LOVELY SURPRISES COME IN SMALL PACKAGES: THIN FILM PHOTOVOLTAICS

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By

Professor Rose Uzoma Osuji
(Distinguished Alumna)
B.Sc. (Nig), M.Sc. (Nig.), Ph.D. (Nig.); LSM, FSESN, MSESN, MNIP, MAIP, MISES, MASES, MAPS, MOWSD, MNIMACON, MA-MRS
Professor of Physics (Solar Energy/Materials Science)
University of Nigeria

SUMMARY OF THE LECTURE

The dwindling supply of fossil fuels and economic/environmental problems has necessitated the massive interest in solar energy research and applications in the recent past. The importance and relevance of solar energy have stimulated the research in this active area. This inaugural lecture has x-rayed extensively the research work in developing thin film materials that find applications in solar cells fabrication, selective surfaces, smart windows, supercapacitors and sensors. Justification for the research field engaged in is because the traditional crystalline silicon technology is capital intensive and the band gap of the crystal wafers are not tuneable as much as for thin films to achieve higher efficiency. On the other hand, the band gaps of thin films are tuneable. Besides, films can also be stacked, one on top of another to form tandem cells or multi-junction cells which yield higher efficiency.

The results of the research work are then presented with highlights of the findings pointed out. Various thin films have been successfully deposited using simple chemical routes; some of which can be used for harnessing solar radiation as absorbers for solar cells, some as antireflective coatings. Some complete solar cells were also fabricated and tested and found to have appreciable efficiency. The discoveries/findings from most of the research

works have led to the establishments of collaborations with renowned scientists from countries like Japan, South Africa, India, Canada, USA, etc. Given the little facilities available, it was possible to publish the research findings in reputable international journals out of which over twenty five have Thomson Reuters Impact Factor. Since environment influences learning and research-work productivity, efforts should be made by all stake holders to support this research. It is not an overstatement to conclude that sustainable development will be achieved if research work in this active area is seriously supported.

PROTOCOL

The Vice Chancellor of the University of Nigeria, **Prof. B. C. Ozumba,**
Members of the Governing Council of the University of Nigeria here present,
The Deputy Vice Chancellors and Principal officers of the University,
Distinguished Alumni and Alumnae here present,
Deans of Faculties,
Distinguished Professors,
Past Inaugural Lecturers,
Distinguished Colleagues,
Directors of Institute and Centre,
Heads of Department and Administrative Units,
My Lords Spiritual and Temporal,
Chiefs and Elders,
Gentlemen of the Press,
Lions and Lionesses,
Ladies and Gentlemen,

SALUTATION

I am sincerely deeply touched to have this august assembly, an array of dignitaries gathered to listen to me, deliver my inaugural lecture. May the **''Three-in-One''** Above who has set this day in the Divine plan take all the honour, adoration and glory. I feel very happy and elated that you found time to come, I say: WELCOME, NNO NU, UNU ABIA, UNU ANWUCHULE, DEJEE NU, ALUA NUOO!

My appreciation goes to my Vice Chancellor, Prof. Benjamin C. Ozumba for giving me approval to deliver this inaugural lecture and for chairing the occasion.

PREAMBLE

An inaugural lecture is an occasion of significance in an academic's career at the university. It provides Professors with the

opportunity to inform colleagues, the university community and the general public of their work to date, including current research and future plans – thus highlighting their contributions to knowledge and research leadership.
I am cognizant of the fact that this audience is a complex one – coming from different disciplines of study, so, I will try to deliver this lecture in a simplified manner to accommodate all as much as possible.

THE FUTURE IS OUR MISSION
When Albert Einstein published his ideas on how atoms and light react with each other in 1916, he, in principle, created the theory for a technology which today influences numerous fields of modern life: THE LASER. More than four decades elapsed between this theoretical description and the first technical realization. Today, the laser is an everyday article whether in a CD player or in the hands of an eye surgeon. At the beginning of this development, there was nothing but scientific curiosity and the goal to understand nature.

It is the curiosity of man and his urge to investigate nature that has always been the driving forces for the development of technology. It is very evident that technological progress has dramatically changed the world in a variety of ways. It has, however, also led to some challenges like environmental degradation which threaten man and nature. We must, therefore, all endeavour to take precautions today for a viable world for the coming generations.
It is evident that **research and development** are the preconditions for solving the complex problems of our time, for example, the rising energy requirement of a rapidly growing population, the Global environmental pollution and climate change.

The mission of science is to explore fundamental processes and to use this knowledge to pinpoint solutions. Our research group which, by the grace of God, I currently lead is facing these challenges in relevant subject areas like:

- **Matter (Thin Film Photovoltaics):** To understand the structure of atoms and the properties of our material world and from this knowledge to develop procedures and products for many fields of technology.
- **Renewable Energy:** To develop options for a long term and environmentally friendly energy supply for a constantly growing world population as already pointed out.

THE VISIONS I HAD

Stimulated by my fore-bearers (who will be mentioned later), who saw the spark in me early in life and motivated and channelled me to greater opportunities made me to become a focussed child determined to succeed in any endeavour. With hindsight now, I can happily say that the divine plan was in my favour.

Then, stimulated by the excitement that knowledge and adventure give, I became scientifically daring. During my secondary school education at Queen of the Rosary College (Q. R. C.), Onitsha before the Nigerian Civil War, I was a star in Mathematics subject that my teachers would always call me and my bosom friend and class-mate, Kate Osakwe, now Dr. (Mrs.) Onubogu up to the black board to solve Math problems for my class. I guess that's from where I learnt to love the chalk and to take to teaching later in life, just to be like my beloved father – the foremost educationist and a mathematician, **late Hon. Francis Alek Mgbulu Amadi.**

It is interesting to note that prior to taking to the chalk, I had visions/ambitions of becoming a Rev. Sister, an astronaut, and a civil engineer like my uncle, late Engr. Ozo Edoga. I responded to that childhood inner call by joining the Missionary Sisters of the Holy Rosary – a sojourn which solidified my character and sharpened my intellect. The rest is history.

After my first degree, I was attracted to the quest for Renewable Source of Energy (RE). But one may ask: **What is Renewable Energy Resource?**

Answer: It is that energy resource that renews itself as it is being depleted or used up. Examples include:

- Solar Energy (photothermal and photovoltaics): Solar photothermal is solar radiation that is converted to heat energy by use of appropriate solar thermal collector materials. While solar photovoltaic energy is the solar radiation that is converted directly to electricity.
- Wind Energy: It is the energy derived from wind power via use of wind blades and turbines.
- Hydro Energy is the energy derived from water where waterfalls are used in turning turbines which subsequently generate electricity.
- Biomass Energy is energy generated from anaerobic decomposition of biodegradable materials, etc.

The quest to be more grounded in my research work after my Master's degree in Physics and Astronomy (with Solar Energy option) made me to travel to different international laboratories to gain research experience. This led me to places like:

- International Centre for Theoretical Physics (ICTP), Trieste, Italy, 1987 for Spring College, in Materials Science on Metallic Materials.
- Ettore Majorana Centre for Scientific Culture, Sicily, Italy, 1988 for Summer School in Materials Science and Technology.
- The University of Cape Coast, Ghana 1989/1990 for ICT training on the Use of Microcomputers in Science and Mathematics Education organised by ICTP and
- The James Franck Research Institute of the University of Chicago, USA, 1990-1992 for research in thin film deposition and characterization techniques.

The desire to seek for an alternative to epileptic electric power supply in our country compelled me to focus on PHOTOVOLTAICS (PV) research.

Photovoltaics, as the name implies, is the science of generating voltage for electricity production by shining light on an appropriate semiconducting material. The phenomenon of the interaction of light with matter was so fascinating that it deepened my interest in this area of research – **to survey the little wonders of the world** – how light shines on a material and it generates current electricity, hence solar electricity, where **Lovely surprises come in small packages: thin film photovoltaics.**

Incidentally, the existence of the freely God given solar energy is the driving force for this research. No path into the future can ignore the sun. In its interior, it operates a gigantic furnace with the lightest of all fuels – with hydrogen. It is obvious to us that we would not exist without the sun; its energy is our elixir of life and as a source of electricity for our machines, the forecast for tomorrow is also a lot of sun!

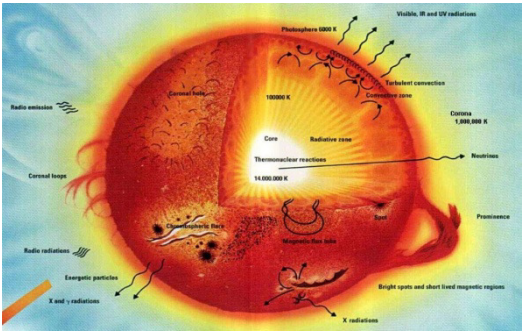


Fig. 1: The Sun Ref: (www.universetoday.com/wp-content/uploads/2008/09/sun_parts_big.gif)

We also consider the sun as a nuclear reactor in which the internal fusion process results in radiation with a power of about 3.8×10^{20} MW with the temperature at its centre of the order of 10^6 degrees while the surface is only about 5762K. Example of reactions taking place in the interior of the sun: (http://astropos.as.arizona.edu/ai2/teaching/a250/pp.html):

$p + p \rightarrow {}^2H + e^+ + \text{energy}$ - 1a

$p + e^- + p \rightarrow {}^2H + \text{energy}$ - 1b

The reactions between equations 1a and 1b produce equation 2

Thus:
$^{2}H + p \rightarrow {}^{3}He + energy$ - 2

Furthermore,
$^{3}He + {}^{3}He \rightarrow {}^{4}He + 2p + energy$- 3
Hence, this energy released oozes out to the sun's atmosphere and from there to the earth. The power density associated with the solar radiation on a plane perpendicular to the direction of the sun at the mean sun-earth distance outside the earth's atmosphere is called the **solar constant** with value approximately **1. 37KWm^{-2}.** The radiation is referred to as **the air mass zero (AMO) radiation** as in Figure 2 below**.**

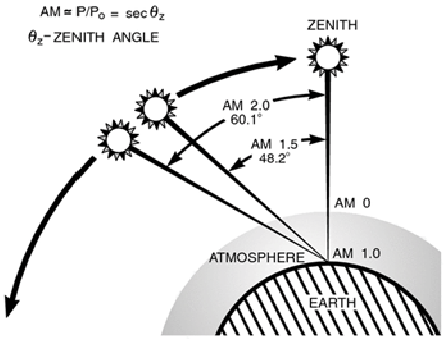


Fig. 2: Air-mass (AM) radiations (http://encrypted-tbn2.gstatic.com/images?q=tbn:ANd9GcRfNtbSHSRIPL48kMHyR_DVrgNYQg0Ecpkz7V-tcXij3m-8SX_FCy1tztk)

We note that because of the depletion of solar radiation by the constituents of our atmosphere (oxygen, nitrogen, ozone, water vapour, carbon dioxide molecules, dust particles etc), the solar spectrum on earth is different in intensity and shape to that emitted by the sun. Furthermore, because of scattering due to these atmospheric constituents, the sun's radiation reach the earth's surface in the form of direct and diffuse radiation.

THE NEED FOR PHOTOVOLTAIC ENERGY CONVERSION

The rapid growth of interest in solar energy applications since 1970 may be attributable to concern over dwindling supply of fossil fuels, and to growing concern over environmental problems. It is also for the sake of the excitement which knowledge gives. Energy from fossil fuels is reaching its limits: oil, gas and coal reserves may already be depleted in a few hundred years. Hence research into future alternatives should be conducted. **These are precisely why we are in it.**

Furthermore, the general worldwide interest and research investment in photovoltaics can be said to be for the following reasons:

Its long term energy potential is enormous; almost everywhere on earth, a typical roof covered with solar cells captures enough solar energy to completely supply its electrical load if enough storage is installed.

The growing worldwide demand for electrical energy will be accompanied by a geographical shift in population. The largest growth rate will be situated in the developing nations. Due to the prevailing rural or agro-industrial nature of these countries, solar electricity is a very attractive approach as it makes possible stand alone systems which are fuel free and highly reliable. Such a decentralised power generation capability is an excellent companion to solar energy. Photovoltaics, therefore, can activate mutually beneficial commercial contacts between industrialised and the emerging economies. This includes technological transfer and the setting up of local industries in the emerging economies.

Photovoltaics makes use of semiconductors and from the viewpoint of materials and processing technology is related to microelectronics. Research in photovoltaics, therefore, can also yield results useful for the microelectronics industry and vice versa. A typical example is the introduction of semiconducting materials such as amorphous silicon that was first used for

photovoltaics but has become important for other electronic devices as well. By supporting photovoltaic research, one invests at the same time in the fast growing microelectronics industry.

It is evident that our everyday world appears in a rich variety of materials. We wear clothes consisting of different fibres; we use tools of metals and alloys. We lubricate engines and bearings with oils and grease, and build houses of stone, glass, wood and plastics. Nevertheless, the material world does not consist of more than a hundred different atomic species. **Their interplay gives rise to the chemical variety of molecules and also to the three known states of matter: SOLID, LIQUID and GASEOUS states.**
You will then agree with me that the goal of basic physical research is to decipher the rules of this atomic interplay in order to ultimately fabricate materials with defined properties. The general mission is to explain the phenomenon of matter perceptible to us – their macroscopic properties – from fundamental principles, i.e. microscopically.

THE PHYSICS OF PHOTOVOLTAICS

At this juncture, it is appropriate to discuss the photovoltaic phenomenon. Sunlight is composed of energy particles called **photons** (i.e lovely surprises that come in small packages) with variable energy values but with constant speed. This sunlight, which in effect is solar radiation, also has a wavelike character. The wavelength, λ is inversely proportional to the photon energy, E. That is:

$$\lambda = hc/E \quad - \quad 4$$

where c is the velocity of light in vacuum (2.998×10^{8} m s^{-1}) and h is the Planck's constant (6.626×10^{-34} J s) (Overstraeten and Mertens, 1986).

Interaction of light with a solar cell: reflection-absorption

When a monochromatic light beam interacts with a semiconductor, some fraction of the incident power is reflected and some absorbed. It is possible to reduce this reflection loss by using what we call anti reflection layers. Now, the absorption properties of a photovoltaic material determine, to a large extent, how much of the incident radiation can be converted to electricity. **You now see where our research comes in**. We research into appropriate materials that can absorb solar radiation and generate electricity and those that can serve as antireflection coatings (selective surfaces). The absorption of light in a semiconductor is chiefly determined by the excitation of an electron from the valence band to the conduction band. This mechanism uses a photon with a minimum energy, slightly lower than (if the absorption is phonon assisted) or equal to the energy gap E_g of the semiconductor. This is the most important transition in a photovoltaic process to convert radiation into free electron and holes. This interaction is best described by the total absorption coefficient $\alpha(x)$ which is defined as the reciprocal of the distance for the energy to fall by a factor of e, given by Lambert's law with assumption of zero reflectance as the number of photons per unit area, per unit time present at a depth x in the material when N $(0, \lambda)$ photons of wavelength, λ are incident on the surface of the material (depth x = 0). Mathematically, we write:

$$N(x, \lambda) = N(0, \lambda) \exp[-\alpha(\lambda) x] \quad - \quad 5$$

If every photon with energy greater than or equal to E_g generates only one electron-hole pair, (i.e. quantum efficiency = 1), the number of electron-hole pairs, g, generated per second per unit volume at depth x is given by:

$$g(x, \lambda) = \alpha(\lambda) N(0, \lambda) \exp[-\alpha(\lambda) x] \quad - \quad 6$$

Equations 5 and 6 are valid for zero reflection from the surface. For non-zero reflections, the values on the right hand side (RHS) of the equations are modulated by the factor $1 - R(\lambda)$ where $R(\lambda)$ is the reflection coefficient of light at the front surface. The magnitude of the absorption coefficient depends on the nature of the semiconductor. While the absorption coefficient itself depends on the complex refractive index $\xi = n - ik$ of the material. Where n is the refractive index of the material and k is the extinction coefficient. Furthermore, the absorption coefficient, α can be calculated from the following equation:

$$\alpha(\lambda) = 4\pi k\lambda^{-1} \quad - \quad 7$$

The total number of electron-hole pairs generated over the complete spectrum is thus given by integration

$$g(x) = \int g(x, \lambda)\, d\lambda = \int^{\lambda g} g(x, \lambda)\, d\lambda \quad - \quad 8$$

where $\lambda_g = hc/E_g$ corresponds to the maximum wavelength for which fundamental absorption can occur. Equation 8 gives after multiplication with the electronic charge, q and after integration over all depths, the maximum short circuit current, I_{sc} that can be obtained from a solar cell.

One may ask how photovoltaics work

Photovoltaics is the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, electric current results and can be used as electricity. Photoelectric effect was first discovered by a French physicist, Edmund Becquerel, in 1839. He noted that certain materials produced small amounts of electric current when exposed to light but the first photovoltaic module was built by Bell Laboratories, USA in 1954. Then, it did not gain popularity owing to its exorbitant cost. The first serious use of the technology to provide power aboard spacecraft was made by the space industry in the 1960s. Consequently, the

technology advanced as its reliability was established and the cost began to decline. Providentially, the energy crisis in the 1970s aided PV technology to gain prominence for power production beyond space application. The diagram below, (Figure 3), illustrates the operation of a basic PV cell, also called a solar cell.

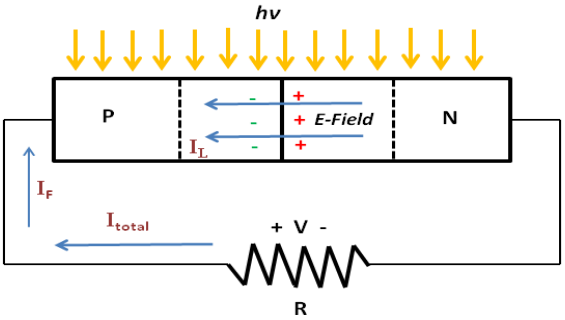


Fig. 3: Schematic representation of the operation of a Basic Photovoltaic Cell (Solar Cell) (Grëtzel, 2001)

Solar cells can be made of the same kind of semiconductor materials, such as silicon, used in the microelectronic industry. For a solar cell, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current – that is, electricity. This electricity can be used to power a load such as a light bulb or a tool as depicted in Figure 4.

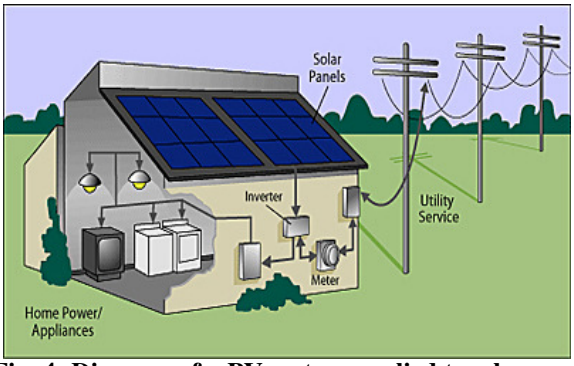


Fig. 4: Diagram of a PV system applied to a house (http://solarcellcentral.com/images/solar_grid_house.jpg)

Conversion Efficiency of a Solar Cell

The conversion efficiency (η) of a solar cell is the percentage of power converted from the absorbed light to electrical energy and collected when the solar cell is connected to an external circuit (Grëtzel, 2001). This term is calculated from the ratio of the maximum power point, P_m to the product of the input light irradiance (E in W/cm^2) under standard test conditions and the surface area of the solar cell (A_c in cm^2).

$$\eta = P_m / (E \times A_c) \quad - \quad 9$$

with

$$P_m = I_m V_m = I_{sc} V_{oc} FF \quad - \quad 10$$

The Fill Factor, FF which is a measure of the squareness of the I – V characteristic in Figure 5 below is given by the ratio of P_m to I_{sc} V_{oc} hence, equation 9 can be rewritten as

$$\eta = (I_{sc} V_{oc} FF) / (E \times A_c) \quad - \quad 11$$

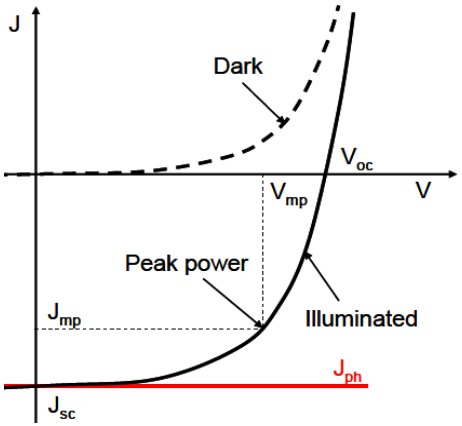


Fig. 5: A Simple I-V Curve of a solar cell showing the relationship between current and voltage. (Grëtzel, 2004)

Solar cells are classified into various groups, depending on their structures. These include:

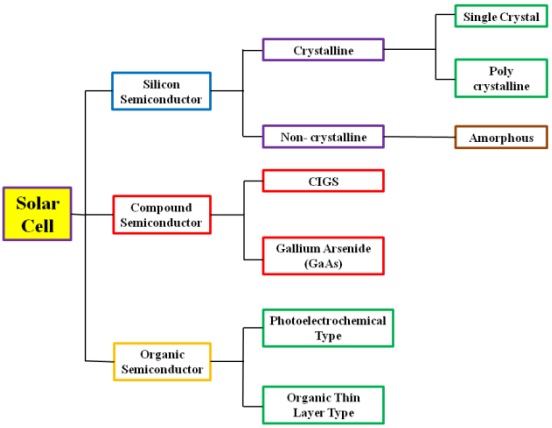


Fig. 6: Classification of solar cells (Grëtzel, 2001)

Our interest is in developing thin films that could be used in fabricating solar cells, therefore, we had to study the deposition techniques. Various techniques for thin film deposition exist. These include:

Thermal evaporation: Here, solid materials vaporise when heated to sufficiently high temperatures. The condensation of the vapour unto a cooler substrate yields thin films. Excellent and detailed review of this subject is given by Pohl and Pringsham (1912), Nahrwold (1887), Faraday (1957) and Holland (1958).

Sputtering process: Sputtering is the ejection of atoms from the surface of a material (referred to as the target) when it is bombarded with energetic particles. The ejected or sputtered ions are condensed on a substrate to form a thin film. This phenomenon has been exploited for film deposition since 1852 (Grove, 1952). Excellent review of the subject exists in the literature (Karminsky, 1965; Massey and Burhop, 1956).

Chemical deposition: The chemical method can be split according to a gas phase deposition or a liquid phase deposition as represented in Figure 7 below, where CVD and Atomic Layer Epitaxy (ALE) are the gas processes.

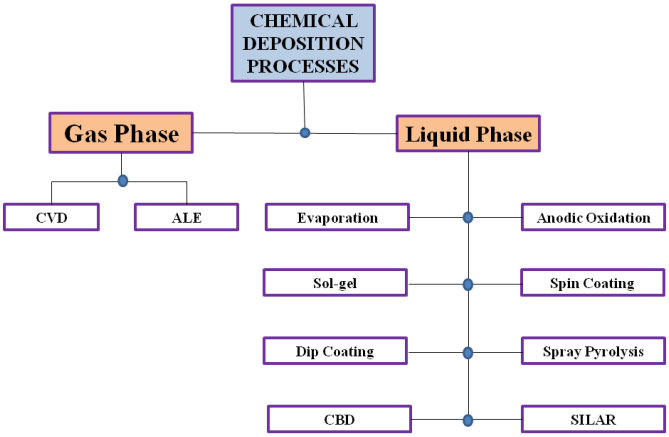


Fig. 7: Summary of chemical thin film deposition technologies.

For our research work, we chose the Chemical Bath Deposition (CBD) and the Successive Ionic Layer Adsorption and Reaction (SILAR) techniques for the following reasons:

- Highly uniform deposits are obtained, with no excessive build up on projections or edges
- The deposits are less porous than electroplated films
- Films can be grown on non-conducting substrates by preheating the substrate surface to make it catalytic
- It is an unsophisticated technique
- It is a convenient and highly reproducible technique
- The deposition parameters are easily controlled and above all,
- The technique is **cost saving.**

The CBD technique otherwise known as electroless method is a process in which **electrolytic action is achieved without an external potential source but rather by chemical reduction of metal ions to form deposits**. A catalytic surface is used to initiate the deposition while the metal should be catalytic to further the deposition. The electrons for the reduction process are provided by a chemical reducing agent in the solution. The schematic representation for the deposition process is given in Figure 8 below.

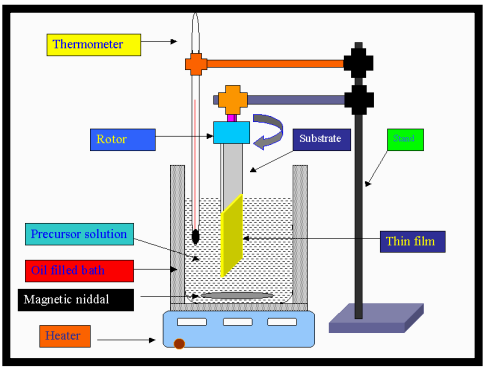


Fig. 8: Experimental set-up for chemical bath deposition (CBD)

Working principle of our adopted method

Before going into our research findings, it is important to mention the working principle of our adopted technique. CBD process works on the principle (Kitae et al, 1965) that in a solution, precipitation of a certain compound occurs if its ionic product (I.P) exceeds its solubility product (S.P) (Kitae et al, 1965; Kaur et al, 1980; Chopra and Das, 1983; Nair and Nair, 1987). However, for thin film formation, spontaneous precipitation is not desirable. This is prevented by using appropriate complexing agent (ligand) which produces stable complex of the metallic ions of interest in solution. This metal complex in turn slowly releases the metal ions on dissociation. Hence, the compound of interest is slowly precipitated onto the substrate as thin film by ion-ion reaction. The following equilibrium reaction (equation 16) describes the existence of free metal ions, M:

$$M(A)^{2+} \leftrightarrow M^{2+} + A \quad - \qquad 16$$

in solution, where A represents the complexing agent. The metal concentration present in the solution is controlled by the concentration of the complexing agent and temperature, hence, controls the deposition rate. There may be cases where the concentration of ions of other species, for example, may be high enough in solution such that the solubility product (S.P) may exceed the ionization product (I. P). This is avoided by controlling the generation of ion from their compounds throughout the solution by the pH value. The concentration of free metals at a given temperature is given by Nair and Nair, (1987):

$$K_i = [M_2^2] + [A] / [M(A^2)] \quad - \qquad 17$$

where K_i is termed the instability constant of the complex ion.

Hence, we use this technique to deposit thin solid films of metallic compounds on glass substrates dipped vertically in the chemical bath solution. These bath solutions comprised, for example, certain

proportions of soluble metallic salts or chalcogenide salts, thiourea, ammonia and an appropriate complexing agent in an aqueous medium at room temperature, approximately 25^{o} C. The growth parameters include concentration, volume and molarity of reacting salts, time of deposition, volume of complexing agent, pH value of chemical bath solution and temperature.

The SILAR Method is a modified version of chemical bath deposition (CBD) technique. This method involves immersing the substrate in cat-ions and an-ions solutions alternatively for a specified duration of time and film growth takes place on the substrate. This process is repeated many times for films of appreciable thickness to grow on the substrate. The deposition conditions such as chemical concentration, pH, temperature, immersion time, immersion cycles, etc. are optimised to get nano-crystalline films. Figure 9 is the set-up for SILAR method.

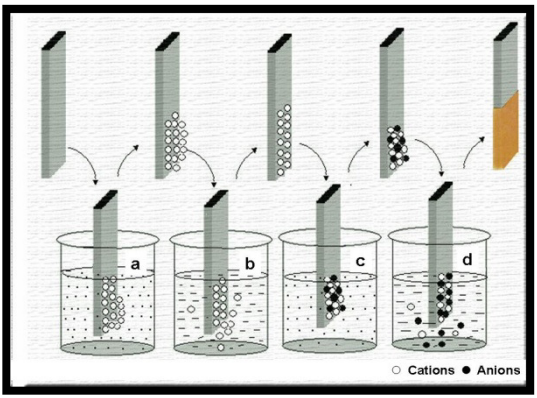


Fig. 9: Experimental set up for SILAR method of film deposition

THIN FILM PHOTOVOLTAIC RESEARCH WORKS

All necessary precautions were taken to produce quality films on appropriate substrates taking cognizance of the fact that structural and electro-optical properties of thin films are greatly influenced by the deposition conditions and growth parameters. Typical

examples of the governing equations for the deposition of the thin films are given hereunder.

Pyrite, F_eS_2 thin film

To produce pyrite, FeS_2 thin film, ethylene diamine tetra acetic acid (EDTA) was used as the complexing agent. The EDTA formed metallic complex with Fe and aided the slow release of metal ions in the chemical bath. The governing equations for the production of FeS_2 films are given in equations 18 to 22 thus:

$$Fe(NO_3)_3 + EDTA + Na_2S_2O_3 \rightarrow Fe(EDTA) + Na_2(NO_3) + S_2O_2 \quad - 18$$

$$S^{2+} + 2O_3^{2-} + 2H^+ \rightarrow S^{2-} + S + H_2O \quad - \quad 19$$

$$3S_2O_3^{2-} + 18H \rightarrow 2S^{2-} + 4S + 9H_2O \quad - \quad 20$$

$$Fe(EDTA) + S^{2-} \rightarrow FeS + EDTA \quad - \quad 21$$

$$FeS + S \rightarrow FeS_2 \quad - \quad 22$$

CdSe film

To deposit CdSe film, triethanolamine (TEA) was used as the complexing agent in the chemical bath. The reaction for the deposition of CdSe thin film is represented thus:

$$(CH_3COO)\,Cd.2H_2O + TEA \rightarrow [Cd(TEA)]^{2+} \quad - \quad 23$$

$$[Cd(TEA)]^{2+} + Na_2SeO_3 + 2OH \rightarrow CdSe + TEA + Na_2SO_4 + H_2O \quad - \quad 24$$

While the chemical equation that led to the formation of **CdS** is

$$[Cd(TEA)]^{2+} + (NH_2)_2CS + 2OH^- = CdS + TEA + (NH_2)_2CO + H_2O \quad - 25$$

Here the availability of Cd^{2+} ions in governed by the following dissociation equilibrium condition,

$$[Cd(TEA)]^{2+} \leftrightarrow Cd^{2+} + TEA \quad - \quad 26$$

The S^{2-} ions are provided by the dissociation of thiourea, SC $(NH_2)_2$ in alkaline or ammoniacal medium thus:

$$SC(NH_2)_2 + OH^- \rightarrow CH_2N_2 + H_2O + SH^- \quad - \quad 27$$

$$SH^- + OH \leftrightarrow S^{2-} + H_2O \quad - \quad 28$$

After deposition, the films were characterised for proper identification and analysis for film utilization. Thus, the characteristics studied included structural, optical and opto-electronic properties. We employed the mechanical (Stylus) method and the gravitational weight differential method for determining film thickness. The absorbance, reflectance and transmittance were measured using the double beam spectrophotometer. The electron-optical methods for examining film morphology and the chemical composition of the films were employed. Some of these electron-optical methods include: the scanning electron microscopy, SEM with a limit of resolution of about 100Å, transmission electron microscopy, TEM (Eckertova, 1986), X – ray diffractometry, ion beam spectroscopy, low-energy ion scattering and Rutherford Back Scattering, RBS, spectroscopy, Amelinckx (1964), Pashley (1964). Figure 10 below is a set-up equipment for RBS analysis.

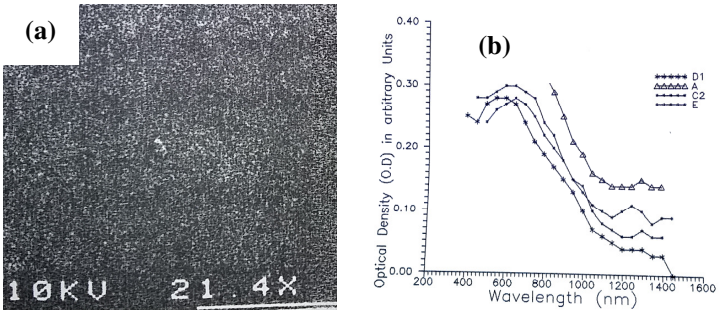
Fig. 10: The inaugural Lecturer determining film composition at iThemba Labs, Cape Town, South Africa using Rutherford Back Scattering, RBS technique. Sept., 2013

OUR RESEARCH FINDINGS

Mr. Vice Chancellor, sir, my research work started with my visibility study of the atmosphere around Nsukka. We needed to find out the extent to which solar radiation is attenuated by the atmospheric fine particles (called aerosols) in Nsukka. This led us to measure the scattering extinction coefficient, b_{sp} of these atmospheric fine particles of diameter less than 2.5μm using an instrument called an integrating Nephelometer, MRI-model 1597 of sensitivity 10^{-7} m^{-1}. We got a maximum value of 10.00×10^{-4} m^{-1} and a minimum of 0.67×10^{-4} m^{-1} (Amadi et al., 1986). **It is interesting to note that the result obtained was first of its kind**. More striking is the knowledge that many researchers in this field are making use of this result. We further investigated the impact of these aerosols on solar radiation in Nsukka, Nigeria and found that for high b_{sp}, mean insolation was generally low. The reverse was the case for low b_{sp} (Amadi et al., 1988). Furthermore, Ekechukwu and Osuji (1990) determined the Ångström's Turbidity Coefficient, β calculated from direct broadband horizontal radiation measurements in Nsukka. The results show that the normal dry season month of March exhibited the lowest turbidity levels, as expected, with β values between 0.05 – 0.30. The dry season months (both harmattan and the normal dry season periods) showed a clearer trend of decreasing turbidity, from the morning to evening hours, than during the wet season. The highest value of β got was about 0.58 during the wet season in the month of May, 1986. We noted that turbidity levels are generally high as to be expected of a typical tropical sub-saharan environment. We emphasize that the import of this research is that this parameter is very vital in the prediction of direct solar irradiance necessary for the design of solar energy devices requiring concentrating collectors. It is also used in the determination of spectral solar irradiance required for the design of most photovoltaic devices (Duffie and Beckman, 1980). Many papers generated from these works are published in reputable journals as listed in the references. Our other research works on solar radiation are given

in (Anikpa et al, 2006), and in the research work carried out by one of my M. Sc. students.

Next in line is our work on thin film photovoltaics for solar energy applications. Mr. Vice Chancellor sir, it is pertinent to note once again that we synthesised thin films of iron pyrite (FeS_2) for the **first time** on glass substrates using the CBD technique earlier discussed (Osuji, et al., 1993). Structural characterization using the RBS technique confirmed that the films grown were FeS_2 (Osuji et al., 1998). With visual optical microscope, the FeS_2 thin films grown were observed to be microcrystalline and adhered well unto the glass slides. The SEM result showed uniform film surface. The film thickness measured with a Dektack surface profiler had an average value of 430 Å and the energy gap had an average value of 1.01 eV, with high absorbance in the ultra violet (0.35 – 0.40 μm), visible (0.39 – 0.77 μm) and in the near infrared (0.70 – 0.85 μm) region of the electromagnetic spectrum (see Figure 11). We remark that these properties make FeS_2 film effective for use in fabricating solar cells and state that these results compared favourably with published results for films deposited with other expensive deposition techniques (Smestad et al., 1989, Abass et al., 1987). **It is important to note that the results from this work are equally being utilised in other areas of research work.**



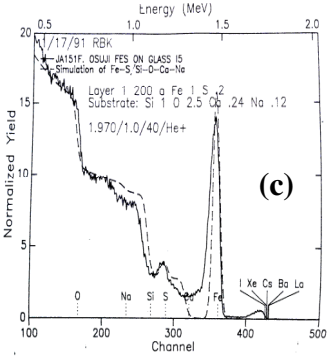
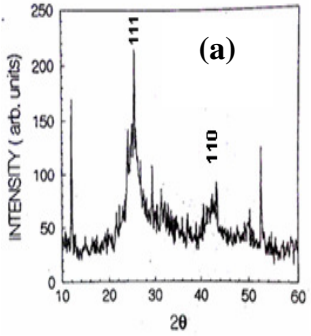
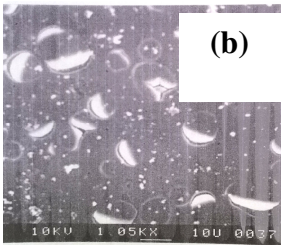


Fig. 11: (a) The SEM image of FeS_2 film (b) Variation of optical density vs. wavelength (c) Rutherford backscattering of FeS_2 film. (Osuji et al., 1993)

Some typical results of CdSe and CdS thin films are displayed in Figures 12 and 13





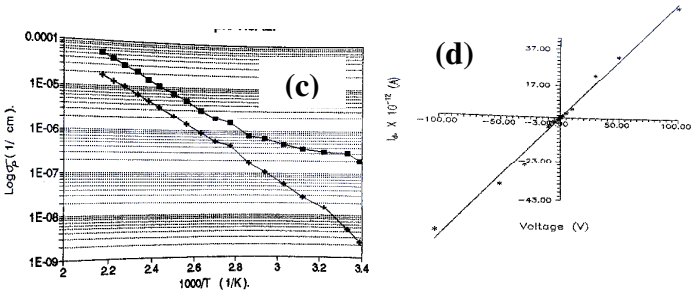
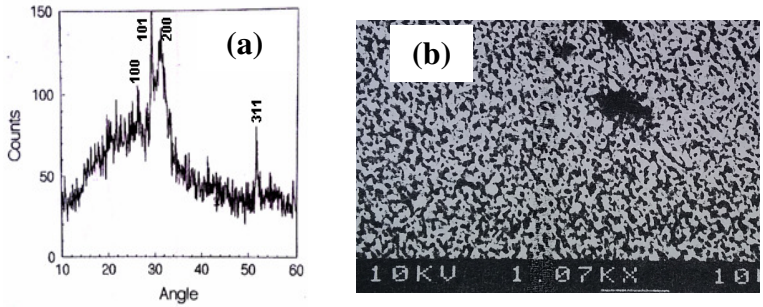


Fig. 12 : (a) The XRD pattern of CdSe (b) The SEM image of CdSe film (c) Variation of Log of photoconductivity with inverse of temperature (d) I-V characteristics of CdSe film. (Osuji, 2003)

The X-ray micrograph shows that the CdSe films crystallized in two phases both cubic in the 111 direction and the hexagonal in the 110 direction. Results also revealed their photoconductive properties.

Other chalcogenide thin films we deposited by the same technique include: CdS, CdS/CIS, Cu_xS films, etc; all of which play important roles in thin film photovoltaics and beyond (Osuji and Okeke, 1998; Osuji, 2001; Osuji, 2003; Ezema et al., 2014).



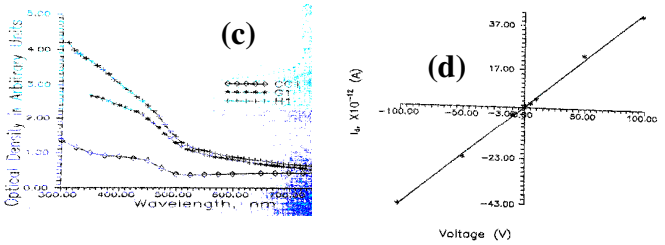


Fig. 13: (a) The XRD pattern of CdS (b) The SEM image of CdS film (c) Variation of optical density vs. wavelength (d) I-V characteristics of CdS film (Osuji, 2003).

The SEM result for CdS film revealed the granular nature of the film, yet with good uniform surface. The average energy gap was 2.15 eV with an absorption coefficient of the order of 10^4 cm^{-1} which gave very good and comparable results (Fahrenbruch et al., 1983).

Osuji (2001) determined the density of states (DOS) and the mobility – life time product, $\mu\tau$ in undoped CdSe thin film from thermo-stimulated conductivity (TSC) and photoconductivity measurements. DOS had values of the order of 10^{25} cm^{-2} eV^{-1} and $\mu\tau$, of the order of 10^{-11} cm^2/V. These values aided the computation of the energy, E_m of the trap distribution which had values ranging from 0.48 to 0.81eV. These values compare well with published results of Zhu and Fritzsche (1986). Also the research of Osuji (2001) on the variation of photoconductivity, σ_p with light intensity for varying temperatures in our CBD undoped CdSe thin films revealed that photo response decreased with increase in O.D.

Mr. Vice Chancellor , sir, I also determined **for the first time,** the drift mobility, μ_d in undoped CdSe thin film deposited by CBD method Osuji (2006) for which my supervisor, Prof Fritzche was so excited and asked whether I was happy. This drift mobility, μ_d of photo-excited carriers was computed to have the value 1.0 x 10^{-3} cm^2/V. s. This was got from a quantitative analysis of the measured steady state photoconductivity and photocurrent decay

time, τ_d. It was also observed that μ_d increased with temperature. **We remark that the determination of μ_d is important because the contribution of photo-excited carriers to the conductivity depends not only on their free life time but also on their drift mobility. All these characteristics count for the effectiveness of the solar cell.**

Our further work on CdS are found in Ezema et al. (2014), where CdS was used as buffer layer of CIS solar cells. From Figure 14, CdS/CIS structure showed that the films have highly oriented crystals with classical hexagonal structure of wurzite type. The film shows good optical properties with high transmittance greater than 80% for wavelength in near infrared (NIR). Again, the estimated direct optical band gap (annealed and unannealed) lies in the range 2.6-2.7eV. However, the solar cells with a device structure of ITO/i-ZnO/CdS/$CuInS_2$/Mo/SLG showed an efficiency of 0.32%.

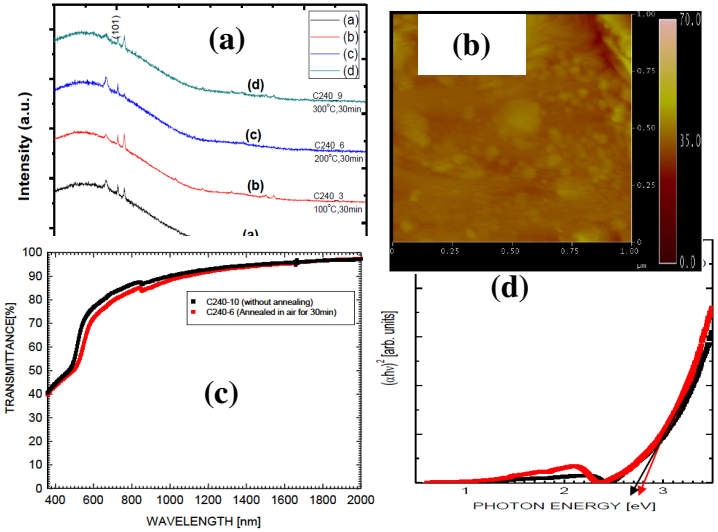


Fig. 14: (a) The XRD pattern of CdS (b) The 2D-AFM image of CdS film (c) Transmittance spectra of CdS (d) Variation of $(\alpha h\upsilon)^2$ vs. $h\upsilon$ (Ezema et al., 2014).

Table 1: Solar cell performances showing annealing-time dependence of CdS buffer layer

Sample	CdS	η[%]	Voc[mV]	Jsc[mA/cm2]	FF
①	without annealing	0.023	13.7	7.47	0.23
②	annealed in air 200° C, 10min	0.32	134	8.24	0.29
③	annealed in air 200° C, 20min	0.011	8.4	5.32	0.24
④	annealed in air 200° C, 30min	0.092	28	14.25	0.23

As we continued research into new photoconductive materials, Ezema and Osuji (2006) deposited $CdCoS_2$ on glass slides from aqueous solution of $CoC_{l2}.6H_2O$, $CdCl_2.21/2H_2O$ and thiourea in which ammonia solution and TEA were employed as complexing agents. The optical characterization showed that the band gap range is between 2.5 and 2.7 eV which is between the band gaps of CoS and CdS. The film had an average transmittance greater than 55% in the VIS-NIR regions and exhibited average reflectance greater than 11% in same regions of the electromagnetic spectrum. Other optical parameters such as refractive index, extinction coefficient, real and imaginary dielectric constants and optical conductivities were determined. It is noted that because this film exhibits poor transmittance in the ultra violet region, it could be used as effective coating for poultry houses because it will not allow the trapped heat to escape. It could also be used for photovoltaic solar cell fabrication.

Next, Ezema et al. (2006) studied the effect of thermal annealing on band gap, E_g and optical properties of CBD ZnSe thin films grown from aqueous solutions of zinc sulphate and sodium selenosulfate in which sodium hydroxide was employed as complexing agent. The as-deposited, red in colour, ZnSe thin films were annealed in an oven at 473 K for 1 hour and on a hot plate in open air at 333 K for 5 minutes. Optical properties such as absorption coefficient, α and extinction coefficient, κ were determined using the absorbance and transmission measurements

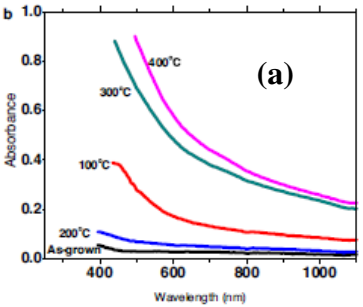
from a Unico UV – 2102 PC spectrophotometer at normal incidence of light in a wavelength range of 200 -1000 nm. The films have transmittance values in the VIS - NIR regions that range between 26 and 87%. The determined E_g values ranged between 1.60 eV and 1.75 eV for the as-deposited samples but the annealed gave 0.15 eV. The high transmittance quality of the films together with the band gap made them good materials for selective coatings for solar cells. The same procedure of film deposition and characterization goes for our other film types deposited by same process.

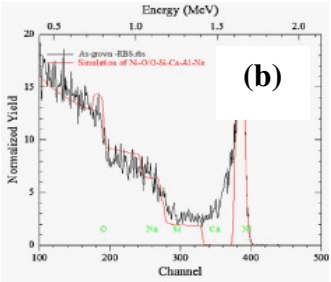
Offiah et al. (2012) did comparative study of Cu_xS and Cu_ySe thin films grown by CBD technique. The structural studies show the presence of chalcocite ($Cu_{1.96}S$) and digenite (Cu_9S_5) phases with average grain size of 13.39nm for Cu_xS thin films. Tetragonal Cu_3Se_2 (umangite) and cubic Cu_2Se with average crystallite size of 35.79 nm were observed for the Cu_ySe thin films. The optical band gap energy for the Cu_xS thin films is between 2.30eV and 2.45eV while the band gaps of the Cu_ySe thin films fall between the range 1.80eV and 1.95eV. Offiah et al. (2012) also studied the structural and spectral analysis of chemical bath deposited copper sulphide thin films for solar energy conversion. We determined the optical properties of CuS thin films deposited by CBD technique. The film thickness ranged between 0.498 and 0.548 μm. The absorbance was greater than 90% in the UV region and the transmittance was between 30% and 65% throughout the entire VIS-NIR spectrum. The refractive index (n) is between 2.07 and 2.26 while the average extinction coefficient is 0.56. With n greater than 2.0, the material is good to be used as protective coatings. The high absorbance makes them suitable for selective coating of photo thermal energy conversion materials (Ezema et al., 2006).

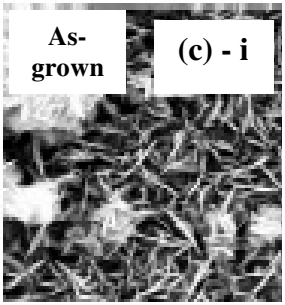
Further work showed the optical properties of Ag_2S thin films deposited by CBD technique. We investigated the band gap shift and optical properties of CBD CdSe thin films on annealing and

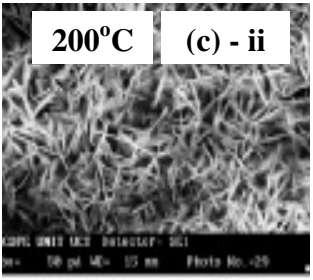
determined the optical and structural properties of Sb_2S_3 thin films grown by same method. We then surveyed other materials and deposited $MnCdS_2$ thin films and studied their optical properties with great success. The quest for new materials further propelled us to grow thin films of nickel oxide, NiO and established their optical properties (Ezema et al. 2007a, 2007b, 2007c, 2007d; Ezema and Osuji, 2007; Ezema et al., 2008). Also PbS-CuS and Sb_2S_3 films were deposited and characterised. The results are published in Asogwa et al., (2009a, 2009b). My research student, Sabastine Ezugwu did optical studies of chemically deposited PVA-capped PbS nanoparticle thin film. He also investigated the effect of deposition time on the band gap and optical properties of chemical bath deposited CdNiS thin films. The findings are all reflected in Ezugwu et al. (2009a, 2009b). Ezema et al. (2010) characterised the optical properties of CdS/CuS and CuS/CdS hetero-junction thin films deposited by CBD method. Ezema et al. (2010) synthesized and characterized CdS nanowires and CdS/TIS nanoflower grown on polymer matrix by CBD method, while Ezugwu et al. (2010) produced and characterised Co doped CdS thin films grown within a polymer matrix. Another of my research students, Mary Nwodo grew and characterized PVP capped Tin Oxide thin films and also studied the effect of thermal annealing on the optical and structural properties of PbO thin film. The findings are in Nwodo et al. (2010, 2011). Onah et al. (2012) synthesised and characterised the structural properties of novel core-shell oxide materials grown by CBD method. One of my Ph.D. students, Uche Okpala synthesised local impurities doped stannous iodide (SnI_2) crystal in silica gel and determined the optical properties of un-doped and potash doped lead chloride crystal in silica gel (Okpala et al. (2012 a and b). Onah et al. (2013) studied the effect of thermal annealing on the optical band gap of nano-crystalline CoO thin films prepared by CBD. Nwanya et al. (2013) characterised the structural and optical properties of CBD silver oxide thin films based on deposition time. Mathew et al. (2013) studied the variation of the optical conductivity;

dielectric function and the energy band gap CdO using cadmium acetate dehydrate. Tyona et al. (2013) reviewed zinc oxide photo-anode films for dye sensitised solar cells based on zinc oxide nanostructures, while Ohwofosirai et al. (2013) synthesised flowerlike zinc oxide, ZnO thin films. In all, their characterization showed that the films can be used for solar cell fabrication. Nwanya et al. (2014) successfully synthesized tungsten oxide and its polyaniline nano-composites films by CBD method and obtained their electro-chromic and electrochemical capacitive properties. Offiah et al. (2014) studied the effects of post-thermal treatments on morphological and optical properties of PVP capped $NiO/Ni(OH)_2$ thin films. XRD results showed that beyond 300 ^oC the films are more transparent due to the conversion of NiOOH to $Ni(OH)_2$ as a result of thermodynamic instability of NiOOH with respect to oxygen evolution (see Figure 15). Upon annealing, the thin films exhibited absorbance as high as 90% in the visible region of the electromagnetic spectrum with energy band gap which decreased with increasing thermal annealing temperature.









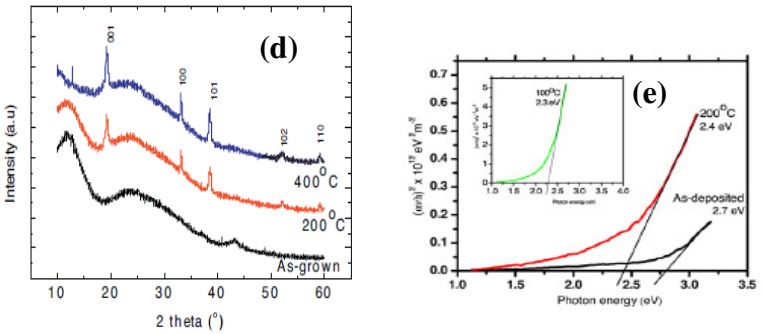


Fig. 15: (a) Absorbance spectra of NiO (b) Rutherford backscattering showing the elemental composition of NiO film (c) The SEM image of NiO film (d) The XRD pattern of NiO (e) Variation of $(\alpha h\upsilon)^2$ vs. $h\upsilon$ (Offiah et al., 2014).

Offiah et al. (2014) carried out work on chemical bath synthesis and physio-chemical characterisation of NiO-CoO composite thin films for supercapative applications. Amaechi et al. (2014) fabricated and found the capacitive characteristics of conjugated polymer composite polyaniline/n-WO_3 hetero-junction that could be used in solar cell fabrication. Uduh et al. (2014) synthesised ZrOS nanopowder and characterised them optically and structurally. The thermal treatment of the ZrOS xerogel revealed an amorphous to polycrystalline material accompanied by a tetragonal zirconia at 450 ^{o}C (see Figure 16). The surface morphology showed that the dense surface appears slightly granular with cracks. The xerogel has slightly less-than average absorbance of light in the visible region, indicating applicability as fairly absorbing material. The estimated value of direct (E_g) band gaps was found to be 2.50 eV.

Further research on the effect of varying deposition cycles on the transformation of thin films of cadmium hydroxide to cadmium oxide was done. Our findings showed that the porous network of CdO grains exhibited polycrystalline structure with transmittance decreasing with increasing SILAR-cycle deposition. The decrease in optical energy band gap was observed to be cycle-deposition dependent as confirmed in Figure 17 (Nwanya et al. 2014). Further, Nwanya et al. (2014) worked on synthesis,

characterisation and gas sensing properties of SILAR deposited ZnO-CdO nano-composite thin film. Iwueke et al., (2015) showed a novel chemical preparation of Ni $(OH)_2$/CuO nanocomposite thin films for super-capacitive applications. Nwanya et al. (2015) determined the conductive impedance and conductivity of agar based ionic conducting polymer electrolytes.

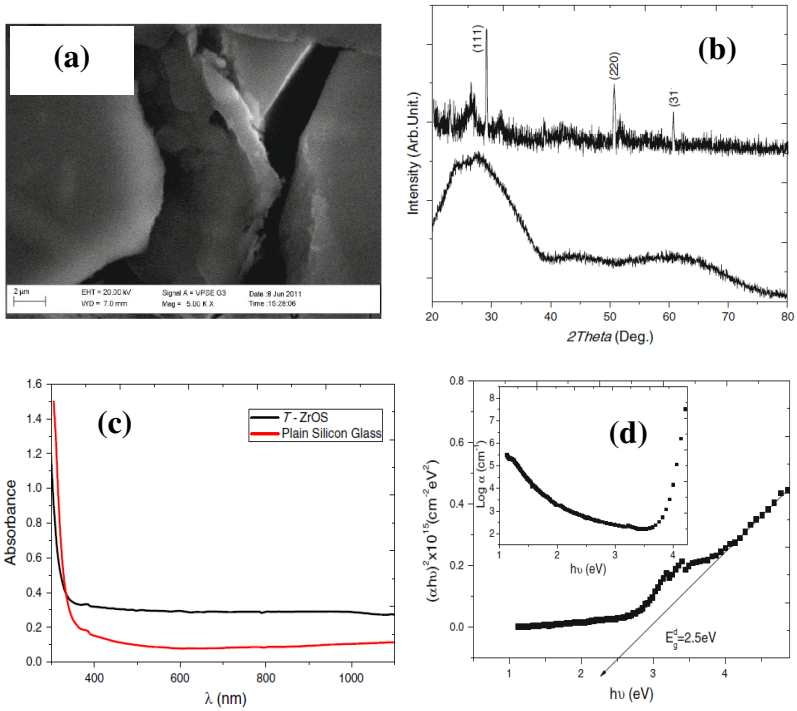


Fig. 16: (a) Scanning electron microscopic image of ZrOS (b) The XRD pattern of xerogel ZrOS (c) Optical absorption of ZrOS film (d) Variation of $(\alpha h\upsilon)^2$ vs. hυ (Uduh et al., 2014).

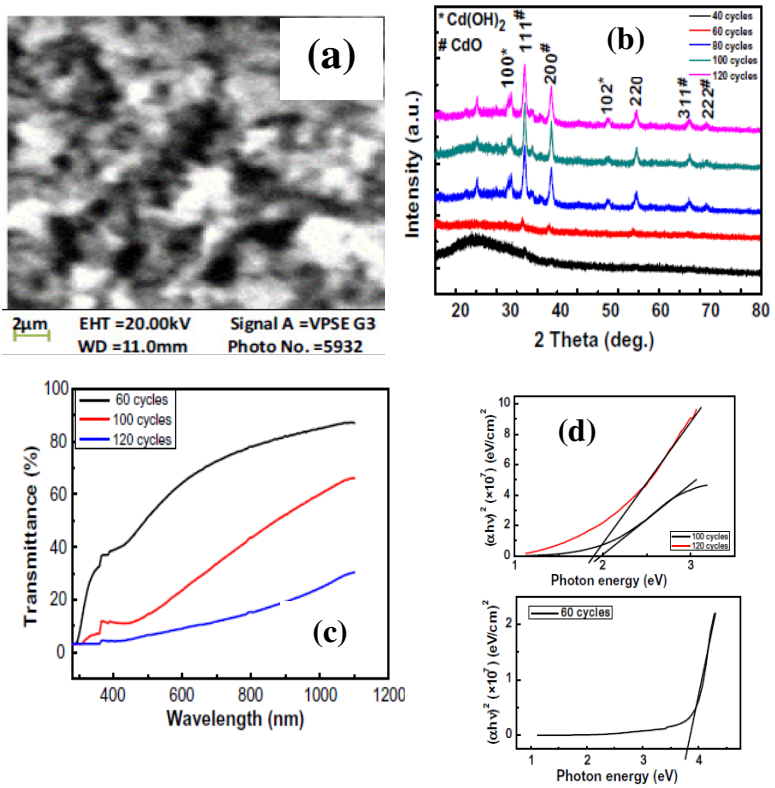


Fig. 17: (a) The SEM image of CdO film (b) The XRD pattern of CdO (c) Transmittance spectra of CdS (d) Variation of $(\alpha h\upsilon)^2$ vs. $h\upsilon$.

Amaechi et al. (2015) determined the Hall coefficient and electrical properties of chemical bath deposited n-WO_3 thin films. Figure 18 showed that an amorphous-to-crystalline transition with monoclinic phase was observed from XRD. Atomic force microscopy (AFM) analysis revealed a homogenous but irregular cluster of faceted spherically-shaped grains with pores. The optical absorption analysis of WO_3 film showed that direct optical transition exists in the photon energy range 3.00 – 4.00 eV with bandgap of 3.70 eV. The temperature dependence of the electrical resistivity of the deposited films followed the semiconductor behaviour with thermal activation energy of 2.0 *m*eV.

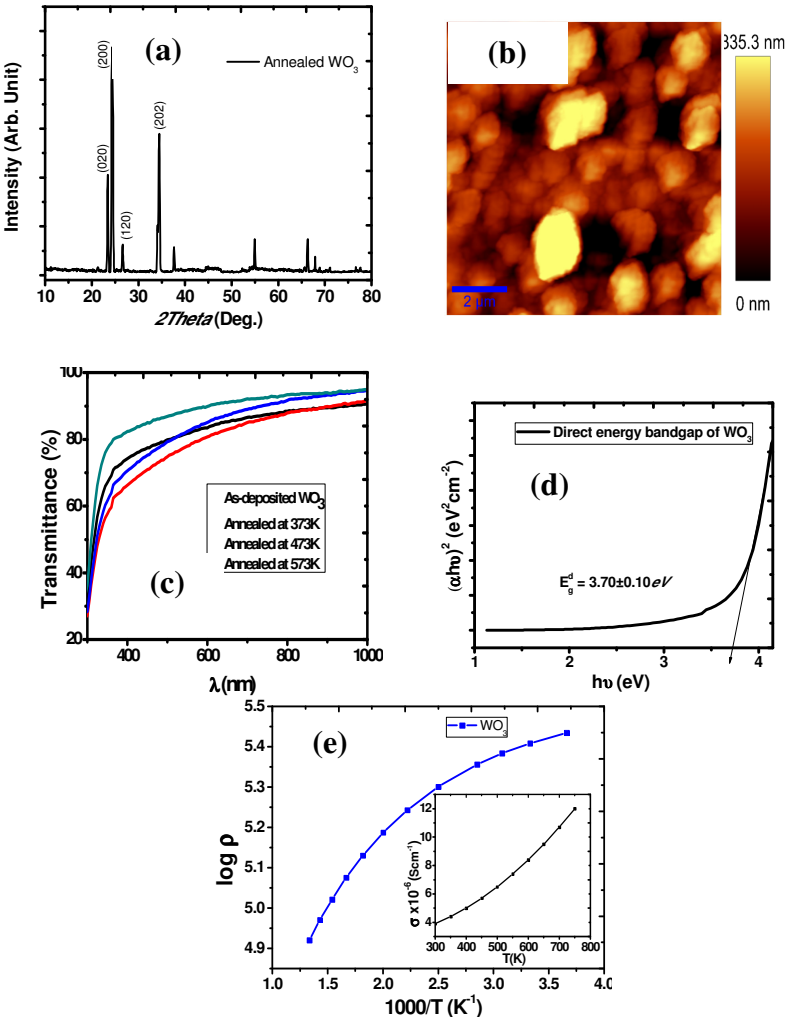


Fig. 18: (a) The XRD pattern of *n*-WO_3 film (b) Atomic force microscopic (AFM) image of *n*-WO_3 (c) Transmittance spectra of *n*-WO_3 film (d) Variation of $(\alpha h\upsilon)^2$ vs. hυ (e) Variation of logarithm of electrical resistivity with inverse of post-deposition temperature (1000/T). Inset: the variation of conductivity with temperature (Amaechi et al., 2015).

Nwanya et al., (2015) fabricated dye sensitised solar cell with natural gel polymer electrolyte and functionalised- multi wall carbon nanotube (f-MWCNT) as counter electrode. The research employed gel polymer electrolytes using agar, gelatine and DNA from plants. The DSSC had an efficiency of 3.38%. Tyona et al. (2105) worked on highly efficient natural dye-synthesised photoelectrochemical solar cells based on Cu-doped zinc oxide (CZO) thin film electrode. The electron injection by photo-excited dye molecules into the conduction band of Cu-doped zinc oxide (CZO) revealed fast charge carrier transport in the semiconductor at 3%. Amaechi et al. (2015) studied the electronic thermal conductivity, thermoelectric properties and supercapacitive behaviour of conjugated polymer nanocomposite (polyaniline-WO_3) thin film. The synergistic effect of nanocomposite yielded specific capacitance of 96 F/g at scan rate of 5 mV/s in 0.5M H_2SO_4 electrolyte and a dimensionless figure of merit, zT of the order of 10^{-3}. Mixed oxide of cerium and vanadium as electrochemical supercapacitor was also studied by Amaechi et al. (2016). The optical, structural and morphological properties were found to depend on post-deposition temperature. The amorphous to polycrystalline transition of the films revealed that the inclusion of CeO_2 was responsible for the widening of the energy band gap from 3.2 eV to 3.8 eV. The supercapacitive behaviour of the electrode was evaluated using cyclic voltammetry (CV) and galvanostatic charge discharge techniques in 1M $LiClO_4$. The specific capacitance of 179 F/g was achieved for the mixed oxide electrode at a scan rate of 20 mV/s.

It is, therefore, pertinent to note that out of all these publications from our work, about 25 of them are in Thomson Reuter's Impact Factor rated journals. It gladdens our hearts to note that analysis of the properties of the thin films we produced showed that some could be used for photovoltaic solar cell fabrication, some as antireflection coatings, some as selective surfaces, hence achieving our aims.

Mr. Vice Chancellor, sir, all these findings have been published in reputable journals and it is interesting and encouraging to note that some of our works are cited by international researchers. From this lecture, you would have observed that we have diversified our research interest, in keeping with the trend in technological advancement. Hence, we have ventured into research areas like electrochemical supercapacitors, nanomedicine and thermoelectricity. Impressive to note also is the fact that our works have attracted foreign/international collaborators from various parts of the world – like South Africa, Japan, India, USA, Canada, etc.

APPLICATIONS OF THIN FILMS

Use is made from the fact that thin films exhibit remarkable optical, electrical, mechanical and other properties. They are also applied in minimizing corrosion, friction etc that occur at surfaces and interfaces of materials.

Mechanical applications

Thin films are used as layers lowering friction, anticorrosion coatings, and for reducing the wearing of mechanically loaded parts (Buckley, 1979). For example, evaporated iridium thin films are used in sliding bearing because of their lubrication power. Other examples abound in Brotheir et al. (1979) and Husa (1980).

Applications in micro/nano-electronics

Growth in thin film application in micro/nano-electronics is evidenced by the miniaturisation of dimensions and weight of electronic systems while stress is laid on long term reliability, operation, speed and low production costs. Those of us in the sciences know that thin films are of paramount importance to the development of multiple duplicated functional elements used in digital computers and other complicated electronic systems, say, in integrated circuits.

Thin films are used as electrical contacts, interconnections and resistors. Some of them are used as capacitors and inductances. For example, from ultra thin layer of high permittivity TiO_2, high capacity thin film capacitors can be made. Diodes and transistors form the basic elements of solid state electronics. The miniaturised form of bipolar and unipolar (field effect) transistors is made possible by the thin film technology.

Use in supercapacitor

A supercapacitor represents a new generation of electrochemical energy storage component, which has a high energy density and capacitance compared to an ordinary capacitor. Supercapacitors are used in power electronics, telecom, actuators, biomedical equipment, standby power systems and electrical hybrid vehicles.

Applications in optics, opto-electronics and integrated optics

Thin films are used in mirrors and filters. Thin films of absorbing substances have been used extensively for optical apparatus e.g. in astronomical reflectors. While thin films of non – absorbing materials are used as antireflection coatings on glass surfaces which enhance the transmittance of the system. Semiconducting thin film elements are used as radiation sources and devices for radiation detection. For example, light emitting diodes (LED) and injection lasers serve as sources of incoherent light.

Solar energy utilization

We can say that gaining control over use of solar energy as the only practically inexhaustible and absolutely '**clean**' energy source is one of the most stringent problems of our civilization. As we have seen, thin films play a very important role in solar energy utilization in different aspects (Chao, 1979). The optical properties of specially designed thin film structures can be used as reflection or anti reflection coatings and selective surfaces (Zerem, 1982; Glaser, 1980). In photothermal collectors and converters, the sun's energy of the entire spectrum is to be collected and converted into

heat energy. We expect an ideal absorber to have an absorption coefficient, α_s almost equal to 1 for wavelength, $\lambda < 2$ μm and the emissivity, $\int \approx 0$ for infrared radiation ($\lambda > 2$ μm), but this is not possible in reality. The goal is to achieve maximum $\alpha/\int$ ratio and thin film technology achieves it. As solar energy is an extensive source, large areas are needed to harness it and the price per unit area is, therefore, a very important parameter. That is why we prefer technologies like chemical bath deposition, SILAR and electro-deposition techniques.

Besides photothermal conversion, the direct radiation to electricity conversion via the photovoltaic effect is very important (Garcia, 1982; Vedel, 1984). We have earlier in this lecture discussed how it works. Suffice it to recap that it is the conversion of the **lovely surprises that come in small packages (photons) to electricity: thin film photovoltaics.** A review by Bucher (1978) states that about 50 types of silicon converters and about 150 converters with other materials were reported. We recall that in principle, a semiconductor with a forbidden gap ~ 1.4 eV (e.g. GaAs) would be optimum for the conversion. Si with $E_g = 1.2$ eV is often used. But because of its low absorption coefficient, it is used in conjunction with another n type semiconductor with wider band gap, $E_g > 2$ eV to serve as a 'window' layer. Hence, this led to the development of thin film Si solar cell technology of various types.

Collaborative Research Work

We want to place on record that we have been engaging in collaborative research work with researchers both from within and outside the country. The articles generated from these collaborative research works are reflected in our joint publications listed in the references. Typical are our works on:

(i) Structural characterisation and electrochemical properties of cerium-vanadium (Ce-V) mixed oxide films synthesised by chemical route

(ii) Dye Sensitised Solar Cell with Natural Gel Polymer Electrolytes and f-MWCNT as Counter Electrode with

Prof. Malik Maaza of iThemba LABS, Cape Town, South Africa.

(i) Synthesis, Characterisation and Gas Sensing properties of SILAR deposited ZnO-CdO nano-composite thin film.

(ii) Highly efficient natural dye-synthesised photoelectrochemical solar cells based on Cu –doped zinc oxide thin film electrodes with Prof. C. D. Lokhande of Shivaji University, Kolapur, India.

(i) Effects of post-thermal treatments on morphological and optical properties of PVP capped $NiO/Ni(OH)_2$ thin films synthesised by solution growth.

(ii) Chemical Bath Synthesis and physico-chemical characterisations of NiO-CoO composite thin films for supercapacitor applications with Prof. F. Giovani of University of West Ontario, Canada.

(iii) Effect of annealing on the properties of chemical bath deposited CdS buffer layer of CIS solar cells with Prof. M. Sugiyama of University of Science, Yamazaki, Japan.

Research Leadership

To the glory of God and in response to my calling as a formator, I currently lead a formidable research team – THE NANO RESEARCH GROUP – in this University which has linkages in South Africa, Europe, Canada, USA, India and Japan. I have successfully graduated two (2) Ph.D students, about seventeen (17) M. Sc. students while I still have under my tutelage about eight (8) Ph.D and ten (10) M.Sc. students. It is worthy of note that about three of my research students are currently studying with our collaborators outside this country. These are: Dan Obi who is in Quebec - Canada with Prof. F. Rosei; Sabastine Ezugwu who is in Ontario - Canada with Prof. F. Giovanni, Faith Ugbo who is in Pretoria - South Africa with Prof. Ncholu Manyala. Under my leadership, we have successfully organised international conferences/workshops on nanotechnology in 2008 and 2014. We are now getting ready for the July, 2016 edition.

CONCLUSION

From the results of our research published in reputable journals and I emphasize that about 25 have Thompson Reuter's Impact Factor, the following conclusions are drawn:

- The successful growth of a new solar energy material, iron pyrite FeS_2 thin film by CBD technique as well as the successful growth of other solar energy thin film materials like CdS, CdSe, Cu_2S, $CdCoS_2$, ZnSe, CuS, Ag_2S, Sb_2S_3, $MnCdS_2$, NiO, NiOx, PbS-CuS, PbS, CdNiS, PVP capped Tin Oxide, CdS/CuS and CuS/CdS heterojunctions, CdS nanowires and CdS/TIS nanoflower, PbO, Cu_ySe e.t.c. by the same technique.
- The structural analysis of these films using X-ray diffraction, SEM, TEM, RBS, Dektack Surface Profiler revealed we deposited crystalline and polycrystalline thin films in the nanometer and micrometer ranges which are appropriate for solar cell fabrication.
- Optical and opto-electronic properties determined by characterisations using spectro-photometry analysis also showed the samples with high absorbance in the UV – VIS and Near INFRA RED (NIR), hence, can be effective for solar photovoltaic cell application; samples with low reflectance are used for antireflection applications.

WAKE UP CALL: FROM RESEARCH TO DEVELOPMENT

A brief look at what is possible might stimulate our governments at all levels and captains of industries to consider setting up industries for the manufacture of thin film solar cells in Nigeria. A starting point could be a collaborative agreement and understanding between relevant government ministries, corporations/private sectors, and the universities to endow Chairs in academic disciplines of their choice. In more specific terms, companies and private entrepreneurs can establish chairs in academic departments, **set up research centres in their names** or

substantially contribute to the establishment of technological centre that could help launch the country's solar energy development.

WHERE WE WOULD LIKE TO BE

Motivated by the injunction of Abdus Salam, the founder of the Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy, and I quote:

> ***'UNLESS IT HAS ITS OWN SCIENCE AND TECHNOLOGY, NO COUNTRY CAN CALL ITSELF FREE'***

Therefore, Nigeria needs to take her destiny in her own hands. In heeding to this injunction, we request you, Mr Vice Chancellor, sir, to upgrade our laboratory facilities to enhance our capabilities. Such facility as a nano research laboratory, (CLEAN ROOM) is a ***sine qua non*** for us to grow the next generation of researchers and achieve our set objectives. This will allow provision to be made for in-situ measurements as the films are being deposited, for easier optimization and faster results. From this presentation, it is obvious that our research team is doing the needful as portrayed in our publications and making the University of Nigeria more visible. Thus, we propose that the Federal Government of Nigeria and captains of industries/entrepreneurs should provide an enabling environment for enhanced research; commercialisation of research results and manufacture of solar cells and panels in our country, Nigeria.

ACKNOWLEDGMENTS

Mr, Vice Chancellor, sir, may I, at this juncture, pay respect to whom respect is due for I stood on many shoulders to see the world. I wish to use this opportunity to express my profound gratitude to all those who knowingly or unknowingly contributed to who I am today, my achievements, successes and failures; whether socially, spiritually, academically and otherwise.

Firstly, I bow to the THREE PERSONS IN ONE GOD who planted me in this planet, EARTH and designed my path in life to

HIS glory. I always keep in mind that **who I am is God's gift to me but what I do with myself is my gift to God;** that is why my maxim in life is: **TO BLOSSOM FOR GOD WHERE EVER HE CHOOSES TO PLANT ME.** Lord, may my life be a psalm of praise welling up to heaven, Amen.

Secondly, I pay deep respect to those who were vessels in the hand of God to steer me to this continent – my beloved parents of blessed memory – my Daddy, Hon. Francis Alek Mgbulu Amadi, a foremost educationist, an alumnus of Oxford and Cambridge University who made a First Class in Classics there. He was the founder and first Principal of Igbo-Etiti Grammar School, Adada River, Nsukka and a member of Federal House of Parliament in the First Republic of Nigeria, representing Nsukka Central. As a teacher and a parent, he was a disciplinarian par excellence with a touch of sensible love. My Mummy, Lady Mary Ulodek Amadi (nee Edoga) (alias M.U.M) of the Edoga Ugwuanyi lineage, a London trained Home Economist who faithfully kept her darling husband's injunction, to see that all his children had university education before leaving the shores of Nigeria. I can never thank God enough for the gift of my generous parents for having brought nine of us into this world, nurtured and provided for our education. There were strict times of prayers, work, study and play. The value of hard work was inculcated in us early in life. It could be said that I was born with **a golden spoon** and that applies to my siblings too, for which I thank God. I thank my siblings, Mrs. Tessy Allanah, Mrs. A.B.C. Osegbe and her husband a consultant Urologist, late Prof. Dominic Osegbe who just passed on less than a year ago, Mrs. Marian Ezeora and her husband Mr. Charles Ezeora who is more of a brother to me than an in-law, Mrs. Ifeyinwa Davis, Mr. Uzo Amadi, Mrs. Betty McClindon and Mrs Obianuju Okpo for the love, joy and care we share and the support we have been to one another through thick and thin. Mrs. Anthonia Amadi and Commander Goddy Omiko deserve special mention because they take the place of my deceased siblings. I could not

have prayed for a better family. I fondly respect the memories of my late brother, Patrick Nicholas Amadi (alias Osseimalik) and my late sister, Lady Carolyn Adaeze Omiko (nee Amadi). I treasure their lives with us. I remember specially my paternal uncle, Chief Celestine Mgbulu Amadi (alias Ale na efungwu) and wife Madam Agnes Amadi (alias Anu enyi) under whose umbrella we all lived happily.

I wish to appreciate my academic parents - My primary school teachers Mrs. Bassey (stds. 3 and 4) and Mrs. Sussana Uzo (stds. 5 and 6) at Immaculate Heart Primary School, Ogbete Enugu. The solid foundation they gave made me excel in my First School Leaving Certificate Examination with DISTINCTION. At O. R. C. Onitsha, I was under the tutelage of the Missionary Sisters of the Holy Rosary, especially Rev. Sr. Mary Joseph Therese Agbasiere (fondly called Sr. J. T. by all). I am especially blessed for the formation I got from them and I say a big thank you. Interestingly, just like my mum and dad, Sr. J. T. lives on in me as I daily try to uphold their legacies. My parents, though they exited this planet very early, laid a solid base for their children to leap from. I know they are smiling down from heaven and nodding in appreciation to what their children have become. I will not forget my maternal grandmother, late Madam Beatrice Oriefi Edoga (nee Odenigbo) (alias 'Nga ama eze') who outlived my mother for almost 21years. Mama Nnukwu, thanks for being there for us when the road was bleak. My great maternal aunt in law, Madam Rose Edoga, aka Mama Nsukka, you have fulfilled the role of our mother since her demise. We thank God you are still with us and ever caring. When I think of you, I know I still have a mother who cares.
Some people touched my life in a very extra ordinary way. For example, my secondary school sports coach, late Mr. Ernest Amobi who believed I could do all kinds of track and field events and channelled me to excel in them with the result that I represented my House and the School in many events. Specifically, I was the overall best athlete during the inter house

sports at Q. R. C. in 1966, winning the VICTOR LUDORUM GOLDEN CUP. The same year, I led my House, St Theresa's Dormitory, of which I was the House Captain (some call it Dormitory Prefect) to emerge as the best House in sports winning the coveted Golden Cup. In 1967, I won the first position in the Women's Senior Hurdle final event during the Inter Secondary Schools Athletic Competition for the Eastern Region in Nigeria held at Enugu. Then, I was gearing up for the world's Olympic Competition in Women's Hurdle event but for the Nigerian Civil War. These sporting events helped, not only in my physical body stability but above all, in my mental alertness, sportsmanship disposition that life can go either way despite all your preparations. What matters is the confidence one brings to it and the ability to let go. So, to the memory of Mr. Ernest Amodi/Sir Coach (alias Amadi do my hurdles), I say thank you for helping me build my self- confidence and for believing in my sporting capabilities. My other secondary school teachers, too numerous to mention, I say thank you for laying the foundation on which I stand.

To my Physics Department family, how do I describe you – from my student days to my lectureship years – there is none like you in this University. I am blessed to have been grilled by scientists like Prof. C. E. Okeke (alias Danger), my academic father and mentor. You gave me a reason to forge ahead in physics research. Prof. S. E. Okoye, aside from being my teacher, pointed out that I am a material for the academic world. Prof. F. N. Ndili also, besides being my teacher, approved my appointment as a temporary staff-Graduate Asisstant (core staff) in the National Centre for Energy Research and Development, University of Nigeria, with a base at the Department of Physics and Astronomy. I owe my allegiance to my other caring lecturers: Prof. A. O. E. Animalu, Prof. B. A. Oli, Prof. P. N. Okeke, Prof. S. Pal, Dr. I. S. O. Muokebe of blessed memory, a soft spoken gentleman who supervised my Master's research work, Rev. Sr. Dr. Heeran, Drs. Huq, Sighn, J. U. Chukwudebelu, P. O. Ezema, Prof. McGruder III, Varkey

Murkopadya and others from my Faculty. I thank my current academic colleaugues, administrative staff and technologists, past and present, for having worked towards the success of my career. Special thanks go to Prof. (Mrs.) F. N. Okeke, a friend and sister who painstakingly joined in editing this work and have been very supportive to me in the Department.

Very special thanks go to my research group- **THE NANO RESEARCH GROUP** – a formidable research team always working assiduously and quietly to put UNN in the RESEARCH GATE MAP. How do I thank you, our anchore-man, Prof. Fabian Ezema; our life wire, my research student in Canada, Mr. Dan Obi; our engine house-my research student, Mrs. Chinwe Nwanya; our power horses: Prof. P. U. Asogwa, Prof. A. A. Attama, Ass. Prof. B. A. Ezekoye, Drs. P. Ugwoke, A. B. C. Ekwealor, Paul Ejikeme, Paul Akpa, Camillus Obayi, David Tyona, Miss Faith Ugbo in South Africa, Mr. Sabastine Ezugwu in Canada, Mr. Ifeanyichukwu Amaechi, Mr. Solomon Offiah, Miss Alice Udounwa, etc. I also thank my foot soldiers, Mr. Mike Nwakanma, Michael Nwachukwu, David Mgbadike, etc. I believe that a teacher who does not reproduce himself or herself in his or her career is a failure. That is why mentoring is a second nature to me. I simply love it for the baton must be handed over to future generation.

Mention must be made of my God given research collaborators: Prof. Helmut Friztsche (Louis Block Professor of Physics) for the rare opportunity granted me to do research in his laboratory at the James Frank Institute, University of Chicago, USA. I treasure his style of academic supervision, direction, encouragement and support. Late Prof. Ted Madey of RUTGER'S University, New Jersey deserves a special mention. Besides being my link to Prof. Friztsche via Prof. Sibena, he afforded my research team the use of his laboratory for characterising our thin films. Prof. Richard Perez of State University of New York donated a Precision Epply

Pyranometer to me in 2001 for solar radiation measurements. This has been very useful to my research students. I want to place on record the financial support I received from the Third World Academy of Sciences, (TWAS) to carry out my Ph.D. research work. The value was $5,000.00 US dollars under Research Grant No. : MP 88 – 33 in 1988. It would interest you to know that it was duly disbursed through the Bursary Department of the University of Nigeria. I equally salute Profs. Malik Maaza of iThemba Laboratory for Accelerated Sciences. Cape Town, South Africa, Federico Rosei of INRS-EMT, University du Quebec - Canada, Facini Giovani of University of Western Ontario - Canada, Wale Soboyejo of Princeton University, New Jersey – USA, and Prof. Peter Kalu of Florida A & M University, USA.

Coming back home, I can never forget my academic godfather who steered me into the Nigerian Nanotechnology Initiative in 2006 and ever since guided, supported and encouraged me in propagating the nanotechnology science before his demise. He is no other than the erudite **Professor O. O. Adewoye** – former Director General of NASENI - a man of many parts. I remember and honour him today for all he had been to me and my research team. He helped to sponsor our conferences/workshops. I pray that his gentle and generous soul rests in perfect peace, Amen. I equally recognize the contributions of our sponsor and mentor, Prof. Wale Soboyejo of Princeton University, New Jersey, who besides sponsoring many resource persons from USA and other African countries to our international conferences and workshops on nanotechnology in 2008 and 2014 also helped in building up our Nano Research Group.

I acknowledge with deep respect the support pillar of our conferences, our revered sponsor, Sir Engineer Emeka Okwuosa, MD/CEO OILSERV' LTD., **'Ekwueme'** of our NANO RESEARCH GROUP. I deeply appreciate you and thank you for all your financial and materials support to our research group. We know you are poised to do more for our research group and the

entire University. We shall always count on your benevolent spirit to support our research work and to build a world class research centre.

To the UNN community, I thank you all for the conducive atmosphere you create for work, study and play. It has been a pleasure living and working in this environment. I also thank members of my first port of call when I landed as an academic staff of this institution, the Energy Research Centre staff: Professors A. O. Odukwe, N. P. Iloeje, S. O. Onyegegbu, Val Ekechukwu, Sam Enibe, O. V. Oparaku etc. You made the ground fertile for academic progress.

It is said that the things that touch us most should be attended to last. I therefore at this juncture pause to appreciate my God given nuclear family, my husband, Prof. Louis Okay Osuji of Chicago State University, USA for sponsoring my stay at University of Chicago to do my Ph.D, research work; my children: Okay Osuji Jr., wife and child in London; Mrs. Ada Onyelucheya, husband and child in the Island of St Kitts and Navis, Barr. Chinenye, Anayo, the Osuji twins - Chinemerem and Chisom and the entire Osuji extended (United Nations) family especially Pa, Sir and Lady S. O. Osuji of blessed memory, for setting our family on a solid foundation. My bosom friends and sisters, from other mothers, deserve special mention – the one and only OWELERESS, Dame Prof. Uche Azikiwe and Prof. Grace Offorma, I thank you for helping me to maintain my equilibrium always. You have been sources of strength to me. Rt Rev. Monsignor Thaddeo Onoyima and Rev. Fr. Emma Ugwu, I thank you for being part of my history.

Finally, I thank once more our **'OKE OSISI'** Vice Chancellor who presently stands tall among the committee of universities in Nigeria. I also thank all those who worked behind the curtains to see that UNN was ranked first among Nigerian Universities. May your light never fade. And to the Senate Ceremonials Committee,

led by the indefatigable Chairman, erudite Professor Malachy Okwueze, I say: **'jide nu ka unu ji'**, thanks a million times.

For more information please visit my website at
www.goroseway.org and ***www.nanotechunn.com***

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REFERENCES

Abass A. K., J of Phys. 61 (1987) 2339.

Amadi R.U., Muokebe I.S.O. and Okeke, C.E. (1986) ***Measurement of Scattering Extinction Coefficient of Atmospheric Fine Particles at Nsukka, Nigeria.*** Nigerian J. of Solar Energy, Vol. 5, PP. 50-59

Amadi R.U., Muokebe I.S.O. and Okeke, C.E. (1988) ***Investigation of the Impact of Atmospheric Particles on Solar Radiation at Nsukka, Nigeria.*** J. of Energy Conversion and Management, Texas, Vol. 28, No. 4, PP. 287-293.

Amaechi I. C., Nwanya A. C., Ekwealor A.B.C., Asogwa P. U., **Osuji R. U.**, Maaza M. and Ezema F. I., ***Electronic thermal conductivity, thermoelectric properties and supercapacitive behaviour of conjugated polymer nanocomposite (polyaniline-WO_3) thin film***. Eur. Phys. J. Appl. Phys., 2015 (69) 30901-p1 – p5).

Amaechi C. I., Asogwa P. U., Ekwealor A. B. C., **Osuji R. U.**, Maaza M., Ezema F. I., 2014, ***Fabrication and capacitive characteristics of conjugated polymer composite p-polyaniline/n-WO3 heterojunction.*** Appl. Phys. A 2014 (117) 1589-1598.

Amaechi C. I**.,** Nwanya A. C., Asogwa P. U., **Osuji R. U.,** Maaza M. and Ezema F. I. "***Hall Coefficient Determination and Electrical Properties of Chemical Bath Deposited n-WO3 Thin Films***". Journal of Electronic Materials, 2015 (44) 1110-1115**.**

Amaechi I. C., Nwanya A. C., Obi D., Ezugwu S. C., Udounwa A. E., A. Ekwealor B. C., **Osuji R. U.**, Maaza M. and Ezema F. I., "***Structural characterization and electrochemical properties of cerium-vanadium (Ce-V) mixed oxide films synthesized by chemical route***", Ceramics International 2016 (42) 3518-3524.

Amelinckx, S., ''The Direct observstion of Dislocations'', Solid State Physics, Supplement 6, Academic Press Inc., New York, 1964.

Anikpa, P.A. and **Osuji R.U.** (2006) ***Comparative Studies of Measured and Estimated Values of Global Solar Radiation Using Epply Pyranometer and Hargreaves Samani-Model at Nsukka Under Varying Climatic Conditions***. Nigerian J. of Space Research (NJSR) Vol 2, p 25-36.

Asogwa P. U., Ezugwu S. C., Ezema F. I., Ekwealor A. B. C., Ezekoye B. A., **Osuji R. U.**, (2009), ***Effect of thermal annealing on the band gap and optical properties of chemical bath deposited PbS-CuS thin films***, J. Optoelectron. Adv. Mater. (JOAM), 11(7), 940 – 944

Asogwa P. U., Ezugwu S. C., Ezema F.I., **Osuji R.U.**, (2009), **Influence Of Dip Time On The Optical And Solid State Properties of As-Grown Sb_2S_3 Thin Films,** Chalcogenide Letters 6(7), 287 – 292

Bucher, E.: Appl. Phys. 17 (1978), 1.

Campbell, D. S. and H. Blackburn, Trans 7th Natl. Vacuum Symp. P. 313, Pergamon Press, New York, 1960.

Chao, A. Y. ; J. Vac. Sci. Technol. 16 (1979), 215.

Chopra K. L. and Das S.R. Thin Film Solar Cells. Plenum Press, New York, 1983. P. 221

D.U. Onah, C.E. Okeke, **R.U. Osuji,** B.A. Ezeokoye, J.E. Ekpe, G.F. Ibeh, A.B.C. Ekwealor and F.I. Ezema, (2013), ***Study of the Effects of Thermal Annealing on the Optical Band Gap of Nanocrystalline CoO Thin Films prepared by Chemical Bath Deposition,*** Chemistry and Materials Research, 3(1): 43-51.

Eckertova, L., Physics of Thin Films, Plenum Press, New York, (1986) p 32.

Ekechukwu, O.V. and **Osuji, R.U**. (1990) ***Ångström's Turbidity Coefficient Calculated from Direct Broadband Horizontal Radiation Measurements at Nsukka, Nigeria.*** Energy and Environment, 5, 3067-3072.

Ezema F. I. and **Osuji R. U.** (2007) ***Preparation and Optical Properties of Chemical Bath Deposited $MnCdS_2$ Thin Films***, FIZIKA A (Zagreb) Vol.16 No. 2, p107–116.

Ezema F. I., Ekwealor A.B.C and **Osuji R.U.**, **2008**, ***Optical properties of chemical bath deposited nickel oxide (NiOx) thin films,*** Superficies y Vacío 21(1), 6-10.

Ezema F. I., Ezugwu S. C., Asogwa P. U., Ekwealor A. B. C., **Osuji R. U.**, (2010), ***Synthesis and characterization of CdS nanowires and CdS/TlS nanoflower grown in a polymer matrix by chemical bath deposition (CBD) method***, Optoelectron. Adv. Mater. – Rapid Comm., 4 (5), 747 – 750.

Ezema F. I., Hile D. D., Ezugwu S. C., **Osuji R. U.**, Asogwa P. U., (2010), ***Optical Properties of CdS/CuS & CuS/CdS Heterojunction Thin Films Deposited by Chemical Bath***

Deposition Technique, Journal of Ovonic Research, 6(3), 99 – 104.

Ezema F. I., Kayama Y., Amaechi I. C., Hiramatsu T., Nwanya A. C., **Osuji R. U.**, Malik M., Sugiyama M., (2014), ***Effect Of Annealing On The Properties of Chemical Bath Deposited Cds Buffer Layer Of Cis Solar Cells.*** Chalcogenide Letters, 2014 (11) 629 – 638.

Ezema F.I. and **Osuji R.U.** (2007). ***Band Gap Shift And Optical Characterization of Chemical Bath Deposited CdSSe Thin Films on Annealing*****,** Chalcogenide Letters, Vol. 4. No. 6, p69-75.

Ezema F.I., Ekwealor A. B. C., Asogwa P. U., Ugwuoke P. E., Chigbo C. and **Osuji R. U.**, (2007). ***Optical Properties and Structural Characterizations of Sb_2S_3 Thin Films Deposited by Chemical Bath Deposition Technique*****.** Turk J Phys Vol. 31, p 205 – 210**.**

Ezema F.I., Asogwa P.U., Ekwealor A.B.C., Ugwuoke P.E. and **Osuji R.U.** (2007) ***Growth and Optical Properties of Ag_2S Thin Films Deposited by Chemical Bath Deposition Technique***. J. of the University of Chemical Technology and Metallurgy, 42, p 217-222.

Ezema F.I., Ekwealor A.B.C. and **Osuji R.U.**, **(2007)**, ***Optical properties of chemical bath deposited nickel oxide (NiO) thin films***, J. Optoelectron. Adv. Mater. (JOAM), 9(6), 1898-1903.

Ezema, F.I. and **Osuji R.U.**, (2006) ***Preparation and Optical Characterization of Chemical Bath Deposited $CdCoS_2$ Thin Films*****.** Journal of Applied Sciences 6 (8):1827-1832.

Ezema, F.I., Ekwealor A.B.C. and **Osuji R.U.**, (2006) ***Effect of thermal Annealing on the Band Gap and Optical Properties of Chemically Deposited ZnSe Thin Films*.** Turk Phys. vol. 30, p1-7.

Ezema, F.I., Nnabuchi M.N. and **Osuji R.U.**, (2006) ***Optical Properties of CuS Thin Films Deposited by Chemical Bath Deposition Technique and their Applications***. Journal of Applied Sciences Research (5) 467-476.

Ezugwu S. C., Asogwa P. U., Ezema F. I., **Osuji R. U.**, (2010), ***Synthesis and Characterization of Co Doped CdS Thin Films Grown within a Polymer Matrix by Solution Growth Technique,*** Journal of Non-Oxide Glasses , 2(2), 121 – 127.

Ezugwu S. C., Ezema F. I., **Osuji R. U.**, Asogwa P. U., Ekwealor A. B. C., Ezekoye B. A., **(2009)**, ***Effect of deposition time on the band-gap and optical properties of chemical bath deposited CdNiS thin films***, Optoelectron. Adv. Mater. – Rapid Comm. 3(2), 141 – 144.

Ezugwu S. C., Ezema F. I., **Osuji R. U.**, Asogwa P. U., Ezekoye B. A., Ekwealor A. B. C., Chigbo C., Anusuya M., Beevi M., **(2009)**, ***Optical studies of chemically deposited PVA-capped PbS nanoparticle thin film***, Optoelectron. Adv. Mater. – Rapid Comm., 3(6), 528 – 532.

Faraday, Phil. Trans. Roy. Soc. London, 147; 145 (1957).

Garcia, F. J., Muci, J., Tomar, N. S.: Thin Sol Films. 97 (1982) 47.

Glaser, H. J.: Proc. 8th Int Vac. Congr., Cannes (1980) I, 723.

Grätzel, M. (2001). Photoelectrochemical cells, *Nature*, **414**, 338–344.

Grove W. R. Phil. Trans Roy. Soc of London 142:87 (1952).

Grätzel, M. (2004). *Conversion of Sunlight to Electric Power by Nanocrystalline Dye Sensitized Solar Cells, J.* Photochem. Photobiol. A, **164**(3), 3-14.

Holland L., Vacuum Deposition of Thin Films, John Wiley & Sons, Inc., New York, 1956.

Iwueke D. C., Amaechi C. I., Nwanya A. C., Ekwealor A. B. C., Asogwa P. U., **Osuji R. U.**, M. Maaza and F. I. Ezema. "***A Novel chemical preparation of Ni(OH)2/CuO nanocomposite thin films for supercapacitive applications***". J Mater Sci: Mater Electron (2015) 26:2236–2242.

Kaur, I. Pandyya, D. K. and Chopra K. L., J. Electro. Chem. Soc 124: 277 (1980).

Kitae, G. A., Uritskaya, A. A. and Mukrushin, S. G. , Russ. J. Phy. Chem. 39 (1965).

M. D. Tyona, **R. U. Osuji**, F. I. Ezema, S. B. Jambure and C. D. Lokhande, "***Highly efficient natural dye-synthesized photoelectrochemical solar cells based on Cu –doped zinc oxide thin film electrodes***", Adv. Appl. Sci. Res., 2015 6(7) 7-20.

Massey H. S. W. and E. H. S. Burhop, Electron and Ion Impact Phenomena,

Mathew D. F., Ohwofosirai A., Aboritoli S., Ogah S., Ezekoye B. A., Ezema F. I. and **Osuji R. U.**, 2013, ***Variation of the Optical Conductivity, Dielectric Function and the Energy Bandgap of CdO Using Cadmium Acetate Dehydrate***, International Journal of Advances in Electrical and

Electronics Engineering, 2013 (2) 331-337

Millazo, G. Electrochemistry, Elsevier Publishing Company, Amsterdam, 1963.

Nahrwold, Wied. Ann. 31, 467 (1887).

Nair, P. K. and Nair M. T. S. ***Prospects of Chemically deposited CdS Thin Films in Solar Cell Applications,*** Soc. 805 (1987).

Nair, P. K., M. T. S., Nair and J. Campus, ***Solar Assissted Chemical Deposition of Highly Photosensitive*** CdS Thin Films. Sol. Energy Mater. 15 (1987), 441 – 448.

Nwanya A. C., Chigbo C., Ezugwu S.C., **Osuji R.U.**, Maaza M. and Ezema F.I., (2014) "***Transformation of Cadmium Hydroxide to Cadmium Oxide Thin Films Synthesized By SILAR Deposition Process: Role of varying Deposition cycles***", *Journal of the Association of Arab Universities for Basic and Applied Sciences*,http://10.1016/j.jaubas.2014.09.001.

Nwanya A. C., Deshmukh P. R., **Osuji R.U.**, Maaza M., Lokhande C. D. and Ezema F.I., (2014), "***Synthesis, Characterization and Gas Sensing properties of SILAR deposited ZnO-CdO nano-composite thin film***" *Sensors & Actuators: B. Chemical*, 10.1016/j.snb.2014.09.111.

Nwanya A. C., Jafta C. J., Ejikeme P. M., Ugwuoke P. E., Reddy M.V., **Osuji R. U.,** Ozoemena K..I., Ezema F. I**.,** **"*Electrochromic and electrochemical capacitive properties of tungsten oxide and its polyaniline nanocomposite films obtained by chemical bath deposition method***". Electrochimica Acta, 2014 (128) 218–225.

Nwanya A. C., Ugwuoke, P. E., Ezekoye B. A., **Osuji R. U.** and Ezema F. I., "***Structural and Optical Properties of Chemical Bath Deposited Silver Oxide Thin Films: Role of Deposition Time,"*** Advances in Materials Science and Engineering, 2013, Article ID 450820, 8 pages, 2013. doi:10.1155/2013/450820.

Nwanya A.C., Amaechi C. I., Ekwealor A.B.C., **Osuji R.U,** Maaza M. and Ezema F. I., ***Dye Sensitized Solar Cell with Natural Gel Polymer Electrolytes and f-MWCNT as Counter Electrode***, (Philosophical Magazine 2015 (95) 1490-1498).

Nwanya A.C., Amaechi C. I., Udounwa A.E., **Osuji R.U,** Maaza M. and Ezema F. I.. "***Complex Impedance and Conductivity of Agar based Ionic Conducting Polymer Electrolytes***" (*Journal of Applied Physics A, 2015 (119) 387-396).*

Nwodo M. O., Ezugwu S.C., Ezema F.I., **Osuji R.U.**, Asogwa P.U., (2011), ***Effect of thermal annealing on the optical and Structural, properties of PbO Thin Film***, Journal of Optoelectronics and Biomedical Materials 3 (4), 95-100.

Nwodo M.O., Ezugwu S.C., Ezema F.I., Asogwa P.U., **Osuji R.U.**, (2010), ***Chemical Bath Deposition And Characterization Of PVP Capped Tin Oxide Thin Films***, Journal of Optoelectronics and Biomedical Materials 2(4), p. 267 – 272.

Offiah S. U., Ugwuoke P. E., Ezema F. I., Ekwealor A. B. C., **Osuji R. U.,** (2012), Comparative ***Study Of Cu_xS and Cu_ySe Thin Films Grown by CBD***, Chalcogenide Letters 9(5), 257 – 264.

Offiah S. U., Ugwuoke P.E., Ekwealor A.B.C., Ezugwu S. C., **Osuji R. U.,** Ezema F. I., (2012), ***Structural and Spectral Analysis of Chemical Bath Deposited Copper Sulfide Thin Films for Solar Energy Conversions***, Digest Journal of Nanomaterials and Biostructures, 7(1), 165 – 173.

Offiah S.U., Nwanya A.C., Ezugwu S.C., Sone B.T., **Osuji R.U.**, Maaza M., C.D. Lokhande and F.I. Ezema, 2014

"***Chemical Bath Synthesis and physico-chemical Characterizations of NiO-CoO Composite Thin Films for Supercapacitor applications***" (International Journal of Electrochemical Science 9, 5837-5848.

Offiah S.U., Nwodo M.O., Nwanya A C., Ezugwu S.C., Agbo S.N., Ugwuoke P.E., **Osuji R.U.** and Ezema F.I., (2014), "***Effects of post-thermal treatments on morphological and optical properties of PVP capped NiO/Ni(OH)2 thin films synthesized by solution growth***". Optik – International Journal of Light and Electrochem Optic 2014 (125) 2905–2908**.**

Ohwofosirai A., Chigbo C., Mammah S.L., Ugwuoke P.E., **Osuji R.U.,** F. I. Ezema, 2013, ***Flower-Like ZnO Thin Film Deposited by Chemical Bath Deposition***, Journal of NanoScience, NanoEngineering & Applications 3(1), 16-21

Okpala V. U., F.I. Ezema and **Osuji U. Rose.** (2012), ***Synthesis and Characterization of Local Impurities Doped Stannous Iodide (SnI2) Crystal in Silica Gel***, Advances in Applied Science Research, 3 (2):1175-1184.

Okpala V. Uche, F.I. Ezema and **Osuji U. Rose**. (2012), ***A Study of the Optical Properties of Un-doped and Potash Doped***

Lead Chloride Crystal in Silica Gel, Advances in Applied Science Research, 3 (1):103-109.

Onah D.U., Okeke C.E., Ezema F.I, Ekwealor A.B.C, **Osuji R.U.**, Ezekoye B.A., (2012), ***Synthesis, Structural And Optical Properties Of Novel Core-Shell Oxide Materials By Chemical Bath Deposition***, Journal of Ovonic Research 8(5), p. 105 – 111.

Osuji, R.U. (2001) ***Variation of Photoconductivity with Light Intensity in Undoped Chemically Deposited Cadmium Selenide (CdSe) Thin films.*** Nigeria Journal of Renewable Energy Vol. 9, Nos. 1&2 pp7-11.

Osuji, R.U. (2003) ***An Evaluation of Institutional Framework for Renewable Energy Education in Nigeria.*** Nigerian Journal of Solar Energy, Vol. 14 pp 25-28.

Osuji, R.U. (2003) ***Analysis of Chemically Deposited CdSe and CdS Thin Films.*** Nigerian Journal of Solar Energy, Vol. 14 pp 90-99.

Osuji, R.U. (2006) ***Photoconductivity and Drift Mobility in Undoped CdSe Electroless Deposited Thin Film on Glass Substrate,*** Nigerian Journal of Solar Energy, Vol. 16, p155-164.

Osuji, R.U. and Okeke, C.E. (2006) ***Study and Analysis of the Photovoltaic Electric Power Requirements of a Farm Village - The Case of Ugwu-Rice, Adani, Nigeria,*** Nigerian Journal of Solar Energy, Vol. 16, p46-53.

Osuji, R.U.(2001) ***Density of States and Mobility-Lifetime Product in Undoped CdSe Thin Film from Thermostimulated Conductivity and Photoconductivity Measurements***, Journal of Applied Sciences, Vol. 4 No. 3 pp 1988-1999.

Osuji, R.U., Okeke C.E. and Muokebe I.S.O., (1993). ***Characterisation of Electroless Deposited FeS_2 Thin Film,*** Nigerian J. of Solar Energy, Vol. 12, P. 80-86.

Osuji, R.U., Okeke, C.E. (1998) ***Electrical Conductivity and Photo-Response of Chemically Deposited CdS and CdSe Thin Films***. Nigerian Journal of Renewable Energy, Vol. 6, Nos. 1 and 2. P. 67-70.

Overstraeten Van R. J. and R. P. Mertens, Physics, Technology and Use of Oxford University press, Fairlawn, N. J. (1956)

Pankove J. I., Optical Processes in semiconducrors, Englewood Cliffs, NJ: Prentice Hall, 1971Photovoltaics, Adam Hilger Ltd. Bristol and Boston, 1986 p 4 – 5.

Pashley, D. W. in Modern Developments in Electron Microscopy, (B.M. Siegel, ed.) p. 149, Academic Press Inc., New York, (1964).

Pohl R. and Pringsheim P., Verhandl. Deut. Physik. Ges. 14:546 (1912).

Potter, E. C., Electrochemistry, Cleaver – Hume, London, 1956

Powell, C. F., J. H. Oxley and J. M. Blocher Jr (eds.) Vapor Deposition, John Wiley & Sons Inc. New York, 1966.

Smestad G. and H. Tributsch et al. Solar Energy Materials 18 1989, p299 – 313.

Tyona M.D., **Osuji R.U.** and Ezema F.I.**,** 2013 ***A review of zinc oxide photoanode films for dye-sensitized solar cells based on zinc oxide nanostructures***, Advances in Nano Research (1) 43-58.

Uduh U. C., Obodo R. Esaenwi M. S., Amaechi C. I., Asogwa P. U., **Osuji R. U.,** Ezema F.I., 2014 ***Sol–gel synthesis, optical and structural characterization of ZrOS nanopowder.*** J Sol-Gel Sci Technol., (71) 79–85).

Vedel, J. Thin Sol. Films, 111 (1984), 121

www.astropos.as.arizona.edu/ai2/teaching/a250/pp.html.

www.universetoday.com/wp-content/uploads/2008/09/sun_parts_big.gif.

Zerem, Y. et al: Thin Solid Films 89 (1982), 286.

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