FUNDAMENTAL STUDY OF DC AND AC ELECTRICAL RESPONSE ON A HETEROJUNCTION DEVICE (AL/ZNO-PTAA/METAL) FOR OPTOELECTRONIC APPLICATION

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ABSTRACT

The combination of organic and inorganic semiconductor materials has unlocked new achievements in the performance of semiconductor devices. In the recent years, technology of hybrid material system consisting of inorganic-organic semiconductors has sufficiently evolved and is becoming popular among researchers. The inorganic semiconductors form huge crystalline networks with strong covalent or ionic bond when deposited onto a substrate layer. The organic semiconductors with smaller molecules, layers itself onto the inorganic film produces a strong grip at the interface. This property leads to a higher electrons and holes carrier mobility in the device. However, all organic based device has been limited by low speed of constituent organic devices and inorganic devices has several disadvantages for high frequency rectification due to their poor current density and low rectification ratio. Therefore, this research focuses on a hybrid inorganic-organic diode composed of two materials with different structural and optical properties. The diode is combination of Zinc Oxide (ZnO) and Polytriarylamine (PTAA) conjugated polymer acting as n-type and p-type semiconductor materials, respectively. Morphology ZnO and PTAA thin films were fabricated by varying the spin speed and temperature using combination of RF sputtering and spin coating techniques repeatedly. The hybrid diode was design by forming a PTAA-ZnO layer in between indium tin oxide (ITO) and aluminium electrode (Al) based on spin speed of 1000 and 2000 rpm with annealing temperature of 100 to 150°C. The X-ray diffraction pattern for ZnO clearly showed a broad diffraction peak at 34.2°. Meanwhile, the PTAA film depicted a broad peak between the angles of 23° to 25°. Besides that, both materials presented a transmittance about 80% and above in the wavelength range of 370 to 850 nm using UV-vis spectrometer. The surface morphological of both thin films was observed using an advanced material microscope (HIROX). The images of ZnO-PTAA thin films indicated the layer of PTAA change colour from light blue to yellowish as the annealing temperature increases, which shows a degradation over high temperature. Furthermore, as the spin speed increases, the distribution is homogenously distributed on the surface of ZnO. The current-voltage (I-V) characteristics were measured using Keithley 2400 source meter from -4.0 to 4.0 V. The turn-on voltages are varying from 1.4 V to 2.5 V depending on crystallinity and homogenous distribution of thin films. Lastly, the frequency dependent electrical response was measured using precision LCR meter in the frequency range up to 100 KHz with various bias voltages of 1.0 to 5.0 V. The results revealed that capacitance was independent towards the high frequency level of 10 Hz to 100 KHz but conductance and series resistance are strongly dependent on the frequency and bias voltage. In conclusion, combination of ZnO and PTAA semiconductors for a heterojunction device showed unique structural and optical properties and significantly improve the electrical properties due to the extended framework of the PTAA with fusion of high crystallinity structure of ZnO on thin film uniformity and performance stability.

ABSTRAK

KAJIAN ASAS TINDAK BALAS ELEKTRIK DC DAN AC PADA PERANTI HETERO-SIMPANG (AL/ZNO-PTAA/ LOGAM) UNTUK APLIKASI OPTOELEKTRONIK

Gabungan bahan semikonduktor organik dan bukan organik telah memberi ruang untuk pencapaian baru dalam prestasi peranti semikonduktor. Dalam tahun-tahun kebelakangan ini, teknologi sistem bahan hibrid yang terdiri daripada semikonduktor organik dan bukan organik telah cukup berkembang dan menjadi popular dalam kalangan penyelidik. Semikonduktor bukan organik membentuk rangkaian kristal yang besar dengan ikatan kovalen atau ionik yang kuat apabila dimendapkan ke lapisan substrat. Semikonduktor organik dengan molekul yang lebih kecil, membentuk lapisan pada filem bukan organik dan menghasilkan cengkaman yang kukuh di antara muka lapisan tersebut. Sifat ini membawa kepada mobiliti pengangkut elektron dan lubang yang lebih tinggi dalam peranti. Walau bagaimanapun, semua peranti berasaskan bahan organik adalah terbatas dengan kadar pernghasilan yang mengambil masa dan peranti bukan organik mempunyai beberapa kelemahan apabila berada dalam keadaan berfrekuensi tinggi disebabkan ketumpatan arus yang lemah dan rendah. Oleh itu, kajian ini memfokuskan pada diod hibrid organik dan bukan organik yang terdiri daripada dua bahan yang mempunyai sifat struktur dan optik yang berbeza. Diod ini ialah gabungan Zink Oksida (ZnO) dan polimer berkonjugat Politriarilamin (PTAA) yang masing-masing bertindak sebagai bahan jenis-n dan bahan semikonduktor jenis-p. Filem-filem nipis morfologi ZnO dan PTAA dibuat dengan mengubah kelajuan putaran dan suhu dengan menggunakan gabungan teknik percikan berfrekuensi radio dan teknik salutan berputar. Diod hibrid ini direkabentuk dengan membentuk lapisan PTAA-ZnO di antara indium tin oksida (ITO) dan elektrod aluminium (Al) pada kelajuan putaran 1000 dan 2000 rpm dengan suhu penyepuhlindapan 100° hingga 150° C. Corak difraksi sinar-X untuk ZnO jelas menunjukkan puncak difraksi yang luas pada 34.2°. Sementara itu, filem PTAA menggambarkan puncak luas antara sudut 23° hingga 25°. Selain itu, kedua-dua bahan membentangkan penembusan kira-kira 80% dan keatas dalam julat panjang gelombang 370 hingga 850 nm menggunakan spektrometer UV-vis. Morfologi permukaan kedua-dua filem nipis diperhatikan menggunakan mikroskop bahan canggih (HIROX). Gambar-gambar filem nipis ZnO-PTAA menunjukkan lapisan PTAA bertukar menjadi kekuningan apabila suhu penyepuhlindapan bertambah. Hal ini menunjukkan kemerosotan pada suhu tinggi. Selain itu, apabila kelajuan putaran meningkat, taburan diedarkan secara sekata pada permukaan ZnO. Ciri-ciri arus-voltan (I-V) diukur dengan menggunakan meter sumber Keithley 2400 dari -4.0 ke 4.0 V. Voltan putaran adalah berbeza daripada 1.4 hingga 2.5 V bergantung kepada pengikatan kristal dan pengedaran filem nipis. Akhir sekali, tindak balas elektrik yang bergantung kepada frekuensi diukur dengan menggunakan meter kejituan LCR dalam frekuensi sehingga 100 kHz dengan pelbagai voltan bias 1.0 hingga 5.0 V. Hasilnya menunjukkan kapasitan dan rintangan siri tidak bergantung kepada frekuensi tinggi dari 10 hingga 100 kHz tetapi konduktansinya sangat bergantung kepada kekerapan dan voltan bias. Sebagai kesimpulan, hasil gabungan semikonduktor ZnO dan PTAA untuk peranti simpang hetero menunjukkan sifat struktur dan optik yang unik dan membuktikan bahawa sifat elektrik meningkat dengan ketara kerana struktur PTAA yang bersesuaian dengan gabungan struktur kristalografi ZnO yang tinggi pada keseragaman filem nipis dan kestabilan prestasi.

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LIST OF ABBREVIATIONS

RFID	Radio Frequency Identification
TFTs	Thin Film Transistor
RF	Radio Frequency
IV	Current - voltage
ITO	Indium Tin Oxide
RPM	Revolution per minute
AC	Alternating Current
DC	Direct Current
EV	valence band
E_C	conduction band
E_g	Energy band gap
HOMO	Highest Occupied Molecular Orbital
LUMO	Lowest Un-occupied Molecular Orbital
FWHM	Full Width Half Maximum
sccm	Standard Cubic Centimetre Per Minute
eV	electron volt
°C	Celsius
K	Kelvin
cm	Centimetre
V	Volt
s	Second
Ω	Ohm
Hz	Hertz

LIST OF SYMBOLS

п	pi
w	spin speed
β_0	initial kinematic viscosity
j	current density
%	percentage
A	Ampere
W	Watt
λ	wavelength
θ	angle
d	Spacing between plane
D	average grain size
β	Width of FWHM
I_l	prefactor current
n	ideality factor
$Ø_b$	barrier height
E_g	band gap energy
X_s	electron affinity of the semiconductor
Y	admittance
Z	impedance
G	conductance
w	angular frequency
f	frequency
C	capacitance
R_s	series resistance
°	degree
Å	Angstrom
σ	electrical conductivity

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Organic- inorganic heterojunctions have a promising future because of the variety of optical and electrical properties, which make them technologically useful for optoelectronics applications. The main idea in developing hybrid devices was to take advantages of the best properties of each component that forms a heterojunction, trying to decrease or eliminate their drawbacks getting in an ideal way of synergic effect that results in the development of the new systems with new properties. Inorganic materials offer a broader absorption of spectrum compared to the organic semiconductors. Its characteristic resemblance as irreplaceable electronic, optical and biocompatible properties which result in improvement of response and sensitivity of the TFTs (Mohamad *et al.*, 2015). Wide range resistance, high optical transperency in the visible light region and wide bandgap energy enhancede the application of oxide material for optoelectronics application (Afishah *et al.*, 2013).

Nowdays organics semiconductor are widely accepted as an active semiconductor materials based on their unique characteristic such as light weight, simple structure, more flexibility, and more versatile than inorganics device (Mohamad *et al.*, 2015). Organic semiconductors is considered as active materials due to van der waals intermolecular forces and offer wide range of optical properties. Combining such organics semiconductors with inorganics semiconductors of wide optical bandgap is promising for optoelectronics applictions such as radio frequency identification (RFID) tags (Cantatore *et al.*, 2006; Gowrisanker *et al.*, 2009). High frequency RFID tags require a diode to operate at 13.56 MHz frequency with maximum current density and a sufficiently large reverse breakdown voltage and low forward turn-on voltage (Finkenzeller, 2011; Pal *et al.*, 2008). The rectification ratio should be in the range 100 to 1000 (Finkenzeller, 2011). A rectifier consists of diode and capacitors. Diodes can be classified into p-n junction, transistors and Schottky diodes. A p-n junction diode integrates p-type and n-type semiconductors.

Organic thin films have been used as a p-type semiconductor since it is an effective hole transport materials with relatively high charge carrier mobility (Hunter *et al.*, 2014). Several publications are also reported that incorporating organic materials such as poly(trialamine) (PTAA) in hetero-structure with different inorganic semiconductors showed promising electrical characterisitics (Heo *et al.*, 2013; Logan *et al.*, 2015). Recently, PTAA-based devices was tested to be air stable under different environment conditions which make it favor for hybrid radio frequency identification (RFID) operates under ambient conditions (Lau *et al.*, 2013). On the other hand, undoped zinc oxide (ZnO) thin films have an n-type conduction and a high resistivity due to low carrier concentration with awide bandgap energy (3.3 eV), a large exciton biding energy (60 meV) and large saturation velocity (100 cm/s), which indicated that ZnO-based devices would be better for high frequency applications, thus making it ideal for optoelectronic applications. (Lee *et al.*, 2010; Prepelita *et al.*, 2010). Despite the extensive research work on the subject, stable p-type ZnO is difficult to manufacture, thus hindering the fabrication of ZnO p-n homojunctions (Fan *et al.*, 2013). Several hetero-junction organic-inorganic devices have been proposed and recently fabrication p-n pentacene/ZnO diode producing uniform layers under ambient condition without involving high energy processes with nonlinear characteristics similar to that of inorganic p-n junction diode was reported (Dzulfahmi *et al.*, 2015)

Most reported organic-inorganic p-n junction diodes have been extensively investigated for their carrier injection mechanism. The inorganic semiconductor forms an extended framework bound by strong covalent or ionic interactions to provide high carrier mobility. Meanwhile, the organic semiconductor facilitates the self-assembly of these materials, enabling heterojunctions to be deposited by the simple, low-temperature as the organic materials. Organic-inorganis diodes with high current density with low operating voltage require a substantial interfacial contact between thin films to operate at high frequency rectification under ambient environment conditions. For high speed and high current density diodes, the interface resistance should be very low at forward bias, low conductance in reverse bias and a high reverse breakdown voltage. A diode only requires electrons and holes flow on nanometer scale lengths from electrodes to the recombination region, current density and speed can be expected to be higher compared to homojunction devices when numerous grain boundaries and defect sites are minimized at the organic and inorganic interface during the fabrication process.

1.2 Problem Statement

Nowdays, the semiconductor technology is becoming one of the most important industrial revolution towards the world demand on clean and green technology that not only save for the environment but also less cost manufacturing. Organic and inorganic based electronics device had temporarily helped the industry to uphold the policy but however the progress in all-organic-based devices has been limited by the low speed of the constituent organic devices. Meanwhile, inorganic-based devices have several disadvantages for high frequency rectification due to their poor current density, very low rectification ratio and relatively lower reverse breakdown voltage. Thus combination organic-inorganic might overcome this drawback using the versatility of the chemical structure of organic with the established properties of inorganic. In spite of many advantages of this combination organic-inorganic, there are few drawbacks which have to be overcome in order to meet application requirement that comparable to the conventional silicon devices. The relative instability and poor electrical performance are among the drawbacks with due to interface traps. As much works focusing on the design and configuration of organic-inorganic heterojunctions such as PTAA-ZnO combination to increase the energy efficiency, less attention on analysis of the dominating conduction mechanism, i.e. direct current (DC) and alternating current (AC) electrical responses, which is very important for the operation of high quality optoeletronic applications.

The main idea in developing organic-inorganic devices was to take advantages of the best properties of each material that forms a heterojunction and trying to decrease or eliminate their drawbacks getting in an ideal way a synergic effect that results in the new systems with new properties. However, little is known about the PTAA-ZnO for their instrinsic interaction at the interface as well as its applications. Charge transport characteristics are key attributes that have important consequence for the device electrical performance. Thus this project is focusing to elucidate the frequency dependent impedance such as frequency dependent conductance, capacitance and current-voltage characteristics using impedance or AC analysis.

1.3 Research Objective

The main aim of this research is to fundamentally investigate the frequency dependent electrical responses on organic-inorganic Schottky diode focused on the optoelectronics application. This research focusses on the following objectives:

- To investigate the effect of annealing temperature on the electrical responses of a heterojunction PTAA-ZnO Schottky diode.

- To determine the dc electrical characteristics of a heterojunction PTAA-ZnO Schottky diode by current-voltage relationship

- To model equivalent circuit based on the current-voltage characteristics of a heterojunction PTAA-ZnO Schottky diode using frequency dependent electrical responses.

1.4 Research Scope

This research focus on design, fabrication and characterization, which conducted to determine the optimum deposition speed and annealing temperature of PTAA during deposition that will optimize the DC electrical characteristics and AC frequency dependent impedance characteristics of the hybrid Inorganic-organic diode. In the process of diode fabrication, radio frequency (RF) sputtering, spin coating technique and thermal evaporation was used as the inorganic-organic semiconductor material deposition technique to form thin film or layer. RF sputtering and spin coater enable the thin film to be fabricate uniformly. Thus, RF sputtering is for the inorganic material with the aid of spin coating technique for organic materials which easily to be dissolved in solvent. Besides that, all experiments to fabricate thin films and hybrid diode were conducted in a controlled environment by minimizing the exposure of the fabricated diode with ambient environment. The DC and AC measurement setup is required to conduct electrical and frequency-dependent impedance of hybrid diodes.

1.5 Thesis Outline

The thesis contains five chapters. Chapter 1 is an introduction that gives a brief explanation of the technology that involving inorganic, organic semiconductor, diode and what is the limitation in achieving high efficiency inorganic-organic diode. The research aim, objective scope of this thesis is presented in this chapter.

Chapter 2 gives a brief explanation about the basic theory behind inorganic-organic semiconductor. A brief review on previous research is written to show the various materials that are used for the development of inorganic-organic devices.

Experimental steps are explained in chapter 3. This chapter explains the details on pre- and post-processing procedures and steps in order to form a thin film or layer and fabricate the hybrid devices. A physical characterization method of determining thin film properties such as X-Ray diffraction and SEM is also briefly explained, while experimental setup for the DC and AC measurement using an LCR meter and computer-controlled current-voltage measurement were also explained to determine the electrical properties of hybrid inorganic-organic devices.

Chapter 4 focusing on the results that obtains from the experiment. The characterization has been selected which is the frequency dependent electrical characteristics and the DC current-voltage (I-V) characteristics of the diode device.

Chapter 5 presenting the summary of the findings, conclusion and also recommendation. All the result of this work is summarized. By the thesis data, a future work regarding the thin film performance is described.

REFERENCES

Afishah Alias, Khairul Anuar Mohamad, Katsuhiro Uesugi, and H. F. (2013). Electrical and Structural Characterization of Zn Doped CuGaO 2 Films, (II), 183–185.

Akkaya, A., Esmer, L., Kantar, B. B., Çetin, H., & Ayyildiz, E. (2014). Effect of thermal annealing on electrical and structural properties of Ni/Au/n-GaN Schottky contacts. *Microelectronic Engineering*, 130, 62–68.

Bae, I.S., Cho, S.-H., Lee, S.-B., Kim, Y., & Boo, J.-H. (2005). Growth of plasma-polymerized thin films by PECVD method and study on their surface and optical characteristics. *Surface and Coatings Technology*, 193(1–3), 142–146. https://doi.org/10.1016/J.SURFCOAT.2004.07.022

Bao, D., Gu, H., & Kuang, A. (1998). Sol-gel-derived c-axis oriented Z, qO thin films. *Thin Solid Films*, 312(X), 37–39. https://doi.org/10.1016/S0040-6090(97)0030

Bensmaine, S., & Benyoucef, B. (2014). Effect of the temperature on ZnO thin films deposited by r.f. magnetron. *Physics Procedia*, 55, 144–149.

Bhagyaraj, S. M., & Oluwafemi, O. S. (2018). Nanotechnology: The Science of the Invisible. In *Synthesis of Inorganic Nanomaterials* (pp. 1-18). Woodhead Publishing.

Bilkan, Ç., Gümüş, A., & Altındal, Ş. (2015). The source of negative capacitance and anomalous peak in the forward bias capacitance-voltage in Cr/p-si Schottky barrier diodes (SBDs). *Materials Science in Semiconductor Processing*, 39, 484–491. https://doi.org/10.1016/J.MSSP.2015.05.044

Birch, W. R. (2004). Cleaning Glass Surfaces. In *Sol-Gel Technologies for Glass Producers and Users* (19–34). Boston, Springer US.

Cantatore, E., Geims, T. C. T., Gruijthuijsen, a F. a, Gelinck, G. H., Drews, S., & Leeuw, D. M. De. (2006). A 13.56 MHz RFID System based on Organic Transponders. *Proc ISSCC*, 15.2(1), 84–92.

Celle, C., Suspène, C., Simonato, J.-P., Lenfant, S., Ternisien, M., & Vuillaume, D. (2009). Self-assembled monolayers for electrode fabrication and efficient threshold voltage control of organic transistors with amorphous semiconductor layer. *Organic Electronics*, 10(1), 119–126.

Chen, Y., Bagnall, D. M., Koh, H., Park, K., Hiraga, K., Zhu, Z., & Yao, T. (1998).

Plasma assisted molecular beam epitaxy of ZnO on *c* -plane sapphire: Growth and characterization. *Journal of Applied Physics*, 84(7), 3912–3918. https://doi.org/10.1063/1.368595

Cheol, K., Young, D., & Ho, K. (1997). The physical properties of Al-doped zinc oxide films prepared by RF magnetron sputtering. *Thin Solid Films*, 305, 201–209.

Cherif, A., Jomni, S., Saghrouni, H., Belgacem, W., Khirouni, K., & Beji, L. (2016). Temperature dependent dielectric studies of Al/Dy2O3/porous Si heterostructure by capacitance and conductance measurements. *Journal of Alloys and Compounds*, 685, 28–33.

Chung, M.-H., Kwon, J.-H., Oh, T.-Y., Lee, S.-J., Choi, D.-H., & Ju, B.-K. (2010). Polymer binder effects on the electrical characteristics of 6, 13-bis(triisopropylsilylethynyl)-pentacene thin-film transistors in different solvents. *Thin Solid Films*, 518(22), 6289–6294.

Cullity, B. D., & Stock, S. R. (2001). Elements of X-ray Diffraction, Third Edition. Prentice-Hall. Retrieved from https://www.scholars .northwestern.edu/en/publications/elements-of-x-ray-diffraction-third-edition

Dzulfadli, M. H. S., Mohamad, K. A., Rusnan, F. N., Ghosh, B. K., Alias, A. and Saad ,I. (2015). Akademia Baru Flexible Spray Coated TIPS-Pentacene Organic P- N Junction Diode Akademia Baru, 14(1), 8–13.

Dogan, H., & Elagoz, S. (2014). Temperature-dependent electrical transport properties of (Au/Ni)/n-GaN Schottky barrier diodes. *Physica E: Low-Dimensional Systems and Nanostructures*, 63, 186–192. https://doi.org/ 10.1016/j.physe.2014.04.019

Doğan, H., Yıldırım, N., Orak, İ., Elagöz, S., & Turut, A. (2015). Capacitance-conductance-frequency characteristics of Au/Ni/n-GaN/undoped GaN Structures. *Physica B: Condensed Matter*, 457, 48–53. https://doi.org/ 10.1016/J.PHYSB.2014.09.033

Edwards-Shea, L. (1996). *The essence of solid-state electronics*. Prentice Hall.

Erray, M., Hanie, M., Boufounas, E.-M., & El Amrani, A. (2018). Effects of carriers charge mobility and work function on the performances of P3HT : PCBM based organic photovoltaic solar cell. *Ieee*, 3–8. https://doi.org/10.1109/ ICOA.2018.8370536

Esopi, M. R. (2018). Tuning the spectral response of ultraviolet organic – inorganic hybrid photodetectors via charge trapping and charge collection narrowing †. *Physical Chemistry Chemical Physics*. https://doi.org/10.1039/C8CP00361K

Fan, J. C., Sreekanth, K. M., Xie, Z., Chang, S. L., & Rao, K. V. (2013). p-Type ZnO materials: Theory, growth, properties and devices. *Progress in Materials Science*, 58(6), 874–985. https://doi.org/10.1016/J.PMATSCI.2013.03.002

Feddes, B., Wolke, J. G. C., Jansen, J. A., & Vredenberg, A. M. (2003). Radio frequency magnetron sputtering deposition of calcium phosphate coatings: The effect of resputtering on the coating composition. *Journal of Applied Physics*, 93(12), 9503–9507. https://doi.org/10.1063/1.1576894

Finkenzeller, K. (2011). *Fundamentals and Applicatioons in Contactless Smart Cards, Radio Frewquency Identification and Near ield Communication. 3rd edition, Wiley.*

Gao, L., Pang, C., He, D., Shen, L., Gupta, A., & Bao, N. (2015). Synthesis of Hierarchical Nanoporous Microstructures via the Kirkendall Effect in Chemical Reduction Process. *Scientific Reports*, 5(October), 1–12. https://doi.org /10.1038/srep16061

Gowrisanker, S., Quevedo-Lopez, M. A., Alshareef, H. N., Gnade, B. E., Venugopal, S., Krishna, R., ... Allee, D. R. (2009). A novel low temperature integration of hybrid CMOS devices on flexible substrates. *Organic Electronics: Physics, Materials, Applications*. https://doi.org/10.1016/j.orgel.2009.06.012

Gupta, R. K., Aydın, M. E., & Yakuphanoglu, F. (2011). Photoconducting and electrical properties of Al/TIPS-pentacene/p-Si/Al hybrid diode for optical sensor applications. *Synthetic Metals*, 161(21–22), 2355–2360. https://doi.org /10.1016/J.SYNTHMET.2011.09.002

Heo, J. H., Im, S. H., Noh, J. H., Mandal, T. N., Lim, C.-S., Chang, J. A., Seok, S. Il. (2013). Efficient inorganic–organic hybrid heterojunction solar cells containing perovskite compound and polymeric hole conductors. *Nature Photonics*, 7(6), 486–491. https://doi.org/10.1038/nphoton.2013.80

Hima, A., Khechekhouche, A., Kemerchou, I., Lakhdar, N., Benhaoua, B., Rogti, F. Saadoun, A. (2018). GPVDM simulation of layer thickness effect on power conversion efficiency of CH 3 NH 3 PbI 3 based planar heterojunction solar cell, 3(2), 37–41.

Hunter, S., Chen, J., & Anthopoulos, T. D. (2014). Microstructural Control of Charge

Transport in Organic Blend Thin-Film Transistors. *Advanced Functional Materials*, 24(38), 5969–5976. https://doi.org/10.1002/ADFM.201401087

Hwang, S.-W., Park, G., Edwards, C., Corbin, E. A., Kang, S.-K., Cheng, H., ... Rogers, J. A. (2014). Dissolution Chemistry and Biocompatibility of Single-Crystalline Silicon Nanomembranes and Associated Materials for Transient Electronics. *ACS Nano*, 8(6), 5843–5851. https://doi.org/10.1021/nn500847g

Imer, A. G., Tombak, A., & Korkut, A. (2016). Electrical and photoelectrical characteristic investigation of a new generation photodiode based on bromothymol blue dye. *Journal of Physics: Conference Series*, 707(1). https://doi.org/10.1088/1742-6596/707/1/012012

Inkson, B. J. (2016). *Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) for Materials Characterization. Materials Characterization Using Nondestructive Evaluation (NDE) Methods*. Elsevier Ltd. https://doi.org/10.1016/B978-0-08-100040-3.00002-X

Intaniwet, A., Keddie, J. L., Shkunov, M., & Sellin, P. J. (2011). High charge-carrier mobilities in blends of poly(triarylamine) and TIPS-pentacene leading to better performing X-ray sensors. *Organic Electronics: Physics, Materials, Applications*. https://doi.org/10.1016/j.orgel.2011.08.003

Ishpal, Kumar, S., Dwivedi, N., & Rauthan, C. M. S. (2012). Investigation of radio frequency plasma for the growth of diamond like carbon films. *Physics of Plasmas*, 19(3). https://doi.org/10.1063/1.3694855

Jung, Y. H., Zhang, H., Gong, S., & Ma, Z. (2017). High-performance green semiconductor devices: materials, designs, and fabrication. *Semiconductor Science and Technology*, 32(6), 063002. https://doi.org/10.1088/1361-6641/aa6f88

Kadaoui, M. A., Bouiadjra, W. B., Saidane, A., Belahsene, S., & Ramdane, A. (2015). Electrical parameters of Au/n-GaN and Pt/n-GaN Schottky diodes. *Superlattices and Microstructures*, 82, 269–286. https://doi.org/10.1016/j.spmi.2015.02.007

Kaech, A. (2002). An Introduction To Electron Microscopy Instrumentation, Imaging and Preparation. *Center for Microscopy and Image Analysis*, 1–26.

Kamalasanan, M. N., & Chandra, S. (1996). Sol-gel synthesis of ZnO thin films. *Thin Solid Films*, 288(1–2), 112–115. https://doi.org/10.1016/S0040-6090(96)08864-5

Kang, S.-K., Park, G., Kim, K., Hwang, S.-W., Cheng, H., Shin, J., ... Rogers, J. A. (2015). Dissolution Chemistry and Biocompatibility of Silicon- and Germanium-Based Semiconductors for Transient Electronics. *ACS Applied Materials & Interfaces*, 7(17), 9297–9305. https://doi.org/10.1021/acsami.5b02526

Karataş, Ş., & Türüt, A. (2010). The frequency-dependent electrical characteristics of interfaces in the Sn/p-Si metal semiconductor structures. *Microelectronics Reliability*, 50(3), 351–355. https://doi.org/10.1016/J.MICROREL.2009.10.017

Kim, M. C., Cho, S. H., Han, J. G., Hong, B. Y., Kim, Y. J., Yang, S. H., & Boo, J.-H. (2003). High-rate deposition of plasma polymerized thin films using PECVD method and characterization of their optical properties. *Surface and Coatings Technology*, 169–170, 595–599. https://doi.org/10.1016/S0257-8972(03)00115-4

Kumar, A., Vinayak, S., & Singh, R. (2013). Micro-structural and temperature dependent electrical characterization of Ni/GaN Schottky barrier diodes. *Current Applied Physics*, 13(6), 1137–1142. https://doi.org/10.1016/j.cap.2013.03.009

Kwon, J. H., Shin, S. Il, Choi, J., Chung, M. H., Oh, T. Y., Kim, K. N. H., ... Ju, B. K. (2009). Channel width effect for organic thin film transistors using TIPS-pentacene employed as a dopant of poly-triarylamine. *Organic Electronics: Physics, Materials, Applications*. https://doi.org/10.1016/j.orgel.2009.02.027

Lau, T., Lorenz, E., & Koyuncu, M. (2013). Lifetime of Poly(triaryl amine) Based Organic Field Effect Transistors under Different Environmental Conditions. *Japanese Journal of Applied Physics*, 52(4R), 041601. https://doi.org/10.7567/JJAP.52.041601

Lee, J.H., Ko, K.H., & Park, B.O. (2003). Electrical and optical properties of ZnO transparent conducting films by the sol–gel method. *Journal of Crystal Growth*, 247(1–2), 119–125. https://doi.org/10.1016/S0022-0248(02)01907-3

Lee, J.H., & Park, B.O. (2003). Transparent conducting ZnO:Al, In and Sn thin films deposited by the sol–gel method. *Thin Solid Films*, 426(1–2), 94–99. https://doi.org/10.1016/S0040-6090(03)00014-2

Lee, Y. , Park, J. , & Choi, J. (2003). Electrical characteristics of pentacene-based Schottky diodes. *Optical Materials*, 21(1–3), 433–437. https://doi.org/10.1016/S0925-3467(02)00178-7

Lee, Y., Lee, J. C., & Su, C.W. (2010). Effects of N-Doping on Magnetic Properties of

ZnCoO Diluted Magnetic Semiconductor Thin Films. *IEEE Transactions on Magnetics*, 46(6), 1565–1568. https://doi.org/10.1109/TMAG.2010.2041045

Li, H., & Guo, X. (2013). Impedance behavior of excess CaO type non-stoichiometric Ca1−xZrO3−δ perovskite ceramic. *Current Applied Physics*, 13(3), 500–504. https://doi.org/10.1016/J.CAP.2012.09.011

Li, L. M., Mani, A. M., Shain, F. L., Alias, A., & Salleh, S. (2015). Effect of Sputtering Pressure on the Structural and Optical Properties of Zno Films Deposited on Flexible Substrate. *Jurnal Teknologi*, 75(7), 45–50. https://doi.org/10.4028/www.scientific.net/AMR.1107.678

Liem, H., Choy, H. S., & Yung, K. C. (2010). A prerequisite to achieving high performance polymer/inorganic thin film diodes. *Solid State Communications*, 150(37–38), 1725–1728. https://doi.org/10.1016/j.ssc.2010.07.038

Liu, J., Walker, B., Tamayo, A., Zhang, Y., & Nguyen, T. Q. (2013). Effects of heteroatom substitutions on the crystal structure, film formation, and optoelectronic properties of diketopyrrolopyrrole-based materials. *Advanced Functional Materials*, *23*(1), 47-56.

Logan, S., Donaghey, J. E., Zhang, W., McCulloch, I., & Campbell, A. J. (2015). Compatibility of amorphous triarylamine copolymers with solution-processed hole injecting metal oxide bottom contacts. *Journal of Materials Chemistry C*, 3(17), 4530–4536. https://doi.org/10.1039/C4TC02593H

Low, F. W., & Lai, C. W. (2018). Recent developments of graphene-TiO 2 composite nanomaterials as e ffi cient photoelectrodes in dye-sensitized solar cells : A review, 82(September 2017), 103–125. https://doi.org/10.1016/j.rser.2017.09.024

Lukasiak, L., & Jakubowski, A. (2010). History of Semiconductors. *Journal of Telecommunications and Information Technology*, 1(IS), 3–9. https://doi.org/10.2320/materia1962.29.18

Lupo, D., Lilja, K. E., Heljo, P., T. (2011). Printed organic rectifying diodes: Issues, interfaces and applications. *In Proceedings of American Association of Textile Chemists and Colorists International Conference 2011 (AATCC 2011) Curran Associates.*

Mäckel, H., & MacKenzie, R. C. I. (2018). Determination of Charge-Carrier Mobility in Disordered Thin-Film Solar Cells as a Function of Current Density. *Physical*

Review Applied, 9(3), 34020. https://doi.org/10.1103/PhysRevApplied .9.034020

Miandal, K., Mohamad, K. A., & Alias, A. (2016). Akademia Baru Annealing heat treatment of Poly (triarylamine) (PTAA) thin films deposited using spin coating Akademia Baru, 1(1), 7–12.

Miandal, K., Tak, H. H., Mohamad, K. A., Chee, F. P., & Alias, A. (2017). The structural and optical properties of poly(Triarylamine) (PTAA) thin films prepared at different spin rate using spin coating method. *Advanced Science Letters*, 23(2), 1337–1339. https://doi.org/10.1166/asl.2017.8363

Mohamad, K. A., Hoh, H. T., Alias, A., Ghosh, B. K., & Fukuda, H. (2017). Frequency and voltage dependent electrical responses of poly(triarylamine) thin film-based organic Schottky diode. *EPJ Web of Conferences*, 162, 26–29. https://doi.org /10.1051/epjconf/201716201060

Mohamad, K. A., Rusnan, F. N., Seria, D. M. H., Saad, I., Alias, A., Katsuhiro, U., & Hisashi, F. (2015). Fabrication and characterization of 6,13-bis (triisopropylsilylethynyl)-pentacene active semiconductor thin films prepared by flow-coating method (p. 020003). https://doi.org/10.1063/1.4928820

Nolan, M., & Elliott, S. D. (2006). The p-type conduction mechanism in Cu2O: a first principles study. *Physical Chemistry Chemical Physics*, 8(45), 5350. https://doi.org/10.1039/b611969g

Nose, Y., Yoshimura, T., Ashida, A., Uehara, T., & Fujimura, N. (2016). Novel chemical vapor deposition process of ZnO films using nonequilibrium N_2 plasma generated near atmospheric pressure with small amount of O_2 below 1%. *Journal of Applied Physics*, 119(17), 175302. https://doi.org/10.1063 /1.4948326

O.Siyanbola, T., F.Akinsola, A., A.Adekoya, J., O.Ajani, O., O.Ehi-Eromosele, C., I. Olasehinde, G., & A. Ajayi, A. (2017). Antimicrobial and Thermal Properties of Coating Systems Modified with ZnO Nanoparticle and its Hybrid Forms: (A Review). *Oriental Journal of Chemistry*, 33(1), 09-16. https://doi.org/ 10.13005/ojc/330102

Özgür, Ü., Alivov, Y. I., Liu, C., Teke, A., Reshchikov, M. A., Doğan, S., Morkọ, H. (2005). A comprehensive review of ZnO materials and devices. *Journal of Applied Physics*, 98(4), 1–103. https://doi.org/10.1063/1.1992666

Pal, B. N., Sun, J., Jung, B. J., Choi, E., Andreou, A. G., & Katz, H. E. (2008). Pentacene-Zinc Oxide Vertical Diode with Compatible Grains and 15-MHz Rectification. *Advanced Materials*, 20(5), 1023–1028. https://doi.org /10.1002/adma.200701550

Park, K. C., Ma, D. Y., & Kim, K. H. (1997). The physical properties of Al-doped zinc oxide films prepared by RF magnetron sputtering. *Thin Solid Films*, 305(1–2), 201–209. https://doi.org/10.1016/S0040-6090(97)00215-0

Park, S. K., Jackson, T. N., Anthony, J. E., & Mourey, D. A. (2007). High mobility solution processed 6,13-bis(triisopropyl-silylethynyl) pentacene organic thin film transistors. *Applied Physics Letters*, 91(6), 063514. https://doi.org /10.1063/1.2768934

Patankar, K. K., Patil, S. A., Sivakumar, K. V., Mahajan, R. P., Kolekar, Y. D., & Kothale, M. B. (2000). AC conductivity and magnetoelectric effect in CuFe1.6Cr0.4O4–BaTiO3 composite ceramics. *Materials Chemistry and Physics*, 65(1), 97–102. https://doi.org/10.1016/S0254-0584(00)00216-9

Pecunia, V., Banger, K., & Sirringhaus, H. (2015). High-Performance Solution-Processed Amorphous-Oxide-Semiconductor TFTs with Organic Polymeric Gate Dielectrics. *Advanced Electronic Materials*, *1*(1-2), 1400024.

Perez, M. R., Mejia, I., Salas-Villasenor, A. L., Stiegler, H., Trachtenberg, I., Gnade, B. E., & Quevedo-Lopez, M. A. (2012). Hybrid CMOS thin-film devices based on solution-processed CdS n-TFTs and TIPS-Pentacene p-TFTs. *Organic Electronics*, 13(12), 3045–3049. https://doi.org/10.1016/j.orgel.2012.08.015

Potje-Kamloth, K. (2008). Semiconductor junction gas sensors. *Chemical reviews*, *108*(2), 367-399.

Prepelita, P., Medianu, R., Garoi, F., Stefan, N., & Iacomi, F. (2010). On the structural and electrical characteristics of zinc oxide thin films. *Thin Solid Films*, 518(16), 4615–4618. https://doi.org/10.1016/J.TSF.2009.12.044

Reddy, V. S., Das, S., Ray, S. K., & Dhar, A. (2007). Studies on conduction mechanisms of pentacene based diodes using impedance spectroscopy. *Journal of Physics D: Applied Physics*, 40(24), 7687–7693. https://doi.org/10.1088 /0022-3727/40/24/015

Rodríguez-Moreno, J., Navarrete-Astorga, E., Martín, F., Schrebler, R., Ramos-Barrado, J. R., & Dalchiele, E. A. (2012). Semitransparent ZnO/poly(3,4-

ethylenedioxythiophene) based hybrid inorganic/organic heterojunction thin film diodes prepared by combined radio-frequency magnetron-sputtering and electrodeposition techniques. *Thin Solid Films*, 525, 88–92. https://doi.org/10.1016/J.TSF.2012.10.067

Hellstrom, S. L. (2007). Basic Models of Spin Coating. *Physics*, 210(Stanford University). Retrieved from http://large.stanford.edu/courses/2007/ph210/hellstrom1/

Sahu, N., Parija, B., & Panigrahi, S. (2009). Fundamental understanding and modeling of spin coating process: A review. *Indian Journal of Physics*, 83(4), 493–502. https://doi.org/10.1007/s12648-009-0009-z

Samarasekara, P. (2010). ITO glass CuO Cu 2 O Cu / Au, 2(2), 3–8.

Sanjeev, S., & Kekuda, D. (2015). Effect of annealing temperature on the structural and optical properties of zinc oxide (ZnO) thin films prepared by spin coating process. *IOP Conference Series: Materials Science and Engineering*, 73(1). https://doi.org/10.1088/1757-899X/73/1/012149

Schroder, D. K. (2006). *Semiconductor material and device characterization*. IEEE Press.

Sendner, M., Trollmann, J., & Pucci, A. (2014). Dielectric function and degradation process of poly(triarylamine) (PTAA). *Organic Electronics: Physics, Materials, Applications*, 15(11), 2959–2963. https://doi.org/10.1016/j.orgel.2014.08.037

Shao, H., Fang, J., Wang, H., Dai, L., & Lin, T. (2016). Polymer-Metal Schottky Contact with Direct-Current Outputs. *Advanced Materials*, 28(7), 1461–1466. https://doi.org/10.1002/adma.201504778

Singh, S., Jha, P. A., Varma, S., & Singh, P. (2017). Large polaron hopping phenomenon in lanthanum doped strontium titanate. *Journal of Alloys and Compounds*, 704, 707–716. https://doi.org/10.1016/J.JALLCOM.2017.02.015

Streetman, B. G., & Banerjee, S. (2014). *Solid state electronic devices*.

Thiagarajan, S., Sanmugam, A., & Vikraman, D. (2017). Facile Methodology of Sol-Gel Synthesis for Metal Oxide Nanostructures. In *Recent Applications in Sol-Gel Synthesis*. InTech. https://doi.org/10.5772/intechopen.68708

Tran Anh Tuan, T., Kuo, D.H., Li, C.-C., & Li, G.Z. (2015). Effect of Temperature Dependence on Electrical Characterization of p-n GaN Diode Fabricated by RF Magnetron Sputtering. *Materials Sciences and Applications*, 6(6), 809–817.

https://doi.org/10.4236/msa.2015.69083

Tsutsumi, N., Kinashi, K., Masumura, K., & Kono, K. (2015). Photorefractive performance of poly(triarylamine)-based polymer composites: An approach from the photoconductive properties. *Journal of Polymer Science, Part B: Polymer Physics*, 53(7), 502–508. https://doi.org/10.1002/polb.23663

Vila-Fungueiria, J. M., Bachelet, R., Saint-Girons, G., Gendry, M., Gich, M., Gazquez, J., Carretero-Genevrier, A. (2015). Integration of functional complex oxide nanomaterials on silicon. *Frontiers in Physics*, 3, 38. https://doi.org /10.3389/fphy.2015.00038

Wang, L., Lin, T., Wang, X., & Kaynak, A. (2005). Frictional and tensile properties of conducting polymer coated wool and alpaca fibers. *Fibers and Polymers*, 6(3), 259–262. https://doi.org/10.1007/BF02875651

Xiong, L., Huang, S., Yang, X., Qiu, M., Chen, Z., & Yu, Y. (2011). P-Type and n-type Cu2O semiconductor thin films: Controllable preparation by simple solvothermal method and photoelectrochemical properties. *Electrochimica Acta*, 56(6), 2735–2739. https://doi.org/10.1016/j.electacta.2010.12.054

Xu, Y., Minari, T., Tsukagoshi, K., Gwoziecki, R., Coppard, R., Balestra, F., & Ghibaudo, G. (2011). Power transfer-length method for full biasing contact resistance evaluation of organic field-effect transistors. *Organic Electronics*, 12(12), 2019–2024. https://doi.org/10.1016/J.ORGEL.2011.08.026

Yadav, A., Yadav, S., Singh, S., & Tripathi, N. (2012). Analysis And Parameter Extraction of Organic Transistor At PTAA With Different Organic Materials. *International Journal of Scientific & Technology Research*, 1(10), 108–113. Retrieved from http://www.ijstr.org/paper-references.php?ref=IJSTR-1112-5516

Yang, T. L., Zhang, D. H., Ma, J., Ma, H. L., & Chen, Y. (1998). Transparent conducting ZnO:Al films deposited on organic substrates deposited by r.f. magnetron-sputtering. *Thin Solid Films*, 326(1–2), 60–62. https://doi.org /10.1016/S0040-6090(98)00763-9

Yimsiri, P., & Mackley, M. R. (2006). Spin and dip coating of light-emitting polymer solutions: Matching experiment with modelling. *Chemical Engineering Science*, 61(11), 3496–3505. https://doi.org/10.1016/J.CES.2005.12.018

Yu, R. S., & Yin, H. H. (2012). Structural and optoelectronic properties of p-type semiconductor CuAlO2 thin films. *Thin Solid Films*, 526, 103–108. https://doi.org/10.1016/J.TSF.2012.11.033

Zaki, T. (2016). *Short-channel organic thin-film transistors.* SPRINGER INTERNATIONAL PU.

Zhang, F., & Srinivasan, M. P. (2008). Structure-related lower surface resistivity and faster doping of poly(thiophene-3-acetic acid-co-3-hexylthiophene) compared with poly(thiophene-3-acetic acid). *Materials Chemistry and Physics*, 112(1), 223–225. https://doi.org/10.1016/j.matchemphys.2008.05.044

Zhou, J., Xu, N. S., & Wang, Z. L. (2006). Dissolving Behavior and Stability of ZnO Wires in Biofluids: A Study on Biodegradability and Biocompatibility of ZnO Nanostructures. *Advanced Materials*, 18(18), 2432–2435. https://doi.org /10.1002/adma.200600200