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Semiconductors: principles and processing: A review

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Abstract:

Increasingly important roles are played by semiconductors. It is used in a variety of electronic and optoelectronic devices, photo voltaic Cells, and so forth. in this review, we provide a describe (briefly) of basic theory, with an emphasis on those Frequently applied to semiconductors - also we are classifying defects according to their dimensionality and their electronic properties. also covers some of the techniques that are currently being employed for evaluating the structural, chemical, electrical, and optical characteristic of semiconductors.

Keywords: *Semiconductors, p-n junctions, p-type, n-type semiconductors, carrier concentration, Electron-hole pair (EHP), accepter donate.*

Introduction

Semiconductors are a material which has a conductivity between conductors (metals) and non-conductors (insulators) such as ceramics.

It can be pure elements, such as germanium or silicon or may be, compounds such as cadmium selenide or gallium arsenide in a process named doping [1]. Usually, a small number of impurities are added to semiconductors (pure) in order a large change in conductivity of materials.

Semiconductors play an important part of our lives due to their role in the fabrication of electronic devices. life without electricity is unimaginable also, the developments in semiconductors technology during the past 50 years have made electronic devices faster, smaller, and reliable [2].

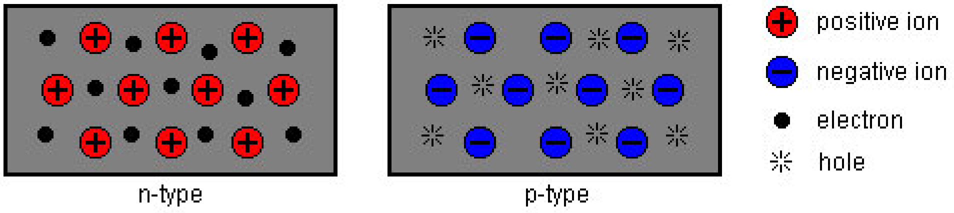
1- Principles of Semiconducting devices

There are two types of junctions: p-n type and metal – semiconductor. A p-n junction is formed when two pieces of a semiconductor, differing in their conductivity type, are bought together [3]. Usually, it can produce metal- semiconductor junctions by depositing metals on clean surface of either p- or -n type semiconductor.

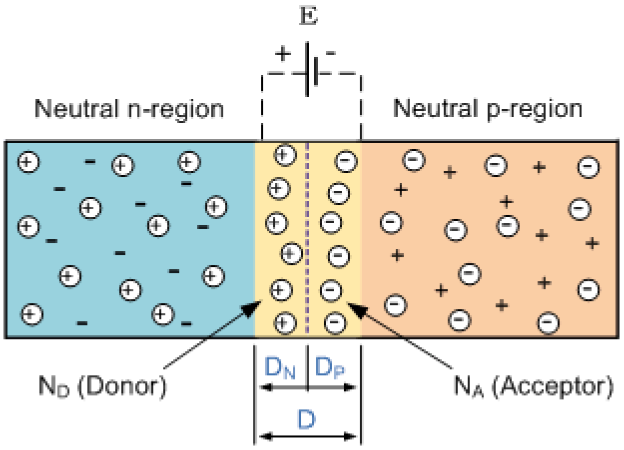
1-1 P-n junctions

Pieces of semiconductor that are doped p- and n- type. Figure. 1a shows that the two materials contain different concentrations of the two types of charge carriers, that is, electrons and holes, imagine now the two pieces are now brought together to form a p-n junction, (figure. 1b). P-type has many mobile holes and ionized accepter but few electrons while n- type material has many mobile electrons, ionized donor but few holes. When two materials meet, the carrier diffuse during the junction due to large concentration gradients in the carrier concentration – holes diffuse from p – side to n- side while, electron diffuse from n- type to p- side (figure. 1c) a result , an electric field is set up across the junction[4]. This field creates drift components current figure. 1c) from n-side to p- side and from p- side to n-side that oppose the diffusion current.

a)



b)



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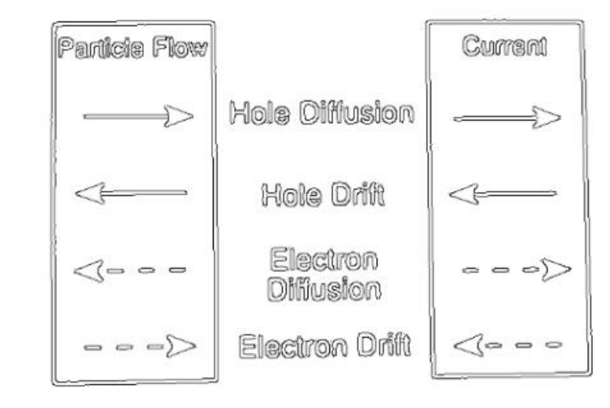


Figure. 1: Schematics showing the behaviour of a P-N junction at equilibrium, a) isolated, neutral pieces of P and N type semiconductors, b) junction showing that depletion region W and the resulting electric field, c) directions of the four components of particle flow within the depletion region and the resulting current directions.

1-2 Metal- semiconductor junctions:

There are two types of metal- semiconductor junction: rectifying and nonrectifying.

1-2-1 Rectifying junctions (Schottky barrier diodes):

It is a junction between a metal and an n- type semiconductor whose band diagram are shown in figure. 2a. in this figure, q ΦM and q ΦS refer to the work function of the metal and the semiconductor respectively and represent the energy required to remove electrons at the respective fermi levels to the vacuum level [5]. When a junction is formed, electrons from the conduction – band states in the semiconductor flow into the metal because they have higher energy. This flow occurs until the fermi levels are aligned as shown in the figure. 2b.

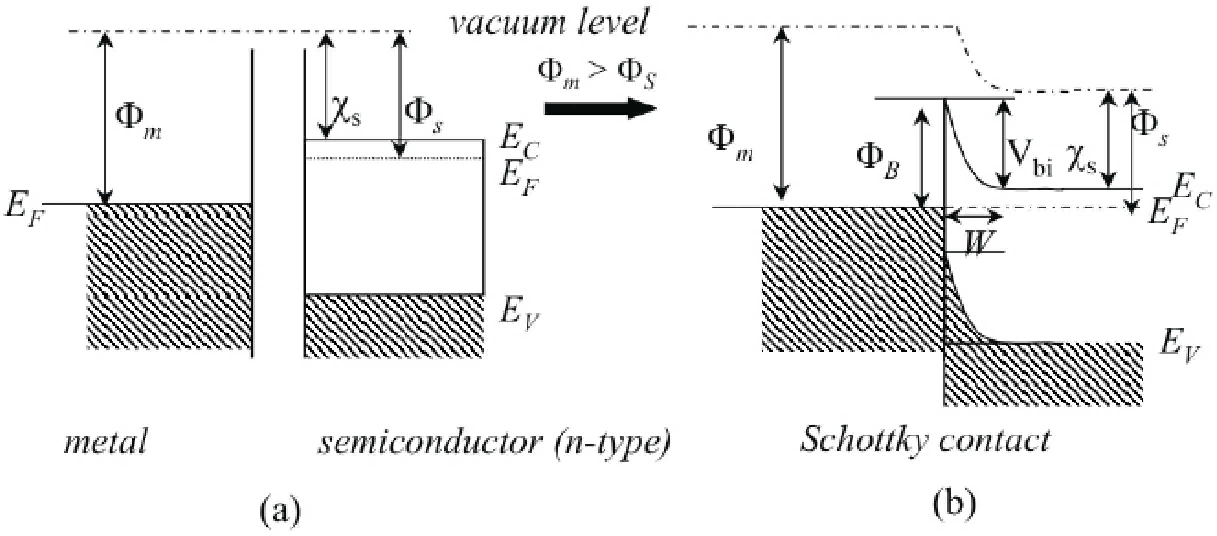


Figure.2: Energy band diagram for a metal-semiconductor (n-type) contact, in the case Φ m > Φs, a) two materials isolated from each other, b) at thermal equilibrium after the contact is made [6].

1-2-2 Non rectifying functions (ohmic Contacts).

An ohmic contact is a metal- semiconductor that has a negligible contact resistance relative to the bulk or series resistance of the semiconductor [7] this can be achieved when metal-semiconductor junctions satisfy the following requirements:

$\Phi M < \Phi S$ for n-type and $\Phi M > \Phi S$ for p-type Semiconductors as shown in (figure. 3)

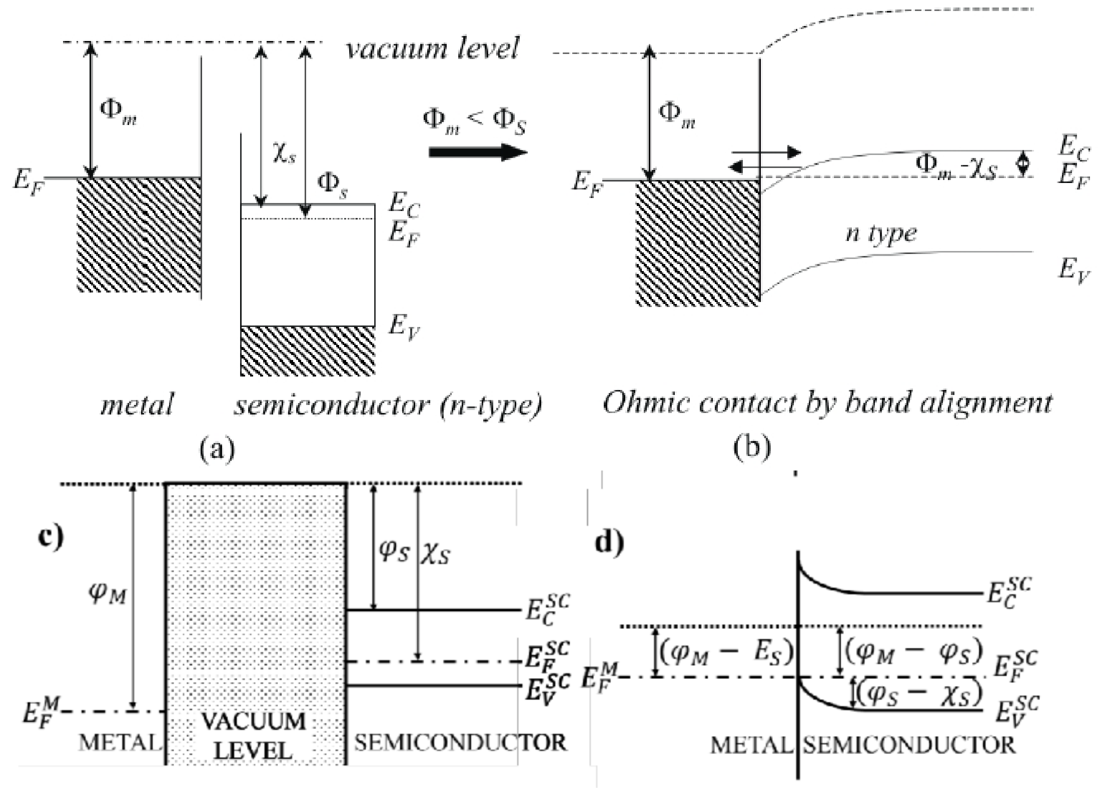


Figure.3 bond diagram for ohmic metal-semiconductor contact: a) $\Phi M < \Phi S$ for n-type semiconductor, b) the corresponding equilibrium band diagram for the junction, c) $\Phi M > \Phi S$ for p-type Semiconductor, and d) the corresponding band diagram for the junction [8].

Methodology

2- Basic Select Devices

we have Choose four examples to familiarize the nonspecialist with the basis of some semiconducting devices: (1) solar cells, (2) light-emitting diodes, (3) bipolar transistors, and (4) field effect transistors.

2-1 Solar cells

Its solar energy Converts to electrical energy [9]. It is a simple device Consisting of p-n Junction that is illuminated by solar radiation. As it known, when the energy of the incident illumination is greater than the band gap of a semiconductor, additional (EHPs) (A pair of two carrier types is called Electron-hole) are produced and they complement the thermally generated EHPs. The rate of optically generated carriers gap depends on the intensity of the radiations [7]. As shown in (figure. 4), it needs to design a solar cell with a large area junction that is located near the surface of the device. Additionally, the junction depth (d) must be less the hole diffusion length in the n-region this situation allows holes generated near the surface to diffuse to the Junction before recombing; a similar consideration applies to the p-region.

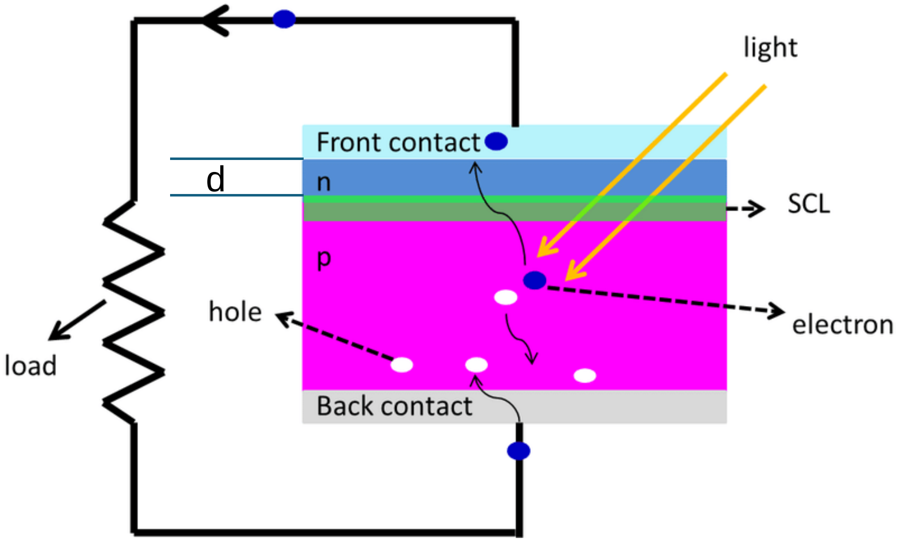


Figure. 4: schematic of an n-p junction solar cell; front and back ohmic contacts and an antireflection coating are shown [10].

2-2 Light-Emitting Diodes:

If minority Carriers are injected across a forward-biased p-n junction, in this case, the Current in the junction is accounted for in terms of carrier recombination in the depletion region and neutral p- and n-regions [9] the Carrier recombination in direct- band gap semiconductors gives off light whose wavelength is directly related to the band gap. This effect is called injection electroluminescence and is observed only in direct -band -gap semiconductor such as, Inpan GaAs [11].

The injection electroluminescent can be used to prepare two types of light-emitting devices: light-emitting diodes (LEDs), which emit income rent spontaneous radiation, and Laser diodes which emit coherent radiation. The major applications of LEDS are invisible displays, indicators and short- haul, infrared light wave Communication systems involving Fused silica fibres as a transmission medium. on the other hand, Laser diodes are extensively used as Light sources in long-haul light wave Communication systems printers, and CD-ROMs.

2-3 Bipolar Junction Transistors (BJT)

Two Junction properties are used, the first, the injection of minority Carriers across the junction under the forward bias [12]. The second, the variation of the depletion with W with the reverse is bias. BJT operates by the injection and Collection of minority carriers. Since the action of both holes and electrons is important in this device, it is called a bipolar transistor.

2-4 Field-Effect-Transition (FET)

An (FET) is a three-terminal device in which the current between the two terminals, called the source and drain, is controlled by the application of a voltage to the third terminal, labelled as the gate [13], it operates by the migration of only one type of carrier, Hence it is a unipolar device. The field-effect transistors have three basic forms: (1) Junction FET, as labeled as JFET, (2) metal- semiconductor FET, referred labelled to as MESFET, and (3) metal insulator FET, labelled as MISFET (11, 12). Figure. 5 a,b and c.

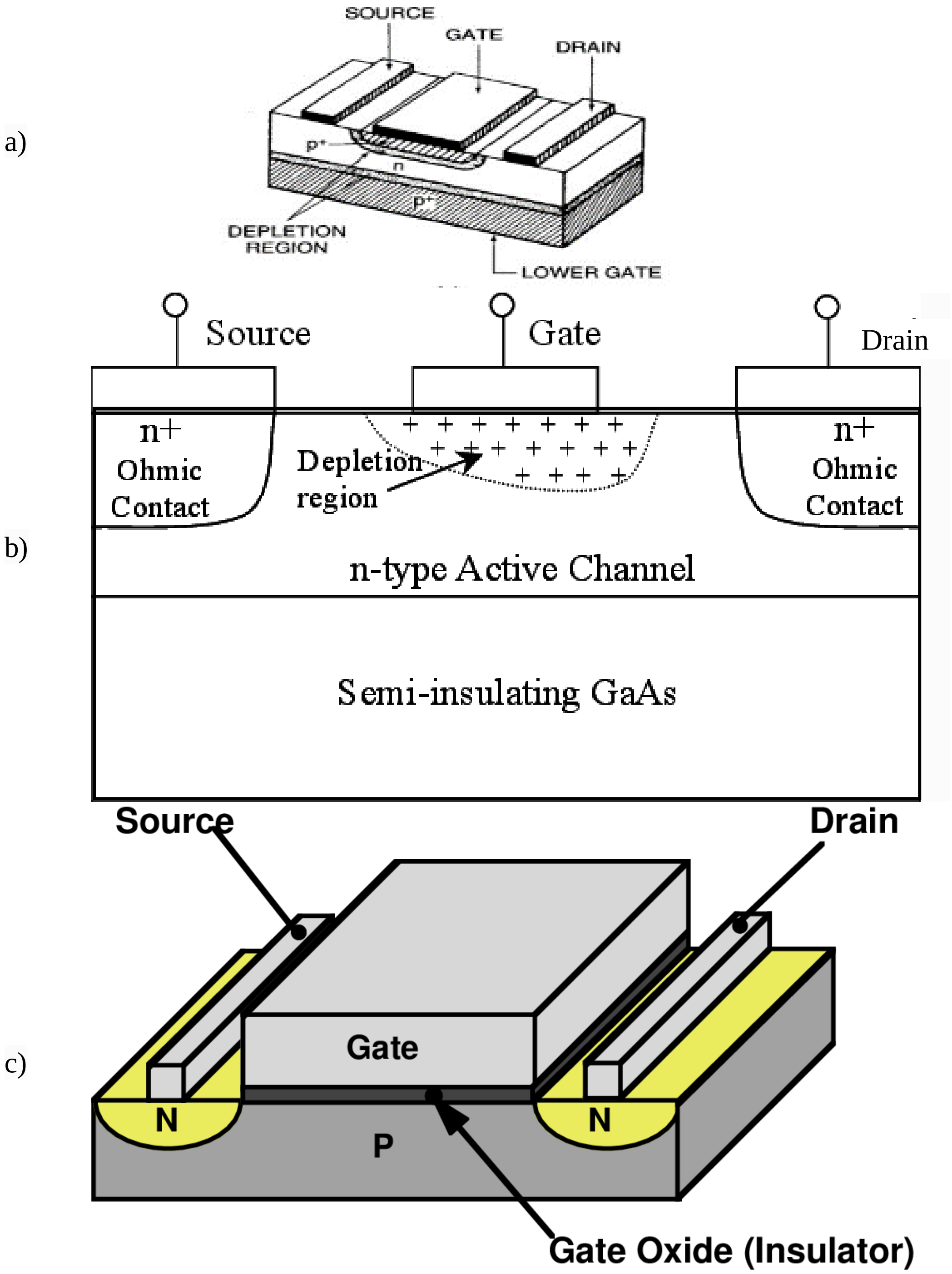


Figure. 5: a) 3 dimensional sketch of a JFET, b) schematic cross section of a GaAs MESFET, and c) schematic cross section of n-channel MOS transistors [14,15].

3- Defects

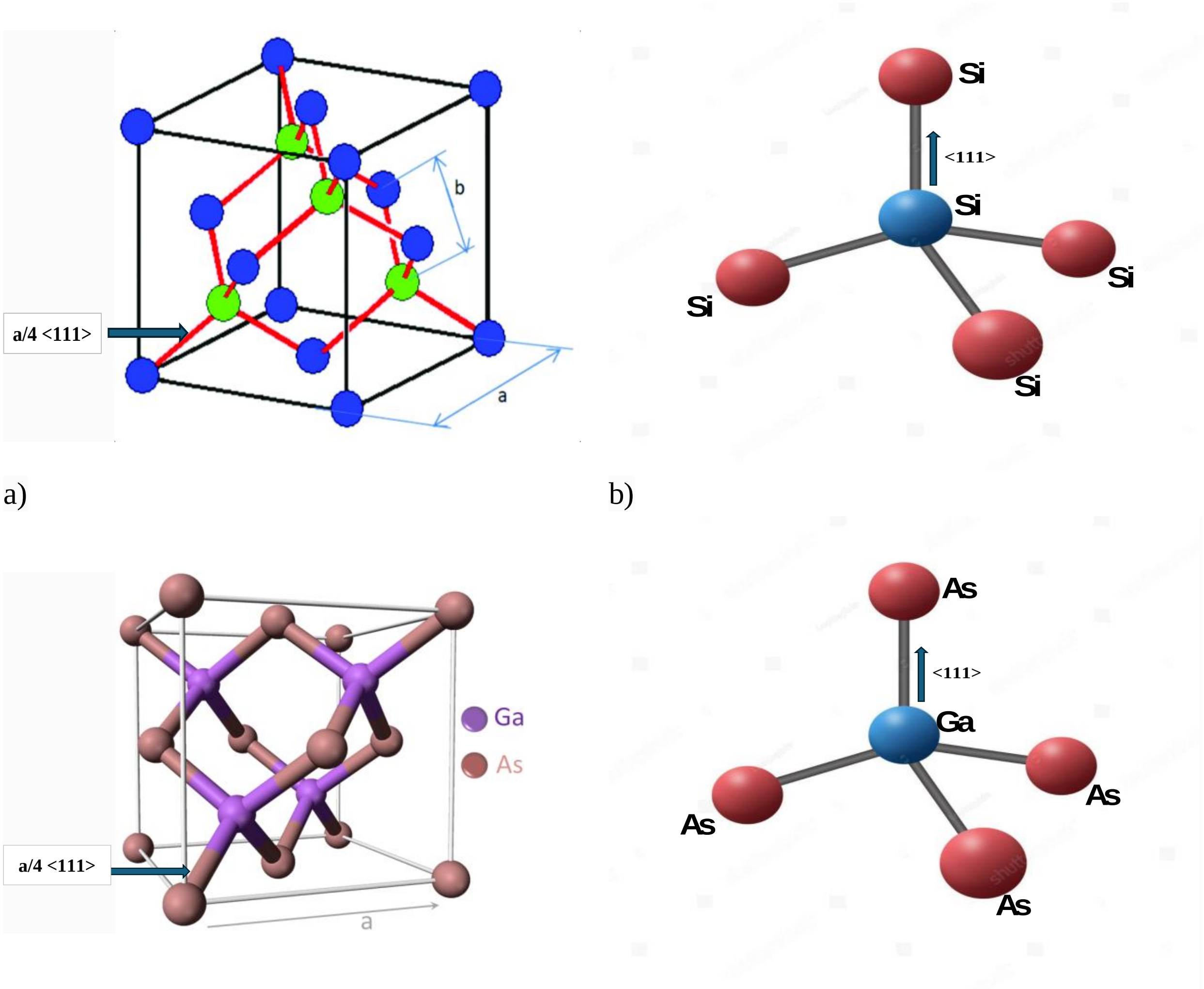
Semiconductors are defect free, that is they do not have any interruption in the three- dimensional periodic arrangement of atoms. This idea situation does not exist in nature: Real Materials always contain defects [16].

3-1 Crystal Structure of important Semiconductors

* Important semiconductors be broadly classified into: elemental, Si, diamond, and Ge while Compound semiconductors as , GaAs Inp, Gasb, AINi Gan, compound semiconductors can be

subdivided in III-V, II-VI, I-I-VI2, and II-VI-V2 where I, II, III, IV, V, and VI represent the group of the constituent atoms in the periodic table [17].

Crystallize in the diamond-Cubic structure (elemental semiconductors), consists of interpenetrating (FCC) unit cell as illustrated in Figure. 6 a, b. one of the (FCC) units is displaced respect to other by a/4 <111>, where a is the lattice parameter of the semiconductor. while, Compound semiconductors, such as, GaAs and CdTe, Crystallize in the Zinc blende structure. The Zinc-blende structure consists of two interpenetrating FCC units Figure. 6 c, d, one of the units occupied by group III or group II atoms, whereas group V or VI atoms reside on the second unit: that is atoms residing on each of the two units are not the same in this case [17].



a) b)

c) d)

Figure. 6: a) arrangement of atoms in the diamond cubic crystal. Each atom has four nearest neighbours, which are arranged at the corners of tetrahedron, b) schematic illustrating the tetrahedron coordination of a Si atom in silicon crystals, c) arrangement of atoms in zinc blend structure. For example, purple solid circle could be Ga atoms, and brown solid circle could be As atoms, and d) schematic illustrating the tetrahedron coordination of a Ga atom in GaAs crystals; symbolically it is written as GaAs [18].

3-2 Structural characteristics of defects

The deformation of defects in semiconductors creates a local electronic disturbance because of the nature of the atomic bonding [19] and depends on the dimensionality of the defect and the type of semiconductor, according to that defects can group into four Categories using dimensionally as acroterion [9].

Zero -dimensional like point defects.
One-dimensional like dislocation defects.
Two-dimensional like stacking faults.
Three-dimensional like precipitations.

3-2-1 Zero -dimensional like point defects

In Zero-dimensional defects which includes: vacancy - interstitial pairs, vacancies interstitials dopant atoms that are intentionally added to control the conductivity of semiconductors and impurities that are contaminants during Material processing and growth. The diamond-cubic unit cell as shown in figure 7, one of tetrahedrally atoms (coordinated) has been removed and the resulting is named "schottky vacancy" resulting in four dangling bonds and pickup electric properties to these defects. Formation and migration for schottky vacancies are ~ 2.3 & 0.18 et respectively in silicon [7]. The second elementary point defect that can be exist are A schottky interstitial, this interstitial defect formed by inserting an atom into one of holes in lattice, as shown in figure 7, which shows some of the interstitial sites in diamond-cubic structure. On the other hand, the energies of creation of these defects in a loosely packed diamond-cubic and Zinc-blende structure are low compared to those in close packed structure (Si) this is because distortion comparing with the interstitial are larger than those in diamond-cubic and Zinc blende.

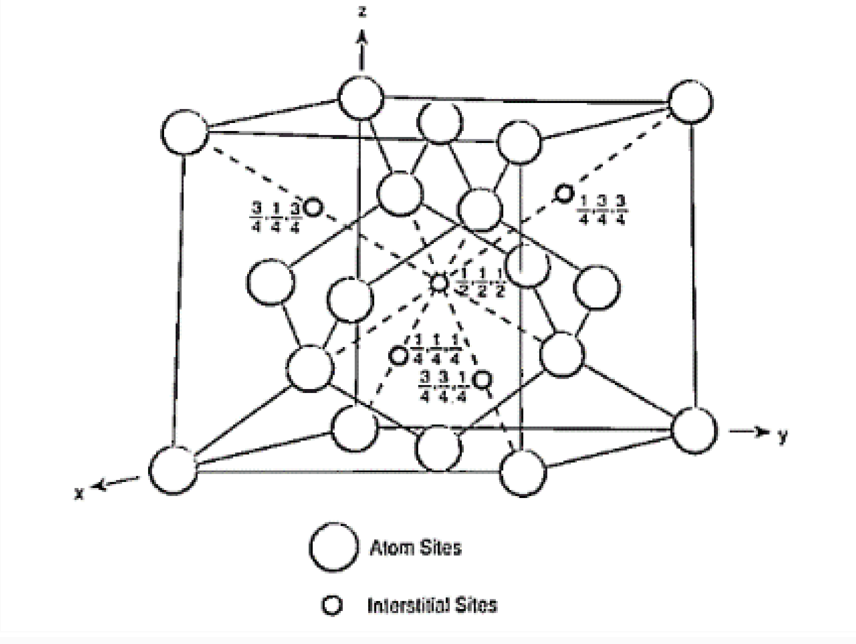


Figure. 7: some of the interstitial sites in the diamond-cubic structure.

On the other hand, energy levels associated with point defect income bound semiconductors are poorly understood for two reasons, first, because of the inherent nature of these materials, a variety of point defects and associated complexes conform. Table (1) shows list of energy levels of vacancies and some of vacancy impurity complexes in gallium arsenide. The second reason, the perfection as well as purity of these materials is not as high as that of elemental semiconductors, so that, it is difficult to discern the electronic properties of point defects [19].

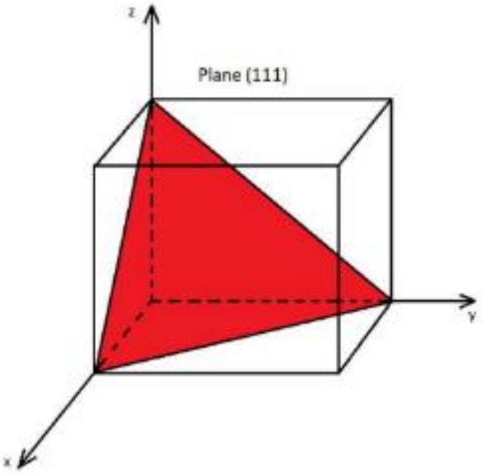
Table. 1: Energy levels associated with vacancies and vacancy-impurity complexes in GaAs [20].

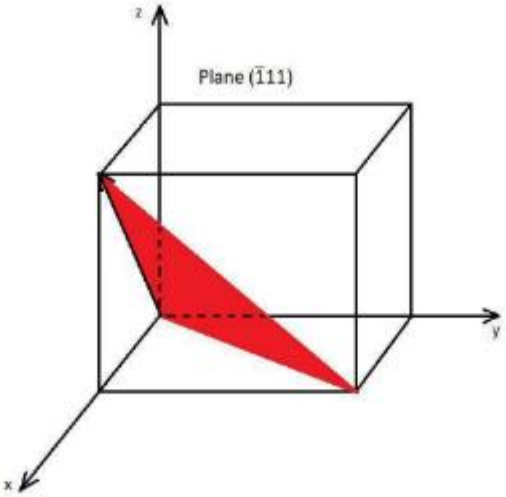
Location from valence- band edge at 5K (eV)	Type of vacancy, and possible impurity associated with it
1.49	VAs(Si)
1.40	VAs
1.37	VGa(Cu)
1.35	VGa
1.20	Oi
1.02	VGaVAs(Si)
0.81	VGa
0.70	VAs(O)
0.58	VGa

3-2-2 One-Dimensional Defects

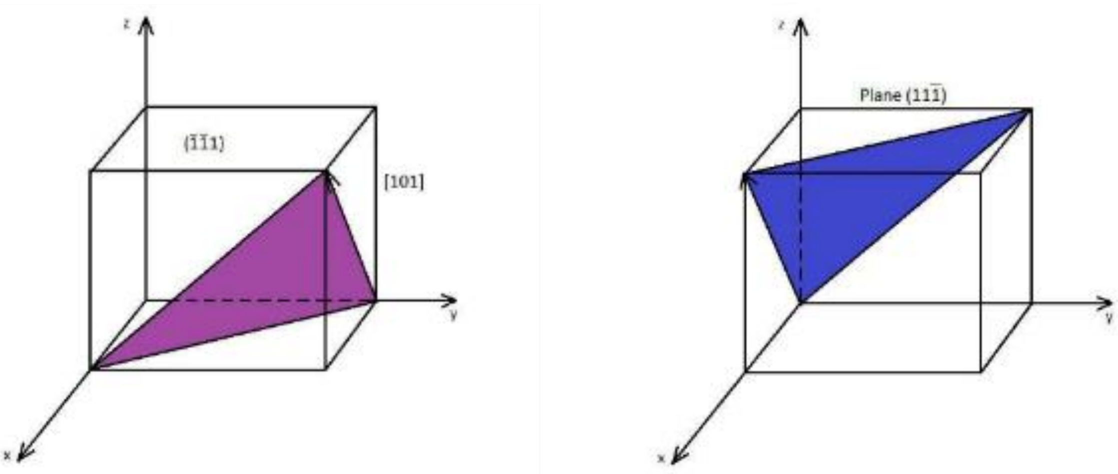
Boundaries between slipped and unslipped regions of a crystal represented to us "Dislocation" [12] In diamond-cubic and Zinc blende Semiconductors, dislocations are glide on {111} planes while, their Burgers vectors is a/2 <110> {111}. All slip systems are shown in Table (2), Figure (8) represented 12 systems, dislocations observed in semiconductors deformed at low and moderate temperature, tend to lie along <110> directions and are of 60o types; the angle between line direction and burgers vector is 60o [13].

Three-dimensional perspectives of 60o glide and shuffle set dislocations are shown in Fig (9), the main characteristics is the creating of "dangling bonds" along the cores of dislocation which impart electrical conductivity to the dislocation in other words can affect carrier concentration as well as mobility of semiconductors. several studies [16,17,21] Confirmed strongly that glide-set dislocation, is the main phenomenon that occurs during the formation behaviour of crystalline materials in diamond-cubic and zinc-blende structures.





a) b)



c) d)

Figure. 8: schematic showing various slip system in the diamond cubic and zinc blende structure.

Table. 2: Slip systems in diamond-cubic and zinc-blende structures.				
Slip planes	(111)	$(\bar{1}11)$	$(1\bar{1}1)$	$(11\bar{1})$
Slip directions	$[1\bar{1}0]$	[110]	[110]	$[1\bar{1}0]$
	$[10\bar{1}]$	[101]	$[10\bar{1}]$	[101]
	$[01\bar{1}]$	$[01\bar{1}]$	[011]	[011]

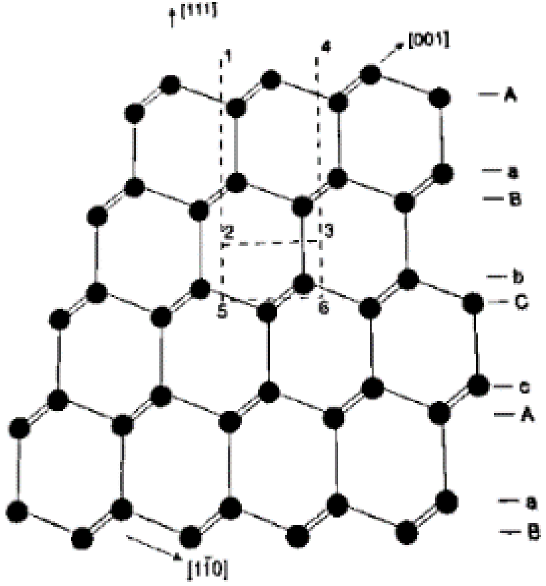


Figure. 9: diamond-cubic lattice projected onto (110) plane.

Two important effects can be produced from introduction of dislocation in covalently bonded semiconductor. First, as a result of the elastic distortion associated with a dislocation band bending occurs and its vicinity. Second dangling bones are created along the core of the dislocation. Many researchers have proposed models to rationalize the electronic properties of dislocation: Jr.w.T. [22,23] assumes that dislocation states can be represented by a one-dimensional band that is empty when the dislocation is in the neutral state. While Schroter and Labusch [24], envisage that the dislocation band is half filled in the neutral state. On the other hand, Hirsch [25] envisages that energy bands associated with screws and 60° dislocation are split and that dislocation kinks give rise to deep donor and acceptors levels, which are located between the dislocation levels.

Both theories can be used to speculate on electron behaviour of perfect dislocation in n and p-type elemental semiconductors. In n-type material, donor impurities can provide electrons to fill either the half-filled band of dislocation, that is, the dislocation behaves as an acceptor, figure (10) or EDA, on the other hand, the p-type material dopants atoms except adequate iron from either a partial default band or EDD. Thus, dislocation behaves as a donor.

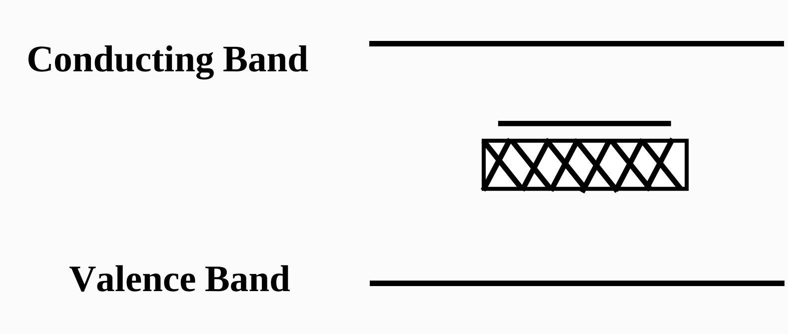


Figure. 10: Schematic of dislocation band models due to (a) Schröter and Labusch (1969).

3-2-3 Two-dimensional defects

Main examples of two-dimensional defects are twin boundaries, surface, sub boundaries, grain boundaries and stacking faults [19]. In the diamond- cubic and zinc-blende structure, stacking faults are form on {111} planes by two different ways: first, by shear while the second by point defects collection, Figure (11) illustrating the formation of stacking faults, and three-layer twin in the diamond-cubic and zinc-blende structures by shearing of (111) planes: a) perfect crystal, b) intrinsic fault, c) extrinsic fault, and d) three layer twin.

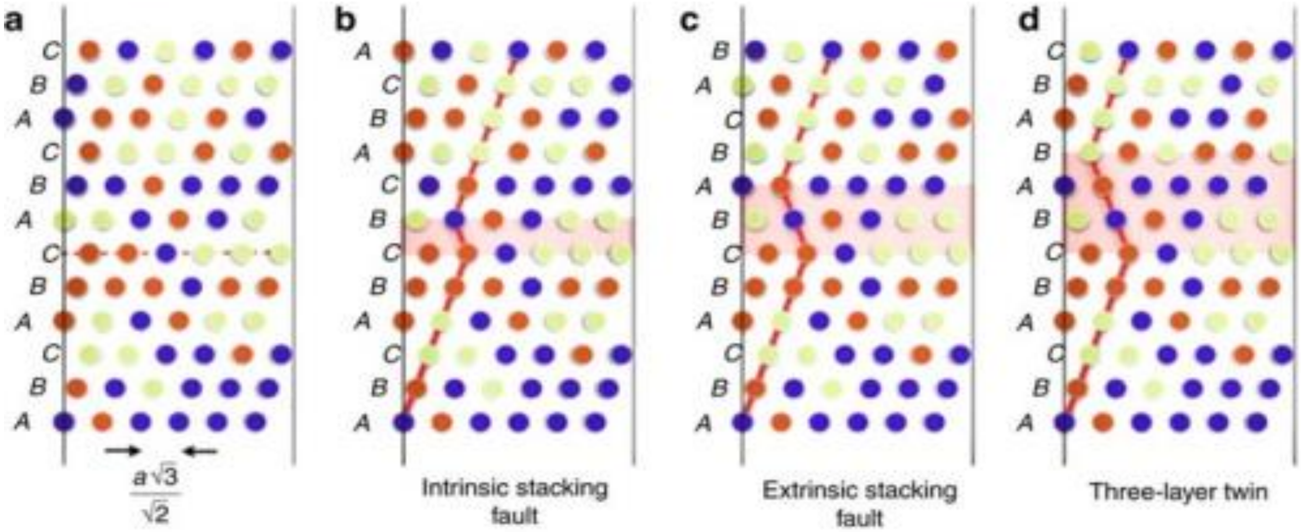


Figure. 11: Example of formation of staking fault and a three-layer twin in the diamond-cubic and zinc blend structures.

3-2-4 Three dimensional defects

Precipitates and inclusion constitute three dimensional defects such as defects could form during the growth of doped crystals when the solid solubility limits of a dopant are exceeded and also during processing of semiconductors. Precipitates can exist in three forms coherent, semi-coherent, non-coherent. If coherent (some crystals structure and lattice parameter similar to that of the matrix, the precipitate can form low energy coherent with the matrix on all sides as shown in figure (12a) [21]. This type of coherency requires the respective lattice to have orientation relationship. While 12b represented a fully coherent precipitate associated with coherency strains when the volume of a precipitate is smaller than that of matrix. While figure (12c) a fully noncoherent precipitate associated with misfit dislocations and strains (12c).

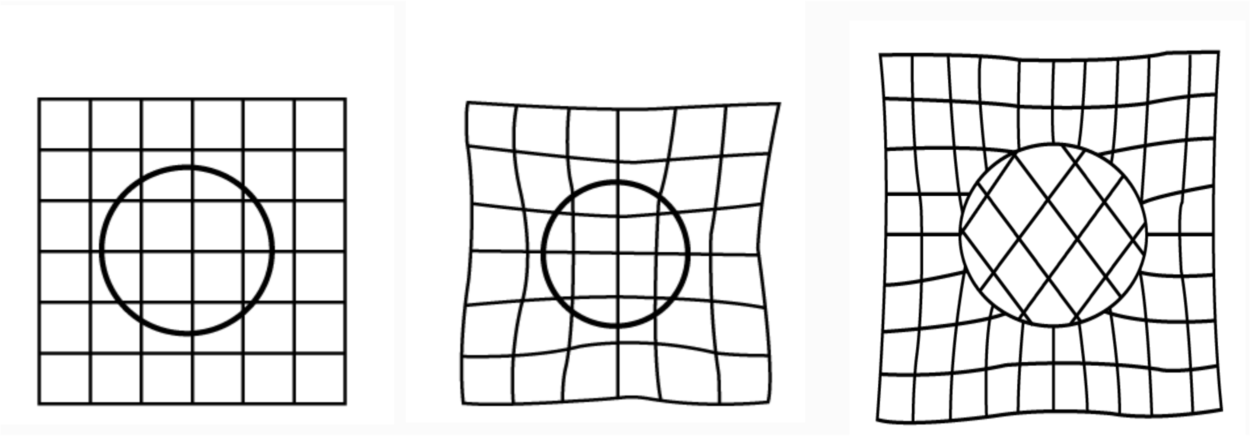

a) b) c)

Figure. 12: Schematics showing (a) a fully coherent precipitate associated with no strains, (b) a fully coherent precipitate associated with coherency strains, and (c) a fully noncoherent precipitate associated with misfit dislocations and strains.

Results and Discussion

4- Evaluation of semiconductors

There are some techniques that are currently being employed for evaluating the structural, chemical, electrical, and optical characteristics of semiconductors.

4-1 Structural evaluation of semiconductor

It involves determining several characteristics: density, dislocation, distribution, and characteristic of virous type of defects considered in the paragraph (1-5). Both macroscopic and microscopic evaluation are necessary to obtain the complete information. Etching, X-ray topography, double crystal diffractometry are used for macroscopic evaluation, while TEM and high-resolution electron microscope (HREM) are usually for microscopy [26].

4-1-1 Defect etching

Etching of semiconductor entails inserting it in a suitable solution called etchant [27]. Since the defectives region each differently from the matrix. It is a powerful method for the evaluation of perfection of as-grown crystal processed wafers and epitaxial layers. There are several reasons for its application: 1) high speed of testing, 2) high reliability and 3) low cost. It is used for investigating the distribution and density of dislocations in semiconductors. It is not very useful when the dislocation exceeds 106 cm-2. Table (3) shows some of dislocation etchants for some compound semiconductors.

Table. 3: Etchants for defect delineation in some compound semiconductors [28–32]

Material	Chemical composition	Remarks
GaAs	Molten KOH at 300oC	good crystallographic dislocation pits

	1 ml HF, 2 ml H2O 8 mg AgNO3 and 1 g CrO3 (A-B Etch)	dislocation lines and striations
GaP	Behaves similarly to GaAs; above Etches can be used	
InP	2 parts H3PO4, 1-part HBr	Good etch {001} surfaces; ambient temperature; etching time up to 2 min.
	HNO3; HBr 1:3	Works well on {001} and $\{\bar{1}\bar{1}\bar{1}\}$B.
CdTe	HF: H2O2: deionized water 30:20:21	Works well on $\{\bar{1}\bar{1}\bar{1}\}$B.

4-1-2 X-ray topography

This technique produces a two-dimensional projection of a three-dimensional distribution and can thus several the defect structure in the volume of the crystal without resorting to sectioning. This technique can resolve like etch pitting, dislocation densities up to 106 cm-2 [33] and cannot reveal features smaller than one Micron. Figure (13) shows a topography obtained from a silicon web using diffraction from different planes. Dislocations on the {111} planes are clearly evident, which is caused by thermal gradient-induced citrus that developed during the web growth.

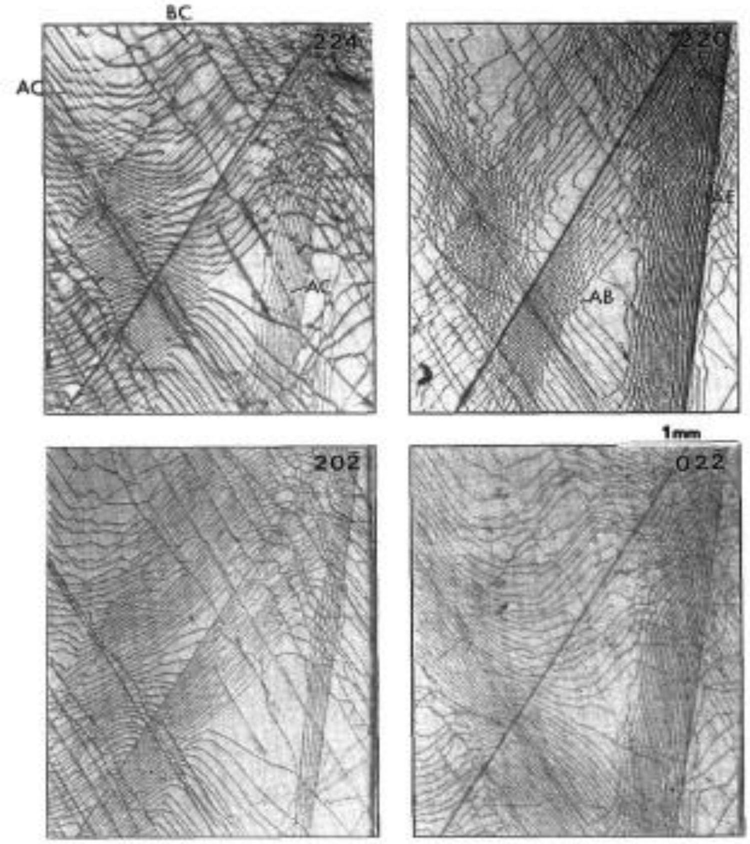
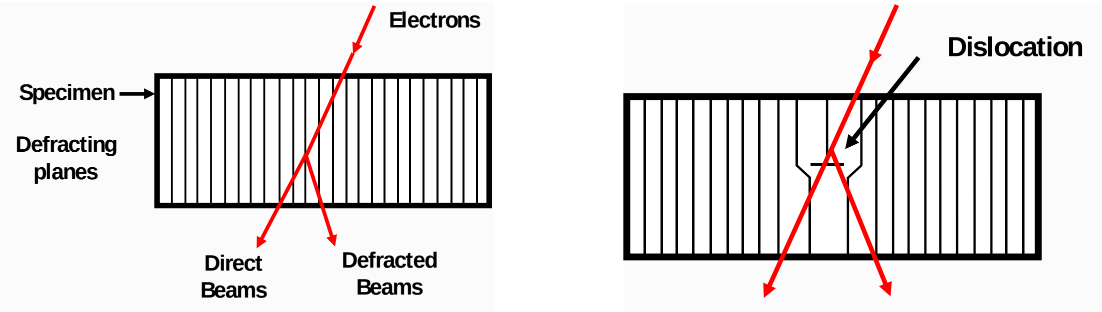


Figure. 13: Dislocation networks in dendritic web silicon obtained by transmission X-ray topography, The four topographs are from the same region imaged by four different reflections [34].

The major advantages of X-ray topography are: 1) it is non-destructive, 2) it can be investigating any single crystal material with low-defect density, 3) it simultaneously images all the defects in the specimen, 4) it can image relatively large areas [35]. But the major drawbacks are that it is time-consuming.

4-1-3 Transmission electron microscopy TEM

The resolution is extremely high (0.18 nm) [36]. In this technique, a high-energy electron is focused electromagnetically and transmitted through thin samples whose thickness are of the order of (100-200 nm), what is showing in figure (14), let us assume that the sample under examination is set for Bragg-diffraction. The electron beam incident from the top is then diffracted from the set of vertical planes as shown in figure 14a. As a result, two beams - direct and diffracted - emerge from the bottom of the specimen. Image of the specimen can be formed by placing an aperture around either the beam and are recorded on photographic plates.



a) b)

Figure. 14: Schematics showing diffraction from (a) a perfect crystal when the Bragg condition is satisfied and (b) a dislocated crystal when it is slightly tilted away from the Bragg position.

Now consider a situation where this dislocation is present in a thin specimen as illustrated in figure (14b). The lattice planes are bent around the dislocation core. If we tilt this slightly away from the exact Bragg condition, a strong diffraction from planes close to the dislocation core and results in a differential contrast between the dislocation on perfect regions of the crystal, as shown in figure 15a which shows a dislocation substructure observed in an (Inp) crystal daubed with Se to 1*1019 cm-3. After tilting the specimen away from Bragg condition, the same area shows in figure 15b. The contrast associated with the strain of the dislocation is reduced. As a result, impurities segregation to the dislocation become visible [37].

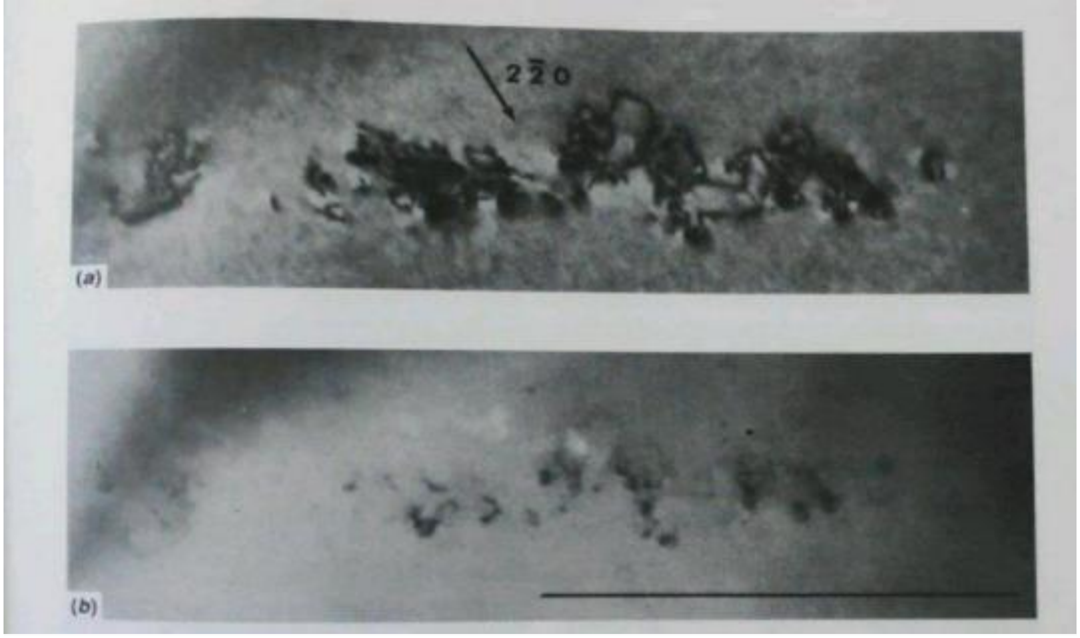


Figure. 15: TEM micrographs obtained from a highly Se-doped crystal: (a) two-beam diffraction condition and (b) quasi-kinematical situation. The plane of the micrographs is ~(001), and the marker represents 1 µm [38].

4-2 Chemical Evaluation

The controlled amounts of impurities are intentionally added to semiconductors to increase their carrier concentration [39]. Impurities can also be introduced during the growth and processing of semiconductors which increase affect the electronic properties of semiconductors.

There are several techniques used such as: neutron activation, electron microprobe, Auger electron spectroscopy, secondary ion mass spectrometry and Rutherford back scattering.

4-2-1 Neutron activation analysis (NAA)

This technique uses neutrons to analyse the elemental composition of a material. These neutrons are absorbed by a material, some nuclei of the elements activated into excited states, which followed by the radioactive decay of these states [40], as follows:

AX + nI -----> AX+1

AX+1 -----> B + radiation

In general, we use thermal neutron (energy in the range of (~ 10-2 ev) NAA of most of the elements in the periodic table. Kruger (1971) points some limitations of NAAi(1) it is inability to distinguish between chemical nature (binding, ionization state) of the elements under consideration, 2) the occurrence of interfering nuclear reaction, and 3) the sensitivity an accuracy limitation associated with sample condition.

4-2-2 electron microprobe analysis (EMPA)

This technique is used to identify the impurities present. EMPA uses two complementary techniques to analyse the immediate X-rays. The wavelength of the X-ray can be determined using crystal diffraction spectrometers (CDS). Whereas their energy can be determined via energy x-dispersive spectrometers (EDS). In CDS the basic components are an analysing a crystal, a detector, and readout electronics [41]. While EDS uses a reverse-based SI detectors to measure the energy of the emitted X-ray indirectly [41]. Figure 17a shows an application of EMPA analyse the chemical of different microstructural features observed in a Ag-Y-Ba-Cu alloy while figure 17b and 17c show respectively X-ray spectra obtained from twinned grains and the intergranular phase indicated in figure 17a. All the concentrations of Ag-Ba-C-Cu-O and Y in the two regions are different.

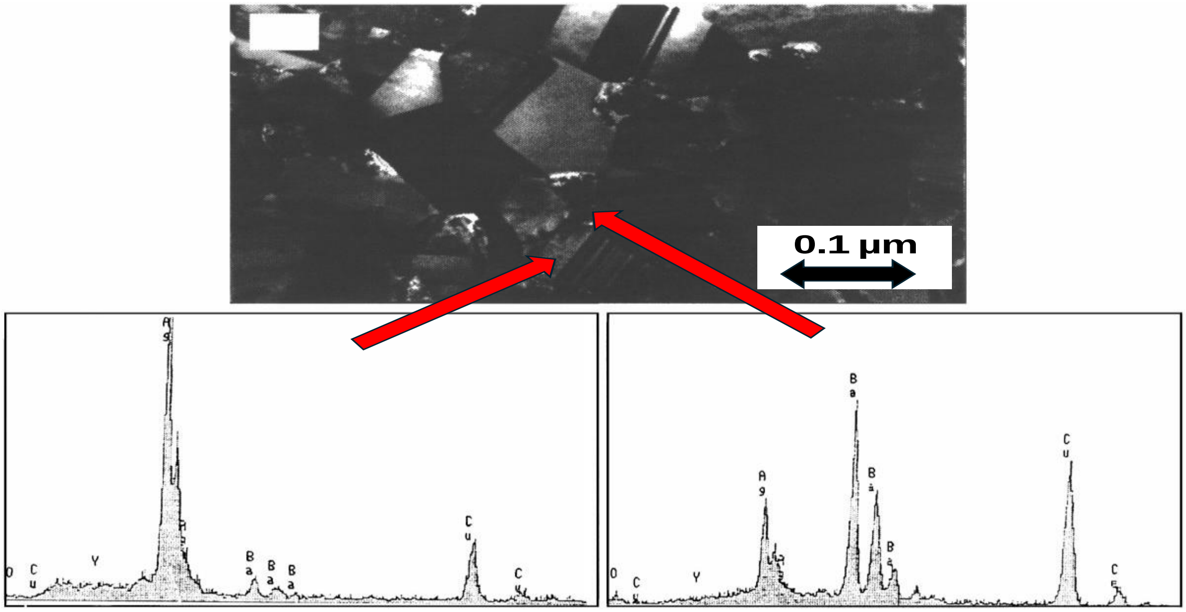


Figure. 17: (a) Transmission electron micrograph of a Ag-Y-Ba-Cu alloy used as a precursor for the formation of a superconducting (b) X-ray spectrum obtained from the twinned grains indicated in (a). (c) X-ray spectrum obtained from the intergranular phase [42].

4-2-3 Auger Electron spectroscopy

It is a powerful technique for determining the elemental composition of a few outer most automatic layers of material. In this technique the specimen is bombarded by electrons with energy between (3-30 ekv). As a result, the core level electrons are ejected from atoms located within a depth of (1 micron). The resulting call vacancy is then filled by an outer level electron. The excess energy is then used to dislodge outer electrons of the atoms. These electrons are called Auger electrons. Figure 18 illustrates this process [43].

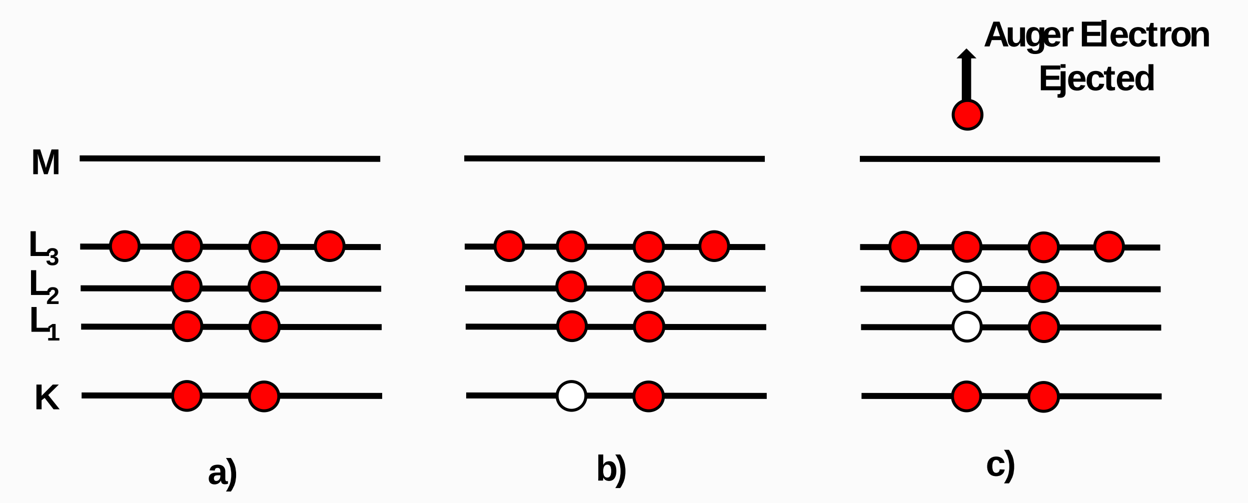


Figure. 18: Schematic illustrating a K L2L3 Auger process: (a) isolated atom showing electrons present in filled K and L levels before an electron is removed from a core level, (b) after removal of an electron from the K level, and (c) following the Auger process where a K L2L3 Auger electron is emitted. In (c) one L-level electron fills the K vacancy and the other L-level electron is ejected due to the energy available on filling the K level [44].

4-3 Electrical and optical evaluation

This section covers the principles of some current techniques for evaluating the electrical and optical characteristics of semiconductors.

4-3-1 Mobility and carrier concentration

The carrier mobility in a semiconductor is an important property. This quantity represents the proportion between the drift velocity of a career and electric field for sufficiently low field. Conductivity σ or resistivity ρ of the semiconductors is given by the equation.

$$\sigma = \frac{1}{\rho} = qn\mu n + qp\mu p$$

Where:

q is the charge of the carrier.

n, p concentration of n- and p-type carrier.

μn, μp= mobilities of N and P carriers [45].

If one type of career dominates, then we can use the hall effect to measure career concentration and the mobility. The Vanderpauw (1958) [46] is used extensively for these measurements because it can be applied to samples of arbitrary shape. Figure 19 represented an electric contact configuration for sample prepared for hall effect.

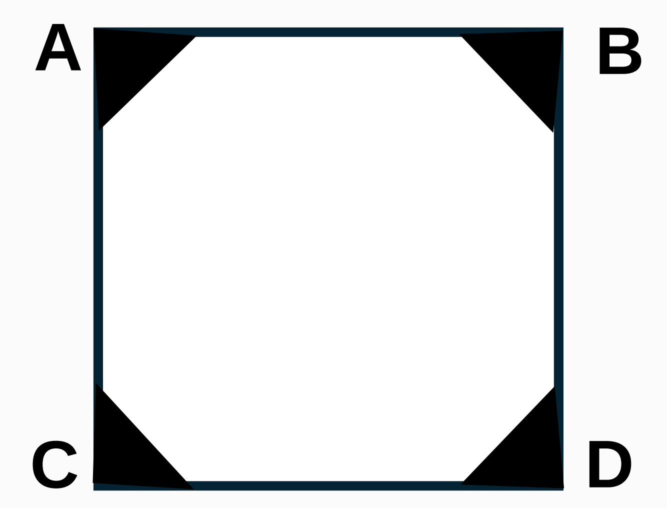


Figure. 19: An electrical contact configuration for a sample prepared for Hall effect measurements using van der Pauw's method [47].

4-3-2 minority carrier lifetime

There are several techniques for measuring the minority carrier lifetime [48] in all cases the basic principle is the same. It involves the generation of excess-charge carriers in semiconductor and measuring the decay time of the generated carriers when the generation source is removed. Usually photoconductivity decay (PCD) is used which involves forming ohmic Contacts on a semiconductor through which we eject a constant current. Then, use a high-intensity light source of short duration to generate excess carrier in the semiconductor. after the source is turned off, the excess Carriers decay, and this decay process is monitored on an oscilloscope. The minority- carrier Lifetime is the time required for the excess Carrier pulse to decay to 1/e of its initial value [49].

4-3-3 Deep-level Transition spectroscopy (DITS)

By measuring the Capacitance transients, we can characterize the carrier traps in semiconductors. (DITS) utilize this approach [50]. (DITS) is a method of determining the concentration and thermal emission rate of semiconductor deep level by measuring capacitance transient as a function of temperature. by this technique, we can determine the activation energy of a trap, that is, its position with the band gap, its Carrier-Capture cross-sections, and the trap concentration figure 20 Shows (DITS) spectra of two-hole traps in an n-GaAs layer.

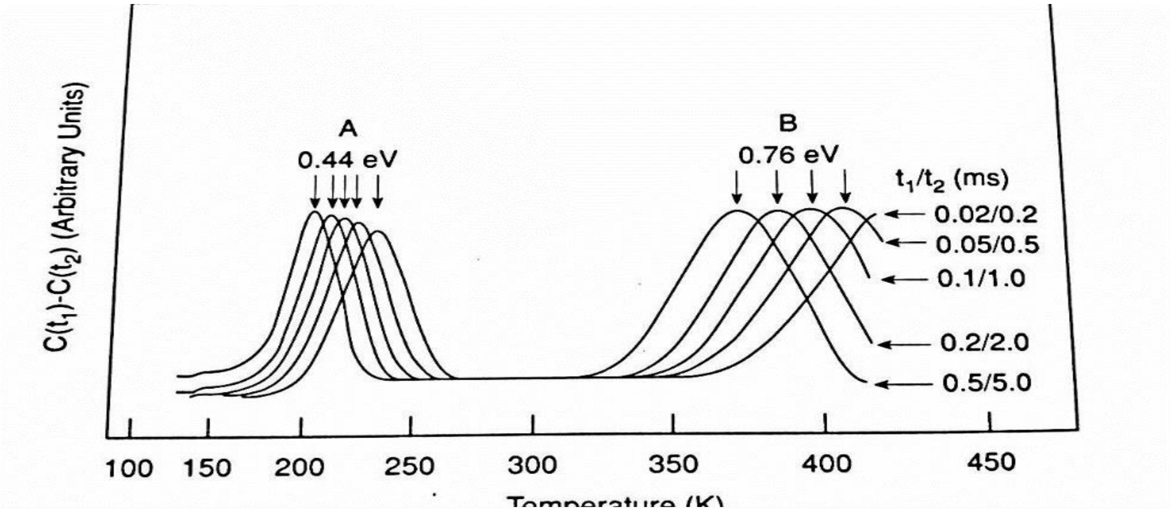


Figure. 20: DLTS spectra of two-hole traps in an n-GaAs layer. The transient sampling times and peaks maxima are indicated [47].

4-3-4 Photoluminescence (PL)

Is one of the most widely diffused experimental techniques for the characterization of semiconductor nanostructure (in particular quantum wells (Qws) and for the study of their electronic properties [51]. As it known, it can create additional electron-hole pair (EHP), semiconductors. by irradiating them. with light whose energy is greater than the band gap of semiconductors. The excess carriers can recombine radiatively and nonradiatively. the radiatively emits lighter this phenomenon of light emissions called. photoluminescence (PL) [52].

It used extensively Fore characterizing III-V bulk - crystals and epitaxial layer. This simple. and elegant technique is used both to understand the Fundamentals of the recombination process and to assess the quality of the semiconductor. in this process, we need a light source for generating excess carrier., an equipment is used to collet, disperse, and detect the illuminscence from the specimen. Figure 21. setup that is used for (PL) studies of III v materials. Possible light sources are Ne- He-Ar and kr lasers- spot light Can be focused on the sample to a size of ~2µm. A mechanical chopper operating at a frequency of 300 to 500 HZ the luminescence from the sample is collected and focused on to the slit on the spectrometer for dispersion and detection.

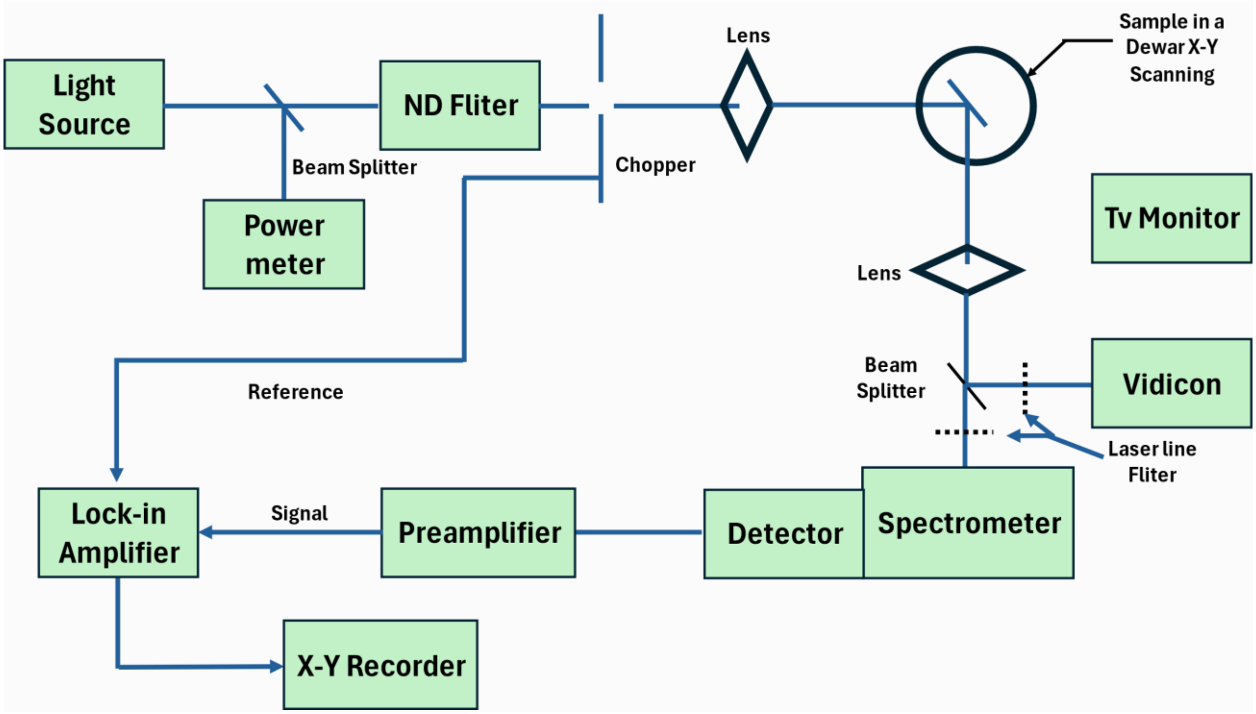


Figure. 21: Experimental arrangement for PL measurements.

This section details the conclusions achieved with this device as it tested alone, and with normal subjects. In addition, It also deals with suggestions that can be added which in turn aim to possible improving the performance of the device,

Pre-Testing The Exoskeleton

After manufacturing the device and making sure it works, different tests were carried alone for flexion/extension for different positions were carried out to examine the functionality of the exoskeleton.

Then the same procedure was carried out with the ROM of the exoskeleton were calculated with gyroscope sensor. **Fig (1)** shows the pre-testing result.

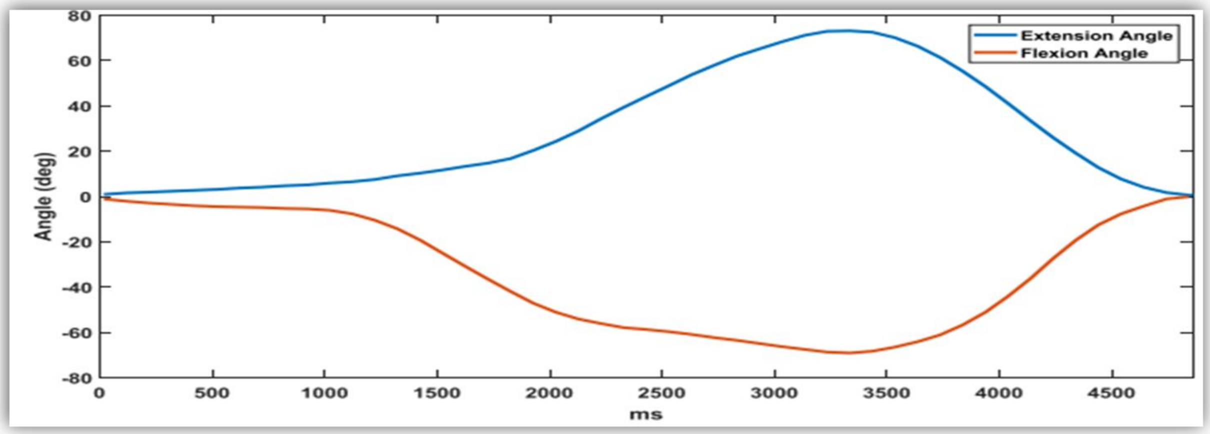


Figure 1 ROM of the Flexion and Extension motion of the exoskeleton..

POST-TESTING THE EXOSKELETON

The exoskeleton was tested with normal subjects, the ROMs and activity of the muscles were recorded with normal human (see **Figure 2)**). The ROM is calculated with gyroscope sensor, the post-testing result of the exoskeleton motion with and without subject is shown in **Table (1)** and **Fig (3)** respectively. The subject has 23yrs old and weighted 80kgs and has 91 cm arm length with no medical condition.[33-35]

Figure 2 The exoskeleton test with normal subject.

Table 1 Normal human average data

Exoskeleton Motion	**Angle**
Elbow Extension	76 º
Elbow Flexion	74 º

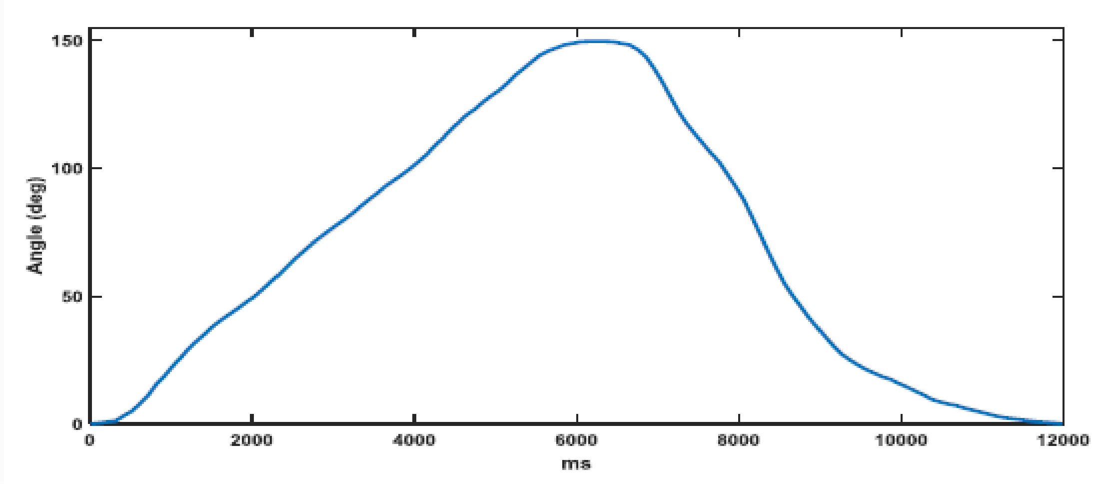


Figure 3 The post-testing result of the Flexion /Extension motion.

Conclusion

In summary, the structural and electrical characteristics of semiconductors have a significant impact on their functionality, making them the building blocks of contemporary electronics and optoelectronics. By creating energy levels within the bandgap, defects, categorized by dimensionality (point, line, surface, and bulk), significantly influence the electrical behavior of semiconductors. These materials' structural, chemical, electrical, and optical properties are examined using a variety of characterisation methods, including photoluminescence, XRD, TEM, and SIMS. For the purpose of maximizing semiconductor performance in devices such as solar cells, transistors, and LEDs, it is essential to comprehend and manage these flaws.

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