CHARACTERISATION OF SHARP EDGES SCHOTTKY CONTACTS WITH NANOSTRUCTURE FILM

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Specially dedicated to my beloved parents

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ABSTRACT

Studies investigating nanostructure on Schottky diode reported that sharp edge of nanostructures produces high electric field. It has been suggested that high electric field improve gas sensing performance on reverse biased mode. Electric field also promotes the ionisation of gas molecule thus improving sensing performance. Thus, the author aims to investigate the effect of sharp edges Schottky contacts towards electric field and Schottky diode performance. This can be achieved through simulation and experiment. COMSOL Multiphysics was used to model Schottky contact shape: circular-, hexagon- and star-shape. Star-shape Schottky contact produced 2.79×10^9 V/m total electric field followed by hexagon- and circular-shape. Acute angle of star-shape at 72˚ contributed higher electric field 4×10^4 V/m than obtuse angle. After that, sensing layer of Schottky diode was fabricated by using Radio Frequency (RF) magnetron sputtering to deposit Zinc Oxide (ZnO) and Titanium dioxide (TiO_2). In addition, highly potential material Carbon Nanotubes (CNTs) were investigated along these materials, which were sensitive towards gas sensing. Platinum was chosen as Schottky contact metal since it is known as a good catalytic metal to help absorption of hydrogen gas into the sensing layer. Finally, the sharp edges Schottky contacts with nanostructure film devices were characterised. Series of current-voltage (I-V) characteristics were recorded using Keithley 2400 and temperature was varied from room temperature to 200˚C towards 1% hydrogen gas in a vacuum chamber. Results show that hexagon-shape Pt/TiO_2/Si Schottky diode gave better barrier height of 494 meV than circular-shape. Furthermore, the response shows that 0.3 mA current changes were observed at star-shape Pt/CNTs/Si Schottky diode based sensors in forward biased mode. On the other hand, 0.21 mA was observed at hexagon-shape Pt/CNTs/Si Schottky diode based sensor on reverse biased mode. This signifies that improvement can be made by tailoring the Schottky contact shape to increase the electric field for sensing purposes.

ABSTRAK

Kajian ke atas struktur nano yang dimendap ke atas diod Schottky telah menunjukkan bahawa sisi tajam struktur nano menghasilkan medan elektrik yang tinggi. Kajian tersebut juga mencadangkan medan elektrik yang tinggi telah meningkatkan prestasi penderia gas di bahagian pincang belakang. Maka, penulis telah mengkaji kesan sisi tajam elektrod Schottky ke atas medan elektrik dan prestasinya sebagai diod Schottky. Ini boleh dicapai melalui simulasi dan eksperimen. COMSOL *Multiphysics* diguna untuk memodelkan tiga bentuk elektrod Schottky: bulatan, heksagon dan bintang. Elektrod Schottky berbentuk bintang menghasilkan 2.79×10^9 V/m jumlah medan elektrik diikuti dengan bentuk heksagon dan bentuk bulatan. Sudut tirus sebanyak 72˚ pada bentuk bintang menyumbang medan elektrik tertinggi iaitu 4×10^4 V/m berbanding sudut cakah. Kemudian, lapisan penderia diod Schottky difabrikasi dengan menggunakan teknologi Radio *Frequency (RF)magnetron sputtering* untuk mendapan Zink Oksida (ZnO) dan Titanium dioksida (TiO_2). Selain itu, material berpotensi tinggi Karbon Tiub-Nano (CNTs) juga dikaji kerana bahan-bahan ini sensitif sebagai penderia gas. Platinum telah dipilih sebagai logam elektrod Schottky kerana dikenali sebagai logam pemangkin yang baik untuk membantu penyerapan gas hidrogen ke dalam lapisan penderia. Akhir sekali, untuk mengkaji sifat diod Schottky, ciri-ciri arus-voltan (I-V) telah direkod menggunakan Keithley 2400 di mana suhu telah diubah daripada suhu bilik ke 200˚C ke atas 1% gas hidrogen di dalam ruang vakum. Keputusan menunjukkan bentuk heksagon Pt/TiO_2/Si memberi ketinggian halangan yang lebih baik sebanyak 494 meV berbanding bentuk bulatan. Keputusan juga menunjukkan perubahan arus sebanyak 0.3 mA diperolehi daripada bentuk bintang Pt/CNTs/Si dalam bahagian pincang hadapan. Manakala, 0.21 mA diperolehi daripada bentuk heksagon Pt/CNTs/Si pada bahagian pincang belakang. Ini menunjukkan bahawa pembaikan boleh dibuat dengan memanipulasikan lapisan elektrod Schottky.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Ag	-	Silver
Au	-	Gold
BOE	-	Buffer Oxide Etch
CNTs	-	Carbon Nanotubes
CO	-	Carbon monoxide
CTAB	-	Cetyltrimethylammonium Bromide
CVD	-	Chemical Vapour Deposition
DI	-	Deionized
DNA	-	Deoxyribonucleic acid
EC	-	Evaporation-Condensation
FESEM	-	Field Emission Scanning Electron Microscopy
GaAs	-	Gallium Arsenide
GaN	-	Gallium Nitride
H_2	-	Hydrogen
H_2S	-	Hydrogen Sulphide
HRTEM	-	High Resolution Transmission Electron Microscopy
InP	-	Indium Phosphide

MFC	-	Mass Flow Controller
mm^2	-	Millimeter square
MoO_3	-	Molybdenum Trioxide
MOS	-	Metal-oxide-semiconductor
MOSFET	-	Metal-oxide-semiconductor field-effect transistors
mph	-	Miles per hour
mTorr	-	milliTorr
MWCNTs	-	Multi-Walled CNTs
NH_3	-	Ammonia
nm	-	Nanometer
NO	-	Nitrogen monoxide
NO_2	-	Nitrogen Dioxide
OSHA	-	Occupational Safety and Health Administration
Pd	-	Palladium
ppm	-	Part per million
Pt	-	Platinum
RF	-	Radio Frequency
sccm	-	Standard cubic centimeters per minute
SEM	-	Scanning Electron Microscopy
Si	-	Silicone
SiC	-	Silicon Carbide
SiO_2	-	Silicon dioxide

SWNTs	-	Single-Walled CNTs
Ta_2O_5	-	Tantalum Oxide
TEM	-	Transmission Electron Microscopy
TiO_2	-	Titanium dioxide
UV	-	Ultra Violet
VLS	-	Vapour-Liquid-Solid
ZnO	-	Zinc Oxide
μm	-	Micrometer

LIST OF SYMBOLS

A	-	Area
A^{**}	-	Richardson constant
Ec	-	Energy at the bottom of conduction band
E_F	-	Fermi level
E_v	-	Energy at the top of the valence band
I	-	Electric current
I_F	-	Forward current
I_H	-	Current levels in hydrogen containing ambient
I_O	-	Current levels in vacuum ambient
I_o, J_o	-	Saturation current
I-V	-	Current-Voltage
k	-	Boltzmann constant
K	-	Kelvin
kT/q	-	Thermal voltage at 300K (0.0259V)
q	-	Elementary charge
R_H	-	Sheet resistance in hydrogen containing ambient
R_O	-	Sheet resistance in vacuum ambient
T	-	Temperature

V	-	Electrical potential difference (Voltage)
V_F	-	Forward voltage
V_R	-	Reverse voltage
ΔV	-	Change in potential difference
ϕ_B	-	Barrier height
φ_m	-	Metal work function
ϕ_n,	-	Energy difference between E_c and E_F
ψ_{bi}	-	Built in potential

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Schottky diode conventionally used either in power or sensor application. The unique configuration of Schottky diode (metal-semiconductor) compared to normal diode(semiconductor-semiconductor) enable it to switch faster than normal diode does and the usage of metal as contact is beneficial especially for gas sensing application. The fabrication process of Schottky diode is very simple, which facilitates the research and development of these types of sensors. Schottky diode based sensors have been fabricated employing a number of different inorganic/organic semiconductors together with thin catalytic metal layers (generally group VIII transition metals such as Pt or Pd) that acts as both a Schottky contact and a catalyst for gas adsorption [6]. The catalytic metal and semiconductor form a Schottky barrier, which varies as the device is exposed to different gas species and determines how sensitive the device can be towards target gas. The type of semiconducting material, its structure and the formation of the junction barrier between the metal and the semiconductor can be controlled and varied to sense different types of particular gases.

However, many of these studies usually used a typical circular shape of Schottky contact [3, 7-10] and to the author knowledge none reported the investigations on effect of varying the shape towards gas sensing performance. It is known that electric field can be enhanced by increasing the edges around the contact [11]. The focus in this research is to study the variation of the Schottky contact shape. Investigation on the factor responsible for the enhancement of electric fields and the effect of the different geometries of Schottky contact are conducted in order to enhance the sensitivity of Schottky diode based sensors. Then, the fabricated Schottky diode based sensor is tested for gas applications.

1.2 Problem Statement

Conventional semiconductor sensor such as FET usually have complicated structure for fabrication. On the other hand, Schottky diode is known for its simplicity in term of fabrication process. It consist layered of Schottky contact, metal oxide thin film, semiconductor substrate and ohmic contact. Several researchers [3] prove that by applying sharp edges nanostructure metal oxide thin film in Schottky diode enhanced the performance of gas sensor. Incidentally, Schottky contact is main part of Schottky diode which function as an electrode as well as catalytic layer. In power diode application, it is known that sharp edges Schottky contact produces leakage current. However, sharp edges produce larger electric field which will help to promote gas ionization. Hence there is need to study on the electric field enhancement at Schottky contact and various geometries of Schottky contact.

1.3 Research Objectives

The objectives of this research are:

i. To obtain in detail the basic behaviour (such as electric field and I-V reverse and forward biased) of Schottky diode based sensor using various nanostructures morphology and Schottky contact shape.
ii. To identify a series of relationships between the different nanostructures morphology and Schottky contact shape
iii. To verify that the obtained geometries of nanostructure and different Schottky contact shape will able to perform better than conventional circular-shape Schottky contact

1.4 Research Motivation

Schottky diode is used either in power or sensing applications. The existence of Schottky contact metal in configuration of Schottky diode differentiate it with the normal diodes. It is generally known that sharp edges Schottky contact is avoided in power application as it produced leakage current which is not favourable in power application. However, this disadvantage is beneficial for gas sensor as it enhanced the local electric field. This enhancement of electric field helps the ionisation of gas molecule into atoms and consequently improve the gas adsorption.

In state-of-the-art technologies, the interest on nanotechnology integrated with solid state sensor has became a trend of research. This includes investigations of increasing the electric field [12] via sharp edges nanostructure on Schottky diode gas sensor. It is believed that by increasing the electric field, it will lead to increased sensitivity of a sensor.

Hence, in this research Schottky diode was investigated by employing the effect of sharp edges at metal contact through varying the Schottky contact shapes. The output of this research will be focused mainly as hydrogen gas sensing application.

1.5 Expected Findings

It is expected at the end of this project it will

i. Provide new knowledge on the findings of factors for electric field enhancement and the effects of the different geometries of Schottky contact for Schottky diode based sensor.
ii. Show performance improvement as a gas sensor compared to conventional circular-shape Schottky contact diode.

1.6 Structure of Thesis

This thesis is divided into several topics to present the main objective of characterisation on sharp edges of Schottky contact with nanostructure thin film. The topics were arranged as follows;

- Chapter 2 presents literature review on state-of-the-art research and findings which related to the Schottky diode with nanostructure film including the materials and nanotechnology used.
- Chapter 3 presents on the theoretical study related to the fundamental of Schottky diode and the explanation of its mechanism in sensing.
- Chapter 4 demonstrates the fabrication process conducted step by step in order to obtain the final device. This chapter also presents the synthesis and deposition of the nanostructure materials.
- Chapter 5 discusses the characterisation conducted to study the materials and morphologies of the nanostructure deposited as the sensing layer.
- Chapter 6 discusses the measurement conducted and performance of the hydrogen sensor towards hydrogen gas by analysing the current-voltage (I-V) characteristic and Schottky barrier height.
- Chapter 7 concludes this thesis and presents the contribution of study with suggestion for future work.

REFERENCES

[1] Lundström, I., A. Spetz, F. Winquist, U. Ackelid, and H. Sundgren. 1990. Catalytic metals and field-effect devices—a useful combination. *Sensors and Actuators B: Chemical*. 1(1–6): 15-20.

[2] Nigam, S., J. Kim, B. Luo, F. Ren, G.Y. Chung, S.J. Pearton, J.R. Williams, K. Shenai, and P. Neudeck. 2003. Effect of contact geometry on 4H-SiC rectifiers with junction termination extension. *Solid-State Electronics*. 47(1): 57-60.

[3] Shafiei, M., J. Yu, R. Arsat, K. Kalantar-Zadeh, E. Comini, M. Ferroni, G. Sberveglieri, and W. Wlodarski. 2010. Reversed bias Pt/nanostructured ZnO Schottky diode with enhanced electric field for hydrogen sensing. *Sensors and Actuators B: Chemical*. 146(2): 507-512.

[4] Carcia, P.F., R.S. McLean, M.H. Reilly, and G. Nunes. 2003. Transparent ZnO thin-film transistor fabricated by rf magnetron sputtering. *Applied physics letters*. 82(7): 1117-1119.

[5] Lu, Y.M., W.S. Hwang, W.Y. Liu, and J.S. Yang. 2001. Effect of RF power on optical and electrical properties of ZnO thin film by magnetron sputtering. *Materials chemistry and physics*. 72(2): 269-272.

[6] Tuller, H.L. and R. Micak. 2000. Advanced sensor technology based on oxide thin film MEMS integration. *Journal of Electroceramics*. 4: 415-425.

[7] Shafiei, M., A.Z. Sadek, J. Yu, R. Arsat, K. Latham, K. Kalantar-zadeh, and W. Wlodarski. 2010. Pt/TiO_2 nanotubes/SiC schottky diodes for hydrogen gas sensing applications. in *International Conference on Nanoscience and Nanotechnology (ICONN)*.

[8] Shafiei, M., J. Yu, M. Breedon, A. Moafi, K. Kalantar-Zadeh, W. Wlodarski, R.B. Kaner, and K. Galatsis. 2010. Pt/MoO_3 nano-flower/SiC Schottky diode based hydrogen gas sensor. in *Sensors, 2010 IEEE*.

[9] Shafiei, M., J. Yu, M. Breedon, N. Motta, Q. Wu, Z. Hu, L. Qian, K. Kalantar-Zadeh, and W. Wlodarski. 2011. Hydrogen gas sensors based on thermally evaporated nanostructured MoO_3 Schottky diode: A comparative study. in *Sensors, 2011 IEEE*.

[10] Trinchi, A., W. Wlodarski, and Y. Li. 2004. Hydrogen sensitive Ga_2O_3 Schottky diode sensor based on SiC. *Sensors and Actuators B: Chemical*. 100(1-2): 94-98.

[11] Lu, Y., G.L. Liu, J. Kim, Y.X. Mejia, and L.P. Lee. 2005. Nanophotonic crescent moon structures with sharp edge for ultrasensitive biomolecular detection by local electromagnetic field enhancement effect. *Nano letters*. 5(1): 119-124.

[12] J Yu, M.S., W Wlodarski, Y X Li and K Kalantar-zadeh. 2010. Enhancement of electric field properties of Pt/nanoplatelet MoO3/SiC Schottky diode. *J. Phys. D: Appl. Phys.* 43(025103).

[13] Orton, J., *The Story of Semiconductors*. 2006, United States: Oxford University Press.

[14] Gergintschew, Z., P. Kornetzky, and D. Schipanski. 1996. The capacitively controlled field effect transistor (CCFET) as a new low power gas sensor. *Sensors and Actuators B: Chemical*. 36(1–3): 285-289.

[15] Pao, H.C. and C.T. Sah. 1966. Effects of diffusion current on characteristics of metal-oxide (insulator)-semiconductor transistors. *Solid-State Electronics*. 9(10): 927-937.

[16] Lundstrom, I., S. Shivaraman, C. Svensson, and L. Lundkvist. 1975. A hydrogen-sensitive MOS field-effect transistor. *Applied physics letters*. 26(2): 55-57.

[17] Schalwig, J., P. Kreisl, S. Ahlers, and G. Muller. 2002. Response mechanism of SiC-based MOS field-effect gas sensors. *Sensors Journal, IEEE*. 2(5): 394-402.

[18] Lechuga, L.M., A. Calle, D. Golmayo, and F. Briones. 1991. Hydrogen sensor based on a Pt/GaAs Schottky diode. *Sensors and Actuators B: Chemical*. 4(3-4): 515-518.

[19] Lechuga, L.M., G. Mier, A. Calle, D. Golmayo, and F. Briones. 1994. Urea biosensor based on ammonia gas-sensitive Pt/GaAs Schottky diode. *Sensors and Actuators B: Chemical*. 21(3): 205-208.

[20] Kim, C., J. Lee, Y. Lee, N. Cho, D. Kim, and W. Kang. 1999. Hydrogen sensing characteristics of Pd-SiC Schottky diode operating at high temperature. *Journal of electronic materials*. 28(3): 202-205.

[21] Luther, B., S. Wolter, and S. Mohney. 1999. High temperature Pt Schottky diode gas sensors on n-type GaN. *Sensors and Actuators B: Chemical*. 56(1-2): 164-168.

[22] Campos, M., L.O.S. Bulhões, and C.A. Lindino. 2000. Gas-sensitive characteristics of metal/semiconductor polymer Schottky device. *Sensors and Actuators A: Physical*. 87(1-2): 67-71.

[23] Kim, C., J. Lee, Y. Lee, N. Cho, and D. Kim. 2000. A study on a platinum-silicon carbide Schottky diode as a hydrogen gas sensor. *Sensors and Actuators B: Chemical*. 66(1-3): 116-118.

[24] Cheng, S.Y. 2003. A hydrogen sensitive Pd/GaAs Schottky diode sensor. *Materials chemistry and physics*. 78(2): 525-528.

[25] Lin, K.W., H.I. Chen, C.T. Lu, Y.Y. Tsai, H.M. Chuang, C.Y. Chen, and W.C. Liu. 2003. A hydrogen sensing Pd/InGaP metal-semiconductor (MS) Schottky diode hydrogen sensor. *Semiconductor science and technology*. 18: 615.

[26] Song, J., W. Lu, J.S. Flynn, and G.R. Brandes. 2005. AlGaN/GaN Schottky diode hydrogen sensor performance at high temperatures with different catalytic metals. *Solid-State Electronics*. 49(8): 1330-1334.

[27] Yu, J., M. Shafiei, C. Ling, W. Wlodarski, and K. Kalantar-Zadeh. 2008. Pt/ZnO/SiC thin film for hydrogen gas sensing.

[28] Shafiei, M., P.G. Spizzirri, R. Arsat, J. Yu, J. du Plessis, S. Dubin, R.B. Kaner, K. Kalantar-zadeh, and W. Wlodarski. 2010. Platinum/graphene nanosheet/SiC contacts and their application for hydrogen gas sensing. *The Journal of Physical Chemistry C*.

[29] Yu, J., S. Ippolito, W. Wlodarski, M. Strano, and K. Kalantar-Zadeh. 2010. Nanorod based Schottky contact gas sensors in reversed bias condition. *Nanotechnology*. 21(26): 265502.

[30] Yu, J., G. Chen, C.X. Li, M. Shafiei, J.Z. Ou, J.d. Plessis, K. Kalantar-zadeh, P.T. Lai, and W. Wlodarski. 2011. Hydrogen gas sensing properties of Pt/Ta2O5 Schottky diodes based on Si and SiC substrates. *Sensors and Actuators A: Physical*. 172(1): 9-14.

[31] Rahbarpour, S. and F. Hossein-Babaei. 2012. Hydrogen Detection with Noble Metal-TiO2 Schottky Diodes. *Key Engineering Materials*. 495: 289-293.

[32] Kinpui, C., H. Ito, and H. Inaba. 1984. An optical-fiber-based gas sensor for remote absorption measurement of low-level CH<inf>4</inf>gas in the near-infrared region. *Lightwave Technology, Journal of*. 2(3): 234-237.

[33] Srinivasan, K., S. Cular, V.R. Bhethanabotla, L. Sang Yup, and M.T. Harris. 2005. Nanomaterial sensing layer based surface acoustic wave hydrogen sensors. in *Ultrasonics Symposium, 2005 IEEE*.

[34] Chen, H.I., Y.I. Chou, and C.K. Hsiung. 2003. Comprehensive study of adsorption kinetics for hydrogen sensing with an electroless-plated Pd-InP Schottky diode. *Sensors and Actuators B: Chemical*. 92(1-2): 6-16.

[35] Soloman, S., *Sensors Handbook, Second Edition*. 2010 1999, McGraw-Hill Professional.

[36] Potje-Kamloth, K. 2008. Semiconductor Junction Gas Sensors. *Chem. Rev*: 367-399.

[37] Lundström, I., T. Ederth, H. Kariis, H. Sundgren, A. Spetz, and F. Winquist. 1995. Recent developments in field-effect gas sensors. *Sensors and Actuators B: Chemical*. 23(2–3): 127-133.

[38] Talazac, L., F. Barbarin, L. Mazet, and C. Varenne. 2004. Improvement in sensitivity and selectivity of InP-based gas sensors: pseudo-Schottky diodes with palladium metallizations. *Sensors Journal, IEEE*. 4(1): 45-51.

[39] Garrido, J., C. Nebel, M. Stutzmann, E. Snidero, and P. Bergonzo. 2002. Capacitance–voltage studies of Al-Schottky contacts on hydrogen-terminated diamond. *Applied physics letters*. 81: 637.

[40] Song, J. and W. Lu. 2010. Hydrogen sensing performance dependence on catalytic metal thickness of Pt/AlGaN/GaN Schottky diodes. *Physica Status Solidi (C) Current Topics in Solid State Physics*. 7(7-8): 1838-1840.

[41] Frietsch, M., F. Zudock, J. Goschnick, and M. Bruns. 2000. CuO catalytic membrane as selectivity trimmer for metal oxide gas sensors. *Sensors and Actuators B: Chemical*. 65(1-3): 379-381.

[42] Yao, B.D., Y.F. Chan, and N. Wang. 2002. Formation of ZnO nanostructures by a simple way of thermal evaporation. *Applied physics letters*. 81(4): 757-759.

[43] Li, G., L. Yang, Y. Jin, and L. Zhang. 2000. Structural and optical properties of TiO_2 thin film and TiO_2 + 2 wt.% $ZnFe_2O_4$ composite film prepared by r.f. sputtering. *Thin Solid Films*. 368(1): 164-167.

[44] Ali, R.A.M., S.A.A. Shariffuddin, S. Omar, and N. Nayan. 2012. Study on the influence of oxygen/argon flow ratio toward the growth of TiO_2 film in reactive magnetron sputtering plasma. in *Enabling Science and Nanotechnology (ESciNano), 2012 International Conference on*.

[45] Yu, X., Y. Li, W. Wlodarski, S. Kandasamy, and K. Kalantar-zadeh. 2008. Fabrication of nanostructured TiO2 by anodization: A comparison between electrolytes and substrates. *Sensors and Actuators B: Chemical*. 130(1): 25-31.

[46] Wang, S.-F., Y.-F. Hsu, R.-L. Lee, and Y.-S. Lee. 2004. Microstructural evolution and phase development of Nb and Y doped TiO2 films prepared by RF magnetron sputtering. *Applied Surface Science*. 229(1–4): 140-147.

[47] Vyas, S., R. Tiwary, K. Shubham, and P. Chakrabarti. 2014. Study the Target effect on the Structural, Surface and Optical properties of TiO2 Thin Film Fabricated by RF Sputtering Method. *Superlattices and Microstructures*, (0).

[48] Sun, Y. and H.H. Wang. 2007. High-Performance, Flexible Hydrogen Sensors That Use Carbon Nanotubes Decorated with Palladium Nanoparticles. *Advanced Materials*. 19(19): 2818-2823.

[49] Wong, Y.M., W.P. Kang, J.L. Davidson, A. Wisitsora-at, and K.L. Soh. 2003. A novel microelectronic gas sensor utilizing carbon nanotubes for hydrogen gas detection. *Sensors and Actuators B: Chemical*. 93(1–3): 327-332.

[50] Sayago, I., E. Terrado, M. Aleixandre, M.C. Horrillo, M.J. Fernández, J. Lozano, E. Lafuente, W.K. Maser, A.M. Benito, M.T. Martinez, J. Gutiérrez, and E. Muñoz. 2007. Novel selective sensors based on carbon nanotube films for hydrogen detection. *Sensors and Actuators B: Chemical*. 122(1): 75-80.

[51] Manohara, H.M., E.W. Wong, E. Schlecht, B.D. Hunt, and P.H. Siegel. 2005. Carbon Nanotube Schottky Diodes Using Ti−Schottky and Pt−Ohmic Contacts for High Frequency Applications. *Nano letters*. 5(7): 1469-1474.

[52] Modi, A., N. Koratkar, E. Lass, B. Wei, and P.M. Ajayan. 2003. Miniaturized gas ionization sensors using carbon nanotubes. *Nature*. 424(6945): 171-174.

[53] Vander Wal, R.L., G.M. Berger, and T.M. Ticich. 2003. Carbon nanotube synthesis in a flame using laser ablation for in situ catalyst generation. *Applied Physics A*. 77(7): 885-889.

[54] Tien, L.C., P.W. Sadik, D.P. Norton, L.F. Voss, S.J. Pearton, H.T. Wang, B.S. Kang, F. Ren, J. Jun, and J. Lin. 2005. Hydrogen sensing at room temperature with Pt-coated ZnO thin films and nanorods. *Applied physics letters*. 87(22): -.

[55] Sze, S.M. and K.K. Ng. 2006. *Metal-Semiconductor Contacts*, in *Physics of Semiconductor Devices*: John Wiley & Sons, Inc. p. 134-196.

[56] Sze, S.M. and K.N. Kwok, *Physics of Semiconductor Devices*. 2007, New York: Wiley.

[57] Tan, J., W. Wlodarski, K. Kalantar-zadeh, and P. Livingston. 2006. Carbon Monoxide Gas Sensor Based on Titanium Dioxide Nanocrystalline with a Langasite Substrate. in *Sensors, 2006. 5th IEEE Conference*.

[58] Kumar, M. and Y. Ando. 2010. Chemical Vapor Deposition of Carbon Nanotubes: A Review on Growth Mechanism and Mass Production. *Journal of Nanoscience and Nanotechnology*. 10(6): 3739-3758.

[59] Craciun, V., J.M. Howard, D. Craciun, and R.K. Singh. 2003. Oxygen trapping during pulsed laser deposition of oxide films. *Applied Surface Science*. 208–209(0): 507-511.

[60] Khan, A. 2010. Raman Spectroscopic Study of the ZnO Nanostructures. *J Pak Mater Soc*. 1(4).

[61] Balachandran, U. and N.G. Eror. 1982. Raman spectra of titanium dioxide. *Journal of Solid State Chemistry*. 42(3): 276-282.

[62] Wang, Y. and J.T.W. Yeow. 2009. A Review of Carbon Nanotubes-Based Gas Sensors. *Journal of Sensors*. 2009.

[63] Kumar, M.K. and S. Ramaprabhu. 2006. Nanostructured Pt Functionlized Multiwalled Carbon Nanotube Based Hydrogen Sensor. *The Journal of Physical Chemistry B*. 110(23): 11291-11298.

[64] Li, W., N.D. Hoa, and D. Kim. 2010. High-performance carbon nanotube hydrogen sensor. *Sensors and Actuators B: Chemical*. 149(1): 184-188.

[65] Cho, J. 2010. Porous Si anode materials for lithium rechargeable batteries. *Journal of Materials Chemistry*. 20(20): 4009-4014.

[66] Cavallini, A. and L. Polenta. 2008. *Electrical characterization of nanostructures*, in *Characterization of Semiconductor Heterostructures and Nanostructures*: Elsevier. p. 55-91.

[67] Park, J.Y., J.R. Renzas, B.B. Hsu, and G.A. Somorjai. 2007. Interfacial and Chemical Properties of Pt/TiO2, Pd/TiO2, and Pt/GaN Catalytic Nanodiodes Influencing Hot Electron Flow. *The Journal of Physical Chemistry C*. 111(42): 15331-15336.

[68] Von Wenckstern, H., G. Biehne, R.A. Rahman, H. Hochmuth, M. Lorenz, and M. Grundmann. 2006. Mean barrier height of Pd Schottky contacts on ZnO thin films. *Applied physics letters*. 88(9): 092102-092102-3.

[69] Liu, P., Y. Wei, K. Jiang, Q. Sun, X. Zhang, S. Fan, S. Zhang, C. Ning, and J. Deng. 2006. Thermionic emission and work function of multiwalled carbon nanotube yarns. *Physical Review B*. 73(23): 235412.