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SOLID STATE PHYSICS:
A COAT OF MANY COLOURS

By

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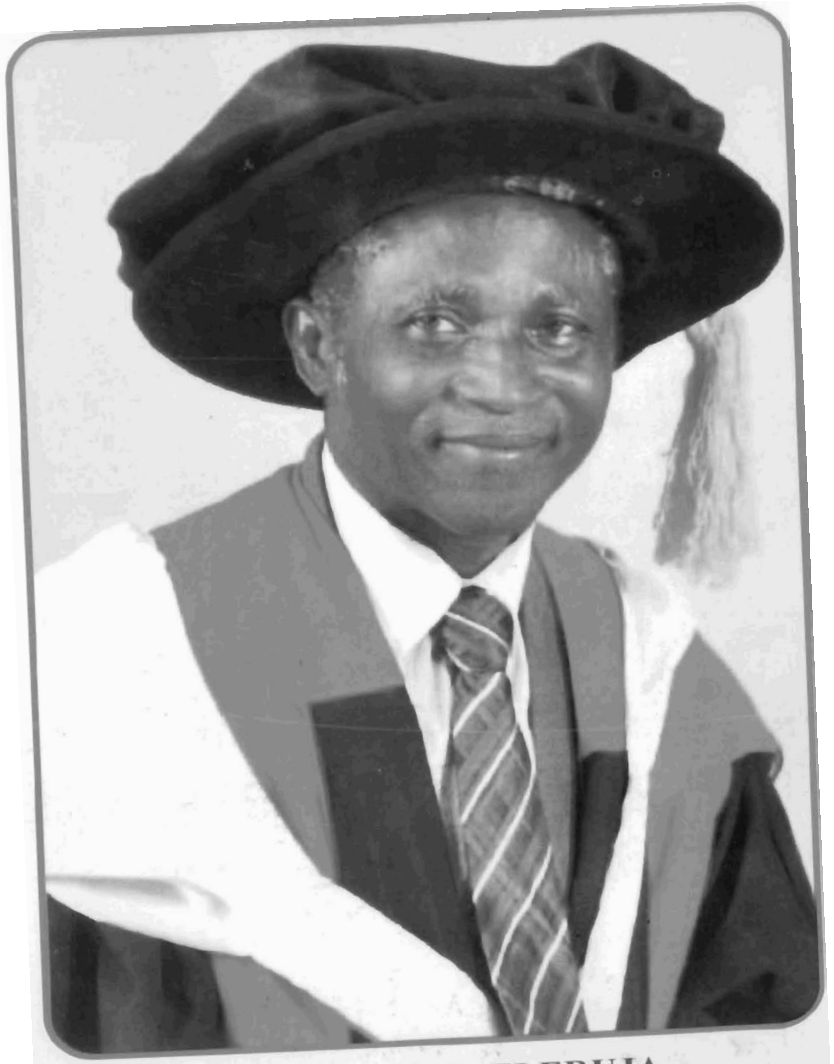

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Preamble

The Vice-Chancellor Sir and my distinguished audience, this Inaugural Lecture is the 328th in the University and the 8th Inaugural Lecture from the Department of Physics and the first after the change of the name of the Department to the Department of Physics and Engineering Physics. The number **8** is the symbol of harmony and balance. In the Holy Scriptures, it signifies resurrection and regeneration (new beginning). It is, therefore my pleasure and a great honour to present the 328th Inaugural Lecture, titled "Solid State Physics: A Coat of Many Colours".

Physics by basic definition is the most fundamental physical science, which uses fundamental principles, concepts and models to describe the universe and explains the nature and properties of matter and energy (Jewett and Serway, 2008). In a more complete sense, Physics is an intellectual activity rather than being a technological one. Physics has explained the energy-mass conversion, time-space relationship, order and disorder, self-organization, chaos, uncertainty, wave-particle duality, etc. (Khan, 2005). Basic physics is subdivided into different areas, such as classical mechanics, relativity, thermodynamics, electromagnetism, optics, quantum mechanics, solid state physics, among others.

As a young boy in Saint Finbarr's College, Akoka, Yaba, Lagos State, I was fascinated by the fact that we started learning Physics as a subject from Class One (equivalent to Junior Secondary School One). We used a textbook titled "Physics is fun" and to God be the glory, Physics had always been "fun" to me all the way.

Introduction

We all make use of various electronic gadgets and appliances in our homes, offices and environment, such as electric fans, mobile phones, electric iron, computers, television, automated street lighting system, solar-powered systems, etc. These are all products of Solid State Physics. I know you will ask that if these are products of Solid State Physics, what then is the role of technology

and engineering? It is the conversion of the basic concepts and ideas of Solid State Physics to these products that gives us the art of technology and engineering. You may wish to ask again, what is Solid State Physics?

What is Solid State Physics?

Solid State Physics is a branch of Condensed Matter Physics, which is the study of rigid matter or solids in form of crystalline and non-crystalline solids, through methods such as quantum mechanics, crystallography, electromagnetism and metallurgy. Solid State Physics is the largest branch of Condensed Matter Physics (Simon, 2013) and forms the theoretical basis of Materials Science. The field of Solid State Physics is a coat of many colours. This is displayed in the forms of its different topical concepts such as structure of solids, interference effects in crystals, lattice dynamics, perfect and imperfect crystals, electrons and electron theory of metals, semiconductors, electrical contact effects, transport phenomena, magnetism, superconductivity among others.

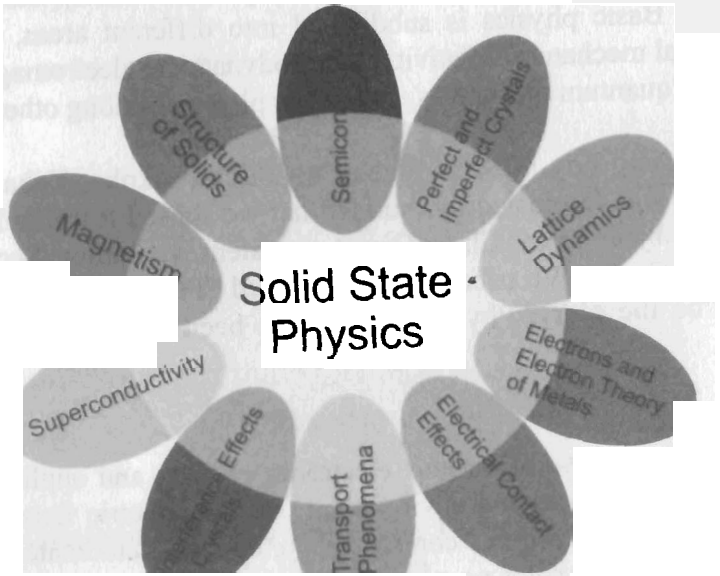


Figure 1: Solid State Physics: A Coat of Many Colours.

An understanding of the various aspects of Solid State Physics is required for good understanding and knowledge acquisition in the different fields in Engineering such as Electrical/Electronic Engineering, Mechanical Engineering, Civil Engineering, Aeronautical Engineering, Computer Engineering, Metallurgical and Mining Engineering and Materials Science and Engineering.

Hopfield (2014) stated that subfields of physics are given birth to, expand, and grow into intellectual scope, then can develop new offspring by subdividing, and can go into extinction by being absorbed in new definitions of the fields of Physics, or may reduce in vigor and membership. He also noted that textbooks, workshops, industrial laboratories and graduate programmes all contributed to the field of Solid State Physics, giving it, its many colours. Newbury, (1993) presented the history of Solid State Physics from the earliest years of the twentieth century through 1960. Hitherto, little has been done to record the contributions of the field (Solid State Physics) to modern civilization in the field of communications, entertainment, computation, information storage and retrieval, to mention just a few.

The Outline of this Lecture

This Inaugural lecture is divided into two major parts, viz. my research and contribution to knowledge and my teaching, mentorship and administrative career.

RESEARCH AND CONTRIBUTIONS TO KNOWLEDGE

My research will be discussed under the following headings:

1. Design and fabrication of passive electrical devices.
2. Syntheses and characterization of metal oxides and metal sulphides for the design and fabrication of simple electrical and electronic devices.
3. Syntheses and characterization of graphene based composite materials for the fabrication of gas sensors, photovoltaic and solar cells.

4. Preparation and Characterization of metal oxide nano-rods for Li-ion battery electrodes and supercapacitors for power generation.
5. Inorganic/organic solar cells.
6. Flexible electronics.

Design and fabrication of electronic devices

Mr. Vice-Chancellor Sir, in my early research voyage, I observed that electronic components such as resistors, capacitors, inductors, etc. were imported from America and Europe and their prices were usually tied to foreign currencies and exchange rates which were always fluctuating and exorbitant. This I considered as a deficiency in our march towards independent scientific and technological growth and development. This was one of the motivating factors which I got as a young researcher. I observed that while this thought was going through me at the University of Ilorin, Ilorin, Nigeria, another group headed by eminent Professors (Professors E. O. B. Ajayi, G. A. Adegboyega, T. A. Kuku, O. Osasona) were engaged in the fabrication of passive and active electronic components at the University of Ife (now Obafemi Awolowo University, Ile-Ife), at an advanced level.

The manufacturing of electronic device components involves four basic steps:

1. identifying the materials for manufacturing of the components,
2. identifying the technologies involved,
3. termination and packaging of the device components, and
4. nominal values of the components.

The materials which are mostly used for the manufacture of passive electronic components include solids (seldom liquids) in form of metals, non-metals and composites. Silver is the best electrical and thermal conductor among all the metals and it is followed by copper. However, silver has some drawbacks which include: humidity, ionic contamination and remarkable susceptibility to electro-migration (the electrochemical process of

dendrite crystal growth between metal electrodes in the presence of electrical potential difference). The dendrites may result in short circuit. Silver is also susceptible to sulfuration (that is, chemical reaction with sulphur and some of its compounds), resulting in the transforming of the silver into silver sulphide and some of its conductivity is lost. Many applications of metals in passive components include: terminals, resistive elements, capacitor electrodes, inductor windings and fusing elements in fuses. Non-metals such as ceramics, polymers and semi-conductors are also of great importance in the fabrication of passive electronic components.

My first effort towards the development and fabrication of polymeric (composition) resistors was the fabrication and electrical characterization of Magnesium/Polyvinyl-Pyrrolidone (Mg-PVP) Resistors (Ajewole and Eleruja, 1996). The Mg-PVP resistors were fabricated using a specially designed moulding assembly. While the resistors contained between 80% and 100% by volume of magnesium were of high stability and quality, the resistors in the composition range 96% - 100% were found to be reproducible. Experimental relation was observed between the electrical conductivity and percentage composition of the resistors and also between the breakdown voltage and percentage composition. The resistors were found to be ohmic, non-capacitative and are of low tolerance value.

The empirical relations between the resistor resistivity and percentage of magnesium in the resistors were found to be

$$\rho = e^{-0.11\,Mg+6.25} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

for the range $80\% \leq Mg \leq 90\%$ and

$$\rho = e^{-0.5\,Mg+41.8} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

for the range $90\% \leq Mg \leq 100$, where ρ is the resistivity of the resistor and Mg is percentage composition of magnesium in the resistor.

The relation between Breakdown voltage, V_{BD} and Mg, percentage of magnesium in the resistors was found to be

$$V_{BD} = e^{-0.07\,Mg+9.37} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Other efforts which were also carried out at the Federal University of Technology, Akure, produced Carbon/Clay resistors which were generally unstable and were found to breakdown with age. The resistors also had contact problem. These efforts were just a few of the attempts I had made at fabricating resistors locally.

In the world of microelectronics, one of the deficiencies of composition (carbon or polymer) resistors and other passive components are the issues of size and weight. Other deficiencies include: high noise, low accuracy, poor stability, water absorption and corrosion (Hienonen and Lalitinen, 2007). Some of the deficiencies of composition resistors were remedied by the introduction of thin films. The fact that thin film materials showed some interesting properties and were also able to overcome some of the inherent deficiencies of bulk passive device components, made them prominent, hence they produced the next group of resistors, capacitors and other passive electronic device components.

Bulk Material versus Thin Film Material

Most engineering materials (usually called bulk materials) have fixed properties like electrical resistivity, optical opacity, etc. hence their applications are limited. When the thickness is reduced beyond certain limits, these properties show a drastic change. This is called size effect and it adds flexibility in designing devices for a particular application. On the other hand, thin films possess attractive properties and therefore can have versatile applications. Thin film devices occupy less space and their fabrication requires less materials, hence they are inexpensive.

What is a Thin Film Material?

A Thin Film material is generally defined as a layer of material which is usually less than 1000 nm (1 μm) in contrast to thick film, whose thickness is greater than one micron (Maissel and Glang, 1970; Therolis, 1973). This will be appreciated more if one considers the fact that the adult human hair is of thickness in the range 20–180 μm (Yang, 2014) and it is still carried by the scalp. This means that an average thin film material may be about a thousand times thinner than the average human hair. Generally, thin films are usually not self-supporting and they require mechanical support, hence they are deposited on carriers called substrates.

Substrates

A substrate accompanies the film from "cradle to grave", but the substrate is often ignored. However, it is general knowledge that there is always an interaction between the thin film and the substrate. The substrate type is determined by the application of the thin film (Hass, 1963; Bailey, 1986; API technologies, 2018; Vishay Intertechnology, 2018). The role and types of substrates has been reviewed extensively by various authors (Hass, 1963, Bailey, 1986). Table 1 shows some common substrate materials and their applications.

Table 1: Common Substrate Materials and Their applications

Material	Typical Uses	Comments
Alumina (Al_2O_3)	Low to medium power DC / microwave circuits using Si, GaAs, or GaN ICs; Edge-coupled filters and power dividers	Cost-effective material with wide range of applications
Aluminum Nitride (AlN)	High power DC / microwave circuits using Si, GaAs, or GaN ICs	Optimal CTE match with silicon devices
Beryllia (BeO)	High power DC / microwave circuits using Si, GaAs, or GaN ICs; High power terminations	Extremely high thermal conductivity
Quartz	Microwave / millimeter-wave circuits requiring extremely low loss or low CTE	Low loss tangent and CTE with very smooth optical surface finish
Titanate*	RF / microwave filter or oscillators requiring high Q resonators; capacitors	Dielectric constants available from 12 to 500
Ferrite*	RF / microwave circulators / isolators	Magnetically activated material
Sapphire*	Millimeter-wave / optical circuits with special electrical or mechanical requirements	Low loss tangent and optical surface finish

Source: Vishay Intertechnology, Inc. Thin Film Substrates Design Guide, 2018

Thin Film Growth, Deposition and Characterization

Thin Film materials play an important role in the advanced energy technologies such as Photovoltaic (PV) cells, electro-chemical cells and batteries to mention those which the Advanced Materials Research Group (to which I belong) is involved in.

Mr. Vice-Chancellor sir, a great portion of my research is in the area of the preparation and characterization of thin films of various material systems. The materials include single metal oxides, mixed metal oxide, single metal chalcogenides, and mixed metal chalcogenides systems (such as metal sulphides, selenides, etc.). These thin film materials have found applications in microelectronics, optoelectronics, optical mirrors, tribology, among others. The details of my involvement in this area of research will be looked at in the subsequent sections of this presentation.

The size, importance, and the economic impact of the semiconductor industry have undergone a sea of change in recent years. The role of equipment has been the catalyst for this change. New processing steps have become necessary, old ones have become cleaner, greener and more sophisticated (Seshan, 2002). For us to have a cleaner deposition system, complexity and hence increased cost of equipment becomes an issue.

It is known that a large fraction of the fabrication cost is the cost of the manufacturing equipment. Cleanliness is a very important factor in the cost of manufacturing equipment and this is determined largely by the understanding of the role of defects and particle size as the lithography moves into the nanometer regime. The role and importance of cleanroom in the fabrication of semiconductor devices was well discussed by Adegboyega (2000). Table 2 shows the importance of cleanliness in semiconductor processing. It also shows how the mask layers increase and the number of defects per unit area have decreased over the years.

In the design and fabrication of various semiconductor devices, multilayered structures are involved, hence, there is need to make masks at different levels. Lithography is an important part of mask making. There are three basic lithography types, viz. optical lithography, electron-Beam lithography and x-ray lithography. Lithography and other patterning techniques have been well discussed by various authors (Pease and Chou, 2008) and I do not

intend to discuss them here. There are various methods of depositing thin film materials on different substrates depending on the application of the device. Some of the deposition methods are listed in Table 3.

Table 2: Projected Increase in Mask Layers and Decrease in Allowable Defects

Year	1999	2001	2003	2006	2009
Technology Generation (nm)	180	150	130	100	70
Mask Count	22	24	24	26	28
Allowable Defect per square metre to get 60% yield	78	60	55	43	34

Source: Seshan (2002). Handbook of Thin Film Deposition Processes and Techniques

Table 3: Survey and Classification of Thin Film Deposition Technologies

Physical Techniques	Evaporation	Thermal Evaporation
		E-Beam Evaporation
		Pulsed Laser Deposition
	Sputtering	DC Sputtering
		DC Magnetron Sputtering
		RF Sputtering
Chemical Techniques	Atmospheric CVD (APCVD)	
	Low Pressure CVD (LPCVD)	
	Homogeneous CVD (HOMOCVD)	
	Metal-Organic CVD (MOCVD)	
	Plasma-Enhanced CVD (PECVD)	
	Photolytic CVD (UVCVD)	
	Laser CVD (LCVD)	

These techniques have been discussed and reviewed extensively by various authors (Lampert, 1981, Lodder, 1993, Lowenhein, 1963). The features of one of such facilities, sputtering facility, which is a complex facility, is described in the next section.

Sputtering

One of the standard deposition methods is the sputtering technique. Sputtering is a physical technique which involves the creation of plasma by the discharge of neutral gas such as helium, acceleration of ions via a potential gradient and the bombardment of a "target" or cathode. Through momentum transfer, atoms near the surface of the target metal become volatile and are transported as vapours to substrate. A typical brand of the Sputtering Deposition Facility (System) at the Department of Physics, Elizabeth City State University, North Carolina is shown in Plate 1.

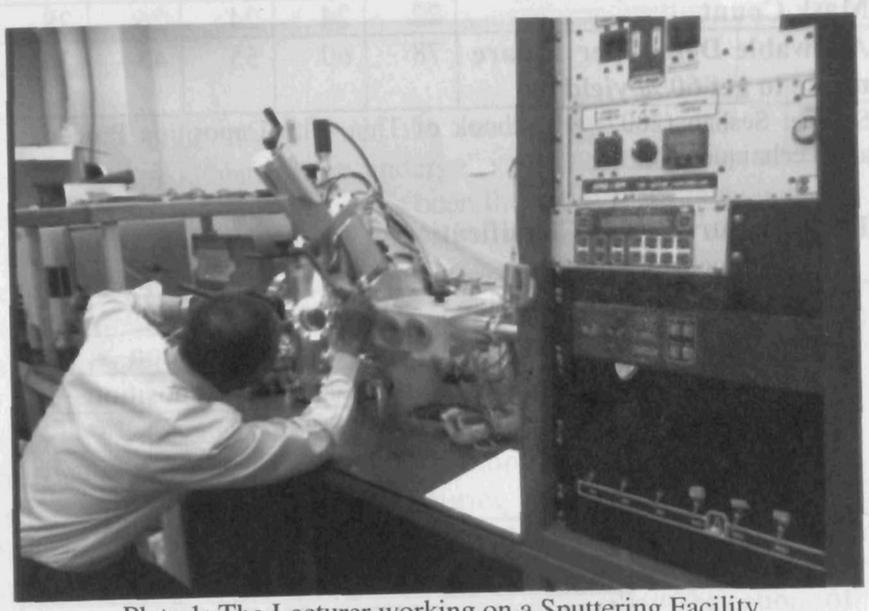


Plate 1: The Lecturer working on a Sputtering Facility

The system is an ultrahigh vacuum magnetism system with three guns (RF, DC and pulsed DC power supplies). The System has the following specifications 10", 12" and 14" Chamber, HV and UHV versions, 1.5", 2" and 3" sputters sources, substrate holders to 6" Φ, load lock. The system has fitted turbo pump and another roughing pump. The complex sophisticated system requires proper cooling which calls for an uninterrupted power supply (a commodity which is scarce in Nigeria). The non-availability of stable power supply and paucity of fund has made it difficult for

most researchers in Nigerian public universities to have access to such sophisticated systems. A good alternative is a low cost simple Metal Organic Chemical Vapour Deposition (MOCVD) system, a variant of which will be described in the course of this lecture.

Characterization of Thin Films

The nature and structure of a material is not understood or useful until the properties of the material are investigated. The process of investigating the properties of a material is referred to as characterization of the material. Material characterization is the process of probing into materials through the measurement of chemical, physical, morphological, structural and magnetic properties of the materials. The characterization of a material can be used to determine not only the properties of the material but also a lot of information about the method of producing the material. In any research study (experimental or theoretical) in the chemistry or physics of solids, it is important that there is a reliable, descriptive, analytical information available about the materials used in study (Hannay, 1968; Laudise, 1972). A good number of techniques are available for use to evaluate the properties and quality of prepared thin film materials. While some of the techniques provide only qualitative properties such as images in the form of micrographs, others give both quantitative and qualitative analyses such as spectra of Fourier Transform Infrared (FTIR) Spectroscopy and Rutherford Backscattering Spectrometry (RBS).

Compositional and Elemental Characterization

The chemical composition and structure of the surface of a solid material can differ significantly from the composition of a bulk form of the same material. Consequently it is necessary to characterize thin films of materials so as to obtain information on the structure and composition of the thin film. Although there are challenges in determining the composition of materials, especially, if light elements and thin coatings ($\leq 0.5\mu m$) are involved (Holloway and McGuire, 1978). It is not my intention to review all the techniques available for investigation of the compositional and

elemental properties of materials, but one or two of the techniques will be discussed for their importance in materials characterization. Compositional techniques may be classified according to the properties to be determined or the type of analysis, depth or lateral analysis. One group of a set of useful tools for compositional analysis is the Ion Beam Analysis (IBA).

Ion Beam Analysis (IBA)

Ion Beam Analysis (IBA) is based on the interaction, at both the atomic and the nuclear level, between accelerated charged particles and the bombarded material. When a charged particle, such as proton or helium ion, moving at high speed strikes a material (the thin film sample), it interacts with the electrons and the nuclei of the material atoms, slows down and possibly deviates from its initial trajectory. This can lead to the emission of particles or radiation whose energy is characteristic of the elements which constitute the sample material. IBA requires the use of an accelerator (Kokkoris, 2010). The scheme of the various methods under the IBA techniques is illustrated on Figure 2 and the acronyms are listed in Table 4.

Rutherford Backscattering Spectrometry

Rutherford Backscattering Spectrometry (RBS) is a typical example of Ion Beam Analysis (IBA). RBS is a nuclear tool used for the compositional characterization of thin film materials. It uses ions with energies of the order 1 MeV/nucleon (such as Helium ions, protons, H, etc.) to bombard the solid sample in vacuum and the output (the intensity of the backscattered Helium ions) are detected and related to the thickness and the atomic numbers of the detected elements. Jeynes *et al.* (2011) reviewed RBS as a method of Ion Beam Analysis. The review covered damage profiling in crystals including studies of defects in semiconductors, surface studies, and depth profiling with sputtering. However, the focus was on thin film depth profiling using Rutherford backscattering,

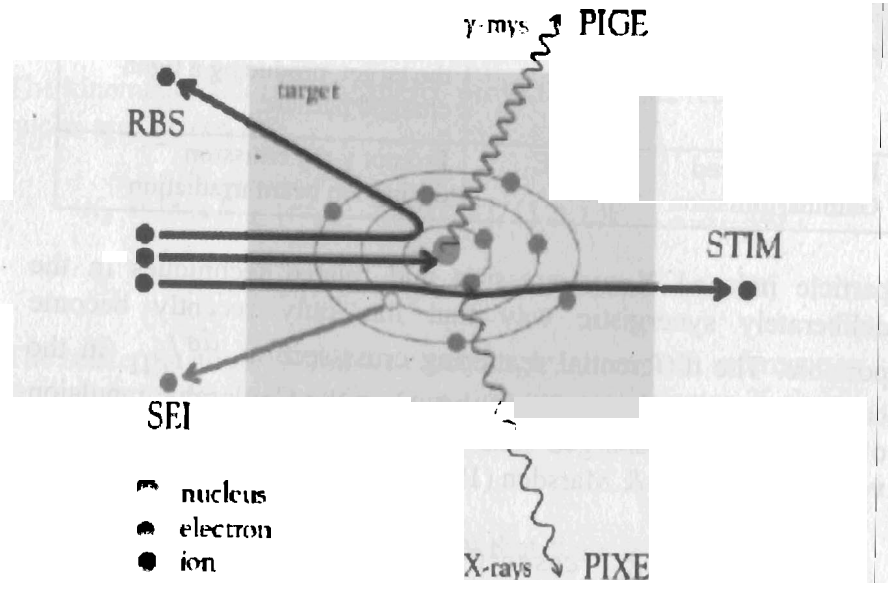


Figure 2: Scheme of the various methods of IBA techniques

Table 4: Acronyms of Methods of IBA

Method	Acronym	Interaction
Particle induced X-Emission	PIXE	Characteristic X-ray emission following **ioniz**ation by the primary beam
Rutherford Backscattering Spectrometry	RBS	Elastic scattering backward at angle
Characteristic X-ray emission following ionization by the primary beam	EBS	Elastic scattering backward at angle
Elastic Recoil Detection Analysis	ERDA	Elastic recoil at forward angles, not necessarily Rutherford

Nuclear Reaction Analysis	NRA	Nuclear reaction between incident beam and nuclei in the target, producing a light charged particle
Particle induced Gamma-Emission	PIGE	Prompt γ-ray emission during ion beam irradiation

particle induced X-ray emission and related techniques in the deliberately synergistic way that has only recently become possible. The differential scattering cross-section, $d\sigma/d\Omega$ (in the centre of mass reference frame) based on the Coulombic repulsion of the positively charged ions was derived by Rutherford (and verified by Geiger & Marsden (1913)) as

$$d\sigma/d\Omega = \{Z_1 Z_2 e^2 cosec^2(\theta/2)/4E\}^2\} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where $d\Omega$ is the solid angle of the detector, θ is the scattering angle, E is particle energy at scattering, Z_i are the atomic numbers of the projectile (positive ion) and the target nuclei (in the sample), and e, is the charge on the electron. The differential scattering cross-section, $d\sigma/d\Omega$ (in the laboratory reference frame) is rather more complex but expanding in ratio M_2/M_1, it reduces to

$$d\sigma/d\Omega = \{Z_1 Z_2 e^2/4E\}^2 \{sin^{-4}\left(\frac{\theta}{2}\right) - 2r^{-2} + \cdots\} \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$r = \frac{M_2}{M_1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where $M_1$and $M_2$are the masses of the projectile and the target respectively. In the Rutherford Backscattering spectrometry, the scattering must be elastic, that is, both kinetic energy and momentum are conserved. Under this condition, kinematics give the split of the initial energy, E_0 between the scattered and the recoiled nuclei and the kinematic factor, K is defined as

$$K = \frac{E}{E_0} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

The kinematic factors for scattered projectile and the recoiled nuclei are derived as:

$$K_s = \{\cos\theta \pm (r^2 - sin^2\theta)^{1/2})/(1+r)\}^2 \ldots\ldots\ldots (8)$$

$$K_r = (4rcos^2\varphi)/(1+r)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

The scattering angle, θ and the recoil angle, φ are with reference to the incident particle (ion) direction. The kinematic factor, K shows high resolution for low values of the target mass, M_2. However, K is insensitive at high values of M_2.

It is important to emphasize the fact that there is no technique or method which can give all the necessary information about a material, hence there is need to use more than one technique so that the techniques can be used to complement each other. For instance, RBS is limited in the detection of light elements on heavy substrates. Apart from the determination of the elemental composition of a material, it is important to investigate the structure and surface morphology of a material since this will also influence the application of the material. There are numerous techniques and methods of determining the structure and surface morphology of materials. These include: X-ray diffactometry (XRD), Scanning Electron Microscopy (SEM), Tunneling Electron Microscopy (TEM), Atomic Force Microscopy (AFM). One of the important methods, SEM is discussed in the next section of this lecture.

Scanning Electron Microscopy

Scanning Electron Microscopy is a method of investigating and probing into the structure and the surface morphology of a material using an electron beam optical system. A Scanning Electron Microscope (SEM) is a tool for seeing otherwise an invisible world of tiny or microscopic objects, using a focused beam of electrons to reveal details and properties which are not visible by the use of

ordinary light microscope or the naked eye (Smith and Oatley, 1955). The high-resolution, three-dimensional images produced by scanning electron microscopes provide useful information about a material. These information include topographical, morphological and compositional analysis of the material (Choudhary and Priyanka, 2017). A typical SEM facility is shown in Plate 2.

Plate 2: (a) Sample Stage of an SEM Facility (b) The Lecturer using the facility at Elizabeth City State University, North Carolina.

The SEM can magnify an object several times (up to 300,000 times depending on the brand and capability). A typical SEM facility consists of source of illumination, Condenser lens, Focusing lens, Electron detector and the Sample stage. These parts are housed in machine as three major parts: the microscope column (which include the electron gun, the column and the sample chamber); the computer system which drives the microscope; and the ancillary system which analyses the composition of the material. One major drawback to the use of SEM is that it operates under vacuum and may require that the sample is conductive. The non-conductive samples are usually coated with carbon or a metal such as gold. After looking at the basic properties such as composition, structure and surface morphology, other properties of a material are also investigated in order to determine or suggest the applications of the material. These studies will involve the optical, electrical, magnetic and mechanical characterization of the material.

Sophisticated Complex Deposition Systems Versus Simple Deposition Systems.

Most of the thin film deposition facilities which are available in developed countries (like USA, UK, France, Germany, etc.) are complex and require constant power supply to achieve high vacuum for a long period of time. Our local situation and condition in Nigeria may not be able to support these sophisticated and complex facilities. For instance a sputtering facility such as the one shown in Plate 1, requires an ultrahigh vacuum in the range (10^{-5} - 10^{-8} torr) (takes a day for the main chamber) but the loading chamber takes a shorter duration (because the loading chamber is smaller). It is general knowledge that getting a 24-hr uninterrupted power supply in Nigeria could be a major issue, meaning that you may never achieve the necessary ultrahigh-vacuum to use such a facility. Do you just give up and fold your hands? You have to do something about it. This probably led Prof. E.O.B. Ajayi to return to the use a simple MOCVD set up for the deposition of In_2O_3 thin film which he used for his Master's research. This is shown in Figure 3. This set-up has been adapted and has now become a useful tool in the Advanced Materials Research Laboratory for the deposition of various thin film systems.

Simple Low Cost Metal Organic Chemical Vapor Deposition (MOCVD) System.

The simple low cost MOCVD System is a simple glass tube assembly system, which operates at atmospheric pressure. The System has a cylindrically shaped working pyrex chamber, placed in an electrically heated furnace. The main chamber is connected to an unheated receptacle which carries the powdered precursor. The precursor is blown into the chamber by a gas (either an inert gas, N_2 or Oxygen or compressed Air), depending on the type of thin film which is to be prepared. The simple System has been used to prepare various thin film systems, which have been characterized using standard techniques, such as Scanning Electron Microscopy (SEM), Rutherford Backscattering Spectroscopy (RBS) and found to have properties comparable with those prepared by more sophisticated deposition systems, such as

Molecular Beam Epitaxy (MBE), Sputtering, Evaporation, etc. The prepared thin films have various technological and engineering applications.

As a young Assistant Lecturer, I remember giving out a project to one of my undergraduate students – Design and Fabrication of a digital Burglar Alarm System". The most important component in the alarm system turned out to be a Cadmium Sulphide thin film sensor. After the design, the student assembled the necessary components on a bread board (and later on a Vero board), the student produced the Burglar system with the sensor mounted on a door. At the time of my involvement in the project, the sensor was like a "black box" to me. Upon my divinely arranged meeting with Professor E.O.B. Ajayi, I got exposed to the art, science and technology of

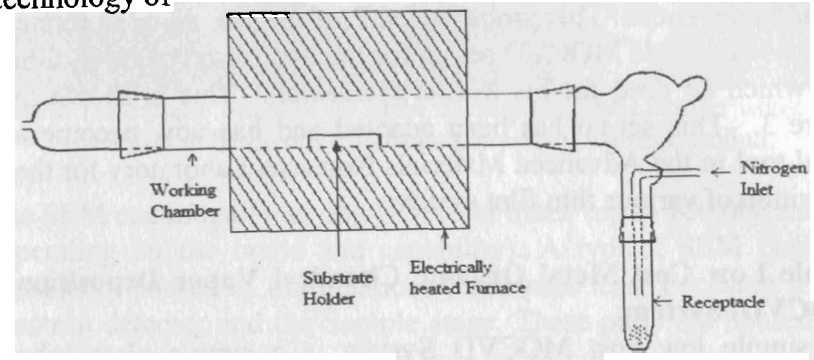
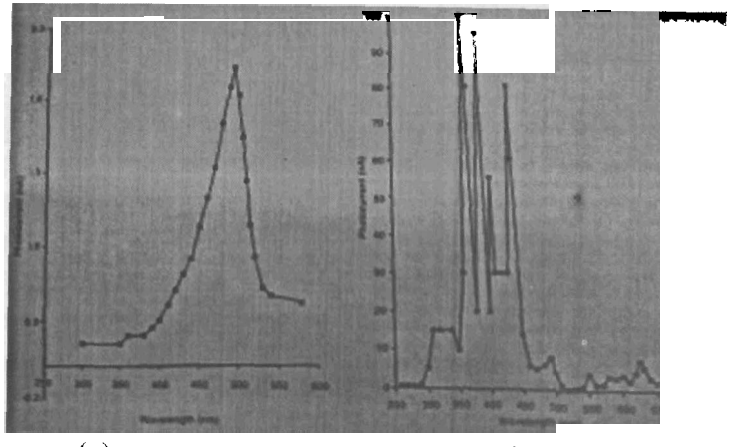


Figure 3: Schematic Diagram of the Homegrown MOCVD Setup.

thin films. By sheer coincidence, one of the graduate students (in the group), who had just completed his Master's programme, worked on CdS thin films. I was asked to respond to some of the questions raised by the reviewers for the paper that came out of the research work. This exercise turned out to be a good training for me. I got something bigger than the training, I observed the photoconductive property of the prepared Cadmium sulphide thin films (which was the most important part of the project executed by my former undergraduate student). The study showed that the

MOCVD CdS thin film prepared using the simple homegrown reactor (Ajayi, *et. al.*, 1994; Ajayi, *et. al.*, 1986; Ajayi, *et. al.*, 1981) is moderately photoconductive and it may be a useful component in the spectral analysis of various lamps for light sources for counting systems, burglar alarm systems and other optoelectronic systems. The CdS thin films which were prepared using the simple homegrown MOCVD system were found to have properties comparable to those prepared using complex systems (Eleruja *et al.*, 1995).

Figure 4a shows the photoresponse of the CdS films when exposed to light from a tungsten lamp, while Figure 4b shows the photoresponse when the films was exposed to light from mercury lamp. The photoresponse of the film in Figure 4a is similar to that of single crystal CdS, but the wavelength of the peak is reduced. This is due to an increase in the structural imperfection of the films and the size effect. The wavelengths of the peaks shown in Figure 4b correspond to the wavelengths of the lines in the photoelectric traces of the mercury spectrum. Photoconductivity in a semiconductor is useful both in its own right as a phenomenon which can be used in commercial applications, and as a valuable tool in the investigation of the properties of imperfections in crystals.



(a) (b)

Figure 4: Photocurrent versus wavelength for (a) Tungsten lamp (b) Mercury lamp

ZnS has for many years been widely used for thin film electroluminescent structure (Vijayalakshimi *et al.*, 1994) and light emitting material for display system. A thin film of this material was prepared by our group from the pyrolysis of bis-(morpholino dithioato-s,s') zinc ($C_{10}H_{16}N_2O_2S_4Zn$) at 420°C (Osasona, *et. al.*, 1997). It was reported that the ZnS thin film has a bandgap of 3.67 eV, which is consistent with most of the values reported by other researchers, who used other methods of deposition (Werninghaus *et al.*, 1993). It was also observed that there was a threshold deposition temperature of 300°C for the film, below which there was no deposition. Alloying of semiconductors is one of the methods used for tailoring the energy band gap, lattice parameters, electronic and other properties to produce materials for specific applications. Generally, these alloy systems, have shown that some of the properties have linear dependence on composition over the entire miscible region following the Vegard's law. There are two ways to prepare mixed metal oxide or sulphide systems, viz. from a physical mixture of the sources of the needed components, such as cobalt acetylacetonate and vanadium acetylacetonate to produce Co-V-O thin films (Adedeji *et. al.*, 2002) and from a single solid source precursor, such as Indium tin acetylacetonate to produce mixed metal oxide system such as Indium tin Oxide (ITO) (Akinwunmi, *et. al.*, 1999) and Uranium Zinc Oxide (Eleruja, *et. al.*, 2002). It has been observed that the mixed metal thin film systems prepared through the first method did not give the same transfer metal ratio from the precursor to the thin film. This has been ascribed to the different aerosol properties of the physically mixed precursors.

In view of the importance of tailored materials in Solid State Physics, electronics and device fabrication, our group (the advanced materials group) has prepared and characterized a good number of these systems. These materials include $Zn_xCd_{1-x}S$ (Eleruja, *et. al.*, 1998), ITO (Akinwunmi, *et. al.*, 1999), ZnCdInS (Adedeji, *et. al.*, 2000), Uranium doped zinc oxide (Eleruja, *et. al.*, 2002), Cobalt oxide (Mordi, et. al., 2009) thin films. All these thin film systems have been prepared using the reported simple

homegrown MOCVD set-up. $Zn_xCd_{1-x}S$ (greenish yellow film), used as a novel insulating material in Metal-Insulator-Semiconductor (MIS) structure in infrared devices and for applications in photovoltaics, was prepared from the pyrolysis of a single solid source precursor, bis-(morpholinoato-s,s')-Cd-Zn. It was observed that Cd to Zn ratio in the precursor and the films are not in one to one correspondence. This is attributed to the possible break down of the metal-metal bonds of the precursor in the vapour phase. The composition from which a band gap of 2.63 eV was obtained was found to be $Zn_xCd_{1-x}S$ ($x = 0.32$) and the PL emission peak position were 430 nm, 460 nm and 470 nm. The observed shift in the PL emission peak towards longer wavelength with increase in excitation wavelength is associated to the quantum size effect (Eleruja, *et. al.*, 1998). Some properties, such as high transmittance in visible range, high electrical conductivity, mechanical strength and chemical stability, have made some of the prepared thin films useful in applications such as transparent conductors, ITO (Akinwunmi, *et. al.*, 1999), liquid crystal displays, energy conversion systems and in solar cells as transparent electrodes, ZnO (Eleruja, *et. al.*, 2002). Other thin films which have also been prepared via this method include molybdenum (II) oxide (MoO) (Ilori, *et al.*, 2005a) and $Li_6O_3MoO_2$ Thin Films (Ilori, *et.al.*, (2005b). These thin film systems are useful as electrodes in Lithium ion batteries.

Generally, materials show different relationships between absorption coefficient, α and the photon energy, E_g. These relationships include direct allowed, direct forbidden, indirect allowed and indirect forbidden transition. The relationships are presented in equation 10.

$$\alpha_{da,df,ia,if} = constant\ (\hbar\omega - E_g)^{n_{da,df,ia,if}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

where $n_{da,df,ia,if} = \frac{1}{2}, \frac{3}{2}, 2, 3$ respectively. Most of the thin film systems that have been prepared by our group have shown direct allowed optical transition. For example, the CdO thin films

(Adekoya, *et. al.*, 2012) showed a direct allowed transition as presented in Figure 5.

In recent times, thermoluminescence techniques had been used to study the deep trapping defect states in thin films deposited on glass substrates (Arafah and Ahmed-Bitar, 1998) and other researchers have also investigated the thermoluminescence properties of thin film materials for dosimetry applications. Similar efforts have been carried out by Balogun, *et. al.* (2004) in the investigation of the influence of pre-irradiation annealing and Li_x-$Co_{(1-x)}$-O thin film deposition on the TL response of soda lime glass. It was observed that heating the sodalime glass prior to irradiation resulted in an enhanced TL response, whereas subsequent deposition of Li_x-$Co_{(1-x)}$-O thin film is observed to suppress it. This effect is shown in Figure 6.

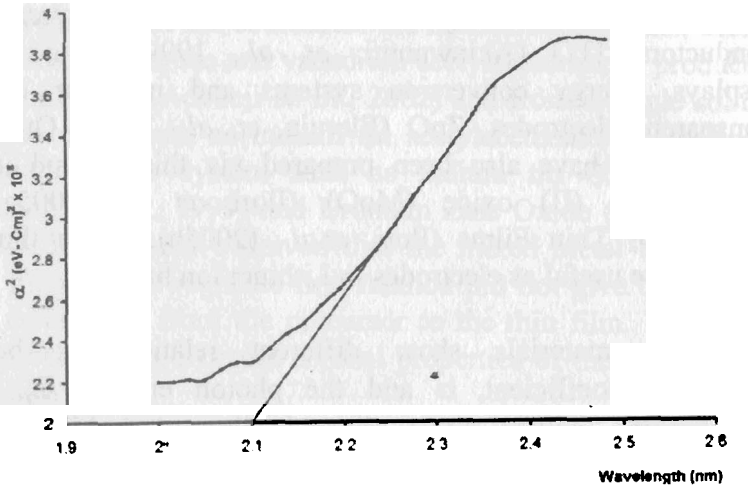
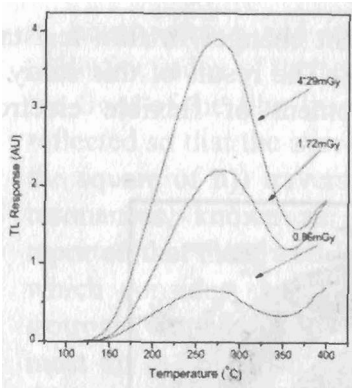
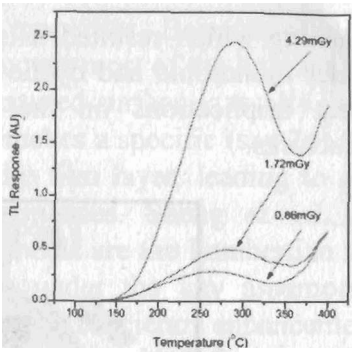


Figure 5: Plot of α^2 versus photon energy for the CdO thin film

A dose dependent shift in the maxima of the glow peaks from the samples was also observed. This shift was attributed to possible structural changes in the deposited thin film and the substrate.



(a)



(b)

Figure 6: TL glow curves of gamma irradiated (a) Annealed sodalime glass at increasing doses. (b) thin film deposited sodalime glass at increasing doses.

Flexible Electronics

Flexible electronics involves materials that are very thin to the extent that they are compliant such as a smart ATM card or any other smart card that does not break when it is either folded or stepped on mistakenly. According to Cheng and Wagner (2009), the term flexible can convey different meanings: bendable, conformally shaped, elastic, lightweight, non-breakable, roll-to-roll manufacturable, or large area. Some of the examples of the applications are shown in Figure 7 as the next generation flexible electronics systems and the key relevant sectors (Agnihotri, *et.al.*, 2013).

As a visiting fellow to Princeton University, Princeton, USA, I was involved in the research in the area of flexible electronics, which is an integral part of microelectronics. Although the research study is still on-going, the initial effort produced a published article (Akogwu *et al.*, 2010). The study investigated the large strain tensile and cyclic damage in nano-scale gold (Au) thin film that were electron beam deposited on a 1 mm thick elastomer, Polydimethylsiloxane (PDMS). The effects of Au thin film thickness of values 50, 75 and 100 nm were investigated. It was observed that large strain deformation gave rise to grain boundary

cracking which resulted in significant changes in film resistance under monotonic and cyclic loading. The result of this study has great implications on the development of flexible electronic structures.

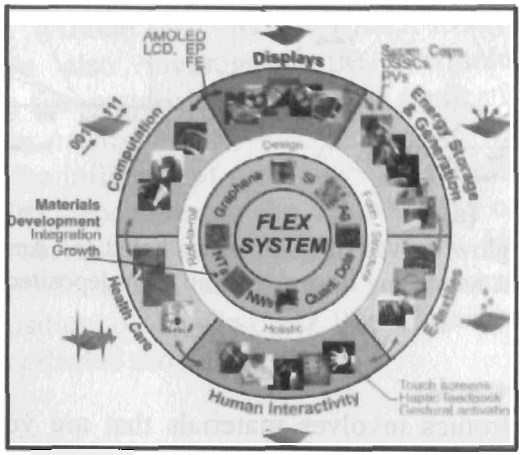


Figure 7. Next Generation Flexible Electronics Systems and the Key Relevant Sectors (Agnihotri, *et al.*, 2013).

In the course of my research, I have in conjunction with the other members of our research group, prepared and characterized a material system, Cadmium Oxide, (an M.Sc. Thesis supervised by me), which showed textured property (Adekoya *et. al,* 2012). This study confirmed a theoretical simulation carried out by a research group in Massachusetts Institute of Technology (MIT), USA, on the use of textured material system to enhance the performance of solar cells (Sheng *et. al.,* 2011). The SEM of the deposited CdO thin films are shown in Plate 3.

The enhanced light absorption in the deposited CdO thin film is not due to the chemical composition of the cadmium oxide system but to the textured structure of the thin films. The enhanced absorption observed in the infrared region in this study is absent in those reported by Dakhel and Henari (2003) and Beevi *et. al.,* (2010). According to Saeta et. al. (2009), it can be assumed that the textured structure may be modeled as having plane, parallel layers

of homogeneous and isotropic properties. Because of the large refractive index of the semiconductor, most of the light incident on the front of the film from the textured surface is totally internally reflected so that the average ray makes a specific (say $2n^2$ (2 times the square of n)) traversals of the film layer, leading to possible resonances, known as Mie resonances. Sheng *et. al.*, (2011) reported that most well-known models are the Lambertian models, which consider surface textures under the key assumptions of isotropic scattering, in which case the efficiency enhancement is at most πn in 2D or $4n^2$ in 3D for a film with index, n, of infinite thickness and spectral range. According to Vasudev *et. al.,* (2012) while the light scattering from absorber layers such as single ZnO, nano beam certainly contribute to the overall absorption enhancement, the coupling of incident light to guided and diffracted modes inside the structure generates the regions of highest magnitude in the absorption enhancement maps .

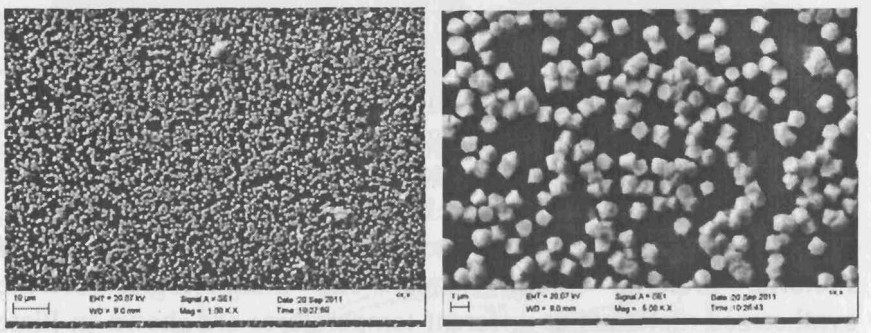


Plate 3: SEM of the deposited CdO thin films

Other Skills learnt

Other skills learnt in the course of carrying out my research include the preparation of various metal organic precursors which are used for the deposition of various thin film systems. These precursors are usually prepared from chemical reagents which can be sourced easily. Some of the prepared precursors are Cobalt acetylacetonate (Mordi *et al.*, 2009), Sodium Nickel acetylacetonate, Sodium cobalt acetylacetonate, Lithium cobalt acetylacetonate, Lithium nickel acetylacetonate, acetylacetonate

(Eleruja, 1998), among many others. This efforts have helped in reducing the cost of preparing some of the precursors since some of them were prepared from easily sourced reagents.

Energy Generation and Energy Materials

Mr. Vice-Chancellor Sir, Nigeria as a nation is tormented with bad leadership. I know this is bad enough but worst still is the lack of adequate power for domestic and commercial use. One of our senior professors, once shared this with me several years ago, that among many issues, energy and water will become big issues in the world and Nigeria in particular. In view of this imminent challenge, I decided to diversify my research into the search for new energy sources.

A trending area of my research is the fabrication of Super-capacitors and Lithium ion batteries as energy storage devices. I was involved in the synthesis and characterization of porous carbon derived from activated banana peels with hierarchical porosity for improved electrochemical performance (Fasakin *et al.*, 2018). We actually used our locally sourced materials to synthesize porous carbon and adopted foreign facilities to fabricate symmetric device in three neutral electrolytes through our collaboration with the Department of Physics, Institute of Applied Materials, SARCHI Chair in Carbon Technology and Materials, University of Pretoria, Pretoria, South Africa. The morphologies of the synthesized materials at different temperatures are shown in Plate 4, while the symmetric electrochemical behavior of the porous carbon material is shown in Figure 8. The novelty in this work is the ability of electrode material to display an increase in specific capacitance of about 192% after voltage holding test for 60 hours. Also, we prepared and investigated Titanium Oxide and Titanium Tin Oxide nanotubes as anode of Lithium ion batteries. The hydrothermal synthesis route similar to the work reported by Tang *et. al.* (2014) was adopted in this work. Electrochemical properties of the prepared electrodes were tested in half cell devices using MACCOR battery testing workstation located at Council for Scientific and Industrial Research (CSIR), Pretoria, South Africa.

The electrode materials showed capacities of 160 and 930 $mAhg^{-1}$ for Titanium Oxide and Titanium Tin Oxide nanotubes respectively (Fasakin, 2018). Plate 5 shows the morphologies of pristine TiO_2 powder and prepared TiO_2 nanotubes. The electrochemical investigation of the assembled device exhibited redox peaks that matched well with intercalation and de-intercalation of TiO_2 and SnO_2 electrode as anode of lithium-ion batteries.

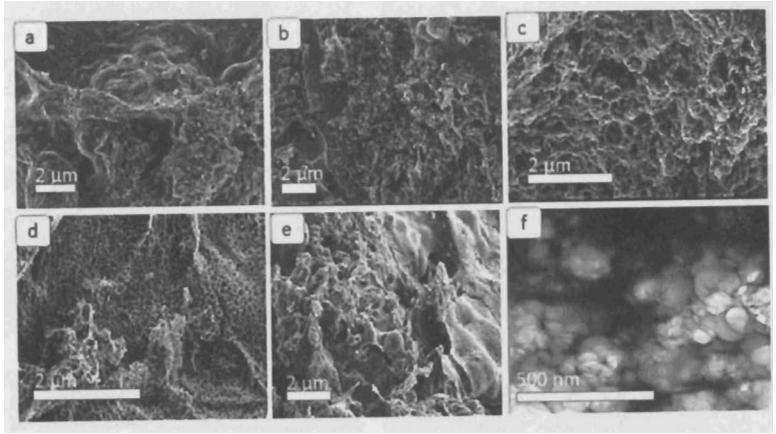


Plate 4. (a) SEM images of activated banana peel samples (ABPs) carbonized at different temperatures: (a) ABP750, (b) ABP800, (c) ABP850, (d) ABP900, (e) ABP950 and (f) TEM image of ABP at 900 ^{0}C.

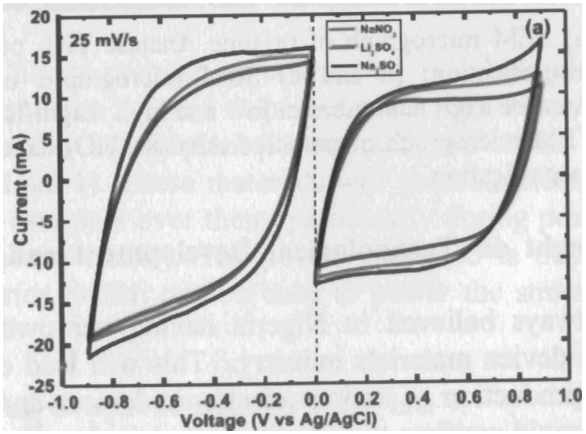


Figure 8: Cyclic Voltammetry (CV) curves of the ABP 900 sample displaying the electrical double layer capacitor response at the positive and negative potentials

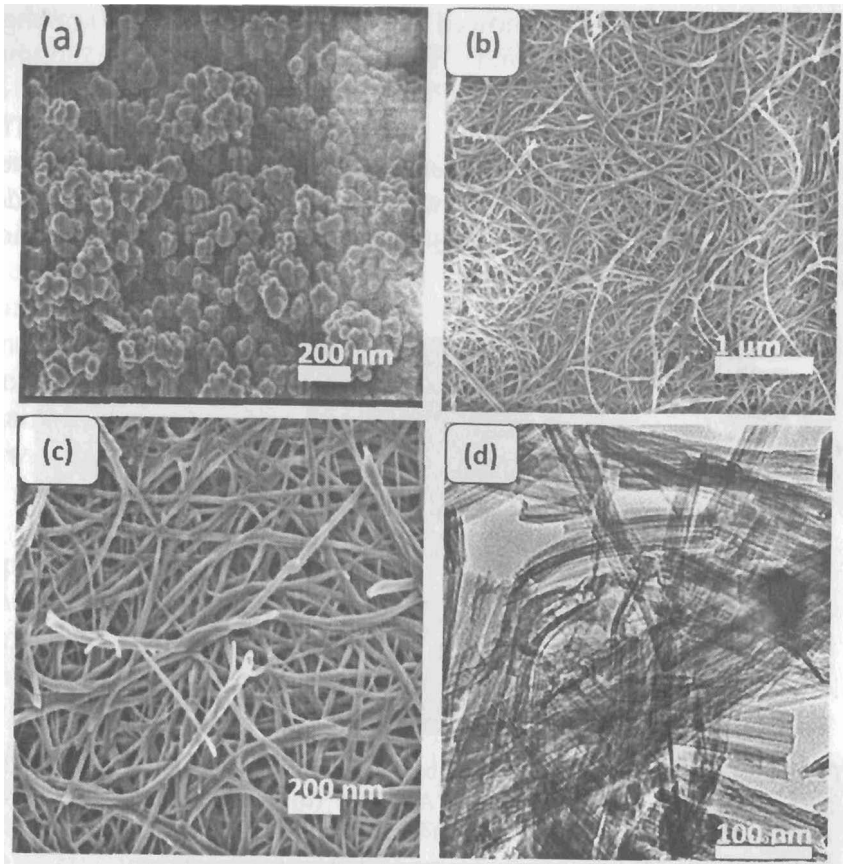


Plate 5: (a) SEM micrograph of pristine Anatase TiO_2 powder at high magnification, (b and c) SEM micrographs of as-prepared Anatase TiO_2 nanotubes at low and high magnifications and (d) TEM micrograph of prepared Anatase TiO_2 nanotubes at high magnification.

My Thought on Technological Development and Growth of Nigeria

I have always believed in Nigeria having her own indigenous electronic device materials industry. This will lead eventually to the local production of various electronic devices and appliances. Nigeria should emulate the Brazilian model of manufacturing car parts of the volks wagen in the 1950s. Brazil as a country started with the assembling of volks wagen cars just like Nigeria. The

parts were imported and assembled in Nigeria. When the whole arrangement started in 1953 all parts were imported from Germany as completely knocked down (CKD) assembly units. In 1956, Kubitschek ruled that car makers would have to do without imported parts after a short initial phase of production. In the same year, Volkswagen laid the foundation stone for its first plant abroad, in Sao Bernardo do campo, a suburb of Sao Paulo. In 1957 the first VW bus lit the market, with half of its components made in Brazil and two years later VW built a "Beetle that was almost exclusively Brazilian-made. If Nigeria had adopted this model, VW Nigeria would not have become a moribund project. Also, this policy or lack of policy is not limited to industry and economy, it is also pervasive in the educational sector.

Mr. Vice-Chancellor, sir, I wish to inform you and this august audience that the properties of the thin films were found to be comparable with those prepared by the more sophisticated techniques. In my quest to utilize the properties of thin films, I have proposed the coating of glass windows in developing energy efficient buildings, in which the interior of such building can be cooled by applying small potential to electrochromic coatings. This will cut-off the infrared portion of the electromagnetic radiation (of sunlight). A reverse of this process may be used to heat up the interior of a building during cold or wet season.

I would also like to propose the concept of "rush hour electricity", which I believe can be used to power street light along the road. This will involve laying piezoelectric materials across the road, especially (Road 1). These materials will generate electric power when motor cars pass over them, particularly during peak periods (period of heavy traffic). The power generated is then used to charge batteries, which can be used to power the street lights at night.

Graphene and Graphene Related Materials

Other areas of research which I have been involved in, are the preparation, characterization and possible applications of graphene

and graphene based materials. Mr. Vice Chancellor, sir, from the available literature, we have observed that only very few universities in Nigeria are currently working in this area of research locally. We hope to intensify this research in collaboration with some of our colleagues in the Department of Chemistry (Obafemi Awolowo University, Ile-Ife)

Graphene is an allotrope of carbon consisting of atomically thin layer of sp^2 hybridized carbon atoms that are densely packed in a honeycomb crystal lattice (Geim and Novoselov, 2007; Rao *et al.*, 2009). This precisely two-dimensional material exhibits unique high conductivity and good electronic quality (Wu *et al.*, 2007; Huang *et al.*, 2011) and has emerged as a promising new nanomaterial for a variety of exciting applications despite its short history (Wan *et al.*, 2012; Compton and Nguyen, 2010; Denk *et al.*, 2014). For nearly three decades, carbonaceous materials such as fullerenes and carbon nanotubes (CNTs) have drawn considerable attention due to their exceptional electronic and mechanical properties.

Graphite, a naturally occurring material is the closest in resemblance to graphene though incomparable in several ways to graphene. The first reported method for producing graphene can be traced back to 1970 (Eizenberg and Blakely, 1970) and rather, the free standing single-layer of graphene was first obtained in 2004 via the isolation of graphene from graphite via micromechanical cleavage at University of Manchester (Novoselov *et al.*, 2004). The delay in the discovery of free standing graphene sheets can be partially attributed to their single-atom-thick nature, which was initially believed to be thermodynamically unstable (Mermin, 1968). However, graphene is not only stable but also exhibits excellent electronic and mechanical properties such as a charge-carrier mobility of 250,000 $cm^2 V^{-1} s^{-1}$ at room temperature (Ortila *et al.*, 2008), a thermal conductivity of 5000 $Wm^{-1}K^{-1}$ (Balandin *et al.*, 2008), an electrical conductivity of up to 6000 Scm^{-1} (Du *et al.*, 2008) and a large theoretical specific surface area of 2630 $m^2 g^{-1}$(Zhu *et al.*, 2010; Weber *et al.*, 2011). In addition, graphene is

highly transparent, with absorption of <2.3% towards visible light (Pang *et al.*, 2011) and indeed, with a Young's modulus of 1 TPa and an ultimate strength of 130 GPa, single layer graphene is the strongest material ever measured (Lee *et al.*, 2008).

The novel catalytic, magnetic and optoelectronic properties of graphene nanocomposites based on the hybridization with nanoparticles (NPs) have attracted significant attention. (Bai and Shen, 2012). Particularly, due to the unique sp2 hybridization of carbon bonds present in graphene, which facilitates the delocalization of electrons, graphene possesses excellent electronic conduction (Novoselov *et al.*, 2004). This electronic conduction of graphene can be enhanced by incorporating various inorganic nanoparticles, including different metal and metal oxide NPs. Due to the enhanced electrical and electronic properties and the synergistic effect between graphene and inorganic nanoparticles, graphene/nanoparticle nanocomposites offer great potential for various applications including energy storage and energy conversion devices (Huang *et al.*, 2012). To date, we have made great efforts to synthesize and apply our graphene and graphene based materials in fields like electronics, chemical sensors, electrochemical, energy conversion and storage.

Previous Research on Graphene

Our research into the world of graphene began in 2014 with the synthesis and characterization of graphene oxide and reduced graphene oxide deposited by spray pyrolysis method (Eluyemi *et al.,* 2016). Having successfully oxidized graphite flakes to obtain graphene oxide (GO), we proceeded to reduce the graphene oxide via chemical route using Hydrazine monohydrate in order to restore the conjugated networks that were altered during the oxidation while also increasing the conductivity of the reduced graphene oxide (RGO). Both graphene oxide (GO) and reduced graphene oxide (RGO) were deposited on glass via spray pyrolysis method. The results of the thin film characterization gave values of sheet resistance and resistivity of GO and RGO films to be 22.9 × 10^6 Ω/sq and 0.6183 Ω-m; 4.95 × 10^6 Ω/sq and 0.13365 Ω-m respectively. Also, our result showed that the use of this method is

a promising technique for the development of GO and RGO thin films for use in various technological applications such as energy storage devices and solar cell applications.

In our quest to fine tune our synthesis method to obtain materials that will offer improved electronic properties for energy storage devices, we synthesized and characterized graphene oxide made from two different routes using the simplified Hummers method by varying the duration of oxidation (Olumurewa *et al.*, 2017). Our result showed that extended period of oxidation is not favourable for producing graphene oxide with the desired properties for utilization in energy storage devices. This is because the extended period of oxidation brought about a greater disruption of the sp2 domains in the 6-day synthesized GO unlike in the 3 day synthesized GO. Our experimental result also confirmed that available density functional calculations that typified partially oxidized graphene oxide is thermodynamically favoured for energy applications. (Boukhvalov and Katsnelson, 2008)

There are drawbacks involved in the chemical reduction of graphene oxide using hydrazine. One of them is that the degree of graphene oxide reduction is not easily controlled, hydrazine is toxic and unstable, it renders GO insoluble and difficult to spread on substrates. In order to overcome these drawbacks, we have recently employed various green method of reducing graphene oxide. We have utilized the hydrothermal means of reducing GO which operates on the principle of overheated supercritical water acting as a reducing agent and thus eliminating the use of toxic organic chemicals. The hydrothermal reduction method has shown great advantages which includes the ability to control crystal size during synthesis. Also, we have embraced the use of other green reductants such as Neem leaves (*Azadirachta Indical*), Pumpkin leaves (*Telfairia Occidentalis*), Spinach leaves (*Amaranthus Hybridus*), Ascorbic acid and Amino acid (Methionine). These green reductants have been shown to be viable alternatives to hydrazine Monohydrate and other chemical solvents in restoring the conjugated networks in graphene. Infact, our RGO obtained via

Amaranthus Hybridus, has shown the lowest band gap amongst the prepared RGOs.

In one of our works, we have extended our GO and RGO synthesis further to mechanical application and analysis. The GO and Polystyrene composite showed that adding graphite and its derivatives to polystyrene will improve its thermal property and make it more suitable to be used as a storage device in a heat tensed condition.

Present Research on Graphene

Our present research is focused on the application of graphene related materials in gas sensing, photovoltaics, supercapacitors and electrodes of Lithium ion batteries. Because of the risk and hazard involved in liquefied petroleum gas, we are working on an electrochemical sensor with reduced graphene oxide as the key material in sensing liquefied gas. Also, we are concerned about increasing the efficiency of graphene related solar collectors by tuning their sheet resistance and transmittance. Figure 9 shows the Raman spectra of a 3-day synthesized GO and 6-day synthesized GO while Plate 6 shows the SEM micrograph of the prepared Graphene Oxide.

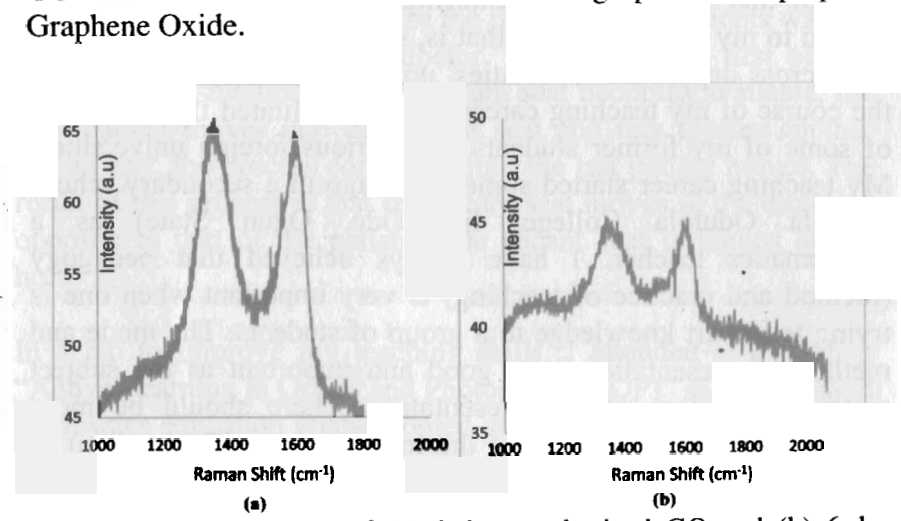


Figure 9. Raman spectra of (a) 3-day synthesized GO and (b) 6-day synthesized GO. (Olumurewa *et al.*, 2017)

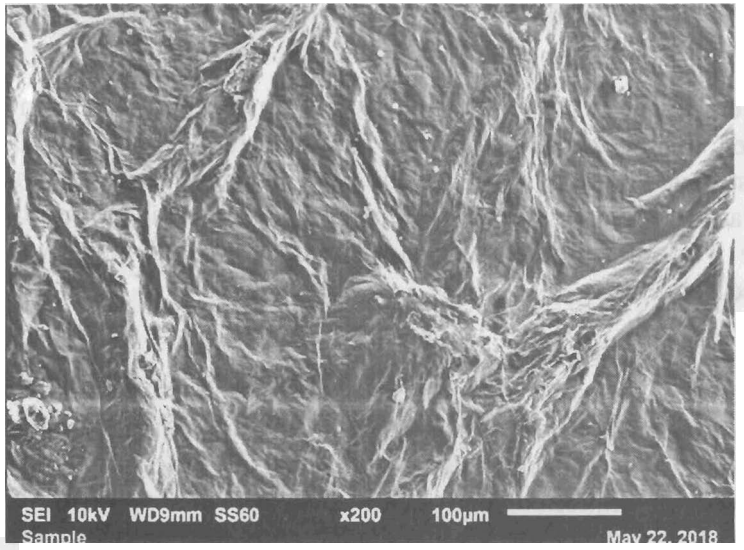


Plate 6. SEM Micrograph of Prepared Graphene Oxide.

MY TEACHING CAREER AND MENTORSHIP

As a trained teacher, teaching has always been my passion and through that I have been mentoring young people. This is not limited to my direct students, that is, students in my department. It cuts across departments, faculties, universities and professions. In the course of my teaching career, I have facilitated the admission of some of my former students into various foreign universities. My teaching career started some years ago in a secondary school (Adeola Odutola College, Ijebu-Ode, Ogun State) as a Mathematics teacher. I have always believed that pedagogy (method and practice of teaching) is very important when one is trying to impart knowledge to a group of students. The mode and method of presentation is as good and important as the subject matter or content of the presentation. There should be more research collaboration between the lecturers in the Department of Physics and their colleagues in Faculty of Education particularly those in the Department of Science and Technology Education (STE). Following the foundation laid by great educators like Babs Fafunwa, who believed that mother tongue should be used in teaching various subjects in schools, I believe that we could have a

unique way of presenting some concepts of Physics to our students in Obafemi Awolowo University, Ile-Ife. This approach will be customized and become Ife-Physics-Presentation technique. Some of examples of these will be given in the course of this inaugural lecture. My interaction with students revealed that most students who do not like the science subjects especially physics were not properly taught physics in their secondary school days, hence there is need to adopt more student friendly (centred) methods of teaching physics and indeed all science subjects. For instance in teaching my Foundation Physics class, a topic like Capacitance, Voltage and Charge, I adopted the following presentation "Who is the man in charge of the University?" The man in Charge (Q) of the university is the Vice (V)-Chancellor (Capacitance) which translates to:

$$Q(Charge) = V(Voltage) \times C(Capacitance)$$

It is usually easier to introduce a topic on "electrons" to students (in an introductory course in solid state physics or electronics) but it is more difficult to introduce the concept of "holes". Holes are generally referred as electron voids in valence band (Shockley, 1950). So, I would normally use the illustration of patients waiting to see or consult a medical doctor. As soon as the first patient enters the consultation room, a vacant seat becomes available, the next patient moves into the vacant seat and this creates another vacant seat, the process continues until the last patient moves. The result of this process is that the vacant seat moves in the direction opposite to that of the patient. The vacant seat is tagged as the hole.

In a bid to improve my teaching skills, I attended a Workshop "Active Learning in Optics and Photonics (ALOP)" in 2015. Based on physics education goals adopted at the 2005 World Conference on Physics and Sustainable Development, the workshop on "Active learning in optics and photonics (ALOP)" has been described as a model for teacher training and professional development. One of the activities in the training sessions showed the use of simple instructional aids to demonstrate the concept of

diffraction (Plate 7). I have adopted such methods in teaching my classes.

In the last twelve years, I have supervised and mentored fourteen MSc. and two Ph.D. research students. Three of these are lecturers in Nigerian tertiary institutions (one in Obafemi Awolowo University, Ile-Ife).

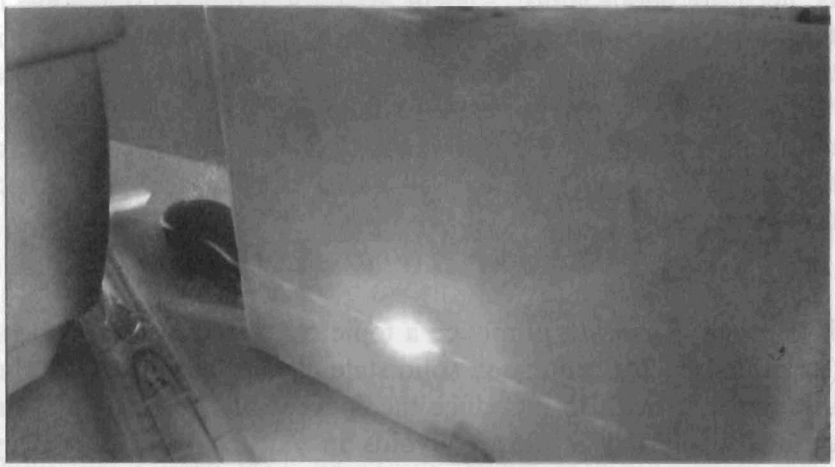


Plate 7: Demonstration of the phenomenon of Diffraction at ALOP Workshop at the University of Lagos, Akoka, Lagos, Nigeria.

MY ADMINISTRATIVE EXPERIENCE

As a young lecturer, I got introduced into administrative assignments such as the computation of students' results in the department, vetting of results at the faculty level and the University. I later became a member of the Sundry application committee (in charge of leave of Absence, permission to register for less than 15 units, deferment of admission, etc.) (2003/2004 – 2007/2008) and chaired the same Committee in the 2008/2009 session. I was the course secretary to PHY101 (General Physics I) and PHY102 (General Physics II) for six (6) semesters. I was the coordinator of Examination Results Compilation Committee (2009-2012); member of Faculty Board of Science (1993-Date); a non-Professorial member of the Faculty Review Panel 2005/2006 – 2006/2007); member – Faculty Conference committee (2007); Chairman - Faculty Conference committee (2008 – 2012); Chairman – Faculty Board of Examiners (2012 – 2014); Vice – Dean of Science April, 2012 –May, 2014). Head of Department, Department of Physics and Engineering Physics (August, 2015 – Date). In the University, I was the Deputy Hall Master, Angola Hall 2015 – 2016, member, University Panel; member, Post-UTME Screening Committee (2014-2015); member, Ceremonials Committee (2014-2015); Examiner (Physics) West African Examinations Council (1987 -2000); External examiner to some Nigerian Universities and external examiner for a Ph.D. Thesis, University of Pune, Pune, India.

RECOMMENDATIONS

Vice-Chancellor Sir, I wish to humbly make some recommendations with a view to making research in Solid State Physics and the teaching of physics more meaningful and eventful. The recommendations are listed as follows:

1. The University should make conscious effort to establish an Innovation Centre, which will have sub units, such as (i) Materials development and improvement unit, (ii) Collation unit for Departmental research output. This will allow for better collaboration and thus will remove the idea of researchers working in silos.
2. Formation of strong linkage between different research groups within the University. This will facilitate a similar linkage between this University and other Universities. I have observed that it is at the level of signing MOU's with foreign universities that the University linkages unit usually advise departments to involve other departments in the University so that the MOU can be fully maximized.
3. There should more synergy between the industry and the academia. The researcher does not need to wait for the industry to seek for his research outputs, he/she should be more enterprising. A research should identify relevant industry and let them know his/her capabilities and areas of

expertise. This may be cheaper for the industry instead of outsourcing such expertise to foreign laboratories.

CONCLUSION

Mr Vice-Chancellor Sir and my distinguished audience, in the course of this Inaugural lecture, I have presented the summary and synopsis of my research and my teaching experience as a scholar. I have given the details of my attempt at preparing resistors locally, which produced composition resistors which are of high stability and quality and were reproducible. I have been able to use a home-grown MOCVD experimental set-up to produce good quality thin films of various metal oxides, metal sulphides (single metal and mixed metal). The prepared thin films have been subjected to various characterization using standard techniques and they were found to possess properties similar to those of the films prepared using more sophisticated deposition methods. I have also reported my humble effort in the area of synthesis and characterization of graphene based compounds. My group is one of the few groups engaged in this type of work in Nigeria. We have prepared and characterized the graphene-based materials and also applied the materials to reinforce some polymer materials. I am currently fabricating gas sensors from the graphene-based compounds and also working on applying the materials to power generation and water purification. I have also joined the army of researchers who are interested in other sources of energy using locally sourced waste materials such as banana peels, cassava peels, etc. I have shown that I am passionate about the mode of presenting Physics, as a subject to my students to make it attractive to them. In doing this, I have adopted and adapted ALOP technique, which can be applied to teach the various aspects of physics, using improvised objects and items.

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My greatest appreciation goes to God almighty for my life and good health that I enjoy. I thank Him and appreciate Him for given me the opportunity to present this Inaugural lecture. To God be the Glory and honour. God has sewn for me, a beautiful coat of many

colours, of a profound teaching and research career in Solid State Physics from the inadequate research resources, the peels of banana, cassava, and wastes. All the Idea was His.

I will not be standing here before you today, if a couple had probably decided to "wash me away" some years ago. Therefore, I thank my Parents, Late Pa Francis Ayekun Eleruja (may his soul rest in peace) and Madam Theresa Eleruja (who is in her mid-nineties - a nonagenarian). I thank them for bringing me into this world and giving me good education (and good morals). Another angel, who God sent to me was my late uncle, Baba Eleruja Agba (as we used to call him). He exposed me to a standard and top rated secondary school (Saint Finbarr's College, Akoka, Yaba), where I enjoyed Lagos State scholarship from Form 2 to Form 5. He was my standard and reference for a simple life style. I thank my siblings and their families, Sister Iyabo (RIP), Sister Yinka (and her husband, Laye) Tunde, Taye and Idowu for their support while I was growing up. I also thank my cousins (who were like my direct siblings), Mrs. Adenowo (mummy Stella) of blessed memory, Mrs. Ogunnupe, Jide, Titi, Foluso and Tosin. Other members, who are also dear to me are my maternal uncles and their families, the Odunsi family (as whole). My in-laws also occupy a significant place in my heart, Pa Peter Adegboyega Araba (of blessed memory), Mama Susan Araba (may God preserve you for us), my wife's siblings and their families, Mr. Patrick Araba, Mrs. Joke Oyaise, Mr. Bola Araba, Mrs. Adenaike, Mr. Niyi Araba and Mr. Dayo Araba.

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the various departments in the University, for instance, core physics programme has specializations like: Solid State Physics, Nuclear Physics, Atmospheric Physics, Geophysics, Theoretical and High energy Physics.

Another group which deserves to be appreciated comprise all my teachers from primary school to the University. I call them destiny helpers. My Principal (Saint Finbarr's College, Akoka), Rev.Fr. Dennis. J. Slattery (of blessed memory), other teachers include Mr. Gunaratman and Mr. Ikediobi (Physics), Mrs. Ugochukwu and Mr. Ajogbashile (Mathematics), Mr. Ajien (Chemistry), Mr. Yeri (English Language), Mrs. Duncan (Literature). My sub-degree programme teachers (England, UK) – Dr. Allen (Physics), Mr. Bradley (Chemistry), Mr. Wild (Biology) and others.

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My pursuit of knowledge in the wilderness of Solid State Physics was not without some sacrifice. Even when I had the opportunity of studying another area of Physics with full foreign scholarship, I turned it down, insisting that it had to be Solid State Physics. Today, I say to God be the Glory.

This is my story, Solid State Physics: A coat of many colours.

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