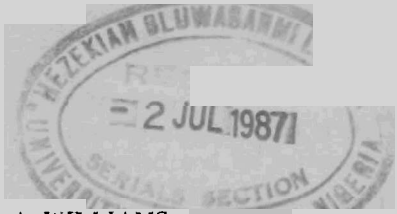
ELECTRONS AND TECHNOLOGY



by

PROFESSOR V. A. WILLIAMS,
Professor of Electronic and Electrical Engineering,
University of Ife, Ile-Ife.

An Inaugural Lecture delivered at the University of Ife
on Tuesday, 27th May 1975.

an Inaugural Lecture Series 32

HISTORICAL SURVEY

The existence of electrical phenomena, and of static electrical charges, had first been recognized and recorded over 2,500 years ago by Thales of Miletus (640–548 BC). The word electricity itself was derived from the Greek word for amber, a substance upon which electrical phenomena was first observed.

The idea that electricity has structure derives directly from the classical studies of Michael Faraday on electro-chemistry. Michael Faraday occupies a very unique and honoured place in the story of electrical science and technology. These studies were 'those which in particular led to the famous laws of electrolysis published in 1833. It is indeed one of those quirks of fate that he could not have brought himself to believe the natural conclusion of his own studies i.e. that charges exist as discrete quanta.

However at the time of Faraday's experiments the idea of corpuscularity in nature was not then accepted and he personally rejected the then atomic theory of matter.

It was Johnstone Stovey in 1881 who first advocated a quantum interpretation of Faraday's electrolytic laws, by which it was proposed that a quantum of electricity in an electrolytic flow was carried by an atom. In 1891 Stovey proceeded further and named this quantum of electricity the ELECTRON. The work of J. Plucker (1858) Hittorf 1869 and J. J. Thompson (including those of Wiechert and Kaufman) 1897 finally led to the discovery of the separate existence and the nature of the electron very much as we know it today. From their work, the electron is describable as a particle with a given fixed rest mass, carrying what is by convention regarded as a quantum of negative electricity. The idea of negative and positive charges of electricity was of course quite old and well accepted. What Thompson and others also discovered in addition to the sign of the electronic charge was the ratio of its charge to its mass, an important physical parameter. This ratio being so large that it enables the electron to move through an electric field with practically no inertia enables for most practical purposes, the motion of electrons to be controlled with no time lag. This is of great consequence to electronics.

Even before the 'so called' discovery of the electron, a great deal of experimental results had led to the inevitable questions on the nature of matter. But no single theory could consistently explain and organize the experimental data for meaningful interpretation.

Printed by Abiprint & Pak Ltd., Matori Ind. Estate, Lagos.

Those who stuck to the atomic theory were beginning to speculate on models of what the atom was like. Thus it was then Planck, (1900) Einstein (1904 Rutherford (1911) and Neils Bohr (1913) came on the scene, and between them developed a new picture of the physical world by establishing a new mechanics — Quantum Mechanics. With this new light, understanding was thrown on matter revealing its nature, and in particular the all-pervading role of the 'ELECTRON' in the scheme of things.

QUANTUM MECHANICS AND PROPERTIES OF MATTER

By the beginning of the twentieth century the inadequacy of causal theory based on Newtonian mechanics, for explaining the observed properties of all types of matter particularly on the subatomic or microscopic scale, had become very evident. Thus it was that Planck's radiation law, quickly paved the way for the new mechanics. Planck's law states that radiation is omitted in discrete bundles or quanta of energy.

$$E = nh\nu$$

where n is any integer, h is a universal constant (now named after Planck) equal to 6.63×10^{-34} Joule-second and ν ($= c/\lambda$) is the frequency of the radiation (c is velocity of light and λ the wavelength).

Neils Bohr (1913) was the first to attempt to apply the new quantum theory to the Rutherford model of the atom. Erwin Schroedinger (1924) using wave mechanics set up the basic equations of motion Hersenberg, Pauli and Dirac perfected the quantum mechanical tool for describing phenomena in atoms, molecules and solids.

Two fundamental differences exist between the classical and quantum theories. First of all classical mechanics permits a bound particle to change its energy in a continuous manner for all time whereas in quantum mechanics such energy changes could occur only in discrete amounts or quanta equal to integral multiples of $h\nu$. Since h is so very small, observations of this effect could only be on a microscopic scale. Secondly whereas the motion of a particle is specified exactly in classical mechanics quantum mechanics determines the probability of occurrence of any event. It turns out that actual experiments on atomic systems involve probabilities of getting certain answers as well as the answers themselves, so that it is not possible to distinguish the motion of individuals but rather the collective behaviour of the whole. The necessary interpretative statistics were developed by Boltzman, Fermi and Dirac.

This phenomena is not a limitation imposed by insufficiently accurate measuring apparatus, but rather a fundamental limitation of nature. Indeed the uncertainty attached to measurements involving submicroscopic particles actually sets a limit on the measuring devices themselves. On the microscopic scale however quantum mechanics passes over to the classical limit. Thus quantum mechanics is capable of explaining practically all observations very satisfactorily.

Based on this it becomes possible not only to determine the structure of the atom, but to determine the distinguishing characteristics of the atom of the individual elements, and so construct the (predictive) periodic table of elements. It has also been possible on the basis of quantum mechanics to explain the aglomeration of atoms that form a solid, and in particular the electronic structure that governs all the observable physical properties of the solid. The important corollary here of course is that *all physical and chemical properties of materials depend on the behaviour of electrons.*

For example electrons are not only responsible for the colour of the material, its electrical and magnetic properties by being involved in the interatomic/intermolecular bonding, are also responsible for both the mechanical and thermal properties as well. For example that a metal reflects light is due to the free electron gas in the metal.

Theoretical explanations and predictions (based of course on quantum mechanics) for phenomena in solids have been most successful in crystalline materials; a crystalline material is one whose atoms or ions are stacked in a regular manner. When the regular stacking of the atoms or ions extends continuously throughout the macro-volume of a specimen, then we say that the specimen is a single crystal. Experimental verification of theory has been made more easily when measurements are made on single crystal specimens. However efforts are being successfully made to describe the properties of liquids and amorphous substances where the ordering of atoms such as ions is extremely short-ranged. These efforts again are based on the properties of the electrons.

ELECTRO

Electrons exis They are containe
the "shells of at ergy wells" in solid
an electron gas. In the bo possess only potential
energy. In the free state the etic energy with which
they have been freed plus en a result of some accele-
ration process. As a quant lectricity the electron possesses
charge wh regarded as a natural unit. The value of

$$1.6 \times 10^{-19} \text{ Coulomb.}$$

A Coulomb is a t of charge transferred by a current of
one ampere flow ugh a point in one second. This means
that one ampere nts 6×10^{18} electrons passing a given
point per second nference of charge involves energy. The
fundamental measure of the energy is obtained from the poten
energy converted to kinetic energy through whatever accelerat
mechanism is employed for the transfer. The reason is sim
one of lence. The velocity f th is less
to determ an the potential dif enc which it
moved. T tential difference is ly Thus whe
electron has fallen through a potential differe ne volt, it has
gained a kinetic energy "electron-vol us 6×10^{18}
electron volts. This repres e ampere thr ne volt which
gives 1 watt-sec. 1 watt-sec nts one Jou nergy.

The rest mass m_o of electron is 9×10^{-31} kg. This mass is not always constant. It changes with the velocity of the electron according to Einstein's relativistic laws. This change can be seen in Einstein's relation between mass and energy:

$$E_o = m_o c^2$$

where c is the velocity of light. As the electron is accelerated to significant proportions of the speed of light, its mass is increased by conversion of the energy to mass. For example at a velocity 1/10 of the speed of light the rest mass is increased in the ratio $\frac{m}{m} = 1.005$ However under ordinary circumstances in electronics, electrons never achieve speeds that significantly change their masses. For electrons confined in solids the mass, in this case called the "effective mass" could due to other reasons change with crystallographic direction in the crystal. This has important consequences which we shall discuss later.

Whether in the shell of an atom or in the electron gas in the solid, the electron spins on its internal axis. This makes the electron a small magnet, possessing a magnetic moment. The spin is quantized and is directional also in a quantized manner; in otherwords, the spin could either be positively or negatively oriented with respect to some sense. This has consequencies on the total energetic arrangement of the electrons when packed in a solid, it has an even more fundamental effect in the packing order of electrons in the shells of atoms.

We now come to the size of the electron. A major difficulty with the size of the electron is due to the fact that under certain conditions the behaviour of the electron is wave like in character. The associated wave-length is related to its momentum by the following relation:

$$\lambda = h/p$$

where λ is the wavelength, h is Planck's constant and p represents the electron momentum. For example an electron accelerated through 10 volts, where the rest mass has not significantly changed, has an associated wavelength of 5×10^{-10} metres. Now this wavelength is larger than the size of an atom by about a factor of ten, so that the electron in a shell of the atom cannot strictly be considered as orbiting about the nucleus of the atom. The question of size then becomes moot, and of little importance. However an important practical consequence of this wave behaviour of the electron finds technological use in the electron microscope, in which the wavelength of electrons is about 2×10^{-9} metres. This results in resolution being hundred times better than the best optical microscope;

ELECTRONS AND ATOMS

An atom consists of a nucleus, and in the simplest case of the Hydrogen atom, one single electron moving round the nucleus, has its negative charge balanced by the positive charge on the nucleus. The nucleus of the hydrogen atom is called the PROTON. The mass of the electron is about 1/2,000 that of the proton. In more complex atomic systems the nucleus consists of a number of protons plus a number of neutrons. Neutrons have mass, but no charge. The total number of electron orbiting round the nucleus would then depend on the number of protons, each carrying a unit positive charge so that total charge due to the protons is equal and opposite to the total charge due to electrons.

The motion of an electron is described fully by quantum mechanics; this motion is conveniently described in terms of the energy states of the motion. The quantum mechanical picture which emerges is that the electron can assume certain energy states in the atom. If there is more than one electron, then these are distributed over the 'allowed' energy states according to very strict packing rules which have been fully worked out.

The states of motion of a single electron round a proton are labelled by quantum numbers:–

n, principal quantum number (n = 1, 2, 3.....)

l ..... angular momentum quantum number (l = 0, 1, 2-n-1)

m_l ..... magnetic quantum number [l, l–1, –(l–1), –l]

In the lowest energy state called the ground state,

$n = 1, l = m_l = 0$

Thus, in the energy state the electron is bound to the proton by an energy which has been calculated to be 13.6eV.

Strictly speaking as has been indicated before it is incorrect to speak of the electron orbiting round the proton. It is far more correct to speak of a charge distribution of the electrons moving about the proton. When the electron is in a higher energy state, the possible number of electronic states are obtained from the quantum numbers above. For instance if n = 2 then we have the set.

$n = 2 \quad l = 0 \quad m_l = 0$

$n = 2 \quad l = 1 \quad m_l = 1$

$n = 2 \quad l = 1 \quad m_l = 0$

$n = 2 \quad l = 1 \quad m_l = -1$

each of these states corresponding to a particular charge distribution round the proton. Now experimentalists in spectroscopy had earlier labelled these states even before the advent of quantum mechanics, and by convention this labelling has come to be adopted. The labelling depends on values of l.

l = 0 is called an 's' state
l = 1 is called an 'p' state
l = 2 is called an 'd' state
l = 3 is called an 'f' state
l = 4 is called an 'g' state

On the other hand, the group of states corresponding to a given value of the principal quantum number is referred to as the "shell" of electrons i.e. for example the states corresponding to n = 1 form the K–shell and those corresponding to n = 2 form the L–shell so that we have:

n = 1 2 3 4 5

K L M N O – shells

In an atom containing more than one electron, electrons are assigned to states and shells using the quantum number and Puli's exclusion rule, which states that not more than two electrons can have the same three quantum numbers. We thus have designated K L M N O ..... shells. In the K–shell therefore there can only be 2 electrons, while in the L–shell, which from the above has four different sets of quantum numbers, there will be a maximum of 2 x 4 = 8 electrons. This situation can be generalized and used to interprete the periodic table of elements in terms of the electron configuration of the atoms. The attached Table gives the electron configuration for the first 36 elements.

THE ELECTRON CONFIGURATION OF THE FIRST 36 ELEMENTS

Atomic Number Z	Element	K n = 1	L n = 2		M n = 3			N n = 4			
		L = 0 s	l = 0 s	l = 1 p	l = 0 s	l = 2 p	l = 2 d	l = 0 s	l = 1 p	l = 2 d	l = 3 f
1	H, Hydrogen	1									
2	He, Helium	2									
3	Li, Lithium	2	1								
4	Be, Beryllium	2	2								
5	B, Boron	2	2	1							
6	C, Carbon	2	2	2							
7	N, Nitrogen	2	2	3							
8	O, Oxygen	2	2	4							
9	F, Fluorine	2	2	5							
10	Ne, Neon	2	2	6							
11	Na, Sodium	2	2	6	1						
12	Mg, Magnesium	2	2	6	2						
13	Al, Aluminium	2	2	6	2	1					
14	Si, Silicon	2	2	6	2	2					
15	P, Phosphorous	2	2	6	2	3					
16	S, Sulphur	2	2	6	2	4					
17	Cl, Chlorine	2	2	6	2	5					
18	A, Argon	2	2	6	2	6					
19	K, Potassium	2	2	6	2	6		1			
20	Ca, Calcium	2	2	6	2	6		2			
21	Sc, Scandium	2	2	6	2	6	1	2			
22	Ti, Titasium	2	2	6	2	6	2	2			
23	V, Nanadium	2	2	6	2	6	3	2			
24	Cr, Chromium	2	2	6	2	6	5	1			
25	Mn, Manganes	2	2	6	2	6	5	2			
26	Fe, Iron	2	2	6	2	6	6	2			
27	Co, Cobalt	2	2	6	2	6	7	2			
28	Ni, Nickel	2	2	6	2	6	8	2			
29	Cu, Copper	2	2	6	2	6	10	1			
30	Zn, Zinc	2	2	6	2	6	10	2			
31	Ga, Gallium	2	2	6	2	6	10	2	1		
32	Ge, Germanium	2	2	6	2	6	10	2	2		
33	As, Arsenic	2	2	6	2	6	10	2	3		
34	Se, Selenium	2	2	6	2	6	10	2	4		
35	Br, Bromine	2	2	6	2	6	10	2	5		
36	Kr, Krypton	2	2	6	2	6	10	2	6		

ELECTRONIC PROCESSES IN MATERIALS

By extensive use of the tools of quantum mechanics, it has become possible to properly describe and explain the following effects of the behaviour of electrons in materials. Clearly, not all phenomena in solids can here be described. We shall not, for instance describe magnetic phenomena amongst a list of other electronic processes.

1. *Electrical Conduction:* The free electron gas is responsible for electrical and thermal conduction. The mechanism is that when a field is applied, electrons are accelerated towards the directon of the field thus moving into higher energy states. However they suffer a scattering process on collision with core ions of the material and because of their much smaller mass transfer, most of their newly gained energy and momentum are lost to the ions. The mean free path of the electron is an important parameter of the motion. The resistance to current flow is inversely proportional to this mean free-path, L say. The electron acceleration due to the potential field is proportional to e/m i.e. charge θ to θ mass ratio so that the resistivity ρ of the metal is given by the expression

$$\rho(\text{resistivity}) = \frac{1}{(\text{conductivity})} = \frac{m v_o}{n_c e^2 l}$$

where v_o is the average velocity of the electrons actually gaining energy from the field and n_c is the number of conduction electrons. Quantum mechanical arguments are then used to explain the observed effects of temperature, type of metal etc. on resistivity.

2. *Super conductivity:* The core ions in a metal or any other material are not at rest at ordinary temperatures. They vibrate about their mean positions in the crystal. Heating up the crystal puts more energy into it. In addition to some other effects, the extra heat increases the vibrational amplitude of the ions and so effectively increases what we may call the scattering cross-section for the electrons. This has the direct effect of reducing the mean free path of the electron and hence the resistivity of the material goes up. Correspondingly cooling the crystal reduces the scattering cross-section, increases the mean-free-path and reduces the resistivity. However if the temperature of the crystal is reduced to about the region of 4°K many metals exhibit abnormally large conductivity termed "Super conductivity". This conductivity really corresponds to zero resistivity. PHONONS are quanta of the lattice ionic vibrations, and behave like particles although they have neither charge

nor mass. However at the temperature which is characteristically critical for a particular material some type of interaction between phonons and the conduction electrons take place leading to a kind of resonance effect, at which the resistivity of the material becomes truly zero. Thus if a superconductor closed loop has current started in it, say by electromagnetic induction, the current continues to flow indefinitely even after removing the inducing field.

Conduction and superconduction of electrons in metals is vital to the Electrical Power Industry. Modern power generation technology favours very large machines for increased efficiency, particularly from the prime-mover side, and reduction in capital cost. The state of the art favours power ranges from 500 Mega watts to 1,200 Mw (1,2 Gega watts) from a single machine. For a 500 Mw generator at 11kV generating voltage a current of 90,000 Amperes has to be carried. Because of the need to conserve this power superconductors have been proposed to carry such large currents to step-up transformers where the current levels can be substantially reduced for onward transmission to the consumer. There is thus a great deal of research effort towards a practical realization of superconducting cables and busbars.

3. *Electron Emission:* Free electrons are in constant thermal motion in metals and other conducting solids. The electrons are kept on the average at the same energy level within the metal, and are unable to escape from this store-house, due to an energy barrier which is called the 'Work function' of the metal. The energy level below which the electrons are kept is called the Fermi level (or in some other context the Fermi Surface). The distribution of electrons over this energy neighbourhood is governed by the Fermi-Dirac Statistics and indeed when considering electrons in this situation they are collectively called 'Fermions'. These electrons will escape out of the metal if they are given sufficient energy (from an external source). The important parameters here are the work function and the nature of the energy source. The most convenient source is through thermal excitation, that is to say the metal is heated up such that a fraction of the fermions acquire enough energy to overcome the work function and escape outside the metal. Once the electrons are outside the metal their subsequent behaviour are to a large extent unrelated to the characteristics of the solid from whence they were emitted. Their behaviour can now be completely described by the theory of electron ballistics, which is largely a macroscopic theory.

Electron emission from solids can also be occasioned by high electric fields, as well as by bombardment by a shower of energetic particles such as light (photons) and even other electrons (secondary emission).

The emission from materials can be enhanced by reducing the work function of the material. This work function being determined by the inter-atomic spacing of the material, it is easy to reduce this work function by introducting some other (foreign) atoms into the lattice of the material, another way is to cover the surface of the material by another material whose work function is much lower, but whose mechanical and electrical properties make it difficult to work with on its own. Thus the oxides of some metals when used to coat thermally and mechanically stable materials like tungsten achieve copious emission with ease of operation and handling. The controlled emission of electrons into a vacuum in which control structures have been incorporated is the historical genesis of electronic technology and the control of the motion of the electrons in a predetermined manner is ELECTRONICS. In particular the emission of electrons from a solid source into vacuum and the subsequent control of the motion in the vacuous space is the basis for vacuum electronics and gives rise to a host of electronic and opto-electronic devices.

4. *Luminescence:* The valence electrons in a solid are the electrons high in the band next to the conduction band. Because of a disallowed energy band-gap a definite quantity of energy is required for the valence electron to jump across the forbidden gap into the conduction band. The valence electron may absorb energy however to reach and temporarily maintain an excited state anywhere below the conduction band. When it has stayed for some time in the excited state, it usually returns to its ground level. The energy which has kept it in the excited state then has to be given up and for *luminescent* materials, this is given off in form of a photon of light according to the Plank's relation.

$$h\nu_{\text{emitted}} = E_{\text{excited}} - E_{\text{ground}}.$$

The colour of the emitted light depends on the frequency ν. This process is called luminescence. Luminescence has many remifications. If the crystal emits light simultaneously with the exciting source (which may be light of some shorter wave-length than that emitted by the substance, or a stream of particles such as electrons,

and others such as X-rays or r-rays, then the material is said to be *fluorescent*. If it takes a prescribed shorter time or longer after the removal of the excitation to emit its light photons then the process is called phosphorescence. Materials that respond in this way to excitation are called phosphors. The colour of emitted light is a function of the phosphor. While a great number of materials luminescence in the pure state, most require a prescribed minimum of impurities – called activators-to render them luminescent. In this case the colour of emitted light is often characteristic of the activator impurity. Most phosphors exhibit an afterglow effect in which luminescence proceeds for a time after the radiation has been removed. This effect is of vital technological importance, as this afterglow, plus the persistence of the retina of the human eye has made possible the realization of present day monochrome as well as colour television systems.

Luminescence can be occasioned not only by photons, (photoluminescence) but also by all of the following:

(a) an impinging beam of electrons (Cathodoluminescence),
(b) by field excitation (Electroluminescence),
(c) by mechanical excitation (Triboluminescence).

5. *Stimulated Emission:* In general, electrons can undergo transitions between two quantum states in a reversible manner. A transition to a higher state will occasion light emission on reverting back to the initial state. When the photon yield is a result of stimulation by energy absorption from a radiation field, the process is called stimulated emission. The emission here is proportional to the of the incident radiation, the frequency of emitted radiation is also the same as that of stimulating radiation. The special feature of the practical aspects of this system is that it is possible to some additional source of energy to arrange for more photons to be emitted than are absorbed, and then the original exciting radiation would have been amplified. A practical system in which this state affairs is achieved is called a LASER i.e. Light Amplification Stimulation of Emission Radiation. One way of achieving this is have three quantum states of energy levels E_1, E_2, E_3. The stimulation is $E_1 \rightarrow E_3$ and emission is $E_2 \rightarrow E_1$. The third level is higher than the second, and it is arranged such that the transition $E_1 \rightarrow E_2$ is allowed with energy of absorption $E_3 - E_1$ and electrons drop spontaneously from $E_3 \rightarrow E_2$ with a radiationless transition. If the probability of the transition $E_2 \rightarrow E_1$ is lower than $E_3 \rightarrow E_2$

then the level E_2 fills up much more rapidly than it empties and so the number of electrons N_2 in that level becomes larger than N_1 the number raised up by photon absorption. When N_2 becomes greater than N_1 we speak of population inversion, and the source of energy for the transition $E_1 \rightarrow E_3$ is called a pump. This is usually an optical pump. The allowed transition $E_2 \rightarrow E_1$ is then the optical output of the laser and results from the stimulation of the optical pump

The special characteristics of laser emission are firstly that the light output is coherent, and secondly the rays are very parallel. A laser is an example of a system deriving strictly from quantum mechanical ideas, as distinct from experimental observations that require quantum mechanics only for valid explanation. The two inventors Schallow and Townes obtained Nobel prizes for their invention. Similar effect is possible at non-optical frequencies, and the first experimental system was obtained at Microwave frequencies.

6. *Semiconductivity:* In a covalent solid, although usually there is an allowed energy band for a pool of electron gas such as could lead to metallic type of conductivity, there are unfortunately very few electrons to fill it. Therefore the material has very poor conductivity in this situation, which also corresponds to the pure state of the material. However, if certain impurities are introduced into the lattice, then this could give rise to conductivity in this very interesting way:– The impurity can cause one of two things to happen. Firstly, it could contribute an electron directly to the pool of the host material, or it could capture for itself an electron from the normally full valence band of the host material leaving behind a "HOLE". This is a quantum mechanical hole, and it behaves like a particle with an effective mass, a positive charge which leads a separate existence quite unrelated to the fate of the electron, the removal of which brought it initially into being. On the application of a field the hole moves in the opposite direction to that of the free electron, thereby contributing to the electric current in the solid. This is extrinsic conductivity.

When the material is "undoped" (as the introduction of impurities into it is called) it is said to be "intrinsic". When impurities have been introduced, the doped material is now an extrinsic semiconductor.

One distinct difference of the semiconductor from an ordinary conductor is that while, as has been explained above, increase in temperature increases the resistivity of a normal conductor, in the case of the semiconductor the reverse is true. This is because the temperature increase may give a valence electron enough energy to move up across the forbidden gap and join the pool of free electron gas in the conduction band of the material, leaving a hole behind. Both hole and electron then proceed to contribute to electrical conduction, – the electron in the conduction band, the hole in the valence band.

It is possible to dope the semiconductor such that the conductivity is either preponderantly by holes or by electrons; when the conductivity is more by holes the semiconductor is called p-type and when conduction is by electrons, the semiconductor is called n-type. When in a single specimen one side is doped to make that side p-type and the other side is doped to make it n-type, the junction between the two sections is called a p-n junction, *and it is on the properties of this junction that all semiconductor devices – Diodes, Transistors, etc. are based.*

Archetype examples of elemental semiconductors are Germanium (Ge) and Silicon (Si). They are such good examples because the energy gap between the conduction band, and the valence band is in each case small, i.e. 1 eV for silicon and less for germanium. It is because of the smallness of this gap that electrons can be thermally excited away from the normally full valence band to the practically empty conduction band.

When an impurity is introduced, depending on what type of material, and its dectronic relationship to the host semiconductor, its own energy level in the host lattice will be somewhere in the forbidden band of the host crystal. Either, near the bottom of the conduction band, for materials that contribute electrons (donore) or near the top of the valence band for materials that contribute holes (acceptor). For the practical realization of semiconductor devices, single crystal specimens of high structural purity are absolutely essential. The deliberate controlled introduction of electrons and holes into the conduction or valence bands respectively of a semiconductor and the subsequent control of the motion of the electron or hedges in an ordered structure of the semiconductor is the basis of all solid state electronic technology.

ELECTRONICS TECHNOLOGY

Electronics technology derives from the fact that the motion of electrons can be controlled in a prescribed manner in a suitably designed device. There are in general two types of electronic technology. The first can be called Vacuum technology and the second Solid-State technology, with a great deal of common techniques between the two. The historical sequence is that the vacuum electronics was developed first and it was in the search for optimisation in performance and extension of scope of applications that the field was broadered to make the first tentative approaches to solid state technology.

In various types of vacuum electron device consists of a cathode from which electrons can be generated usually by heating and an anode which when biased electrically positive with respect to the cathode will attract any electrons emitted by the cathode. It is in the course of the motion of electron between the cathode and the anode that control may be impossed on their motion by suitable means so as to achieve a desired effect on an external electrical circuit network. In this situation the equivalent electrical circuit of the device forms part of the total electrical network.

The Cathode, anode and control electrodes are all enclosed in a glass (or sometimes metal) bulb which is evacuated and sealed. All Vacuum devices have this in common that the motion of the electron is in vacuum. The need for the vacuum is to reduce the probability of electrons colliding in a random manner with environmental gas atoms or molecules so that their journey from the cathode to the anode is subject only to the externally impossed control.

The first vacuum tube or *valve* was made by Fleming in 1904. There are vacuum valves dissipating as little as few mW while others dissipate up to hundreds of kW. Vacuum valves are used for voltage and power amplification or as oscillators for generating desired signals at all power ranges. The availability of the electronic vacuum tube of various types forms the basis of modern telecommunication techniques and a vast range of technologies arising there from. Its application in process control has revolutionized many industrial techniques and made possible other process technologies.

One important class of electron tubes consist of a cathode, anode an electron – optical system and finally, a phosphorescent screen. In this case by using the techniques of electron optics it is possible to focus a beam of electrons on to the phosphor screen at a

controlled beam energy. The impact of the electron beam with the phosphor screen makes the screen to emit visible light. This is the cathode-ray tube, which is a display device. In some other cases, instead of the phosphor screen a photo emissive material may be substituted. In this case exposure of the screen to light would displace electron from the screen and so leave the screen with a charge pattern which can subsequently be read by the electron beam. This is the basis of an electronic camera. In both cases, a scanning type of control of the beam is incorporated. This takes the form of a facility for deflecting the beam in a two dimensional pattern across the screen. By further suitable electronic circuitory external to these devices, they can be made to perform specific jobs such for instance as in the one case displaying some electrical signal, and in the other recording a scenery. When the recorded scenery from a "camera" is processed electronically and sent to a remote display device for reproduction, we have the basis for Television. On the other hand an extended application of the electronic display tube made possible one of the earliest electronic digital computers. The display tube in this case in combination with logical switching circuits formed the store of the computer. The electronic computer technology has almost caught up with communications technology in scope ramifications.

The technology for fabricating vacuum elec mainly on three other technologies:

(a) Large scale high vacuum technology.

(b) Metallurgy and processing of the refrac and special cathode materials.

(c) Glass science and technology and in part seals.

The feedback from these three activities into general technological development has been very rich. Furthermore, the need for space conservation and for reliability of the devices led to extensive developments in microminiaturization through the development of true mechanics and the tools for achieving precision technology But the three are practical limits to what could be achieved in this way.

All the same research and development in (a) (b) & (c) above have led to:

(i) Development of new large capacity electronic ps with ultimate pressures in the range 10^{-10} Torr. This had had considerable impact on space technology.

(ii) Development of the properties and handling characteristics of new types of metal alloys with excelle characteristics. This has made considerable co in particular to materials technology.

(ii) A clearer picture of the properties of glasses, leading to the development of techniques for the design and realization of new glasses with prescribed electrical, mechanical and thermal properties. This has also contributed to modern building technology.

In addition to the technology of actual devices, there is also t technology of the systems in which they are used. For grea reliability and ease of assembly as well as for applications unc extreme physical conditions the printed circuit technology v developed. In this, lines joining components are etched on a copp plated insulating board by specially developed photolithographic techniques. Electrical components are then mounted on the insulating side of the board with their leads coming through to the plated side. Soldering could then be automated. With this technique components failure as well as failure rate for sub-assemblies were reduced.

Equipment using printed circuit boards are more compact and are more easily maintained, as in some designs whole sub-assemblies could be changed by merely unplugging a faulty board and replacing this by a new board. It is possible by suitable design of the sub-assembly boards to arrange a whole equipment in a manner analogous to a book each sub-assembly being analogous to a sheet in the book. Compler system such as electronic computer require this type of technology so as to antomate fault finding and maintenance.

SOLID STATE TECHNOLOGY

We have already explained what a semiconductor is, in the semiconductor, control of charge flow analogous to that in vacuum valves is achieved by a different mechanism. As explained earlier the p-n junction in a semiconducting chip is the basic building block for a device. At the p-n junction an irreversible current flow on the application of a field is achieved, thus obtaining rectification stic

This is the semiconductor DIODE. The TRANSISTOR is in effect two p-n junctions back to back on a semiconductor chip which achieves current amplification by an injection mechanism.

The first practical advantage of the semiconductor device is its physical size. It could be as small as the available facilities for miniaturization would permit. Standard sizes range from 0.1mm x 0.1mm x 0.025mm. It is usual after electrodes have been affixed to mount this on special mechanical header and then encapsulate, resulting in a small, compact and robust device. The semiconductor device thus has an inherently greater mechanical reliability than the vacuum device.

However the technology of the semiconductor device is far more complex than that of the vacuum devices. In the first place single crystals of the starting material is required, which gives rise to a vast range of self-sustaining technologies depending on the material and hence profitable industries have been generated from these. Into a small chip of this has to be diffused as appropriate the necessary dopants. Then follows the question of affixing electrodes. These are very demanding techniques. Because of the complexity and the great demand for precision it is usual for the solid state components industry to be divided roughly into two groups – a material group, manufacturing and developing single crystals of suitable semiconducting materials.

Although the first transitor was invented in 1948 Bardeen, Brattain and Shockley) using germanium as the starting material, the technology has swung over to silicon. There are inherent physical defects in germanium that has made silicon more popular. Silicon technology has therefore been very highly developed with the aim of realizing.

(i) Better and faster transitors and diodes.

(ii) Integrated circuits and multifunction Large Scale Integrated Circuits.

In integrated circuits an attempt is made to eliminate external circuit components such as resistors, capacitors and inductors by using the base material as resistive and capacitive paths between active components such as transistors and diodes formed on a single chip. Very significant successes have been achieved, and coupled with the use of logic circuitory there has been established practical technologies for large scale integrated circuitory for the electronic industry.

Semiconductor technology, more than any other has welded together various technological disciplines for its successful realizations, Chemists, Metallurgists, Physicists and Engineers all have to play significant roles in device design, processing and realization.

In addition to developing the technology of elemental semiconductors, a highly coordinated search is going on for suitable compound semiconductors. Compound semiconductors consist of suitable chemical combinations of the groups III and V series of elements of the periodic table. The most successful so far has been (GaP) Gallium Phosphide and GaP Gallium Arsenide. The importance of these two are that they become viable solid state laser sources that would enable the full technological exploitation of the laser to be realized. Because of the frequency of the laser light, its coherence and parallelism, it has great telecommunication possibilities. However one defect has been the difficulty of modulating conventional gas and solid state laser with information. In GaP or GaAs system, it seems that this possibility may now be realized.

DEVELOPMENT OF ELECTRONIC TECHNOLOGY IN NIGERIA

Nigeria needs to develop her own electronic technology and the industry. She should become fully developed in both the infrastructural as well as the various aspects of the industry itself. The objectives of such a programme should be:

(i) To develop local expertise in its broadest sense in the technology of production of all aspects of electronics that is to say, components – active and passive –, electronic systems in communications instrumentation entertainment and health and defence.

(ii) By having local expertise to build production capacity for an economically viable electronics industry so as to first reduce and ultimately eliminate the dependence on the foreign market for all electronic products.

In order to achieve these objectives a complete electronic technology transfer is required to be achieved. This has wide implications in education and training and in the policy for industrial development of the nation. The major advantage of such a venture would however be to place the country on a footing such as to enable the industry to develop at a rate tailored to the nation's requirements and not to depend on the whins and caprices of foreign supplier, who, having at present a stranglehold on the currently existing electronic assembly plants, could manipulate them to their own advantage at Nigeria's expense. The cost of locally produced electronic equipments for local consumption, such for example as radio and television services, tape and cassette recorder/players are beyond the financial resources of the generality of Nigeria people. This is not because these sets need be so expensive, nor, do I suspect, is this due to the much preferred excuse of Customs and Excise duties, but because it is in the interest of the suppliers of the components for the assembly plants, who also manufacture and export to Nigeria radio and TV receivers and other communications equipment, to assure a ready market for their products, by ensuring that the costs of the locally produced equipment do not compete with those imported ones to the latter disadvantage. This is achieved by manipulating the price of the components and sub-assemblies that go into the locally assembled appliances, as well as their deliveries and other financial processes in such a manner as to fill the advantage towards imported equipment.

The Department of Electronic and Electrical Engineering of this University has on its priority list for R & D projects designed for the complete transfer of electronic technology through the development of and techniques for all manner of active and passive electronic and allied devices and components.

(a) Initiation and development of Silicon technology for solid state devices such as transistion and diodes and packaged fabrication steps as a basis for industrial production.

(b) Research and development of passive components such as resistances and capacities.

(c) Research into new semiconductor devices as well as semiconductor/luminophor opto-electronic devices.

(d) Investigation of the development of local raw materials as starting bases in order to achieve a complete transfer package.

The Department is not interested in developing the technology for the fabrication of these components and devices purely as an academic exercise. It is interested primarily in their ultimate economic production in this country, and is therefore also deeply concerned with the training of the personnel for carrying out the fabrication processes so as to make such expertise available to any eventual industry.

The programme therefore is firstly to perfect the techniques of fabricating the standard type devices and then to interest in, and collaborate with indigenous organisations or industries in the exploitation of these for use in locally designed, developed and manufactured equipment. Indeed the ultimate objective of the Department is to establish a Consulting, Advisory and Training Centre with advice on equipment and processes for the development and fabrication of these devices as well as others may be sought for and obtained, and process supervision and quality control as well as standardisation of the products also obtained.

The Federal Government ought to look into this problem on a matter of urgency since policy decision are required for the establishments of an appropriate industrial atmosphere for such a venture, and some infrastructural industries are vital, which require governmental initiatives.

The Department of Electronic and Electrical Engineering, University of Ife and sister departments in other Nigerian Universities can be of great help in assisting the setting up of an indigenous electronics components industry, of internationally acceptable standards for the purposes of interchangeability. The availability of standard components would then in the next step make feasible the design and manufacture of equipment and complete system and complexes.

It is vital for government to accept and appreciate the strategic importance of an electronic industry in Nigeria, for in addition to its economic consequences, there is also the defence aspect. Defence in order to be credible and of viable integrity requires independence in the choice of type, design and development of equipment for strategy and tactics. A defence is not truly viable under it has privacy in the planning, executing and systamatization of its strategic and tactical weaponry. Since practically all modern defence system are based on electronics, an indigenous electronics industry is highly strategic to

the achievement of the necessary defence as well as strike capability. Furthermore, with Nigeria apparently slowly rising to a position of consequence in the world and in particular in African affairs, more and more attention requires to be placed on defence matters. There dearly has to be priorities; however the case for placing a high priority on an electronic industry hinges not only on the matter of defence but also largely on the infrastrucutral consequences to all aspects of the national cultural and socio-economic life.