIS spectrophotometer shown in figure 2.2, over the range from 350 to 800 nm.

Figure 2.3: UV-visible spectrophotometer

2.5 Energy-dispersive X-ray spectroscopy (EDX)

The chemical composition of the ITO samples was obtained using an Energy-dispersive X-ray spectroscopy (EDX) to examine the indium (In), tin (Sn), and oxygen O_2 concentration of the ITO films.

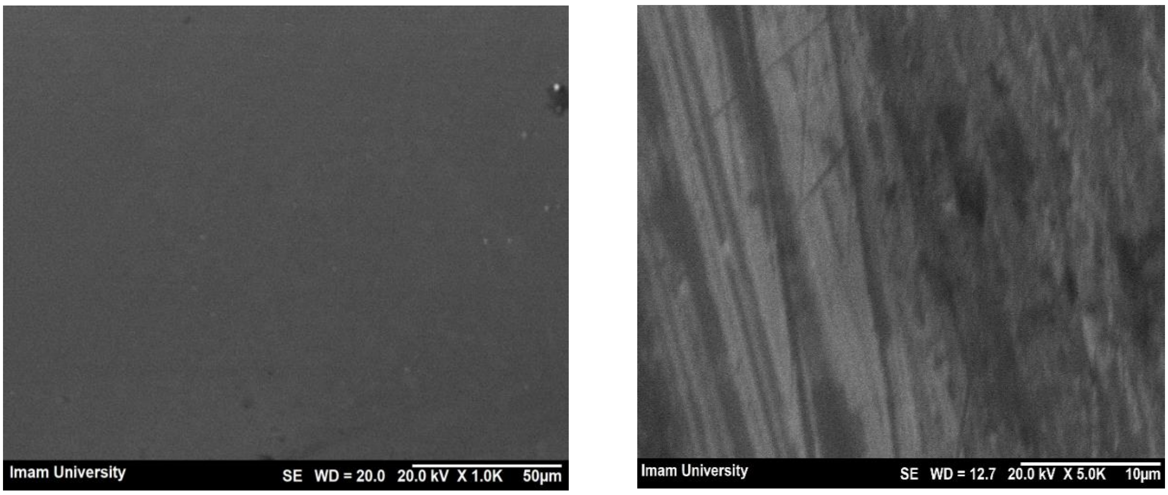
Chapter 3

Results and discussions

The morphology and composition of the ITO film were obtained through examination with SEM and EDX, respectively.
The results of morphological characterization were obtained by SEM using a magnification of 1000× and 5000x for the ITO surface layer. The energy gap was calculated from the absorption spectrum**.**

3.1 ITO morphology

Figure 3.1. (a) and (b) of the ITO surface morphology with various magnifications. Even with magnification 1K and 5K, the ITO film shows no features, this may be due to lack of magnification it was the small grain size of the film in the range (25-35) nanometers. It is also clear that the ITO film adheres well to the glass substrate

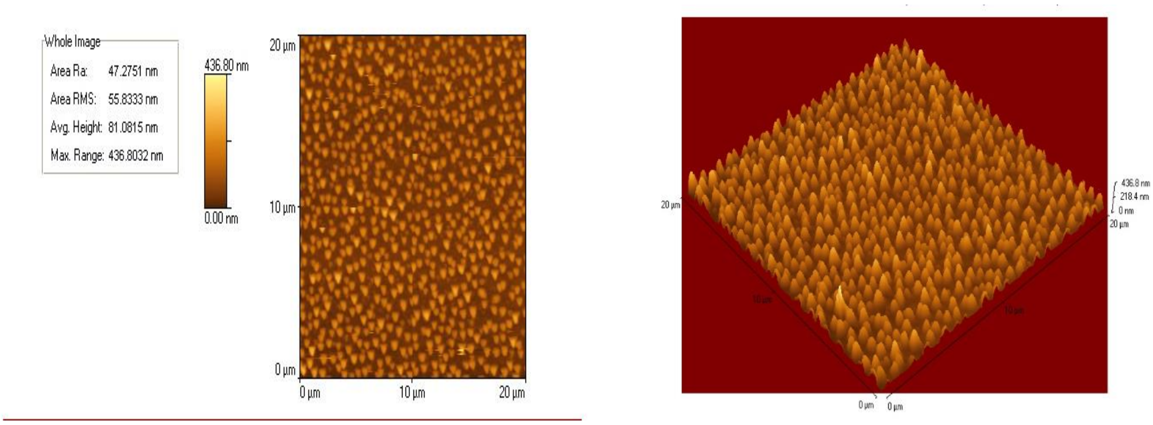


(a)1K **(b)5K**

Figure 3.1. ITO surface morphology images with magnifications: (a) 1K and (b) 5K.

3.2 Atomic Force Microscopy (AFM)

Figure 3.2: shows AFM images of the morphology and surface roughness of ITO films. We can observe from figure (3.2-a) that the grains are clear and small in size. Average roughness ($R_{avg.}$) of the ITO films was about 15-20 nm of film with a thickness of 150 nm as shown in fig. 3.2-b).



a) Morphology b) Surface Roughness

Figure 3.2: AFM images of (a) the Surface of as-deposited ITO thin film with small grains and (b) and roughness of the film

3.3 Optical Properties

3.3.1: Transmission

Transmission was measured at wavelengths range (300 - 800) nm.

Transmission is a fundamental property of thin films, determining their ability to allow light to pass through. In this study, the transmission of ITO was measured at wavelengths ranging from 300 to 800 nm, reflecting the film's efficiency in utilizing solar energy. The results indicate that ITO exhibits a high transmission rate of 88% at a wavelength of 550 nm, making it suitable for optical applications such as solar cells. It is also important to note that increasing the film thickness may negatively impact transmission, necessitating a balance between thickness and optical performance.

Figure 3.3: Depicts a graph of the transmission of the film across wavelengths ranging from 300 to 800 nm, demonstrating the film's capability to transmit light in this range, making it suitable for optical applications such as solar cells.

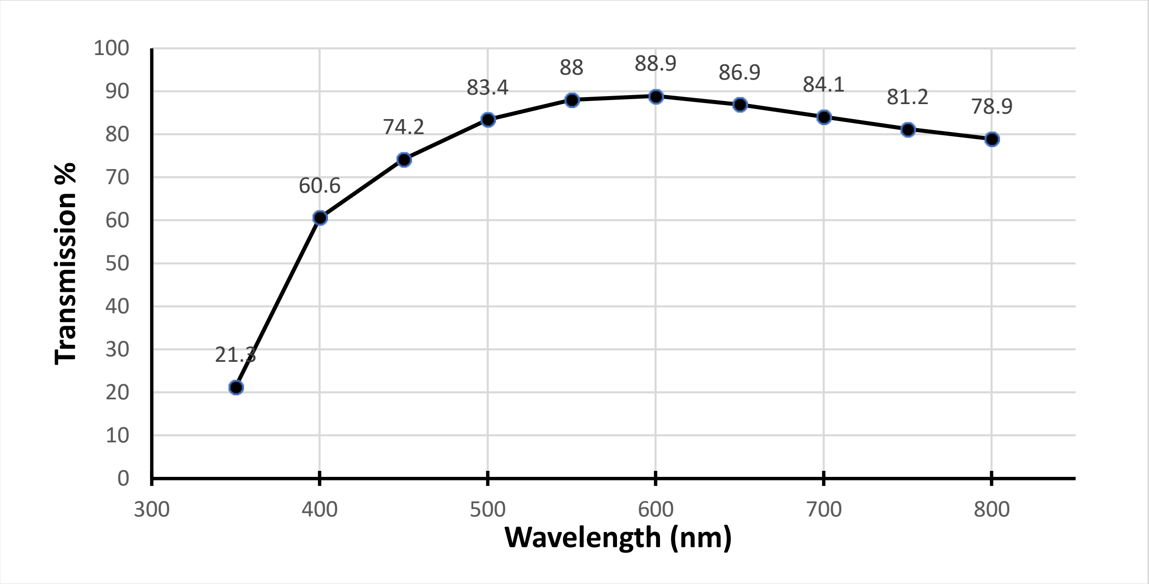


Figure 3.3: The transmission versus wavelength of ITO film in the range 300-800 nm

3.3.2: Reflection

Reflection of ITO films was measured at wavelengths range (300 - 800) nm.

Reflection measures the extent to which the film can reflect incident light, a crucial factor in optical applications. In the study, the reflection percentage was measured at 7.8% at a wavelength of 550 nm. This low reflection rate enhances the film's transmission efficiency, allowing maximum light to reach the active layers in solar cells. The low reflection is attributed to the structural and physical properties of the film, indicating a good compatibility between optical and morphological characteristics.

Figure 3.4: Shows a reflectance graph across the same wavelength range, indicating that the low reflectance at a particular wavelength enhances the film's efficiency in transmitting light by minimizing reflection, which boosts the device’s optical efficiency.

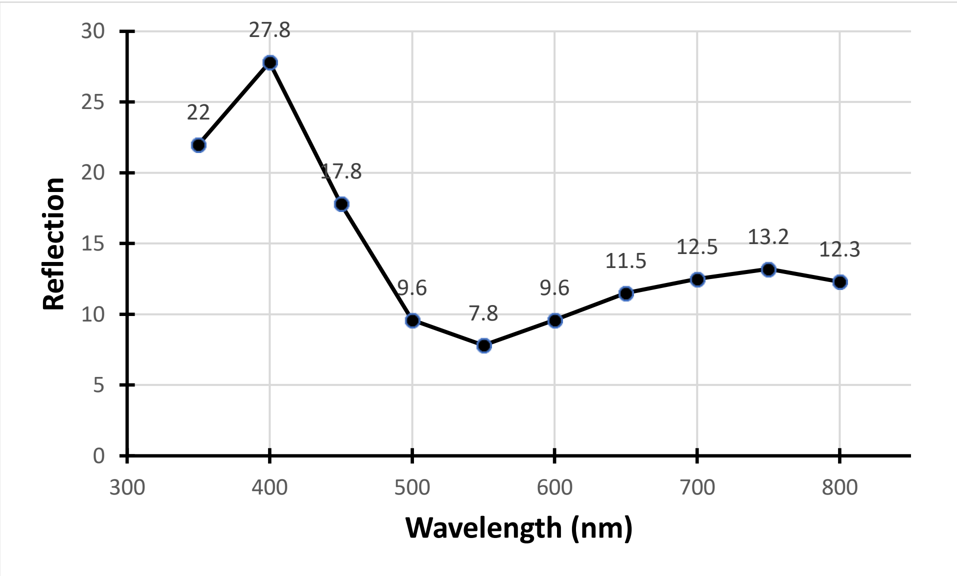


Figure 3.4: The reflectance versus wavelength of ITO film in the range 300-800 nm.

3.3.3: Absorption

Absorption was calculated using the relation (T + R + A = 1), which is essential for understanding how the material interacts with light. In this research, the absorption was reported to be 4.2% at a wavelength of 550 nm. This low absorption indicates that the film has a high capacity for transmitting light, a significant advantage in applications requiring light to reach active layers. The structural properties of the film can influence the absorption rate, thereby affecting overall performance in optical applications.

3.4: Energy Band Gap

The optical band gap energy E_g of each film was deduced from the absorption spectra by using the Tauc model.

The Tauc relation is written in equation (1) as:

$$(\alpha h\nu)^2 = C\left(h\nu - E_g\right) \qquad (1)$$

where α the absorbance coefficient, $h\nu$ is the photon energy, C is a characteristic Constant of the materials and E_g is the optical band gap energy between the valence and conduction bands.

Figure 3.5: Displays the optical band gap relation of the film with photon values, which serves as a key indicator of the material's electron transport capability, aiding in assessing its suitability for applications in optical devices such as light-emitting diodes and solar cells.

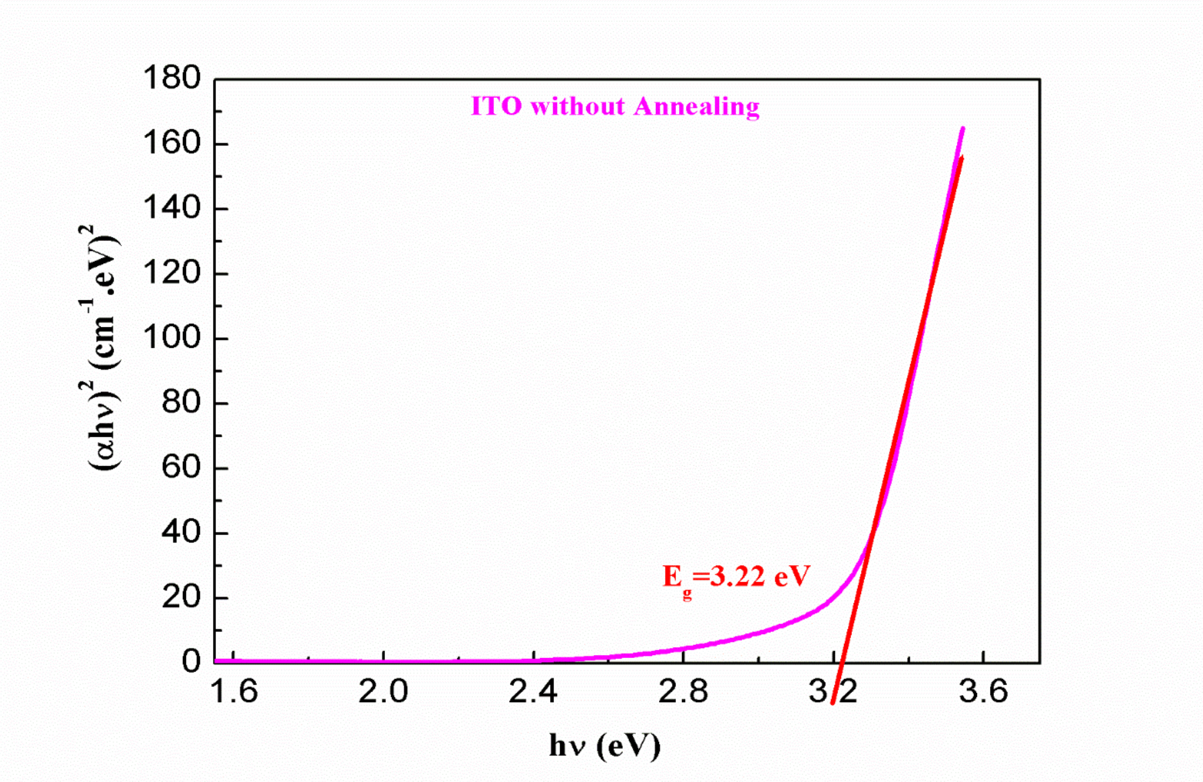


Figure 3.5: Direct optical band gap corresponding to $(\alpha h\nu)^2$ versus hν of the ITO film on glass substrate.

Table3.1: Summary of the optical properties with calculated Energy gap (Eg)

Sample	T%	R%	A%	Eg (ev)
ITO	88	7.8	4.2	3.22

N.B: T, R and A measured at wavelength 550 nm.

3.5 Energy Dispersive EDX

EDX is a vital technique for analyzing the chemical composition of thin films. Through energy spectrum analysis, precise information regarding the percentage of elements in the ITO film was obtained, revealing 50.9% oxygen, 4.4% tin, and 44.7% indium. These percentages reflect the ideal composition of the film and contribute to understanding how chemical composition affects the optical and electrical properties. Additionally, these results provide insights into how to optimize the preparation process to achieve better characteristics for use in optoelectronic applications.

Figure 3.6: Shows the Energy-Dispersive X-ray Spectroscopy (EDX) results for the ITO layer, providing information on the chemical composition of the thin film. The percentage of key elements such as oxygen, tin, and indium is displayed, which enhances the film's properties for optical applications.

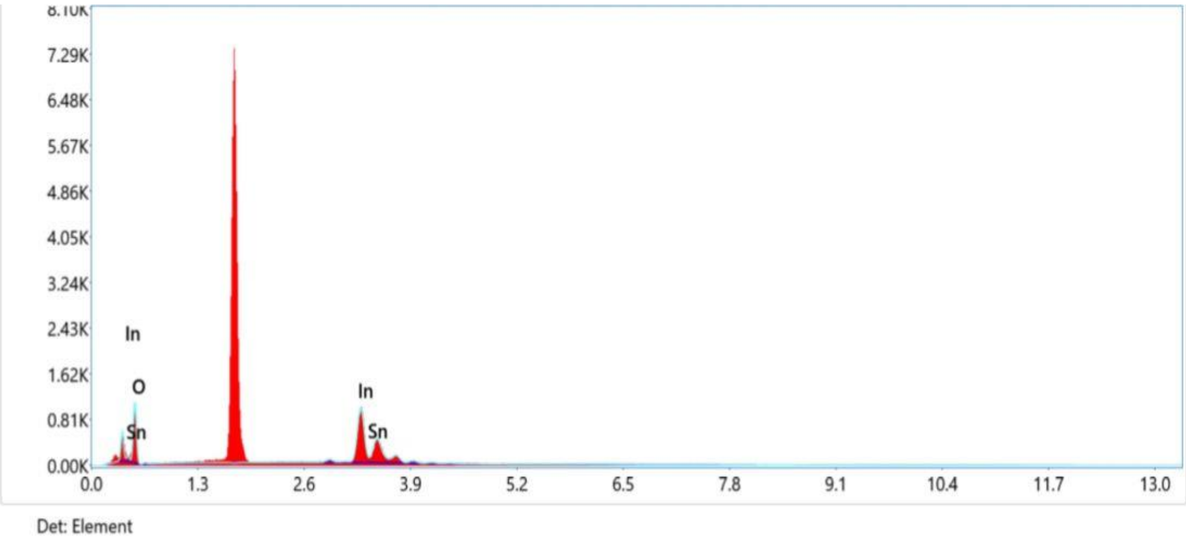


Figure 3.6: EDX of the ITO film

Chemical composition of the ITO film is shown in table 3.2

Table 3.2: EDX results of the ITO film.

Element	Weight %	Atomic %
O	50.9	88.2
In	44.7	10.8
Sn	4.4	1.0
Total	100.00	

Conclusion

In this research, we assessed optical and morphological properties of ITO films deposited onto glass substrates to confirm its suitability as a transparent anode for opto-electronic devices such as light emitting diodes and solar cells. High Optical transparency was maintained > 88% 550nm. The study successfully demonstrated that ITO, with its high transmission (88%), low reflection (7.8%), and minimal absorption (4.2%), is a promising candidate for use in optoelectronic applications, particularly in solar cells and light-emitting diodes. The analysis using EDX confirmed the favorable chemical composition of the ITO films, which is essential for optimizing their performance in practical applications. Overall, the results indicate that careful control of deposition methods and parameters can lead to the fabrication of high-quality ITO films, paving the way for advancements in the field of transparent conductive oxides. Future work should focus on exploring different deposition techniques and their effects on the film properties to further enhance performance and applicability.

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