THE IMPROVEMENT OF THE PHYSICAL PROPERTIES OF INDIUM TIN OXIDE THIN FILM THROUGH ANNEALING PROCESSES

MEHDI QASIM ZAYER

DOCTOR OF PHILOSOPHY (PHYSICS)

UNIVERSITI MALAYSIA PAHANG

SUPERVISORS' DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy in Physics.

____

(Supervisor’s Signature)

Full Name	: DR. MOHAMAD ASHRY BIN JUSOH
Position	: SENIOR LECTURER
Date	: / / 2016

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I hereby declare that the work in this thesis is my own except for quotations and summaries, which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

____

(Author's Signature)

Name : MEHDI QASIM ZAYER

ID Number :

Date : / / 2016

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MEHDI QASIM ZAYER

Thesis Submitted in Fulfillment of the Requirements for the Award of the Degree of Doctor of Philosophy in Physics Nanotechnology

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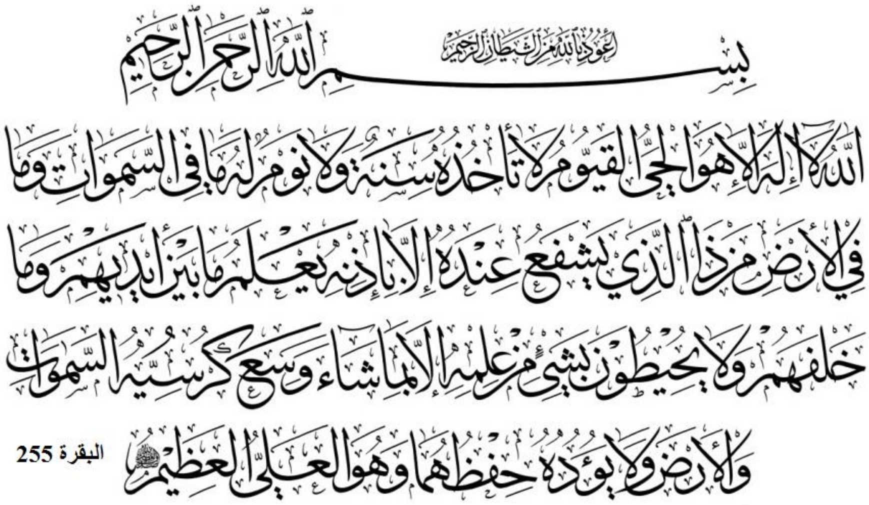
DEDICATION



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IN GOD WE TRUST

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LIST OF SYMBOLS

ε_0	dielectric constant in vacuum
ε_r	relative permittivity
β	broadening factor
θ	Bragg angle, peak angle position of diffracted X-ray
λ	X-ray wavelength
μ	mobility of free carriers
μ_N	mobility
ρ	Fluid Density;
σ	Electrical conductivity
τ	mean size of the crystalline domain
$\alpha\ (\lambda)$	absorption coefficient,

LIST OF ABBREVIATIONS

Symbol	Description
a	angle of attack
a_0	effective Bohr radius
AFM	Atomic Force Microscopy
1-D	one direction
CF	correction factor determined by the ratio of the
DMSO	Dimethylsulfoxid-6
d	Distance between atomic planes
DC	Direct Current
D_λ	Dark intensity at wavelength λ
e	evaporation rate
e	electron charge,
EBP	Emslie, Bonner, and Peck
ESCA	Electron Spectroscopy for Chemical Analysis
E_f	Fermi energy
eV	electron Volt
$F(\zeta_d)$	screening function
FPP	Four point probes
f_1	finite sample thickness
f_2	sample width correction factors
FESEM	Field Emission Scanning Electron Microscopy
g	Acceleration Due to Gravity
h	Planck’s constant
I	current
I(hkl)	measured intensity of a particular (hkl) plane,
In(hkl)	intensity of the nth peak
ITO	Indium Tin Oxide
m	film viscosity
K	shape factor,
L	mean-free path length
ln_2O_3	Indium Oxide
m	fluid viscosity

m	mass flux of solvent
m*	effective mass of the conduction electrons
n	significant peaks observed in the corresponding diffractogram
N	number of pixels within a given area
N	carrier concentration
nc	density
Ne	number of molecules evaporated from the unit area per second,
N_i	density of the charged scattering centers
N_n	concentration of neutral impurities
w	angular velocity
O	doubly charged vacancies
O_2	oxygen
P	Pressure;
Pe	Equilibrium vapor pressure (in Torr)
PVD	Physical Vapor Deposition
q	fluid flow rate
r	fluid density
r	radial distance
RF	Radio Frequency
RMS	Root Mean Square
R_λ	Reference intensity at wavelength λ
sccm	Standard Cubic Centimeters per Minute
s	fluid surface tension
s	probe spacing
SC	Spin Coating
SEM	Emission Scanning Electron Microscope
Sn	extrinsic dopants
SnO_2	tin dioxide
S_λ	Sample intensity at wavelength λ
r	solvent density
t	film thickness,
TCO	Transparent Conducting Oxide
TEM	Transmission Electron Microscopy

h	thickness
UV	Ultraviolet-Visible
V	potential difference , Voltage
v	substrate velocity
w	angular velocity
XRD	X-ray diffraction
Y	sputtering yield
z	Height
Zm	mean surface level within a given area,
$R(\lambda)$	normal incidence reflectivity,
$k(\lambda)$	extinction coefficient
$n(\lambda)$	real refractive index
TCOs	Transparent conducting oxides

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ABSTRACT

Many optoelectronic devices such as mobile screens, flat panel displays, solar cells and optical storages use Indium Tin Oxide (ITO) due to its ability to retain its good physical properties during the thin film preparation. Therefore, it is of great importance to study the related issues in applications utilizing ITO such as transparency and resistance as well as the underlying cost. These problems can be overcome by the enhanced annealing treatment which is called the Oil Thermal Annealing (OTA) technique in the current work. In this study, ITO thin films of thickness 200 nm are deposited on glass substrates by three preparation techniques, i.e. RF magnetron sputtering, thermal evaporation, and spin coating. The 200 nm ITO thin film is selected due to its relatively lower sheet resistance and higher transparency as compared to those thin films of thicknesses ranging from 100 nm to 300 nm. The RF magnetron sputtering technique is the best candidate in improving the ITO thin film properties. Upon the preparation process, the thin film is treated by OTA, argon and nitrogen operating at temperature range: 150 °C < T < 300 °C with the annealing time of 2, 6 and 10 min. Measurements and calculations are conducted before and after the preparation and treatment processes. The structural properties and surface morphology of ITO thin films are examined by X-Ray Diffraction (XRD), Atomic Force Microscopy (AFM) and Field Emission Scanning Electron Microscopy (FESEM) before and after the annealing process. The XRD analysis reveals that a polycrystalline structure of maximum diffraction intensity at $2\theta = 30.5^{o}$ and (222) orientation exists in the ITO thin film. FESEM and AFM analyses show that the formation of continuous and homogeneous films are fully covered by pyramidal shaped particles, and roughness value decreases with increasing annealing time. It is also observed that by using OTA treatment, the sheet resistance of ITO thin films prepared by the RF magnetron sputtering technique reduces significantly to 20.8 Ω/sq after 10 min of annealing time. On the other hand, the sheet resistance values of 70.8 Ω/sq and 72.6 Ω/sq are obtained via argon and nitrogen gas treatments, respectively. The As-deposited sheet resistance is 2.8 kΩ/sq. The visible spectrum obtained from the spectrophotometer has shown high transparency values of 95.6 %, 89.9 % and 85 % for RF sputtering which are treated by OTA, argon and nitrogen respectively. OTA gives the highest transparency value, due to the fact that the thermal distribution on the ITO thin film surface treated by OTA is better than those by using argon and nitrogen gases. The OTA treatment process is shown to be successful in improving the ITO thin film properties, which is valuable for many optoelectronic applications. The OTA process can be applied in nano-layers of various sizes and thicknesses at minimum production cost. The total costs incurred after the preparation process (via RF magnetron sputtering technique) and the annealing process (performed at temperature 300 ºC with time 10 min annealing time) using OTA, argon and nitrogen are RM 4.40, RM 46.60 and RM 46.06, respectively. From the current work, it is found that the adhesion strength of the ITO thin film prepared by the RF magnetron sputtering technique and treated by OTA is the highest. Also, the structural, optical and electrical properties can be improved as well by using the proposed technique.

ABSTRAK

Banyak peranti optoelektronik seperti skrin mudah alih, paparan panel rata, sel suria dan penyimpanan optik menggunakan Timah Indium Oksida (ITO) kerana kemampuannya untuk mengekalkan ciri-ciri fizikal yang baik semasa penyediaan filem nipis. Oleh itu, adalah amat penting untuk mengkaji isu-isu yang berkaitan dalam aplikasi menggunakan ITO seperti ketelusan dan rintangan. Masalah-masalah ini boleh diatasi dengan rawatan penyepuhlindapan dipertingkatkan yang dipanggil teknik penyepuhlindapan haba minyak (OTA). Dalam kajian ini, filem nipis ITO berketebalan 200 nm didepositkan pada substrat kaca dengan tiga teknik penyediaan, iaitu percikan pemagnetan RF, penyejatan haba, dan putaran saduran. Filem nipis ITO 200 nm dipilih kerana rintangan lembaran yang rendah dan ketelusan yang lebih tinggi berbanding dengan filem-filem nipis berketebalan antara 100 nm hingga 300 nm. Percikan pemagnetan RF adalah teknik yang baik dalam meningkatkan sifat filem nipis ITO. Setelah proses penyediaan, filem nipis dirawat dengan OTA, argon dan nitrogen beroperasi pada julat suhu: 150 °C < T < 300 °C dengan masa penyepuhlindapan daripada 2, 6 dan 10 minit. Pengukuran dan pengiraan dijalankan sebelum dan selepas proses penyediaan dan rawatan. Sifat-sifat struktur dan permukaan morfologi filem nipis ITO diperiksa oleh pembelauan sinar-X (XRD), Mikroskop Daya Atom (AFM) dan Mikroskop Pengimbas Elektron Emisi Medan (FESEM) sebelum dan selepas proses penyepuhlindapan. Analisis XRD menunujukkan bahawa terdapat struktur polihabluran dengan keamatan puncak maksimum pada $2\theta = 30.5^{o}$ dan orientasi (222) wujud dalam filem nipis ITO. Analisis FESEM dan AFM menunjukkan bahawa pembentukan filem yang berterusan dan seragam dilindungi sepenuhnya oleh puncak piramid berbentuk zarah, nilai kekasaran permukaan lebih tinggi dengan peningkatan masa penyepuhlindapan. Ia juga diperhatikan bahawa dengan menggunakan rawatan OTA, rintangan helai daripada ITO filem nipis yang disediakan oleh teknik percikan pemagnetan RF berkurang dengan ketara kepada 20.8 Ω/ persegi selepas 10 minit masa penyepuhlindapan. Sebaliknya, nilai rintangan helai pada 70.8 Ω/ persegi dan 72.6 Ω/ persegi diperolehi masing-masing melalui rawatan gas argon dan nitrogen. Rintangan helai As-deposit adalah 2.8 kΩ/ persegi. Spektrum nampak diperolehi daripada spektrofotometer menunjukkan nilai-nilai ketelusan yang tinggi pada 95.6 % , 89.9 % dan 85 % untuk percikan pemagnetan RF yang dirawat masing-masing oleh OTA, argon dan nitrogen. OTA memberikan nilai ketelusan tertinggi, disebabkan oleh fakta bahawa pengagihan haba di permukaan filem nipis ITO yang dirawat oleh OTA adalah lebih baik daripada menggunakan gas argon dan nitrogen. Proses rawatan OTA ditunjukkan berjaya dalam meningkatkan sifat-sifat filem nipis ITO, yang bernilai untuk banyak aplikasi optoelektronik. Proses OTA boleh digunakan dalam pelbagai saiz dan ketebalan nanolapisan pada kos pengeluaran yang minimum. Jumlah kos yang ditanggung selepas proses penyediaan (melalui teknik percikan pemagnetan RF) dan proses penyepuhlindapan (dilakukan pada suhu 300 °C dengan masa masa 10 minit penyepuhlindapan) menggunakan OTA, argon dan nitrogen adalah masing-masing RM 4.40, RM 46.60 dan RM 46.06. Dari kajian semasa, didapati bahawa kekuatan lekatan filem nipis ITO yang disediakan dengan teknik percikan pemagnetan RF dan dirawat dengan OTA adalah yang tertinggi. Juga, sifat-sifat struktur, optik dan elektrik boleh diperbaiki dengan menggunakan teknik yang dicadangkan.

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