UNIVERSITI PUTRA MALAYSIA

OPTICAL PROPERTIES OF ZINC OXIDE THIN FILMS FABRICATED VIA RADIO FREQUENCY MAGNETRON SPUTTERING FOR OPTICAL HYDROGEN GAS SENSOR APPLICATION

SITI NOR ALIFFAH BINTI MUSTAFFA

FS 2018 94

OPTICAL PROPERTIES OF ZINC OXIDE THIN FILMS FABRICATED VIA RADIO FREQUENCY MAGNETRON SPUTTERING FOR OPTICAL HYDROGEN GAS SENSOR APPLICATION

By

SITI NOR ALIFFAH BINTI MUSTAFFA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

October 2017

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

OPTICAL PROPERTIES OF ZINC OXIDE THIN FILMS FABRICATED VIA RADIO FREQUENCY MAGNETRON SPUTTERING FOR OPTICAL HYDROGEN GAS SENSOR APPLICATION

By

SITI NOR ALIFFAH BINTI MUSTAFFA

October 2017

Chairman: Suriati binti Paiman, PhD
Faculty: Science

This thesis focused on the optimization of zinc oxide (ZnO) thin films for optical hydrogen (H_2) gas sensor using radio frequency (RF) magnetron sputtering technique. Various strategies were adopted to produce optically controlled thin films with the desired properties. This work focused on the effect of deposition parameters that included deposition time, RF power, argon/oxygen (Ar/O_2) gas percentage, and annealing condition on thin film thickness, surface roughness, crystal phase, phonon modes, and optical band gap. The thin films' surface morphology and thickness were characterized carefully using atomic force microscopy (AFM) and surface profilometry, respectively, while crystallographic structure was examined using X-ray diffraction (XRD). Ultraviolet visible spectroscopy (UV-VIS) was used to investigate the optical transmittance and band gap of the produced films. Fourier transforms infrared spectroscopy (FTIR) was performed to examine the functional group, while Raman spectroscopy was used to characterize the phonon modes.

Deposition time was found to have a very significant effect on thin film thickness, where the thicker thin film obtained when deposited for 180 min was 851.35 ± 4.45 nm. XRD analysis confirmed that RF power of 150 W with influence of post-deposition annealing was able to promote growth of crystal structure with crystal plane orientation of (002) as hexagonal wurtzite structure. Furthermore, increasing the RF power from 50 to 150 W also reduced the surface roughness from 88.2 to 6.86 nm. In order to improve the optical properties, O_2 gas percentage was reduced from 50% to 4%. However, there was an existence of diffraction peak at (011) plane despite improving the intensity of diffraction peak at plane (002) at 4% of O_2 gas percentage. This was due to O_2 atoms that induced the breaking and reforming of Zn-O bonds, which could modify the ZnO bonding network. Finally, optimized ZnO thin films

were successfully deposited with RF power of 150 W and 4% of O_2 gas percentage for 180 min. It was found that Raman active phonon modes for the optimized ZnO thin films were at E2 (high) and A1 (LO) which were 440 and 565 cm^{-1}, respectively. The FTIR analyses showed that ZnO absorption bands in the fingerprint region between 500-450 cm^{-1} had arisen from inter-atomic vibrations due to stretching of Zn-O bond. Hence, the optimized ZnO thin films were tested for H_2 optical sensing application. At the operating temperature of 27 ^{o}C with concentration of H_2 gas at 2 mol%, it was found that gas sensing characteristic of novel RF-sputtered ZnO thin film was strongly influenced by crystalline at the size of 124.10 nm, thickness of 399.43 ± 1.47 nm and surface roughness of 18.9 nm. The gas sensing mechanism of the novel RF-sputtered ZnO thin film was based on the surface reaction between adsorbed oxygen and the H_2 gas where more oxygen was chemisorbed in the form of O_2^-, O^-, and O^{2-} by ZnO thin film. The calculated molar absorptivity, ε increased with the increase of rms surface roughness whereby relatively high surface roughness is better to optically absorb H_2 gas.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENCIRIAN OPTIK SAPUT TIPIS ZINK OKSIDA MENGGUNAKAN PERCIKAN MAGNETRON RADIO FREKUENSI UNTUK SENSOR OPTIK GAS HIDROGEN

Oleh

SITI NOR ALIFFAH BINTI MUSTAFFA

Oktober 2017

Pengerusi: Suriati binti Paiman, PhD
Fakulti: Sains

Kajian ini menumpukan kepada saput tipis zink oksida (ZnO) untuk tujuan aplikasi sensor optik gas hidrogen (H_2) yang telah dihasilkan dengan teknik percikan magnetron radio frekuensi (RF). Terdapat pelbagai pendekatan strategi bagi mengawal penghasilan ciri-ciri tertentu saput tipis ZnO. Oleh itu, kajian ini memfokuskan kepada kesan durasi pemendapan, kuasa RF, nisbah gas argon/oksigen (Ar/O_2) dan proses sepuh lindap ke atas ketebalan saput tipis, kekasaran permukaan, fasa kristal, mod fonon dan jurang jalur optik. Pencirian kekasaran permukaan dan ketebalan saput tipis masing-masing menggunakan mikroskopi daya atom (AFM) dan profilometri permukaan. Di samping itu, spektroskopi ultralembayung (UV-VIS) digunakan untuk mengenalpasti kehantaran optik dan jurang jalur saput tipis. Selain itu, spektroskopi transformasian Fourier inframerah digunakan bagi mengkaji kumpulan berfungsi, manakala spektroskopi Raman untuk mencirikan mod fonon.

Hasil dapatan kajian mendapati bahawa durasi pemendapan memberi kesan yang ketara ke atas ketebalan saput tipis. Hal ini demikian kerana pada durasi pemendapan selama 180 minit, saput tipis setebal 851.35 ± 4.45 nm telah dihasilkan. Tambahan itu, analisa XRD mengesahkan bahawa kuasa RF sebanyak 150 W dan proses sepuh lindap dapat menggalakan pertumbuhan struktur kristal pada satah (002) sebagai struktur wurtzit heksagon. Begitu juga dengan peningkatan kuasa RF daripada 50 kepada 150 W telah mengakibatkan nilai kekasaran permukaan saput tipis menurun daripada 88.2 kepada 6.86 nm. Bagi menambahbaik ciri-ciri optik saput tipis ZnO, nisbah gas O_2 telah direndahkan kepada 4% daripada 50%. Walaubagaimanapun, terdapat kemunculan puncak belauan pada satah (011) selain peningkatan keamatan puncak belauan (002) ketika nisbah gas O_2 pada 4%. Ini berpunca daripada atom O_2 yang mempengaruhi pemutusan dan pembentukan semula ikatan Zn-O, sekaligus mengubahsuai jaringan pengikatan ZnO. Dalam pada itu, mod fonon Raman juga dikesan pada E2 (tinggi) dan A1 (LO) iaitu pada 440 dan 570 cm^{-1}, masing-masing. Kajian transformasian Fourier inframerah pula mendapati bahawa jalur serapan ZnO adalah pada jurang 500 – 450 cm^{-1} yang berpunca daripada hasil getaran atom yang disebabkan oleh regangan ikatan zink dan oksigen. Akhir sekali, saput tipis ZnO yang optimum telah digunakan bagi tujuan aplikasi pengesanan gas H_2 secara optik. Pada suhu 27 ^{o}C dengan kepekatan gas H_2 sebanyak 2 mol%, pencirian saput tipis ZnO didapati amat dipengaruhi oleh saiz kristal bernilai 124.10 nm dengan ketebalan saput tipis iaitu 399.43 ± 1.47 nm selain kekasaran permukaan sebanyak 18.9 nm. Mekanisme pengesanan gas ialah berasaskan kepada interaksi reaksi permukaan antara oksigen yang dijerap dengan gas H_2 di mana lebih banyak oksigen telah diserap secara kimia dalam bentuk O_2^-, O^- dan O^{2-} oleh saput tipis ZnO. Daya penyerapan molar yang telah dikira, ε didapati meningkat dengan peningkatan kekasaran permukaan rms. Secara konklusinya, kekasaran permukaan yang agak tinggi adalah dirumuskan sebagai lebih baik untuk menyerap gas H_2 secara optik berdasarkan dapatan kajian ini.

ACKNOWLEDGEMENTS

In the name of Allah s.w.t The Most Gracious, The Most Merciful. An infinite gratitude highly dedicated to Him for His abundant rahmah and bless.

First and foremost, an infinite gratitude for my supervisor, Dr. Suriati binti Paiman for she had passionately provided the vision, encouragement and advice necessary for me to proceed through and complete thesis with success. Beyond Physics which sometimes seemed to be nothing more than a distant dream, she has been a compatible lecturer for many times as well as a mentor and possessed the greatest quality in a student's life. Equally significant, technical assistance and constructive ideas from my wonderful co-supervisors a.k.a *The Heroes*; Dr. Nizam bin Tamchek and Prof. Dr. Abdul Halim bin Shaari, are undoubtedly gave major contribution in this Master journey. No words can describe how thankful I am to them all.

In the various lab works and research experiences, I have been aided with many months in studying researches published, running the equipment, and result analysis by a great supportive team. I offer them; Dr. Mohd. Hanif bin Yaacob, Mr. Ahmed Lateef, Ms. Azelah and Ms. Nurul Assikin, my sincere thanks for their patience and knowledge whilst allowing me the room to work in my own way and easy access to any particular area I interested on.

In prior, I would love to express my heartfelt love and gratitude towards my family and tremendous friends, for their unwavering faiths and support towards me. Financial support from Ministry of Higher Education (MyBrain15) and UPM (GRF) are gratefully acknowledged.

APPROVAL

I certify that a Thesis Examination Committee has met on (date of viva voce) to conduct the final examination of (student's name) on his (her) thesis entitled ("Title of Thesis") in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the (insert the name of relevant degree).

Members of the Thesis Examination Committee were as follows:

Name of Chairperson, PhD
Title (e.g., Professor/Associate Professor/Ir; omit if irrelevant)
Name of Faculty
Universiti Putra Malaysia
(Chairman)

Name of Examiner 1, PhD
Title (e.g., Professor/Associate Professor/Ir; omit if irrelevant)
Name of Faculty
Universiti Putra Malaysia
(Internal Examiner)

Name of Examiner 2, PhD
Title (e.g., Professor/Associate Professor/Ir; omit if irrelevant)
Name of Faculty
Universiti Putra Malaysia
(Internal Examiner)

Name of External Examiner, PhD
Title (e.g., Professor/Associate Professor/Ir; omit if irrelevant)
Name of Department and/or Faculty
Name of Organisation (University/Institute)
Country
(External Examiner)

____
(Insert name of current Deputy Dean)
(E.g. XXXXX XXXX, PhD)
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Suriati binti Paiman, PhD
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Nizam bin Tamchek, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Member)

Abdul Halim bin Shaari, PhD
Professor
Faculty of Science
Universiti Putra Malaysia
(Member)

ROBIAH BIN YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ________________________ Date: __________________

Name and Matric No.: ____

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature : ______________________________
Name of Chairman of Supervisory Committee : Prof. Madya Dr. Suriati binti Paiman

Signature : ______________________________
Name of Member of Supervisory Committee : Dr. Nizam bin Tamchek

Signature : ______________________________
Name of Member of Supervisory Committee : Prof. Dr. Abdul Halim bin Shaari

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Ar	Argon
DC	Direct Current
FT-IR	Fourier Transform Infrared
H_2	Hydrogen
IR	Infrared
LO	Longitudinal Optical
MOS	Metal Oxide Semiconductor
O_2	Oxygen
PVD	Physical Vapour Deposition
RF	Radio Frequency
TO	Transverse Optical
UV-VIS-NIR	Ultraviolet-Visible-Near Infrared
XRD	X-ray Diffraction
ZnO	Zinc Oxide

CHAPTER 1

INTRODUCTION

This chapter highlights the project background, motivation, problem statement and research objectives of metal oxide semiconductor thin film for optical gas sensor technology.

1.1 Background and Motivation

Before man's civilization era in industrialization began, air pollution was mainly contributed by open fire burning that resulted in carbon dioxide (CO_2) and carbon monoxide (CO). With the beginning of man-made industries, the emission of numerous air pollutants rose with time. Diseases such as asthma, lung cancer, heart disease, chronic obstructive pulmonary disease (COPD), and other examples of dangerous health consequences are connected to harmful gases according to the American Heart Association (Lang et al., 2009; Matamis et al., 2012). Hence, gas sensor technology is a worldwide hit agenda and vigorously adopted by many industries to monitor the chemical species and their concentrations.

Hydrogen (H_2) gas, while not considered a pollutant gas itself, is proclaimed to be the fuel of the future (Pimentel et al., 2008). Hydrogen is the most abundant element in the universe, and is nominated as the most potential sustainable energy supply system (Dincer, 2008). In medical purposes, hydrogen gas mixture can be an exclusive antioxidant (Ishibashi, 2013). In solid state science, despite its potential as an electron donor in many oxide materials, hydrogen gas can also help to stabilise material properties by saturating broken ("dangling") bonds of amorphous silicon and amorphous carbon (Wang et al., 2016).

Hydrogen is nature's lightest and smallest atom with atomic number 1, non-toxic, odorless, and tasteless. With less than 12% of oxygen concentration in a closed system, a small leak of H_2 gas will cause immediate unconsciousness and severe asphyxiation, a deficient supply of oxygen to the body that arises from abnormal breathing (Pan et al., 2016). At a standard atmospheric temperature, 4-75% concentration of hydrogen is flammable, and at 15-59% concentration, it could possibly cause an explosion (Al-Salman et al., 2013).

Additionally, the H_2 gas leak is extremely hazardous because common electrostatic discharge (ESD) or lightning is enough to be the source of ignition.

Other than that, metal hydrides technology is mainly used for hydrogen storage, but brittle metal hydride is due to mechanical instability in the corroded metals caused by the H_2 gas itself (Lototskyy et al., 2015). Without exception, highly sensitive H_2 gas sensors with low operating temperatures are also demanded in many critical applications such as hydrogen generation plants (Henriksen et al., 2016), fuel cell electric vehicle (Abdollahi et al., 2012), and volatile nuclear reactors (Moore, 2017). Therefore, studying the sensing material and sensing mechanism of H_2 gas is extremely crucial as conducted throughout this project.

1.2 Metal Oxide Semiconductor Thin Film for Optical Gas Sensing Technology

In this 21st century, the ultimate capability of a gas sensor has progressed rapidly. The biggest challenge is to identify and gain comprehensive information about the variety of gases present in an air ambient environment. Different applicability and inherent limitations of gas sensor technology influenced the characteristic of measured gas. Despite the rising number of gas sensors being introduced, metal oxide semiconductor (MOS) gas sensor still remains far from being satisfactorily understood.

MOS such as SnO_2, Fe_2O_3, TiO_2, ZnO, In_2O_3, and WO_3 are being widely investigated for gas detection application because of their intriguing working mechanism. It was found that the surface morphology of MOS thin film plays an important role in gas sensing performance (Sun et al., 2012). On top of that, ZnO thin film demonstrates good sensitivity with the chemical environment and reliable material towards high temperature application.

Various chemical and physical deposition techniques have been employed to produce ZnO thin film, for example, chemical vapor deposition (Ye et al., 2003), physical vapor deposition (Pattini et al., 2015) and pulsed laser deposition (Zhao et al., 2007) methods. In this work, such properties of ZnO thin films deposited using radio frequency magnetron sputtering will be used towards gas sensor application. Furthermore, structural, optical, and surface morphology features of ZnO thin film will be studied to investigate their effects on H_2 gas sensing mechanism.

The general detection mechanism responsible for ZnO gas sensor is the change of electrical resistance due to the electron conduction across grain boundaries (Gruber et al., 2003). These oxygen rich grain boundaries lead to potential barriers that deplete the carriers surrounding them and impede the current flow.

Apparently, the integration of ZnO thin film with the optical gas sensor is believed to yield better performance by incorporating it with optical fibre (Dikovska et al., 2007). The optical techniques employed to measure the response in gas sensing are mounted on absorbance, reflectance, refractive index or luminescence change induced by the interaction between ZnO thin film and test gas. In this work, H_2 gas sensing mechanism and properties of pure ZnO thin film deposited on glass substrates are therefore studied using the optical gas sensor at room temperature.

1.3 Problem Statements

At present, several major research challenges in the field of gas sensing specialization have been gaining attention. A sensing element is expected to have high selectivity, stability, and sensitivity towards the targeted gas with the ability to operate at room temperature with low electrical power consumption. Other than that, there is no environmental degradation during its usage and without using expensive noble transition metals or dopant materials during the fabrication process.

Multifunctional semiconducting metal oxide, particularly ZnO, is being investigated for H_2 gas detection application. Recently, numerous studies have focused on how to optimize the structural and optical properties of ZnO thin films during its preparation. Several techniques have been employed for the preparation of ZnO thin film. Nonetheless, a few methods often suffer from the disadvantages of using noble metal catalyst and requiring high temperature, which causes a more complex preparation procedure and leaving catalyst impurities that degrade the properties of ZnO thin films. Therefore, an alternative technique such as radio frequency (RF) magnetron sputtering is the most suitable method that satisfies these limitations.

Besides that, post-deposition annealing will be implemented to improve the structural properties of ZnO, because of its capability to promote crystallinity of ZnO thin films and control the thin film's thickness. This work will also focus on the contribution of both surface roughness and grain size on optical gas sensing mechanism.

Essentially, thickness plays a vital role in optical gas sensor application and clearly needs to be optimized during the deposition process. Therefore, it is believed that by increasing the deposition time, it will also enhance the ZnO thin film's thickness. Apart from that, the phase structure of ZnO thin film is also a concern towards efficiency in sensing mechanism. For that, the optimization of other parameters such as RF power and O_2 gas percentage will significantly improve the crystallinity of ZnO thin films. Yet, the sensing mechanism is one of the crucial properties of optical-based ZnO gas sensor. However, the changes of optical properties in terms of absorptivity of pure ZnO thin films when exposed to H_2 gas are yet to be fully explored.

To conclude these research questions, the author focused the investigation on pure ZnO thin films deposited by RF magnetron sputtering. It is expected that a sensitive and responsive sensor will be realized by RF-sputtered ZnO thin film with slightly high root mean square surface roughness after post-deposition annealing. It is also proposed that the crystallized ZnO thin films possess the ability to exhibit optical sensing interaction with H_2 gas at room temperature. The ZnO thin films' characterization combined with the gas sensing performance contribute to the fundamental understanding of the gas interaction mechanisms in optical gas sensors.

1.4 Research Objectives

This research aims to deposit ZnO thin films using RF magnetron sputtering technique for optical H_2 gas sensor application. These outlined objectives are to attain the emphasized aim:

i. To deposit ZnO thin films via RF magnetron sputtering technique with various deposition conditions (time, RF power, O_2 gas percentage ,and post-deposition annealing);
ii. To characterize the structural properties (thickness, crystal structure, surface roughness, and grain size) of ZnO thin films through Surface Profilometry, XRD, and AFM;
iii. To investigate the optical properties (transmittance, band gap energy, functional group, and phonon modes) of ZnO thin films through Raman, FT-IR, and UV-VIS; and
iv. To study the optimized ZnO thin films on H_2 gas molecules-sensing layer absorptivity interaction at room temperature through UV-VIS-NIR.

REFERENCES

Abdollahi, M., Yu, J., Liu, P. K. T., Ciora, R., Sahimi, M. and Tsotsis, T. T. (2012). Ultra-Pure Hydrogen Production From Reformate Mixtures Using A Palladium Membrane Reactor System. *Journal of Membrane Science*, *390–391*, 32–42. http://doi.org/10.1016/j.memsci.2011.10.053

Acosta, M., Riech, I. and Martín T., E. (2013). Effects Of The Argon Pressure On The Optical Band Gap Of Zinc Oxide Thin Films Grown By Nonreactive RF Sputtering. *Advances in Condensed Matter Physics*, *2013*. http://doi.org/10.1155/2013/970976

Al-Hardan, N. H., Abdullah, M. J. and Aziz, A. A. (2010). Sensing Mechanism Of Hydrogen Gas Sensor Based On RF-Sputtered Zno Thin Films. *International Journal of Hydrogen Energy*, *35*(9), 4428–4434. http://doi.org/10.1016/j.ijhydene.2010.02.006

Al-Salman, H. S. and Abdullah, M. J. (2013). Fabrication And Characterization Of Zno Thin Film For Hydrogen Gas Sensing Prepared By RF-Magnetron Sputtering. *Measurement*, *46*(5), 1698–1703. http://doi.org/10.1016/j.measurement.2013.01.004

Bhunia, A. K., Jha, P. K., Rout, D., Saha, S. (2016). Morphological Properties and Raman Spectroscopy of ZnO Nanorods. *Journal of Physical Science*, *21,* 1-118.

Bigey, C. and Maire, G. (2000). Catalysis on Pd/WO_3 and Pd/WO_2 -II. Effect of Redox Treatments in Hexanes and Hexene Reforming Reactions. *Journal of Catalysis*, *196,* 224-240.

Cheng, Y. C., Jin, C. Q., Gao, F., Wu, X. L., Zhong, W., Li, S. H. and Paul, K. (2009). The Raman Scattering Study of Zinc Blende and Wurtzite ZnS. *Journal of Applied Physics*, 106, 123505. http://doi.org/10.1063/1.3270401

Chin, H. S. and Chao, L. S. (2013). The Effect Of Thermal Annealing Processes On Structural And Photoluminescence Of Zinc Oxide Thin Film. *Journal of Nanomaterials*. http://doi.org/10.1155/2013/424953

Choopun, S., Hongsith, N., Mangkorntong, P. and Mangkorntong, N. (2007). Zinc Oxide Nanobelts By RF Sputtering For Ethanol Sensor. *Physica E: Low-Dimensional Systems and Nanostructures*, *39*(1), 53–56. http://doi.org/10.1016/j.physe.2006.12.053

Chu S.Y., Water, W. and Liaw, J.T. (2003). Influence Of Postdeposition Annealing On The Properties Of Zno Films Prepared By RF Magnetron Sputtering. *Journal of the European Ceramic Society*, *23*(10), 1593–1598. http://doi.org/10.1016/S0955-2219(02)00404-1

De Julián Fernández, C., Manera, M. G., Pellegrini, G., Bersani, M., Mattei, G., Rella, R. and Mazzoldi, P. (2008). Surface Plasmon Resonance Optical Gas Sensing Of Nanostructured Zno Films. *Sensors and Actuators, B: Chemical*, *130*(1), 531–537. http://doi.org/10.1016/j.snb.2007.09.065

Decremps, F., Pellicer P. J., Saitta, A. M., Chervin, J.C. and Polian, A. (2002). High-Pressure Raman Spectroscopy Study Of Wurtzite ZnO. *Physical Review B - Condensed Matter and Materials Physics*, *65*(9). http://doi.org/10.1103/PhysRevB.65.092101

Della G. E., Guglielmi, M., Martucci, A., Giancaterini, L. and Cantalini, C. (2012). Enhanced Optical And Electrical Gas Sensing Response Of Sol-

Gel Based NiO-Au And ZnO-Au Nanostructured Thin Films. *Sensors and Actuators, B: Chemical*, *164*(1), 54–63. http://doi.org/10.1016/j.snb.2012.01.062
Dikovska, A. O., Atanasov, P. A., Tonchev, S., Ferreira, J. and Escoubas, L. (2007). Periodically Structured Zno Thin Films For Optical Gas Sensor Application. *Sensors and Actuators, A: Physical*, *140*(1), 19–23. http://doi.org/10.1016/j.sna.2007.05.032
Dincer, I. (2008). Hydrogen and Fuel Cell Technologies for Sustainable Future. *Jordan Journal of Mechanical and Industrial Engineering*, *2*(1), 1–14.
Fang, Z. B., Yan, Z. J., Tan, Y. S., Liu, X. Q. and Wang, Y. Y. (2005). Influence Of Post-Annealing Treatment On The Structure Properties Of ZnO Films. *Applied Surface Science*, *241*(3–4), 303–308. http://doi.org/10.1016/j.apsusc.2004.07.056
Fujimura, N., Nishihara, T., Goto, S., Xu, J. and Ito, T. (1993). Control Of Preferred Orientation For Znox Films: Control Of Self-Texture. *Journal of Crystal Growth*, *130*(1–2), 269–279. http://doi.org/10.1016/0022-0248(93)90861-P
Gabás, M., Díaz, C. P., Agull, R. F., Herrero, P., Landa, C. and Ramos B. J. R. (2011). High Quality Zno And Ga:Zno Thin Films Grown Onto Crystalline Si (100) By RF Magnetron Sputtering. *Solar Energy Materials and Solar Cells*, *95*(8), 2327–2334. http://doi.org/10.1016/j.solmat.2011.04.001
Georg, A, Graf, W, Neumann, R. and Wittwer, V. (2000). Stability of Gasochromic WO_3 Films. *Solar Energy Materials and Solar Cells*, *63*, 165-176.
Gruber, D., Kraus, F. and Müller, J. (2003). A Novel Gas Sensor Design Based On $CH_4/H_2/H_2O$ Plasma Etched ZnO Thin Films. *Sensors and Actuators, B: Chemical*, *92*(1–2), 81–89. http://doi.org/10.1016/S0925-4005(03)00013-3
Gupta, V. and Mansingh, A. (1994). Effect Of Post Deposition Annealing On Sputtered Zinc Oxide Film. In *IEEE International Symposium on Applications of Ferroelectrics*.
Haarindraprasad, R., Hashim, U., Gopinath, S. C. B., Kashif, M., Veeradasan, P., Balakrishnan, S. R., Mishra, and Y. K. (2015). Low Temperature Annealed Zinc Oxide Nanostructured Thin Film Based Transducers: Characterization For Sensing Applications. *PLoS ONE*, *10*(7), 1–20. http://doi.org/10.1371/journal.pone.0132755
Henriksen, M., Bjerketvedt, D., Vaagsaether, K., Gaathaug, A. V, Skjold, T. and Middha, P. (2016). Accidental Hydrogen Release In A Gas Chromatograph Laboratory: A Case Study. *International Journal of Hydrogen Energy*, *42*(11). http://doi.org/http://dx.doi.org/10.1016/j.ijhydene.2016.05.299
Hernandez, C. N., Rivas, G., Hernandez, F. J. and Mejia, I. (2015). Materials Science In Semiconductor Processing Ultraviolet Photodetectors Based On Low Temperature Processed ZnO/PEDOT : PSS Schottky Barrier Diodes. *Materials Science in Semiconductor Processing*, *37*, 1–5. http://doi.org/10.1016/j.mssp.2014.12.063
Hernandez, R. F., Prades, J. D., Jimenez D. R., Fischer T., Romano R. A., Mathur, S. and Morante, J. R. (2009). On The Role Of Individual Metal Oxide Nanowires In The Scaling Down Of Chemical Sensors. *Physical Chemistry Chemical Physics : PCCP*, *11*(33), 7105–7110. http://doi.org/10.1039/b905234h

Hernández A., Maya L., Sánchezmora E. and Sánchez E. M. (2007). Sol-Gel Synthesis, Characterization And Photocatalytic Activity Of Mixed Oxide ZnO-Fe_2O_3. *Journal of Sol-Gel Science and Technology*, *42*(1), 71–78. http://doi.org/10.1007/s10971-006-1521-7

Hiramatsu, T., Furuta, M., Matsuda, T., Li, C. and Hirao, T. (2011). Behavior Of Oxygen In Zinc Oxide Films Through Thermal Annealing And Its Effect On Sheet Resistance. *Applied Surface Science*, *257*(13), 5480–5483. http://doi.org/10.1016/j.apsusc.2010.11.128

Hoon, J. W., Chan, K. Y., Krishnasamy, J., Tou, T. Y. and Knipp, D. (2011). Direct Current Magnetron Sputter-Deposited Zno Thin Films. *Applied Surface Science*, *257*(7), 2508–2515. http://doi.org/10.1016/j.apsusc.2010.10.012

Hsu, Y. H., Lin, J. and Tang W. C. (2007). Optimization And Characterization Of RF Sputtered Piezoelectric Zinc Oxide Thin Film For Transducer Applications. *Proceedings - IEEE Ultrasonics Symposium*, 2393–2396. http://doi.org/10.1109/ULTSYM.2007.602

Huang, C.Y. and Lai, J.H. (2016). Efficient Polymer Light-Emitting Diodes With ZnO Nanoparticles And Interpretation Of Observed Sub-Bandgap Turn-On Phenomenon. *Organic Electronics*, *32*, 244–249. http://doi.org/10.1016/j.orgel.2016.02.031

Iftiquar, S. M. (2002). Structural Studies On Semiconducting Hydrogenated Amorphous Silicon Oxide Films. *High Temperature Material Processes*, *6*, 35–53. http://doi.org/10.1615/HighTempMatProc.v6.i1.40

Ippolito S. J., Kandasamy, S. Kalantar-zadech, K. and Wlodarski, W. Hydrogen Sensing Characteristocs of WO_3 Thin FIlm Conductometric Sensors Activated by Pt and Au Catalyts. S. M. (2002). Sensors and Actuators B: Chemical, 108, 154-158

Ishibashi, T. (2013). Molecular Hydrogen : New Antioxidant And Anti-Inflammatory Therapy For Rheuma- Toid Arthritis And Related Diseases. *Current Pharmaceutical Design*, *19*, 6375–6381. http://doi.org/10.2174/13816128113199990507

Ismail, A. and Abdullah, M. J. (2013). The Structural And Optical Properties Of ZnO Thin Films Prepared At Different RF Sputtering Power. *Journal of King Saud University - Science*, *25*(3), 209–215. http://doi.org/10.1016/j.jksus.2012.12.004

Jiménez G. A. (1998). Optical And Electrical Characteristics Of Aluminum-Doped Zno Thin Films Prepared By Solgel Technique. *Journal of Crystal Growth*, *192*(3–4), 430–438. http://doi.org/10.1016/S0022-0248(98)00422-9

Joshi, S., Nayak, M. M. and Rajanna, K. (2014). Effect Of Post-Deposition Annealing On Transverse Piezoelectric Coefficient And Vibration Sensing Performance Of ZnO Thin Films. *Applied Surface Science*, *296*, 169–176. http://doi.org/10.1016/j.apsusc.2014.01.067

Kamalasanan, M. and Chandra, S. (1996). Sol-Gel Synthesis Of ZnO Thin Films. *Thin Solid Films*, *288*, 112–115. http://doi.org/10.1016/S0040-6090(96)08864-5

Kim, J. H., Rho, H., Kim, J., Choi, Y. J. and Park, J. G. (2012). Raman Spectroscopy of ZnS Nanostructure. *Journal of Raman Spectroscopy*, *43*(7), 906-910. http://doi.org/ 10.1002/jrs.3116

Koyano, M., Quoc B. P., Thanh B. L. T., Hong H. L., Ngoc L. N. and Katayama, S. (2002). Photoluminescence And Raman Spectra Of ZnO Thin Films By

Charged Liquid Cluster Beam Technique. *Physica Status Solidi (A) Applied Research*, *193*(1). http://doi.org/10.1002/1521-396X(200209)193

Kumar, H. and Rani, R. (2013). Structural And Optical Characterization Of ZnO Nanoparticles Synthesized By Microemulsion Route. *International Letters of Chemistry, Physics and Astronomy*, *14*, 26–36. http://doi.org/10.18052/www.scipress.com/ILCPA.19.26

Lang, C. C., Karlin, P., Haythe, J., Lim, T. K. and Mancini, D. M. (2009). Peak Cardiac Power Output, Measured Noninvasively, Is A Powerful Predictor Of Outcome In Chronic Heart Failure. *Circulation: Heart Failure*, *2*(1), 33–38. http://doi.org/10.1161/CIRCHEARTFAILURE.108.798611

Liao, L., Lu, H. B., Li, J. C., He, H., Wang, D. F., Fu, D. J. and Zhang, W. F. (2007). Size Dependence Of Gas Sensitivity Of Zno Nanorods. *Journal of Physical Chemistry C*, *111*(5), 1900–1903. http://doi.org/10.1021/jp065963k

Liu, Y., Yang, S., Wei, G., Song, H., Cheng, C., Xue, C. and Yuan, Y. (2011). Electrical And Optical Properties Dependence On Evolution Of Roughness And Thickness Of Ga:ZnO Films On Rough Quartz Substrates. *Surface and Coatings Technology*, *205*(11), 3530–3534. http://doi.org/10.1016/j.surfcoat.2010.12.029

Liu, F. C., Li, J. Y., Chen, T. H., Chang, C. H., Lee C. T., Hsiao, W. H and Liu, D. S. (2017). Effect of Silver Dopants on the ZnO Thin Films Prepared by a Radio Frequency Magnteron Sputtering Co-Sputtering System. *Journal of Material*, *10*(7), 797. http://doi.org/ 10.3390/ma10070797

Lototskyy, M., Satya Sekhar, B., Muthukumar, P., Linkov, V. and Pollet, B. G. (2015). Niche applications of metal hydrides and related thermal management issues. *Journal of Alloys and Compounds*, *645*, S117–S122. http://doi.org/10.1016/j.jallcom.2014.12.271

Lupan, O., Chai, G. and Chow, L. (2008). Novel Hydrogen Gas Sensor Based On Single ZnO Nanorod. *Microelectronic Engineering*, *85*(11), 2220–2225. http://doi.org/10.1016/j.mee.2008.06.021

Mang, A., Reimann, K. and Rübenacke, S. (1995). Band Gaps, Crystal-Field Splitting, Spin-Orbit Coupling, And Exciton Binding Energies In ZnO Under Hydrostatic Pressure. *Solid State Communications*, *94*(4), 251–254. http://doi.org/10.1016/0038-1098(95)00054-2

Mani, G. K. and Rayappan, J. B. B. (2013). A Highly Selective Room Temperature Ammonia Sensor Using Spray Deposited Zinc Oxide Thin Film. *Sensors and Actuators, B: Chemical*, *183*, 459–466. http://doi.org/10.1016/j.snb.2013.03.132

Mariappan, R., Ponnuswamy, V., Suresh, P., Ashok, N., Jayamurugan, P., and Chandra Bose, A. (2014). Influence of Film Thickness on The Properties of Sprayed ZnO Thin Films For Gas Sensor Applications. *Superlattices and Microstructures*, 71, 238–249. http://doi.org/10.1016/j.spmi.2014.03.029

Matamis, D., Pampori, S., Papathanasiou, A., Papakonstantinou, P., Tsagourias, M., Galiatsou, E. and Nakos, G. (2012). Inhaled NO And Sildenafil Combination In Cardiac Surgery Patients With Out-Of-Proportion Pulmonary Hypertension Acute Effects On Postoperative Gas Exchange And Hemodynamics. *Circulation: Heart Failure*, *5*(1), 47–53. http://doi.org/10.1161/CIRCHEARTFAILURE.111.963314

Mera, J., Cordoba, C., Gómez, A., Paucar, C. and Morán, O. (2012). Amorphous Phase As Possible Origin Of Additional Absorption Bands In

Polycrystalline Zno Films. *Journal of Non-Crystalline Solids*, *358*(23), 3229–3233. http://doi.org/10.1016/j.jnoncrysol.2012.08.025
Milton, O. "Substrates Surfaces and Thin Film Nucleation." Material Science of Thin Film, *Elsevier Science*, 2002, pp. 357–415.
Mitra, P., Chatterjee, A. P. and Maiti, H. S. (1998). Zno Thin Film Sensor. *Materials Letters*, *35*(1), 33–38. http://doi.org/10.1016/S0167-577X(97)00215-2
Moore, J. (2017). Thermal Hydrogen: An Emissions Free Hydrocarbon Economy. *International Journal of Hydrogen Energy*, 1–17. http://doi.org/10.1016/j.ijhydene.2017.03.182
Morita, A., Watanabe, I. and Shirai, H. (2011). Chemical Activity Of Oxygen Atoms In The Magnetron Sputter-Deposited Zno Films. *Thin Solid Films*, *519*(20), 6903–6909. http://doi.org/10.1016/j.tsf.2010.11.055
Nair, P. B., Justinvictor, V. B., Daniel, G. P., Joy, K., Ramakrishnan, V. and Thomas, P. V. (2011). Effect Of RF Power And Sputtering Pressure On The Structural And Optical Properties Of Tio2 Thin Films Prepared By RF Magnetron Sputtering. *Applied Surface Science*, *257*(24), 10869–10875. http://doi.org/10.1016/j.apsusc.2011.07.125
Nakanishi, Y., Miyake, A., Kominami, H., Aoki, T., Hatanaka, Y. and Shimaoka, G. (1999). Preparation Of Zno Thin Films For High-Resolution Field Emission Display By Electron Beam Evaporation. *Applied Surface Science*, *142*(1), 233–236. http://doi.org/10.1016/S0169-4332(98)00654-0
Nwanya, A. C., Deshmukh, P. R., Osuji, R. U., Maaza, M., Lokhande, C. D. and Ezema, F. I. (2015). Synthesis, Characterization And Gas-Sensing Properties Of SILAR Deposited Zno-Cdo Nano-Composite Thin Film. *Sensors and Actuators B: Chemical*, *206*, 671–678. http://doi.org/10.1016/j.snb.2014.09.111
Ondo-Ndong, R., Ferblantier, G., Al Kalfioui, M., Boyer, A. and Foucaran, A. (2003a). Properties Of RF Magnetron Sputtered Zinc Oxide Thin Films. *Journal of Crystal Growth*, *255*(1–2), 130–135. http://doi.org/10.1016/S0022-0248(03)01243-0
Ondo-Ndong, R., Pascal-Delannoy, F., Boyer, A., Giani, A. and Foucaran, A. (2003b). Structural Properties Of Zinc Oxide Thin Films Prepared By R.F. Magnetron Sputtering. *Materials Science and Engineering: B*. http://doi.org/10.1016/S0921-5107(02)00406-3
Pal, B. and Sharon, M. (2002). Enhanced Photocatalytic Activity Of Highly Porous Zno Thin Films Prepared By Sol-Gel Process. *Materials Chemistry and Physics*, *76*(1), 82–87. http://doi.org/10.1016/S0254-0584(01)00514-4
Pan, X., Li, Z., Zhang, C., Lv, H., Liu, S. and Ma, J. (2016). Safety Study Of A Wind Solar Hybrid Renewable Hydrogen Refuelling Station In China. *International Journal of Hydrogen Energy*, *41*(30), 13315–13321. http://doi.org/10.1016/j.ijhydene.2016.05.180
Park, H. K., Jeong, J. A., Park, Y. S., Kim, H. K. and Cho, W. J. (2009). Electrical, Optical, And Structural Properties Of InznsnO electrode films grown by unbalanced radio frequency magnetron sputtering. *Thin Solid Films*, *517*(18), 5563–5568. http://doi.org/10.1016/j.tsf.2009.02.138
Parler, C. M., Ritter, J. A. and Amiridis, M. D. (2001). Infrared Spectroscopic Study Of Sol-Gel Derived Mixed-Metal Oxides. *Journal of Non-Crystalline Solids*, *279*(2–3), 119–125. http://doi.org/10.1016/S0022-3093(00)00401-4

Pattini, F., Annoni, F., Bissoli, F., Bronzoni, M., Garcia, J. P., Gilioli, E. and Rampino, S. (2015). Comparative Study About Al-Doped Zinc Oxide Thin Films Deposited By Pulsed Electron Deposition And Radio Frequency Magnetron Sputtering As Transparent Conductive Oxide For Cu(In,Ga)Se2 Based Solar Cells. *Thin Solid Films*, *582*, 317–322. http://doi.org/10.1016/j.tsf.2014.11.071

Pérez-Pacheco, A., Prieto, C., Castañeda-Guzmán, R. and García-López, J. (2009). Influence Of The Growth Conditions On The Stoichiometry And On The Optical Properties Of Titanium Oxide Thin Films Prepared By Reactive Sputtering. *Thin Solid Films*, *517*(18), 5415–5418. http://doi.org/10.1016/j.tsf.2009.01.050

Pimentel, D., Herz, M., Glickstein, M., Zimmerman, M., Allen, R., Evans, J. and Sarsfeld, R. (2008). Energy : 19 Renewable Current and Potential Issues, *52*(12), 259–276.

Porto, S. P. S., Tell, B., and Damen, T. C. (1966). Near-Forward Raman Scattering in Zinc Oxide. *Physical Review Letters*, 16(11). http://doi.org/10.1103/PhysRevLett.16.450

Potje-Kamloth, K. (2008). Semiconductor Junction Gas Sensors. Chemistry Review. 108, 367–399.

Quiñones-Galván, J. G., Tototzintle-Huitle, H., Hernández-Hernández, L. A, Arias-Cerón, J. S., De Moure-Flores, F., Hernández-Hernández, A. and Araiza, J. J. (2014). Study Of The Structure, Optical Properties, Surface Morphology And Topology Of Zno Thin Films Grown By Sol–Gel On Silicon Substrates. *Materials Research Express*, *1*(3), 36404. http://doi.org/10.1088/2053-1591/1/3/036404

Rahmane, S., Aida, M. S., Djouadi, M. A. and Barreau, N. (2015). Effects Of Thickness Variation On Properties Of ZnO:Al Thin Films Grown By RF Magnetron Sputtering Deposition. *Superlattices and Microstructures*, *79*, 148–155. http://doi.org/10.1016/j.spmi.2014.12.001

Rolo, A. G., Ayres De Campos, J., Viseu, T., De Lacerda-Arôso, T. and Cerqueira, M. F. (2007). The Annealing Effect On Structural And Optical Properties Of Zno Thin Films Produced By R.F. Sputtering. *Superlattices and Microstructures*, *42*(1–6), 265–269. http://doi.org/10.1016/j.spmi.2007.04.069

Samavati, A., Nur, H., Ismail, A. F. and Othaman, Z. (2016). Radio Frequency Magnetron Sputtered ZnO/SiO_2/Glass Thin Film: Role Of Zno Thickness On Structural And Optical Properties. *Journal of Alloys and Compounds*, *671*, 170–176. http://doi.org/10.1016/j.jallcom.2016.02.099

Sanusi, A., Musa, M. and Kasim, U. S. (2014). Growth Mechanism And Optical Properties Of Zinc Oxide Thin Film. *International Journal of Renewable Energy Technology.* 5(12). https://doi.org/10.1504/IJRET.2014.060358

Sekimoto, S., Nakagawa, H., Okazaki, S., Fukuda, K., Asakura, S., Shigemori, T. and Takahashi, S. (2000). A Fiber-Optic Evanescent-Wave Hydrogen Gas Sensor Using Palladium-Supported Tungsten Oxide. *Sensors and Actuators B: Chemical*, *66*(1), 142–145. http://doi.org/10.1016/S0925-4005(00)00330-0

Serrano, J., Manjón, F. J., Romero, A. H., Widulle, F., Lauck, R. and Cardona, M. (2003). Dispersive Phonon Linewidths: The Phonons Of Zno. *Physical Review Letters*, *90*(5).

Sharma, S., Vyas, S., Periasamy, C. and Chakrabarti, P. (2014). Structural And Optical Characterization Of Zno Thin Films For Optoelectronic Device

Applications By RF Sputtering Technique. *Superlattices and Microstructures*, *75*, 378–389. http://doi.org/10.1016/j.spmi.2014.07.032
Sun, Y. F., Liu, S.B., Meng, F.L., Liu, J.Y., Jin, Z., Kong, L.T. and Liu, J.H. (2012). Metal Oxide Nanostructures and Their Gas Sensing Properties: A Review. *Sensors*, *12*(3), 2610–2631. http://doi.org/10.3390/s120302610
Tan, S. T., Chen, B. J., Sun, X. W., Fan, W. J., Kwok, H. S., Zhang, X. H. and Chua, S. J. (2005). Blueshift Of Optical Band Gap In Zno Thin Films Grown By Metal-Organic Chemical-Vapor Deposition. *Journal of Applied Physics*, *98*(1), 1–5. http://doi.org/10.1063/1.1940137
Terukov, N. H. N. (2005). *Zinc Oxide- A Material for Micro- and Optoelectronic Applications*. *CEUR Workshop Proceedings* (Vol. 1542). http://doi.org/10.1017/CBO9781107415324.004
Turgut, G., Duman, S., Sonmez, E. and Ozcelik, F. S. (2016). A Study Of Eu Incorporated Zno Thin Films: An Application Of Al/Zno:Eu/P-Si Heterojunction Diode. *Materials Science and Engineering: B*, *206*, 9–16. http://doi.org/10.1016/j.mseb.2016.01.006
Vrinceanu, N., Petre, A. B., Hristodor, C. M., Popovici, E., Pui, A., Coman, D. and Tanasa, D. (2013) Zinc Oxide -- Linen Fibrous Composites : Morphological , Structural , Chemical , Humidity Adsorptive and Thermal Barrier Attributes.
Wang, C., Zhou, G., Li, J., Yan, B. and Duan, W. (2008). Hydrogen-Induced Metallization Of Zinc Oxide Surface And Nanowires: The Effect Of Curvature. *Physical Review B - Condensed Matter and Materials Physics*, *77*(24), 1–7. http://doi.org/10.1103/PhysRevB.77.245303
Wang, F., Wang, L. and Xue, Q. (2016). Fluorine And Sulfur Co-Doped Amorphous Carbon Films To Achieve Ultra-Low Friction Under High Vacuum. *Carbon*, *96*, 411–420. http://doi.org/10.1016/j.carbon.2015.09.084
Wang, F., Wu, M. Z., Wang, Y. Y., Yu, Y. M., Wu, X. M. and Zhuge, L. J. (2013). Influence Of Thickness And Annealing Temperature On The Electrical, Optical And Structural Properties Of AZO Thin Films. *Vacuum*, *89*(1), 127–131. http://doi.org/10.1016/j.vacuum.2012.02.040
Wang, H.T., Kang, B. S., Ren. F., Tien, L. C., Sadik, P. W., Norton, D. P., Pearton, S. J. and Lin, J. (2002). Effect Of Preheating And Annealing Temperatures On Quality Characteristics Of ZnO Thin Film Prepared By Sol-Gel Method. *Applied Physics Letter*, 86, 243503–243505.
Wang, M., Wang, J., Chen, W., Cui, Y. and Wang, L. (2006). Effect Of Preheating And Annealing Temperatures On Quality Characteristics Of ZnO Thin Film Prepared By Sol-Gel Method. *Materials Chemistry and Physics*, *97*(2–3), 219–225. http://doi.org/10.1016/j.matchemphys.2005.07.072
Wang, S. K., Lin, T. C., Jian, S. R., Juang, J. Y., Jang, J. S. C. and Tseng, J. Y. (2011). Effects Of Post-Annealing On The Structural And Nanomechanical Properties Of Ga-Doped Zno Thin Films Deposited On Glass Substrate By RF Magnetron Sputtering. *Applied Surface Science*, *258*(3), 1261–1266. http://doi.org/10.1016/j.apsusc.2011.09.088
Wang, X., Zeng, X., Huang, D., Zhang, X. and Li, Q. (2012). The Properties Of Al Doped Zno Thin Films Deposited On Various Substrate Materials By RF Magnetron Sputtering. *Journal of Materials Science: Materials in Electronics*, *23*(8), 1580–1586. http://doi.org/10.1007/s10854-012-0632-x
Wright, J.S., Lim, W., Norton, D.P., Pearton, S.J., Ren, F., Johnson, J.L. and

Ural, A. (2010) Nitride And Oxide Semiconductor Nanostructured Hydrogen Gas Sensors. Semiconductor Science and Technology. http://doi.org/10.1088/0268-1242/25/2/024002.

Xiong, G., Pal, U., Serrano, J. G., Ucer, K. B. and Williams, R. T. (2006). Photoluminescence And FTIR Study Of ZnO Nanoparticles: The Impurity And Defect Perspective. *Physica Status Solidi (C) Current Topics in Solid State Physics*, *3*(10), 3577–3581. http://doi.org/10.1002/pssc.200672164

Ye, J., Gu, S., Zhu, S., Chen, T., Liu, W., Qin, F. and Zheng, Y. (2003). Raman And Photoluminescence Of ZnO Films Deposited On Si (111) Using Low-Pressure Metalorganic Chemical Vapor Deposition. *Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films*, *21*(4), 979. http://doi.org/10.1116/1.1580836

Yen, C. Y., Jian, S. R., Chen, G. J., Lin, C. M., Lee, H. Y., Ke, W. C. and Juang, J. Y. (2011). Influence Of Annealing Temperature On The Structural, Optical And Mechanical Properties Of ALD-Derived ZnO Thin Films. *Applied Surface Science*, *257*(17), 7900–7905. http://doi.org/10.1016/j.apsusc.2011.04.088

Zhang, Y., Du, G., Liu, D., Wang, X., Ma, Y., Wang, J. and Yang, S. (2002). Crystal Growth Of Undoped Zno Films On Si Substrates Under Different Sputtering Conditions. *Journal of Crystal Growth*, *243*(3–4), 439–443. http://doi.org/10.1016/S0022-0248(02)01569-5

Zhao, J., Hu, L., Liu, W. and Wang, Z. (2007). Properties Of Zno Thin Films Grown On Si Substrates In Vacuum And Oxygen Ambient By Pulsed Laser Deposition. *Applied Surface Science*, *253*(14), 6255–6258. http://doi.org/10.1016/j.apsusc.2007.01.089

BIODATA OF STUDENT

Siti Nor Aliffah binti Mustaffa received her Master of Science (Nanoscience) and Bachelor of Science (Honour) Physics from the Universiti Putra Malaysia in 2017 and 2013, respectively. Her main research interests are in the field of thin film, material science and nanotechnology. She can be reached by email noralifah@gmail.com.

LIST OF PUBLICATIONS

Peer Reviewed Journal

Siti Nor Aliffah Mustaffa, Nurul Assikin Ariffin, Suriati Paiman, Nizam Tamchek, and Abdul Halim Shaari. Post-Annealing Effects on the Structural Properties of RF-sputtered ZnO Thin Films. Journal of Solid State Science and Technology, Vol. 25, No. 2 (2017), page 145-151. ISSN 0128-7389 | http://journal.masshp.net

Siti Nor Aliffah Mustaffa, Ahmed Lateef Khalaf, Mohd. Hanif Yaacob Nizam Tamchek, and Suriati Paiman. Room Temperature H_2 Optical Sensing of RF-Sputtered ZnO Thin Films (*in progress*)

Nurul Assikin Ariffin, **Siti Nor Aliffah Mustaffa**, Suriati Paiman, Nizam Tamchek, and Abdul Halim Shaari. Effect of Post-Annealing Treatment on the Structural Properties of RF-Sputtered Germanium Thin Layers. Solid State Science & Technology Letters, 17(2), page 191-194.

Ahmed Lateef Khalaf, **Siti Nor Aliffah Mustaffa**, Hayder Abdulbari, Suriati Paiman, Mohd Adzir Mahdi, and Mohd. Hanif Yaacob. Ammonia Gas Sensing using Sputtered Au/WO3 Integrated Side-Polished Optical Fiber (*in progress*)

Oral Presentations

Suriati Paiman, **Siti Nor Aliffah Mustaffa**, Nizam Tamchek, Ahmad Lateef Khalaf and Mohd. Hanif Yaacob. Zinc Oxide Thin Films for Optical Gas Sensor Applications. Symposium on Advanced Materials and Nanotechnology (18 & 19 July 2017) at Bangi Hotel, Putrajaya.

Siti Nor Aliffah Mustaffa, Suriati Paiman, Nizam Tamchek, Ahmad Lateef Khalaf and Mohd. Hanif Yaacob. Structural and Optical Properties of RF-sputtered ZnO Thin Films for Optical Gas Sensor Application. Fundamental Science Congress (9 & 10 August 2016) at Faculty of Science, UPM.

Siti Nor Aliffah Mustaffa, Suriati Paiman, and Nizam Tamchek. Effect of Film Thickness on Surface Roughness of RF-sputtered ZnO Thin Films. Fundamental Science Congress (12 & 13 November 2015) at Faculty of Science, UPM.