Growth and structure of films

General features - Nucleation theories - Post-nucleation growth - Four stages of film growth incorporation of defects during growth - Thin film structures - Structural defects.

Thickness Measurement Methods: Electrical methods Mass methods – Optical interference method – Photometric – Ellipsometry – multiple beam Interferometry – Other methods – Substrate cleaning.

Nucleation theories

Nucleation is typically defined to be the process that determines how long an observer has to wait before the new phase or self-organized structure appears.

Post-nucleation growth

Post-nucleation stage particles are formed by an atom-by-atom building process. Re-evaporation of adatoms and migration along the edge of already formed particles

Four stages of film growth incorporation of defects during growth

Spray pyrolysis

It is a **process** in which a thin film is deposited by **spraying** a solution on a heated surface, where the constituents react to form a chemical compound. The chemical reactants are selected such that the products other than the desired compound are volatile at the temperature of deposition.

Principle:

Spray pyrolysis involves a thermally stimulated chemical reaction between constituent ions to form the required compound. In this technique, a solution containing the soluble salts of the constituent atoms of the required compound is sprayed on to a hot substrate in the form of fine droplets, using a sprayer. Usually compressed air will be the carrier gas. But compressed nitrogen is also used as carrier gas to avoid the presence of oxygen. The sprayed droplets reaching the hot substrate surface undergo pyrolytic decomposition and form the compound as a thin film on the surface of the hot substrate. In fact it is the hot substrate which provides the thermal energy needed for the decomposition and subsequent recombination of the constituent species. The other volatile by-products and the excess solvents are converted into vapourphase and are removed-from the site of chemical reaction by using an exhaust fan. Carrier gas here plays an active role in the pyrolytic reaction process especially in the case of oxide films. Doping can be easily accomplished by simply dissolving the dopants in the required quantity in the spray solution. Only thing to be noted here is that the soluble salt of the dopant should be available. Such an attempt is made in the present work in order to prepare indium doped cadmium supplied films. Here characterization of the film is required for knowing the quantity of dopant available in the film. Actually in Our work, we varied the concentration of the dopant and the characterization of the films was also done. Even multi component doping can be done on different layers of the film, using this technique.

The growth rate of the sprayed films depends upon the chemical and topographical nature and temperature of the substrate, the chemical nature and concentration of spray solution and its additives. Another factor that affects the growth rate is the spray parameters like scanning speed of the spray head, the distance of the spray head from the substrate, the angle of incidence of the droplet on the substrate etc. The thickness of the film increases almost linearly with spraying time, i.e. with the amount of sprayed solution. In general, the spray pyrolysis process affects the substrate surface. When it is not desirable for the substrate to take part in the pyrolytic reactions, neutral substrates such as glass/quartz, ceramics are employed. The chemical composition of the film is found to depend on the kinetics of the pyrolytic process. Under appropriate conditions, stoichiometric supplied and selenide films and nearly stoichiometric oxide films can be obtained. The stoichiometry of the supplied films does not vary appreciably with the metal-to Sulphur ion ratio in the spray solution for ratios ranging from 1: 1 to 1: 1.5, but the microstructure of the film is strongly influenced by this ratio. But on the other hand, stoichiometry of oxide films is dependent on relatively more complex reactions. In the case of Sn02, the deviation from stoichiometry (i.e., the number of oxygen vacancies) is equal to the number of Sn4+ species reduced to Sn2+ ions, and this is controlled by the water and alcohol content in the spray solution. The oxygen content in the film is also influenced by the rate of cooling of the films after the spray is over, owing primarily to the adsorption of oxygen. The spray deposited films are strongly adherent, mechanically hard, free from pin hole and stable with time and temperature. Post deposition annealing of films generally affects the oxygen dominated electrical properties significantly. The samples annealed Sn02 films at 250°C, both in air and

vacuum. They observed no change in optical properties, whereas there is a significant improvement in electrical properties. This is due to the oxygen chemisorption desorption mechanisms at grain boundaries. In the present work, we made use of this technique for the preparation of tin oxide thin films and cadmium supplied thin films.

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It is a physical vapor deposition (PVD) process that is sometimes called *ion assisted deposition* (IAD) or *ion vapor deposition* (IVD) and is a version of *vacuum deposition*. Ion plating uses concurrent or periodic bombardment of the substrate, and deposits film by atomic- sized energetic particles. Bombardment prior to deposition is used to sputter clean the substrate surface. During deposition the bombardment is used to modify and control the properties of the depositing film. It is important that the bombardment be continuous between the cleaning and the deposition portions of the process to maintain an atomically clean interface.

In ion plating the energy, flux and mass of the bombarding species along with the ratio of bombarding particles to depositing particles are important processing variables. The depositing material may be vaporized either by evaporation, sputtering (bias sputtering), and arc vaporization or by decomposition of a chemical vapor precursor chemical vapor deposition (CVD). The energetic particles used for bombardment are usually ions of an inert or reactive gas, or, in some cases, ions of the condensing film material (“film ions”). Ion plating can be done in a plasma environment where ions for bombardment are extracted from the plasma or it may be done in a vacuum environment where ions for bombardment are formed in a separate *ion gun*. The latter ion plating configuration is often called Ion Beam Assisted Deposition (IBAD). By using a reactive gas or vapor in the plasma, films of compound materials can be deposited.

Ion plating is used to deposit hard coatings of compound materials on tools, adherent metal coatings, optical coatings with high densities, and conformal coatings on complex surfaces.

Vacuum evaporation:

It is the most widely used method for preparing stoichiometric thin films, as it is very simple and convenient. Here the only requirement is to have a vacuum environment in which sufficient amount of heat is given to the evaporate to attain the vapor pressure necessary for evaporation. Then the evaporated material is allowed to condense on a substrate kept at a suitable temperature. Deposition consists of three distinguishable steps.

1) Transition of the condensed phase (solid or liquid) into the gaseous state.

2) Traversal of the vapor from the vapor source to the substrate.

3) Condensation of the vapor at the substrate.

When evaporation is made in vacuum, the evaporation temperature will be considerably lowered and the donation of the oxides and incorporation of impurities in the growing layer will be reduced. Evaporation is nominally done at a pressure of 10-5 tort. At this pressure, a straight line path for most of the emitted vapor atoms is also ensured, for a substrate-to-source distance of nearly 10-50 cm. The details of this technique is also available in the standard books mentioned earlier [2-5]. Depending upon the nature of heating there are several types of vacuum evaporation techniques. The most popular types are briefly described in the following section.

For molecules of a liquid to evaporate, they must be located near the surface, they have to be moving in the proper direction, and have sufficient kinetic energy to overcome liquid-phase intermolecular forces.When only a small proportion of the molecules meet these criteria, the rate of evaporation is low. Since the kinetic energy of a molecule is proportional to its temperature, evaporation proceeds more quickly at higher temperatures. As the faster-moving molecules escape, the remaining molecules have lower average kinetic energy, and the temperature of the liquid decreases. This phenomenon is also called evaporative cooling. This is why evaporating sweat cools the human body. Evaporation also tends to proceed more quickly with higher flow rates between the gaseous and liquid phase and in liquids with higher vapor pressure. For example, laundry on a clothes line will dry (by evaporation) more rapidly on a windy day than on a still day. Three key parts to evaporation are heat, atmospheric pressure (determines the percent humidity), and air movement.

On a molecular level, there is no strict boundary between the liquid state and the vapor state. Instead, there is a Knudsen layer, where the phase is undetermined. Because this layer is only a few molecules thick, at a macroscopic scale a clear phase transition interface cannot be seen.

Liquids that do not evaporate visibly at a given temperature in a given gas (e.g., cooking oil at room temperature) have molecules that do not tend to transfer energy to each other in a pattern sufficient to frequently give a molecule the heat energy necessary to turn into vapor. However, these liquids *are* evaporating. It is just that the process is much slower and thus significantly less visible.

Methods of Sputtering:

Sputtering sources often employ magnetrons that utilize strong electric and magnetic fields to confine charged plasma particles close to the surface of the sputter target. In a magnetic field, electrons follow helical paths around magnetic field lines, undergoing more ionizing collisions with gaseous neutrals near the target surface than would otherwise occur. (As the target material is depleted, a "racetrack" erosion profile may appear on the surface of the target.) The sputter gas is typically an inert gas such as argon. The extra argon ions created as a result of these collisions lead to a higher deposition rate. The plasma can also be sustained at a lower pressure this way. The sputtered atoms are neutrally charged and so are unaffected by the magnetic trap. Charge build-up on insulating targets can be avoided with the use of **RF sputtering** where the sign of the anode-cathode bias is varied at a high rate (commonly 13.56 MHz).[4] RF sputtering works well to produce highly insulating oxide films but with the added expense of RF power supplies and impedance matching networks. Stray magnetic fields leaking from ferromagnetic targets also disturb the sputtering process. Specially designed sputter guns with unusually strong permanent magnets must often be used in compensation.

1. A) Ion-beam sputtering:-

Ion-beam sputtering (IBS) is a method in which the target is external to the ion source. A

source can work without any magnetic field like in a hot filament ionization gauge. In a Kaufman source ions are generated by collisions with electrons that are confined by a magnetic field as in a magnetron. They are then accelerated by the electric field emanating from a grid toward a target. As the ions leave the source they are neutralized by electrons from a second external filament. IBS has an advantage in that the energy and flux of ions can be controlled independently. Since the flux that strikes the target is composed of neutral atoms, either insulating or conducting targets can be sputtered. IBS has found application in the manufacture

of thin-film heads for disk drives. A pressure gradient between the ion source and the sample chamber is generated by placing the gas inlet at the source and shooting through a tube into the sample chamber. This saves gas and reduces contamination in UHV applications. The principal drawback of IBS is the large amount of maintenance required to keep the ion source operating.[5]

2. **b) Reactive sputtering**:-

In reactive sputtering, the sputtered particles undergo a chemical reaction before coating the substrate. The deposited film is therefore different from the target material. The chemical reaction that the particles undergo is with a reactive gas introduced into the sputtering chamber such as oxygen or nitrogen; oxide and nitride films are often fabricated using reactive sputtering. The composition of the film can be controlled by varying the relative pressures of the inert and reactive gases. Film stoichiometry is an important parameter for optimizing functional properties like the stress in Six and the index of refraction of six.

3. **c) Ion-assisted deposition:-**

In ion-assisted deposition (IAD), the substrate is exposed to a secondary ion beam operating at a lower power than the sputter gun. Usually a Kaufman source, like that used in IBS, supplies the secondary beam. IAD can be used to deposit carbon in diamond-like form on a substrate. Any carbon atoms landing on the substrate which fail to bond properly in the diamond crystal lattice will be knocked off by the secondary beam. NASA used this technique to experiment with depositing diamond films on turbine blades in the 1980s. IAD is used in other important industrial applications such as creating carbon surface coatings on hard disk platters and hard transition metal nitride coatings on medical implants.

4. d) High-target-utilization sputtering (Hiatus):-

Sputtering may also be performed by remote generation of a high density plasma. The plasma is generated in a side chamber opening into the main process chamber, containing

the target and the substrate to be coated. As the plasma is generated remotely, and not from the target itself (as in conventional magnetron sputtering), the ion current to the target is independent of the voltage applied to the target.

5. e) High-power impulse magnetron sputtering (Hippies):-

Hippies is a method for physical vapor deposition of thin films which is based on magnetron sputter deposition. Hippies utilizes extremely high power densities of the order of kW/cm^2 in short pulses (impulses) of tens of microseconds at low duty cycle of < 10%.

6. f) Gas flow sputtering:-

Gas flow sputtering makes use of the hollow cathode effect, the same effect by which hollow cathode lamps operate. In gas flow sputtering a working gas like argon is led through an opening in a metal subjected to a negative electrical potential. Enhanced plasma densities occur in the hollow cathode, if the pressure in the chamber *p* and a characteristic dimension *L* of the hollow cathode obey the Panchen's law 0.5 Palm < *poll* < 5 Palm. This causes a high flux of ions on the surrounding surfaces and a large sputter effect. The hollow-cathode based gas flow sputtering may thus be associated with large deposition rates up to values of a few µm/min.

Reactive sputtering:-

In reactive sputtering, the sputtered particles undergo a chemical reaction before coating the substrate. The deposited film is therefore different from the target material. The chemical reaction that the particles undergo is with a reactive gas introduced into the sputtering chamber such as oxygen or nitrogen; oxide and nitride films are often fabricated using reactive sputtering. The composition of the film can be controlled by varying the relative pressures of the inert and reactive gases. Film stoichiometry is an important parameter for optimizing functional properties like the stress in Six and the index of refraction of six.

Radio frequency or (RF) sputtering

It is a technique that is used to create thin films, such as those found in the computer and semiconductor industry. Like direct current (DC) sputtering, this technique involves running an energetic wave through an inert gas to create positive ions. The target material, which will ultimately become the thin film coating, is struck by these ions and broken up into a fine spray that covers the substrate, the inner base of the thin film. RF sputtering differs from DC sputtering in the voltage, system pressure, sputter deposition pattern, and ideal type of target material.

During the sputtering process, the target material, substrate, and RF electrodes begin in a vacuum chamber. Next, the inert gas, which is usually argon, neon, or krypton, depending on the size of the target material's molecules, is directed into the chamber.

The RF power source is then turned on, sending radio waves through the plasma to ionize the gas atoms. Once the ions begin to contact the target material, it is broken into small pieces that travel to the substrate and begin to form a coating.

Since RF sputtering uses radio waves instead of a direct electron current, it has different requirements and effects on the sputtering system. For instance, DC systems require between 2,000 and 5,000 volts, while RF systems require upwards of 10^{12} volts to achieve the same rate of sputter deposition. This is largely because DC systems involve the direct bombardment of the gas plasma atoms by electrons, while RF systems use energy to remove the electrons from the gas atoms' outer electron shells. The creation of the radio waves requires more power input to achieve the same effect as an electron current. While a common side effect of DC sputtering involves a charge build-up on the target material from the large number of ions in the chamber, overheating is the most common issue with RF systems.

As a result of the different powering method, the inert gas plasma in an RF system can be maintained at a much lower pressure of less than 15 moor, compared to the 100 moor necessary for optimizing DC sputtering. This allows for fewer collisions between the target material particles and the gas ions, creating a more direct pathway for the particles to travel to the substrate material. The combination of this decreased pressure, along with the method of using radio waves instead of a direct current for the power source, makes RF sputtering ideal for target materials that have insulating qualities.

Thin film structures

Poly-crystalline thin films with grain sizes ranging from a few nanometers to **cm** the thin films

Single crystalline thin films, but full of defects like dislocations, precipitates, point defects.

Structural defects

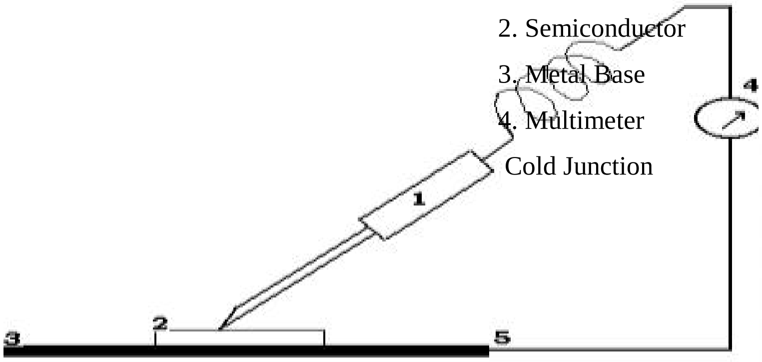
Structural defects like dislocations determine the mechanical properties of materials. The local distortion of the atomic lattice in the vicinity of the dislocation does influence the mechanical strength. In thin films, those strain fields are limited by the finite thickness of the layer, which sometimes leads to new effects. In a diffraction experiment, those strain fields can be made visible through the diffuse scattering underneath the coherent diffraction peaks.

Electrical methods

Hot Probe Method

Any semiconductor material film, after preparation has to be identified for its nature. The *n*-type and *p*-type semiconductors differ by the nature of their majority carriers, for the former it is the electrons and for the latter it is the holes. The simple technique for assessing the nature of the carriers in a semiconducting film is based on the fact that when a piece of semiconductor is momentarily heated at one end while the other end being cold, carriers flow from the hot end to the cold end. So for the *n*-type, the conventional current will be from the cold end to the hot end while for the *p*-type it will be the other way round. Therefore, if a technique is developed to find the direction of electron flow through a semiconductor in an electric circuit, it may be possible to determine the nature of the semiconductor and this technique is called as the "Hot Probe Technique". The experimental arrangement is shown in the Figure.4.8.

The semiconductor thin film coated substrate is placed on a metal plate. A fairly long metal rod with one end formed into a tip (usually a soldering iron) is taken. The tip is heated and one end of the semiconductor is to be touched with the heated tip for a short time, while the other end of the rod is connected to the metal base/other end of the thin film through a Galvanometer.



1. Hot Probe
2. Semiconductor
3. Metal Base
4. Multimeter
5. Cold Junction

The end of the metal base, which is connected to the galvanometer, is called the cold junction and the hot tip, the hot junction. When the hot probe momentarily touches the semiconductor film, a current passes from the cold junction to the hot junction for a *n*-type semiconductor, whereas for the *p*-type, the current passes from the hot junction to the cold junction . All the deposited films have been tested by this technique to find their semiconducting nature. The type of electrical conduction of the TiO_2 thin film samples prepared for the present study was found to be *n*-type as verified by the hot-probe technique.

Electrical characterization study

The electrical resistivity of the transparent conducting oxide (TCO) thin films strongly depend on several factors such as rate of deposition, thickness, temperature and purity. The intrinsic defects, more precisely oxygen vacancies, can be attributed

to the electrical conductivity of metal oxides and the presence of a large number of defects around boundaries strongly affects the motion of charge carriers. These defects act as traps for the free charge carriers and thereby reduce the electrical conduction.

Mass methods

A method is proposed for easy determination of the mass thickness of thin films using electron-probe microanalysis.

Optical interference method

Photometric

Photoluminescence spectral study is an important technique for measuring the purity and crystalline quality of semiconductors. Fluorescing sample (both films and solids) can be analyzed, using luminescence spectrophotometer generally on excitation with higher energy radiation such as UV (with wavelength selected). These samples give light in the lower energy region (usually in the visible region), which when wavelength scanned, yields emission spectrum characteristics of the given luminescent species.

Ellipsometry

Electromagnetic radiation from an Ultraviolet-Visible source passes through a wavelength selected cell as in a spectrophotometer. Unlike the measurement of absorption in a Spectrophotometer, however a portion of the emitted radiation that exists from the cell is measured. Because the luminescent radiation can be emitted in broad band that are centered at different wavelengths, a second wavelength selector is required in the path of the emitted radiation between the cell and the detector. The emitted radiation is not usually measured in-line with the exciting radiation, as in absorptive measurements, owing to possible spectral interference from the exciting radiation. Photoluminescence has been measured at many angles relative to the incident radiation and at many locations within the hole. The most common practice is to measure the emitted radiation of 90° from the path of the exciting radiation and at the center of the cell. The signal from the detector is amplified, if required and routed to a read out device.

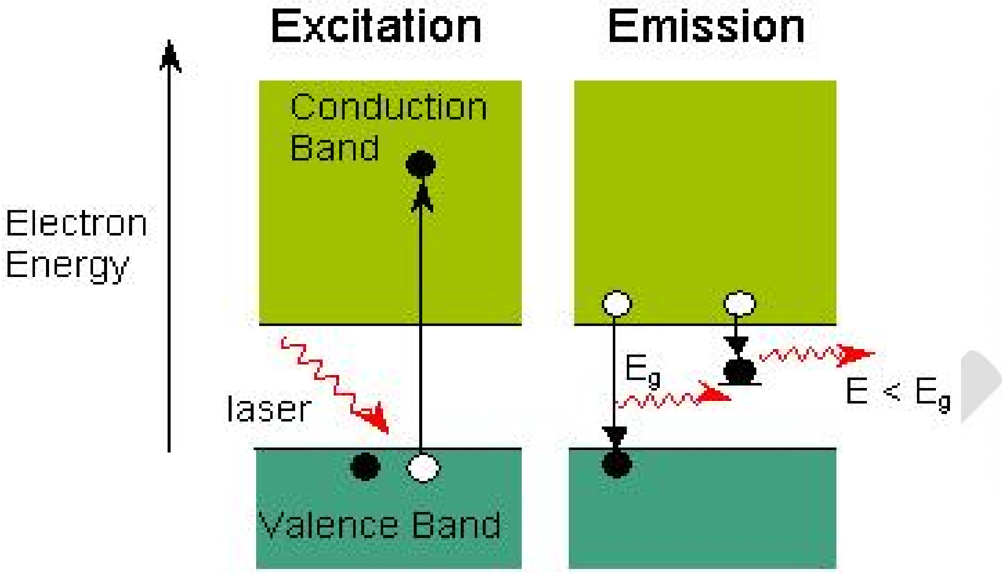


Figure: Excitation and Emission mechanisms in photoluminescence

Scanning instruments can be used to obtain two types of spectra (Figure 3.10). If the wavelength at which the emission observed is held constant, the wavelengths at which excitation occur (excitation spectrum) can be scanned. If the wavelength of the excitation radiation is fixed then the wavelength at which the emission occurs (emission spectrum) can be scanned.

Substrate cleaning

Substrate cleaning plays an important role in the deposition of thin films. Transparent microscopic glass slides cut into 2.5 x 2.5 cm^2 have been used as substrates and were subjected to the following cleaning process to remove the unwanted impurities present on their surface.

- The glass substrates were washed with detergent by scrubbing with cotton dipped in liquid soap to remove oil and grease.
- The glass plates were then rinsed thoroughly in deionized water to remove any traces of the soap solution left on the surface followed by rinsing with acetone.
- Then the glass plates were soaked in hot chromic acid (at 90 ^{o}C) for about two hours to dissolve the fine silica layer formed on the surface.
- Finally, the substrates were rinsed thoroughly in deionized water and kept in ultrasonic water bath for 15 minutes and dried at 100 ^{o}C for one hour in an air oven.

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THIN FILM PHYSICS (18PHP205C)

UNIT - I

QUESTIONS UNIT I	**CHOICE1**	**CHOICE2**	**CHOICE3**	**CHOICE4**	**ANSWER**	ANSWER
The process of flash evaporation is similar to ________.	Chemical evaporation	Thermal evaporation	Vapour phase evaporation	None of these	2	B
With the help of ________ method a constant composition film can be produced.	Flash evaporation	Resistance heating	Multi evaporation	Chemical evaporation	1	A
The simultaneous deposition process from different sources is known as ________.	Co-evaporation technique	Electron beam technique	Multi evaporation technique	None of these	1	A
Film composition depends upon ________.	Rate and time of deposition	Nature of deposition	Speed of deposition	Rate of deposition	1	A
________ method is generally adopted when a material has a tendency to decompose or dissociate during evaporation	Multi evaporation	Flash evaporation	Thermal evaporation	Chemical evaporation	2	B
In flash evaporation method the composition of the gaseous phase will be ________ the same as that of the charge.	More or less	More	Less	None of these	1	A
In distribution of deposit, the velocity distribution will follow the cosine law and decrease with ________ of y.	Increase	Decrease	Both	None of these	1	A
In distribution of deposit, the velocity distribution will follow the cosine law and decrease with increase of y. Such a source is called ________.	Directional source	Cylindrical source	Point source	Surface source	3	C
Vacuum should be as high as possible in ________ method.	Thermal deposition	Chemical deposition	Flash evaporation	Multi evaporation	1	A
If y = 0, then a surface source resembles a ________ source except that it is not spherical.	Directional source	Cylindrical source	Point source	Surface source	3	C
In distribution of deposit, the heating sources are made from _________ refracting material.	Tungsten	Graphite	Quartz	Platinum	1	A
The amount of deposits received by a substrate will depend on _________.	Nature of the source	Inclination of the vapour stream	Inclination of the vapour stream &Nature of the source	None of these	1	A
In distribution of deposit, maximum amount of deposition takes place when _________.	q = 0	y = 0	Both will be zero	All the above	4	D
The quality and the characteristics of the deposit will depend on the _________.	Nature of deposition	Rate of deposition	Velocity distribution	None of these	2	B
_________ technique is particularly suitable for film composition.	Flash evaporation	Chemical evaporation	Multi evaporation	None of these	3	C
In _________ method the composition of the gaseous phase will be more or less the same as that of the charge.	Multi evaporation	Multi twinning	Flash evaporation	None of these	3	C
In point source dm is _________.	$\frac{m}{\pi} \cos \psi \, d\omega$	$\frac{m}{\pi} \sin \psi \, d\omega$	$\frac{m}{4\pi} d\omega$	None of these	3	C
The process of _________ is similar to thermal evaporation.	Chemical evaporation	Flash evaporation	Vapour phase reaction	None of these	2	B
The simultaneous evaporation process from _________ sources is known as co-evaporation technique.	Same	Different	Both a & b	None of these	2	B
A high substrate _________ generally improves the physical characteristics of the deposited films.	Pressure	Density	Temperature	None of these	3	C
High vacuum is essential for_________.	Thermal deposition by resistive heating	Sputtering of cathode material in presence of inert gas	Thermal deposition by resistive heating & Sputtering of cathode material in presence of inert gas	Chemical vapour deposition	3	C

_________ is the most commonly used technique adopted for the deposition of metals and alloys.	Thermal decomposition	Thermal deposition in vacuum	Both a & b	None of the above	2	B
Thermal deposition in vacuum involved _________ of the material in vacuum by thermal energy.	Decomposition	Evaporation or sublimation	Both a & b	None of the above	2	B
The quality and characteristics of the deposit depends on _________.	Rate of deposition	Substrate temperature	Ambient pressure	All the above	4	D
At steady state of evaporation vapour atoms or molecule will have an equilibrium pressure (P) which is given by the relation _________.	$P = \frac{V}{N} kT$	$P = \frac{V}{k} NT$	$P = \frac{N}{V} kT$	$P = \frac{V}{T} Nk$	3	C
Sticking coefficient has maximum value of _________.	0	1	2	4	2	B
Sticking coefficient has minimum value of _________.	0	1	2	4	1	A
Thermal deposition is the most common used technique adopted for the deposition of _________.	Metals	Alloys	metal & alloys	None of these	3	C
_________ in vacuum involve evaporation or sublimation of the material in vacuum by thermal energy.	Physical deposition	Thermal deposition	Chemical deposition	None of the above	2	B
_________ is essential for thermal deposition by resistive heating.	High pressure	High vacuum	Low vacuum	None of the above	2	B
A thin film is a solid layer having thickness varying from a few Å to about _________.	10 mm	15 mm	20 mm	5 mm	1	A
Based on the thickness of the thin films, they are categorized into _________.	Ultra thin, thin, comparatively thicker one	Ultra thin & thin	Thin & comparatively thicker one	None of these	1	A
Thick films are obtained by the process of _________ and subsequently fixing a paste composed of a mixture of metals/alloys along with or without glass suspended in some organic solvents.	Screen printing	Chemical vapour deposition	Thermionic emission	Electroless plating	1	A
The thickness of ultra thin film ranges from _________.	25 – 50 Å	50 – 100 Å	100 – 1000 Å	More than Å	2	B
The dimension along _________ direction is known as the film thickness.	x & y	y	z	y & z	3	C
Highly conducting Na, K, rubidium, gold & platinum in the bulk form show _________ temperature coefficient in their thin film states.	+ ve	– ve	Both a & b	zero	2	B
Thin bismuth films unlike bulk showed super conductivity properties at _________ temperature.	low	high	medium	All the above	1	A
Due to the unbalancing forces near the surface region _________ characteristics are observed near a thin film.	Thermionic emission and absorption of gases	Solid state reaction	Thermionic emission & catalysis	All the above	4	D
Thick films have thickness about _________.	10 mm	5 mm	20 mm	None of the above	1	A
TCR stands for _________.	Temperature coefficient of resistance	Temperature conducting resistance	Temperature controlling resistance	None of the above	1	A
Which one of the following is a refractory metal?	Tantalum	Titanium	Aluminum	None of these	1	A
If M_A & M_B are the molecular weights of A & B then the ratio	$\frac{E_A}{E_B} = \left(\frac{p_A}{p_B}\right)\left(\frac{M_B}{M_A}\right)^{\frac{1}{2}}$	$\frac{E_A}{E_B} = \left(\frac{p_A}{p_B}\right)\left(\frac{M_A}{M_B}\right)^{\frac{1}{2}}$	$\frac{E_A}{E_B} = \left(\frac{p_B}{p_A}\right)\left(\frac{M_B}{M_A}\right)^{\frac{1}{2}}$	these	2	B
are generally used in the form of wire or strip having	Same	Different	Circular	these	2	B
The higher vapour pressure will tend to vapourize at a _________ temperature than the other.	higher	medium	lower	None of the above	3	C
The composition rate of nichrome alloy is _________.	60 Ni : 20 Cr	20 Ni : 60 Cr	80 Ni : 20 Cr	20 Ni : 80 Cr	3	C
According to Holland, the ratio of evaporation of two components A & B from the alloy will be _________.	$\frac{E_A}{E_B} = \frac{W_B}{W_A}\left(\frac{P_A}{P_B}\sqrt{\frac{M_B}{M_A}}\right)$	$\frac{E_A}{E_B} = \frac{W_B}{W_A}\left(\frac{P_B}{P_A}\sqrt{\frac{M_B}{M_A}}\right)$	$\frac{E_A}{E_B} = \frac{W_A}{W_B}\left(\frac{P_A}{P_B}\sqrt{\frac{M_B}{M_A}}\right)$	none of these	3	C
Melting point of aluminum is _________.	961 °C	659 °C	710 °C	573 °C	2	B
What is the melting point of Al_2O_3?	820 °C	710 °C	2030 °C	2530 °C	3	C
Metal films were formed by sputtering of cathodes with _________ energy positive ions.	low	high	medium	None of the above	2	B
The melting point of carbon is _________.	3700 °C	1418 °C	535 °C	772 °C	1	A
The evaporant material doesn’t react with the refractory metal at _________ temperature evaporation.	low	medium	high	none of these	3	C
All the surface impurities of the filament or the strip are removed by the evaporation and this process is called _________.	Flash cleaning	Thermal evaporation	Flash evaporation	None of these	1	A

The evaporation rate of a species depends on its _________.	Pressure	Temperature	Density	All the above	2	B
The charge consists of two or more constituents which have _________ vapour pressure.	same	Different	high	none of these	2	B
Raoult's law of depression of vapour pressure is valid for _________.	Binary alloy	Nichrome alloy	both	none of these	1	A
The vapour pressure of each component is depressed compared to that of the pure state by an amount _________ to its concentration.	Inversely proportional	Directly proportional	Equal	None of these	2	B
The melting point of Barium is _________.	659 °C	710 °C	2100 °C	961 °C	2	B
Which among of the following is a refractory oxide?	BeO	MgO	Al_2O_4	SiO_3	3	C
The melting point of BeO is _________.	271 °C	573 °C	2530 °C	573 °C	3	C
The melting point of Au is _________.	2100 °C	817 °C	573 °C	1063 °C	4	D

$\boldsymbol{\alpha_c = \frac{E_1 - E_R}{E_1 - E_S}}$ $\alpha_c = \frac{E_1 - E_R}{E_1 + E_S}$ $\alpha_c = \frac{E_1 + E_R}{E_1 - E_S}$ $\alpha_c = \frac{E_1 + E_R}{E_1 + E_S}$

$\boldsymbol{\frac{\lambda}{n}}$ $\frac{\lambda}{n}$ $\frac{n}{\lambda}$ $\frac{n}{\lambda}$

$\frac{d_1 - d_2}{d_1 d_2}$ $\frac{d_1}{d_1 - d_2}$ $\boldsymbol{\frac{d_1 d_2}{d_1 - d_2}}$ $\frac{d_2}{d_1 - d_2}$

Thickness measurement and Nucleation and Growth in Thin Film:

Thickness measurement: electrical methods – optical interference methods – multiple beam interferometry – Fizeau – FECO methods – Quartz crystal thickness monitor. Theories of thin film nucleation – Four stages of film growth incorporation of defects during growth.

Weight difference method

Name of the measurement system itself defines its aspect of calculation of thickness where the weight of the substrate is measured before and after deposition of material hence the weight materialise calculated. But only the weight of material is not significant to be calculated hence it requires knowing the dimensions of deposition also, i.e., area of the substrate. Suppose that ‘m’ Isa mass of the film deposited on the substrate which covers area ‘A’ cm2, the thickness
Fizeau – FECO methods‘t’ is calculated by using mass of deposit ‘m’ and density ‘ρ’ of the material. The value pertaining to the bulk material is usually taken for ‘ρ’ even though the actual density of thin film is low. The thickness is calculated using the equation

.

Fizeau – FECO methods

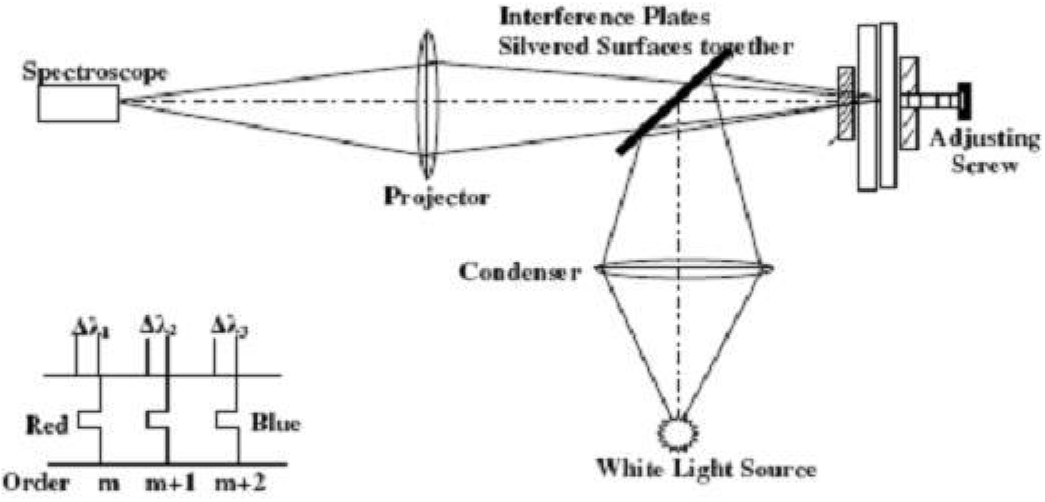
When two reflecting surfaces are brought into close proximity, interference fringes are produced, the measurement of which makes possible a direct determination of the film thickness and surface topography with high accuracy.Two types of fringes are utilized for thickness measurements, (a) Fazio methodoffringes of constant thickness using multiple beam and (b) Fringes of equal chromatic order method (FECO). The Fazio fringes of equal thickness are obtained in an optical apparatus of the type shown in Fig. 3.1. The interferometer consists of two slightly inclined optical flats, one of them supporting the film, which forms a step on the substrate. When the second optical flat is brought in contact with the film surface, and the interferometer is illuminated with a parallel monochromatic beam at a normal incidence and viewed with a low-power microscope, dark fringes can be observed which trace out the points of equal air-gap thickness. The two adjacent fringes are separated by/2 (where is the wavelength of light used). If the surfaces of the optical flats are highly reflecting and very close to each other, the reflected fringe system consists of very fine dark lines against a white background with a

fringe width which can be made as small as/100. By adjusting the relative positions of the flats to forma wedge-shaped air gap, the fringes can be made to run in straight lines perpendicular to the steps on the opaque film. The fringes show a displacement expressed as a fraction of the λ/2 fringe spacing gives the film thickness and it can be measured to about tenth of a fringe.

In second method, instead of the air wedge, two parallel plates illuminated with white light are used. Fringes occur at wavelength for which t/is constantsothatresultant spectrumis banded. This method is called as “Fringes of Equal Chromatic Order (FECO)”. In reflection,

fringes appear dark on bright background. If one of the plates is covered by a film, a displacement Δis seen in the nthorder fringe, fromwhichfilmthickness can be calculated as,

$$t = \frac{m}{2\ \Delta\ \lambda}\ \overset{\circ}{\mathrm{A}}$$



(b) FECO

Nucleation theory

In fact, the classical nucleation theory says nothing about such processes, other than that theyare possible. In any case, for a film to form on the substrate surface, it is necessary that either nuclei formed by such homogeneous processes are able to grow or that a sufficient number of surface defects are available to serve as sites of heterogeneous nucleation. The mode of film formation is determined by the relative values of the various energies involved in the process, and this mode largely determines the eventual structure of the film. There are two main comparisons to be considered. One of these contrasts the height of the delusion barrier Edtothe background thermal energy. Fideism large compared to the background thermal energy then surface mobility of ad atoms is very low. Under such conditions, ad atoms more or less stick where they arrive on the substrate surf

For growth of crystalline fialms, it is important that'd be less than the background thermal energy so that ad atoms are able to seek out and occupy virtually all available equilibrium sites in the film crystal lattices it grows. This requires the substrate temperature and/or the degree ofsupersaturation of the vapor to be high enough to insure such mobility.Supposethatthisisindeedsoandthattheadatomsareabletomigrateover the surface.

The other important energy comparison concerns the propensity for atoms of film material to bond to the substrate. This is represented by the magnitude offs, relative to their tendency to bond to other, less well-bound, atoms offilmmaterial, as represented by Ef. Two kinds of growth processes can be distinguished, one withers larger in magnitude than Ef, and a second with the relative magnitudes reversed. If Efs is the larger of the two energy changes in magnitude, then film growth tends to proceed in a layer by layer mode, as indicated in the schematic diagram in Figure 1.8. Ad atoms are more likely to attach to the substrate surface than to other film material surfaces. Once small stable clusters of ad atoms form on the surface, otherad atoms tend to attach to the cluster at its periphery where they can bond with both substrate and film atoms, thereby continuing the planar growth,. This layer-by-layer film growth mode is often called the Frank—van der Merwe growth mode or FM mode, according to categorization of growth modes proposed by Bauer (1958) on the basis of more macroscopic considerations of surface energy. This alternate point of view will be considered

On the other hand, fief is larger in magnitude than Efs, thenit is energetically favorable for ad atoms to form three-dimensional clusters or islands on the surface of the substrate. Film growth proceeds by the growth of islands until they coalescence; this type of growth is commonly called the Volmer—Weber growth modeortheVWmodeA third type of growth, which combines features of both the Frank {Vander Merwe and the Volker {Weber modes, is called theStranski—Krastanovgrowth mode or SK mode. In this mode, the film material tends to prefer attachment to the growth surface rather than the formation of clusters on the growth surface; that is, Eves is greater in magnitude than Ef.However, after a few monolayers of film material are formed and after the structure of the film becomes better denned as a crystal in conformity with the substrate, the tendency is reversed. In other words, once the planar growth surface becomes established as film material, subsequent ad atoms tend more together into clusters than to continue planar growth. The magnitude ofEfsappears to depend on the thickness of the film in the early stages of growth, decreasing from values larger than the magnitude off to values that are smaller. The occurrence of this mode is most likely when the first few layers of film material are heavily strained due to the constraint of the substrate.

<u>Four stages of film growth incorporation of defects during growth.</u>

- Grain Structure: Nano to Micro Size; Dense; Porous; Columnar; Granular

- Morphology: Particles; Quantum Dots; Nano-wires, - rods,-tubes,-sponges; Films; Multilayers (Super lattices, Wells…)

- Microstructure: Amorphous; Nano to Micro-Crystalline; Oriented; Epitaxial

- Topography: Atomically smooth to micron scale rough

- Crystal Structure: Normal; Polymorphic; Metastable

- Chemical Structure: Normal; Variable and Extended Solubility; Non-equilibrium structuresOpto-electronic Properties of Micro & Nano-structured Films depend very strongly on nucleation and growth processes and hence on numerous deposition parameter.

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UNIT II

RF sputtering can be done at pressure _________ the ordinary g	Greater than	Lower than	Equal to	none of these	Lower than
In RF sputtering method an impedance matching between ____	Power suppl	Discharge tu	Power suppl	Electrodes and DC voltage	Power supply and discharge tube
RF sputtering technique is particularly useful for the deposition	Insulator	Dielectrics	Semiconduct	Conductor	Dielectrics
To increase the efficiency of DC sputtering by applying ______	High frequen	High pressur	High tempera	High voltage	High frequency
The deposition of films from gaseous phases by chemical reacti	Chemical de	CVD or vapo	RF sputterin	Cathodic sputtering	CVD or vapour plating
The organometallic compounds of silicon such as tetra ethoxy s	Pyrolysis	Vapour phas	Vapour trans	Disproportionation method	Pyrolysis
In pyrolysis process _________ is introduced as a reactant carri	Carbon	Hydrogen	Oxygen	Nitrogen	Oxygen
Philips process is an example of _________.	Vapour trans	Disporportio	Pyrolysis	Vapour phase reaction	Vapour phase reaction
In vapour transportation method, vapours of two reacting consti	Low tempera	High tempera	Very low ten	Very high temperature	High temperature
Vapour transportation technique is often used for the preparatio	Thin films	Thick films	Very thin fil	Very thick films	Very thick films
In disproportionation method the higher valency sate compound	Low	high	Very low	very high	Low
Disproportionation method is often used for the preparation of l	Si & I	Ge & Si	Ge & CdS	Ge & I	Ge & Si
Chemical deposition method depends on the deposition of the fi	Current	Temperature	Pressure	None of these	Current
_________ method is widely used for the fabrication of the con	Vapour phase	Chemical dep	Sputtering	Flash evaporation	Chemical deposition
In order to obtain a good anodic oxide film, the bath compositic	AC voltage	DC voltage	both	either a or b	DC voltage
The thickness of the anodic oxide layer increases with the passa	Current	voltage	frequency	temperature	Current
Chemical displacement _________ on the difference in relative	Depends	Doesn’t depen	Either a or b	None of these	Depends
_________ method is suitable for the deposition of some active	Anodic oxidat	Electro deposi	Electroless pl	Chemical displacement	Electroless plating
In chemical reaction process, the deposition is by the reduction	Organic	Metal salts	Inorganic	None of these	Metal salts
The advantage of electroless plating process is possible to coat	Conducting	Non-conducti	Dielectrics	Semiconducting	Non-conducting
_________ is one of the reducing agent in the deposition by che	Formaldehyde	Acetylene	Chloride	Silicon	Formaldehyde
The films deposited by _________ are generally porous, non-ad	Chemical reac	Electroless pla	Chemical disp	Anodic oxidation	Chemical displacement
In anodic oxidation, the film thickness may be between_______	1 – 10 nm	1 – 10 cm	1 – 10 mm	1 – 10 micron	1 – 10 micron
In _________ process, metal films can be deposited without pas	Anodic oxidat	Electroless pla	Electro deposi	Chemical displacement	Electroless plating
Low pressure sputtering is normally carried out at _________ g	10^{-9} torr	10^{-2} torr	10^{-3} torr	10^{-15} torr	10^{-3} torr
The ionization of gas molecules under low pressure sputtering i	$10^{-9} – 10^{-6}$	$10^{-1} – 10^{-2}$	$10^{-4} – 10^{-5}$	$10^{-6} – 10^{-8}$	$10^{-1} – 10^{-2}$
In low pressure sputtering the ionization can be achieved simply	Decreasing	Increasing	Either a or b	None of these	Increasing
Low pressure sputtering is carried out by the use of _________	IR	Radio	UV	visible	Radio
In low pressure sputtering the ionization is increased by increas	Straightening	Spiraling	Curving	none of these	Spiraling
In normal sputtering cases only _________ gases are used.	noble	inert	both a & b	none of these	inert
In reactive sputtering, if O_2 or N_2 are used as media, then the io	Sulphite or ca	Oxide or nitric	Oxide or calci	Sulphite or nitride	Oxide or nitride
Materials used for sputtering usually made of _________.	Conductor	Metals	Insulator	none of these	Metals
In glow discharge sputtering due to ionization a number of posit	–ve glow	+ve glow	High intensity	High intensity –ve glow	–ve glow
In glow discharge sputtering the positive ions formed from colli	Anode dark sp	Crooke’s dark	Cathode dark	Faraday dark space	Faraday dark space
In glow discharge sputtering the composition of the sputtered fi	Anode & ener	Cathode & en	Anode & mon	Cathode & momentum	Cathode & momentum
In glow discharge sputtering the positively charged ions formed	Osmosis	Diffusion	Temperature g	Pressure gradient	Pressure gradient
In _________, the electron beam comes out of a loop type of a	Work accelera	Self accelerate	Bend beam el	None of these	Work accelerated gun
If the sputtering process doesn’t involve any chemical reaction,	Physical sputt	Reactive sputt	High pressure	None of the above	Physical sputtering
Sputtering decreases with the _________ of the ion energy.	Increase	Large increase	Decrease	Large decrease	Large increase
In _________ gun the electrons are emitted from hairpin type o	Work accelera	Self accelerate	Bend beam el	None of the above	Self accelerated gun
If the sputtering process involves some reactions, it is known as	Physical sputt	Reactive sputt	High pressure	None of the above	Reactive sputtering
Minimum voltage at which break down takes place is called ___	Break down	Threshold	line	None of the above	Break down
In _________ gun a beam of electron is bend by an appropriate	Work accelera	Self accelerate	Bend beam	None of the above	Bend beam
The glow discharge technique can be understood from the beha	low	high	very low	very high	high
In Townsend region a _________ in current at constant voltage.	Increase	Large increase	Decrease	Large decrease	Large increase
The region where there is large increase in voltage as well as cu	Townsend reg	Normal catho	Abnormal glo	None of the above	Abnormal glow
In glow discharge sputtering, the graphs show a sharp fall of vo	Increase	decrease	Increase or de	None of the above	Increase
A continuous sputtering can take place only in _________ regio	Townsend	Normal catho	Abnormal glo	None of the above	Abnormal glow
In glow discharge sputtering, the voltage falls across gaseous co	maximum	minimum	Either a or b	None of the above	maximum
The ejection of atoms from the cathode surface under a ______	low	very low	high	very high	high
An electron emitted from the cathode passing through the catho	Negative glow	Cathode glow	Faraday dark	None of the above	Negative glow
Because of the _________ temperature of working, the electron	low	very low	high	very high	high
In _________ region a considerable amount of positive ion elec	Negative glow	Cathode glow	Faraday dark	None of the above	Negative glow
The sputtered atoms have _________ energies than those of the	higher	lower	Either a or b	none of these	higher
In _________ method, an electron beam is accelerated and focu	Electron beam	Cathode sputt	Reactive sputt	RF sputtering	Electron beam
In _________ gun, the electrons are focused through a Wehnelt	Work accelera	Self accelerate	Bend beam el	None of these	Self accelerated
The sputtering increases with the _________ of the bombarding	energy	mass	energy and m	None of the above	energy and mass
When sputtering increases, the angle of incidence to the target v	Increase	Decrease	Increase or de	None of the above	Decrease
In cathode sputtering phenomenon, for the rejection of atoms w	inert	noble	both of the al	None of the above	noble
Auger transition takes place along with the emission of _______	a - electron	b - electron	g - electron	None of the above	g - electron

Electrical properties of metallic thin films

Sources of resistivity in metallic conductors – sheet resistance - Temperature coefficient of resistance (TCR) – influence of thickness on resistivity – Hall effect and magneto resistance – Annealing – Agglomeration and oxidation.

Unit III

The electrical properties of interest are the type of carriers, resistivity, and mobility and carrier concentration. Here we describe the commonly used parameters.

Resistivity.

The most commonly used technique for measurement of resistivity ofsemicondctors is the "four probe method". Four collinear metal probes are placed on the semiconductor. A constant current (I) is passed between the two outer probes and the voltage (V) between the inner two probes is measured. Resistivity is then calculated from the relation

Where so is the distance between the probes. Another parameter usually measured in thin film samples is the sheet resistance, which is expressed in Q / D. This is measured using a simple two probe method, selecting a square geometry for the specimen. The sheet resistivity is then calculated by multiplying the sheet resistance with the thickness of the film. The sheet resistance is independent of the size of the square we select.

Electrical Characterization and Four point probe method and resistivity of thin films

The use of thin films as resistors, contacts and interconnections has lead to extensive study of conductivity, temperature dependence, the effect of thermal processing stability and so on. Investigationofthe critical resistivity as a highly structure sensitive properties make it possible to gain insight into the structuralandelectrical properties of the metal films which is

important from both the theoretical and practical point of view. The contact methods are most widely used for the measurement of resistivity. These methods include two-point probe, four- point probe and the spreading resistance. The two-point probe method is simple, easy to use and useful for high resistive thinfilms.In this method constant voltage ‘V’ is applied between two fixed position probesseparation ‘d’ in cm and current passing through a sample of known dimension (crosssectional area ‘A’ inis measured with anappropriate currentmeter. For uniformsample, resistivity is given by,

$$\rho = \left(\frac{AV}{Id} \right) \quad \Omega\text{-cm}$$

In case of semiconducting thin films, the resistivity decreases with increase intemperature.The thermal activation energies ‘Ea’ are calculated by using equation

$$\rho = \rho_0 \exp\left(\frac{-E_a}{KT}\right)$$

where symbols have their usual meanings. Hence we plot Log (ρ) versus 1/T and itsslope leads to the estimation of activation energy. The experimental setup used to study the variation of resistivity with temperatureis schematically shown in Fig. 3.6. The brass plate of size 10 cm ×0.5 cm is grooved atthe bottomside soas to fit theheating element (Toni, 60 watt) parallel to the length of the plate, in order to achieve the uniformtemperature. The sample is mounted on the topof the plate.The thin film of size 1 ×1 cm2on the glass substrate is used for theresistivity measurement. Silver paste was applied for making the good ohmic contacts tothe film. A mica sheet was used between the filmand thebrass plate to provide theinsulation. The temperature is measured with chromel-alumel thermocouple, which isfixed at the center of the sample. The temperature was recorded on digital panel meter (0to 199.9 mV range) (DPM) supplied by Omega Electronics, Jaipur. Aplab power supplyis used for passing current through the film and the current was measured with MECOmade (MIC-60E) digital currentmeter.

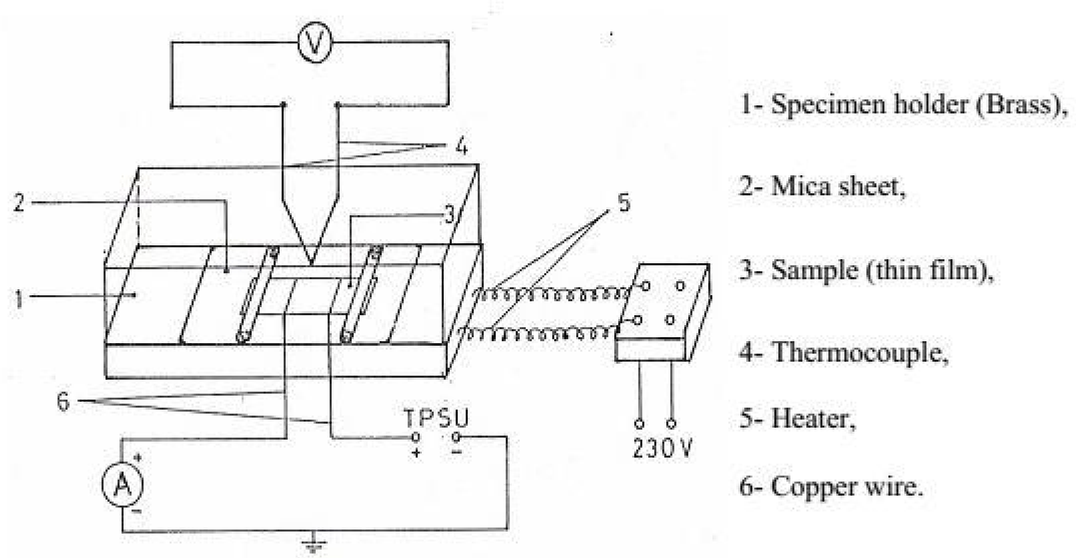

Fig. 3.6 Schematic circuit diagram for the measurement of electrical resistivity of thin film [Lab. setup]

Annealing Process

In the present work of junction fabrication, we prepared p-CdS samples by the thermal annealing of copper deposited over n-CdS under high vacuum. Since this process forms the major part of our work, it needs an elaboration.The annealing chamber was made of a glass tube over which nichrome wire was wound uniformly over the entire length of the tube. Length of the glass tube is such that three samples (5 x 1.2 cm2) can be placed well inside the tube,so that a uniform heating was ensured for the samples. The tube was placed inthe vacuum coating chamber and the pressure was measured using a penninggauge (Hindhivac, model STA 6P4M). Temperature was controlled bycontrolling the current through the nichrome wire connected to a variac and wasmeasured using a Chromel-alumel thermocouple. The heating and cooling ratefor all the annealing was kept at the rate of 2°C/minute.

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UNIT III

For a tetragonal tin the plane is _________.	(112)	(111)	(311)	(331)	4
All single crystals have _________ nature leading to imperfections in the crystals.	Mosaic	Similar	Individual	Material	1
Schottky defects are generally observed in _________ crystals.	Rhombic	Monoclinic	Ionic	Metallic	3
Schottky defects are caused by the movement of _________ ions.	Positive	Negative	Neutral	Neither negative nor positive	2
The vacancy concentration in a crystal is _________.	High	Very high	Low	very low	3
The vacant sites give rise to colouration of crystals by absorption of light, these sites are known as _________ centres.	F centre	V centre	F' centre	V' centre	1
In Schottky defects the lattice bonding are rather weak as in _________ halides.	Aryl halides	Metal halides	Alkali halides	Benzyl halides	3
At low concentration of defects may cause _________ change in the conductivity of the material.	low	small	large	high	3
A _________ density of substitution may create a further disorder in the crystal.	very high	high	very low	low	2
If a pentavalent ‘P’ is introduced in the lattice, a new _________ energy state will be created which is known as the donor level.	Electronic	Vibrational	Rotational	Transitional	1
The dislocations involving some lattice translations in the direction of the dislocation line known as _________.	Burger vector	Zero vector	Null vector	None of these	1
An edge dislocation is _________ to the Burger vector.	Perpendicular	Normal	Horizontal	None of these	2
The line defect observed in a region where the deformed portion meets the rest of the undistorted crystal is called _________.	Screw dislocation	Point defect	Edge dislocation	Vacancy	3
The crystal may partly or fully deformed and it cannot be come back to its original condition then the phenomenon is called _________.	Microscopic defect	Plastic deformation	Screw dislocation	Edge dislocation	2
The lattice fault arising from plastic deformation is called _________.	Vacancy	Screw dislocation	Point defect	Dislocation	4
The dislocation density can be estimated from the ratio is _________.	SV	S/V	V/S	None of these	2
The movement of atom is by an amount so as to cause the same registry, then the process is called_________.	Dislocation	Slipping	Defect	Vacancy	2
The slipping of a layer of atoms over another in a crystal takes place in its cleavage plane and this phenomenon give rise to a band known as _________ band.	Dislocation	Slipping	vacancy	edge	2
The Burger vector lies _________ to the screw dislocation.	Perpendicular	Parallel	Normal	None of these	2
_________ is introduced in the lattice a new electronic energy state will be created which is known as the donor level.	Pentavalent	Divalent	Trivalent	Monovalent	1
The Newton ring method using a _________ light for the estimation of film thickness.	sodium	red	white	green	3
The _________ method depends on the change in the transmittance of light at normal incidence with the increase of film thickness.	Optical	Photometric	Ellipsometric	Chemical	2
The change in the transmittance of light at normal incidence with the increase of film thickness is given by _________ law.	Lambert	Lorentz	Ampere’s	None of these	1
A transmittance ($T = I/I_c$) versus film thickness graph on a semi-log scale will be a _________ line.	Parallel	Straight	Perpendicular	None of these	3
_________ method is suitable for measuring the thickness of surface layers or films and their optical constants.	Optical	Chemical	Ellipsometry	Photometric	4
The use of a polarized light for reflection from a film or surface layers on a substrate at a non-normal incidence at an angle of incidence _________.	35°	65°	48°	45°	4

In ellipsometric measurements the basic equation can be written as _________.	$r_s/r_p = \tan\psi \exp(j\Delta)$	$r_p/r_s = \tan\psi \exp(j\Delta)$	$r_p/r_s = \tan\psi$	$r_s/r_p = \tan\psi$	2
Ellipticity of the reflected light is measured from the ratio of _________ axis.	major	minor	Major to minor	minor to major	4
_________ instrument is used to measure the different parameters of the elliptically polarized.	Ellipsometer	Photometer	Echometer	None of these	1
The technique involves the use of a polarized light for reflection from a film or surface layer on a substrate at _________ incidence.	Normal	Non-normal	sme	None of these	2
The term Cf_o is the _________.	Sensitivity for mass determination	Sensitivity for frequency determination	Sensitivity for temperature determination	Sensitivity for volume determination	1
The change in the transmittance of light at normal incidence with the _________ of film thickness is given by the Lambert law.	Constant	Decrease	Increase	None of the above	3
The microbalance technique depends on the increase of the weight of a film due to its _________.	temperature	pressure	mass	volume	3
The quartz fibre is used in _________.	Crystal oscillator method	Micro balance method	Ellipsometry	Interferometry	2
In Lambert law $I = I_o \exp(-\alpha t)$, α is _________.	Absorption coefficient	ce coefficient	Emission coefficient	None of the above	1
In film thickness measurement techniques, _________ decreases with the increase in film thickness.	mass	pressure	temperature	frequency	4
TCF stands for _________.	Temperature control of the frequency	Temperature coefficient of frequency	Temperature common to frequency	None of the above	2
The sensitivity of quartz thickness monitor is about _________.	10^{-8} g/cm^2	10^{-10}g/cm^2	10^{-9}g/cm^2	10^{-7}g/cm^2	1
A _________ metal electrode is deposited on the central area of quartz crystal in deposition of films.	Circularly shaped	Elliptically shaped	Square shaped	None of the above	1
The films deposited on a substrate are _________.	Heterogeneous	Non homogeneous	Homogeneous	None of the above	3
The distance between fringes or lines in interferometry depends on the _________ as well as the wavelength of the monochromatic light.	Air gap	Band gap	Distance	All the above	1
Thickness of sharp fringe perpendicular to stop with equal displacement will be determined by‘t’ equal to _________.	bλ/2a	λa/2b	λ/2ba	None of these	1
In FECO method, film thickness‘t’ can be calculated from the relation_________.	mΔλ/2	mΔλ/4	mΔλ	mΔλ/3	1
Film thickness can also be measured accurately from interference fringes using _________.	Beam interferometry	Interferometry	Multiple beam interferometry	None of these	3
Distance between fringes or lines in interferometry depend on air gap as well as on the _________ of the monochromatic light.	Band gap	Frequency	Amplitude	Wavelength	4
In other methods of interferometry basic assumption is that the film properties such as resistance, capacitance, Hall voltage etc. depends only on -_________, but not on the deposition conditions.	Materials used	Film thickness	Deposition parameters	None of these	2
The method which also measures the roughness of a surface known as _________.	Stylus method	Deposition method	FECO method	None of these	1
An instrument known as _________ measures the variation in the height of the film from a base as it travels along the surface of the film.	Ellipsometer	Interferometer	Talysurf	Stylus	3
An instrument used for measuring the rate of deposition is _________.	Optical meter	Rate meter	Photometric meter	All the above	2
The absorption is generally an exponential function of _________.	Substrate thickness	Target thickness	Film thickness	None of the above	3

The strain created on crystal by effect of stress is released by slipping of some atomic layer by _________.	Translational	Vibrational	Rotational	Either a or c	4
Releasing of strain causes disordering of crystalline material in _________ region.	Contact	Bulk	Thin	Thick	1
The method of removal of defects is by suitable _________.	Partial annealing	Self annealing	Both a & b	None of the above	1
Vacancies, dislocations etc. in thin films can be minimized by _________ process.	Diffusion	Annealing	Absorption	None of the above	1
Thin and ultra thin film cannot often subjected to _________ temperature.	high	low	very high	very low	1
T_D can be as low as _________ of melting point of bulk material.	1/3	1/4	3/4	2/3	1
The removal of defect and stabilization of films should be subjected to annealing treatment in vacuo below certain temperature termed as _________.	Continuity temperature	Transition temperature	Discontinuity temperature	Critical temperature	3
Due to thermal vibration atoms in crystal lattice will oscillate about their mean position giving rise to _________.	Standing wave	Phonon wave	Sinusoidal wave	Longitudinal wave	2
_________ are considered as excited states of atoms or ions which are capable of migration of one lattice to another.	Exciton	Phonon	F- centre	V- centre	1
Phonons can be created by _________ oscillation.	Piezo-electric	Pyro-electric	Ferro-electric	None of the above	1

Transport Properties:

Surface transport phenomena are well known to have a strong influence on theelectronic properties of bulk semiconductors. When transport takes place through thinspecimens, the carriers are being subjected to considerable scattering by the boundarysurface in addition to normal bulk scattering. This additional scattering will reduce theeffective carrier mobility below the bulk value and will thus give rise to quantum sizeeffects. A study of these size effects can yield information on the electronic structure ofa surface and is therefore of considerable fundamental and practical importance. Thesephenomena play an important role in the transport properties of semiconducting film ofabout 1μm thickness and having carrier concentration upto 1018cm-3. Surface transportphenomena in bulk semiconductor have received much attention in recent years. The important transportproperties i.e. electrical resistively, thermoelectric power (TEP) are discussed below.

a) Electrical Conductivity:

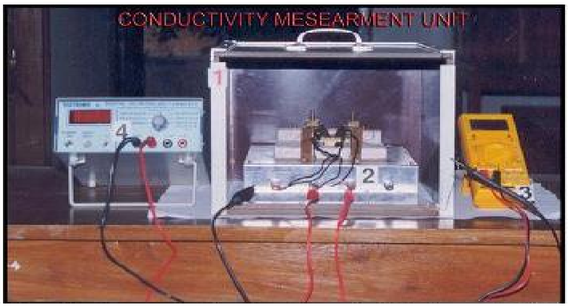
The use of thin films as resistors, contacts and interconnections has lead toextensive study of conductivity, its temperaturedependence, the effect of thermalprocessing stability and so on. Investigations of the electrical resistivity as a highly structure sensitive properties make it possible to gain insight into the structural andelectrical properties of the metal film which is important from both the theoretical and practical point of view. The contact techniques are most widely used for themeasurement of resistivity. These techniques include two-point probe, four point probeand the spreading resistance methods. The two-point method is simple and easy to use.In this technique a constant current I is passed through a sample of known dimensions(cross-sectional area 'A'). And the d.c. voltage 'V' between two fixed position probes(separation'd') measured either with impedance voltmeter or potentiometrically. Foruniform sample resistively is given by

$$\rho = (A/I)\,(V/d)$$

In case of semiconducting thin films, the resistivity decreases with increase intemperature. The thermal activation energies 'Ea' are calculated by using followingrelation:

$$\sigma = \sigma_o \exp^{(-\Delta E/\kappa T)}$$

Where ΔE is the activation energy for the conductionis Boltzmann constant and is the pre exponential constant depending on the material. The two brass plates of the size 10 x 5 x 0.5cm are grooved at the centre to fix the heating elements. Two strip heaters (65 Watts)were kept parallel in between these two brass plates to achieve uniform temperature.The two brass plates are then screwed to each other. The sample was mounted on theupper brass plate at the centre. To avoid the contact between the film and the brassplate, a mica sheet was placed between the film and brass plate. The area of the film was defined and silver emulsion (paste) was applied to ensure good electrical contact tothe films. The working temperature was recorded using a Chromel-Alumel thermocouple(24 gauge) fixed at the centre of the brass plates. Testronix model 34 C (power supplyunit) was used to pass the current through the sample. The potential drop across thefilm was measured with the help of Meco 801 digital multimeter and current passedthrough the sample was noted with a sensitive 4 digit picoammeter (Scientificequipment, Roorkee DPM 111).The measurements were carried out by keeping the filmsystem in a light tight box, which was kept at room temperature.



b) Thermoelectric Power (TEP):

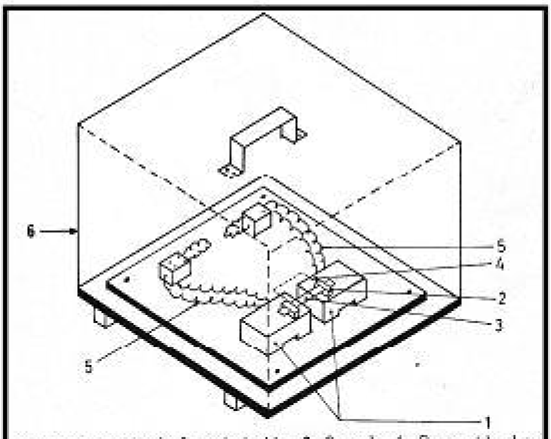
If some metal contacts are applied to the two ends of a semiconductor and if onejunction is maintained at higher temperature than the other, a potential difference isdeveloped between the two electrodes. This thermoelectric or Seebeck voltage isproduced party because

i) The majority carriers in the semiconductor diffuse from hot to cold junction, thus givinga potential difference between the ends of the specimen. This voltage builds upto avalue such that the return current just balances the diffusion current when a steadystate is reached.

ii) Other part which contributes to the thermoelectric voltage is the contact potentialdifference between metal and emiconductor, which occurs at two junctions.In the semiconductor, if the charge carriers are predominantly electrons, the coldjunction becomes negatively charged and if the charge carriers are positive holes, thecold junction becomes positively charged. The magnitude of the developed voltage isproportional to the difference in temperature between the hot and cold junction, if thetemperature difference is small. From the sign of the thermoelectric voltage it is thuspossible to deduce whether a given specimen exhibits n-or p-type conductivity.The thermoelectric power (TEP), which is defined as the ratio of thermallygenerated voltage to the temperature difference across the piece of semiconductor,gives the information about the type of carriers in the semiconductor.

Thermoelectric power measurement apparatus consist of two brassblocks. One brass block was used as a sample holder-cum-heater. Other brass blockwas kept at room temperature. The hot and cold junction was kept thermally isolated byinserting an insulated barrier between the junctions. The size of the film used in thisstudy was 40 mm x 12.5 mm x 1.35 mm on amorphous glass substrates, were fixed ontwo brass blocks. Chromel – Alumel thermocouples (24 gauze) were used to sense theworking temperature. A 65 watt strip heater was used for heating the sample. Thetemperature of the hot junction was raised slowly from room temperature, with a regularinterval of 10 K. the thermo emf was noted up to the highest temperature of 500 K.Silver paste contacts were made to films with copper wire. A backellite box was used forproper shielding of the TEP unit, which also minimises to some extent, thermal radiationlosses. The mean temperature was measured with a Meco 801 digital multimeter whilethe differential thermal gradient and thermoelectric voltage were measured with digitalTestronix microvoltmeter.

Fig 2.19 a. ***Photograph showing the thermoelectric power measurement assembly.***



1-Thermocouple; 2-Sample holder; 3-Sample; 4-Brass blocks; 5-Heaters; 6-Shield.
b) Design and schematic arrangement for measurement of theremoelectric power.

Fig. 2.19 b. Cross sectional view of *the thermoelectric power measurement unit.*

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THIN FILM PHYSICS (18PHP205C)

UNIT IV

_________ is a very sensitive method to identify the elemental composition of a film.	Electron microscopy	Mass spectroscopy	Scanning electron microscopy	X-ray photoelectron spectroscopy	2
Residual gas analyzer method is used for _________.	Analyzing structures of matter	Identifying elemental composition	Surface film analysis	Studying the refractory metal surfaces	3
Mass spectroscopy is a very sensitive method to identify the _________ of a film.	Elemental composition	Surface topography	Structures of matter	None of the above	1
RGA technique has sensitiveness of about less than _________ of the element.	Microgram	Nanogram	Milligram	None of the above	2
The mass spectroscopy involves _________.	Vapourization in high vacuo of the material	Its ionization	Accelerating the different ionized species	All of the above	1
Nucleation is a process which involves _________.	Addition and adsorption	Desorption and migration	Addition and migration	All of the above	4
The probability of condensed atoms sticking to the substrate surface is known as _________.	Activity coefficient	Sticking coefficient	Viscosity coefficient	None of the above	2
Sticking coefficient α_c is given by _________.	$\alpha_c = \frac{E_1 - E_R}{E_1 - E_S}$	$\alpha_c = \frac{E_1 - E_R}{E_1 + E_S}$	$\alpha_c = \frac{E_1 + E_R}{E_1 - E_S}$	$\alpha_c = \frac{E_1 + E_R}{E_1 + E_S}$	1
At a steady state the flux of impinging atoms on the substrate will be _________ to the re-evaporation flux of the atoms.	greater	smaller	equal to	not equal	3
In the prenucleation stage the impinging atoms can be reflected back to vapour state without _________.	Evaporation	Condensation	Adsorption	Addition	2
Capillarity model is the extension of the classical theory for _________ of a supersaturated vapour phase to the liquid state.	Vapourization	Condensation	Evaporation	Adsorption	2
_________ is the extension of the classical theory for the condensation of a supersaturated vapour phase to the liquid state.	Capillarity model	Liquid drop model	Both a & b	None of these	1
Island structure stage consists of comparatively larger nuclei or embryos say greater than _________.	100 Å	10 Å	1000 Å	1 Å	2
The surface migration distance of ad-atoms of silver or gold deposited from the vapour phase on MoS_2 substrate at $T_s \approx$ 400 °C has been estimated to about _________.	1500 Å	5000 Å	500 Å	5500 Å	3
In island structure stage the diffusion controlled process is more commonly observed except at _________.	Low substrate temperature	High substrate temperature	Medium substrate temperature	Very high substrate temperature	1
With increasing film thickness, these holes or gaps will _________ in size.	Increase	Decrease	Not changing	decreasing or increasing	2
The minimum film thickness for the continuous stage is also dependent on _________.	Nature of the deposits	Modes of deposition	Deposition parameters	All the above	4
For a non-metallic deposit continuous film stage is generally achieved when average film thickness is say between _________.	500 to 1000	100 to 500	1000 to 1500	None of the above	1
The process of thermal annealing treatment for a sufficiently long period of time will cause migration of some atoms leading to a stable phase is known as _________.	Ageing of films	Agglomeration	Phase transition	None of the above	1
Two important factors which contribute to the dissociation of nuclei are _________.	Thermal energy	Low binding energy	Both a & b	None of the above	3

A permanent stable nucleus will be formed when_________.	$r > r^*$	$r < r^*$	$r = r^*$	$r \neq r^*$	1
The number of grain boundaries can be reduced by the _________ process.	Pyrolysis	Thermal annealing	Anodic oxidation	Vapour plating	2
Stacking faults often arises due to the _________ equilibrium condition of the deposition.	Thermodynamic	Non-thermodynamic	Thermal	None of these	2
The change of incident angle from area to area causes deposition rate _________.	Lesser	Greater	Equal	No change	1
The rate at which impinging atom hit different areas will differ depending on_________.	Solid angle	Distance from the source	Both a & b	None of these	3
_________ suggested that different orientations observed in a growing film might result from the surface roughness of the substrate.	Bauser	Brown	Cabrera	Born	1
Agglomeration of nuclei increases with the _________ of deposition time.	Increase	Decrease	stability	All the above	1
At lower T_s, the grain size is _________.	low	maximum	higher	negligible	1
Increase of deposition time result in the _________ of nucleation density.	Increase	Decrease	stability	maximum	2
The grain size is often too _________ to yield any coherent electron diffraction.	small	high	medium	None of the above	1
At higher T_s, the grain size is _________.	medium	high	small	maximum	2
Electron beam should be _________.	coherent	monochromatic	high intense	both a & b	4
_________ electrons are used in electron diffraction technique.	High energy	& large energy	Low energy	Very high energy	2
More commonly used method for generating high energy electron is _________.	Thermionic emission	Gas discharge	Spontaneous emission	Stimulated emission	1
The diffraction effect was of _________, if the distance from the specimen both to the electron source and the screen or photographic plate were infinitely large compare to the inter atomic distances of diffracting specimen.	Fraunhofer type	Fresnel type	Both a & b	None of these	1
If the distance from specimen to the screen as well as to the beam source is small compare to the inter atomic distance in the specimen, the diffraction should be _________.	Fraunhofer type	Fresnel type	Both a & b	None of these	2
In electron diffraction camera _________ works as the anode normally at the earth potential.	Mono chromatic electron beam source	Specimen	Diaphragm	Focusing coil	3
In electron diffraction camera _________ is used to evacuate the equipment.	A high vacuum pumping system	Low vacuum pumping system	Very low pumping system	Very high pumping system	1
In the HEED method the accelerating potential of the electron is about _________.	40 to 100 eV	30 to 40 KeV	10 to 20 KeV	20 to 40 KeV	1
For transmission method the material thickness should be _________.	low	high	very high	very low	1
In an electron diffraction camera monochromatic electrons pass through an aperture of a _________.	Diaphragm	Specimen	Focusing coil	Screen	1
The vacuum condition in LEED is much more stringent and an order of _________ is essential for studying the surface.	10^{-9} to 10^{-10} torr	10^9 to 10^{10} torr	10 to 100 torr	.1 to 10 torr	1
The ultimate resolving power of a good electron microscope is about _________ for a non-periodic material.	2-5 Å	5-10 Å	10-15 Å	Below 2 Å	2
When a beam of light falls on a convex lens the emergent beam follows a new path and the bending of light ray depend on _________.	Lens curvature	Focal length	Both a & b	None of the above	1
According to Abbe's condition the resolution in the optical case is governed by the diffraction aberration of the aperture given by _________.	$\Delta r_d = K\frac{\lambda}{\mu}\sin\alpha$	$\Delta r_d = K\frac{\lambda}{\mu}\cos\alpha$	$\Delta r_d = K\frac{\mu}{\lambda}\sin\alpha$	$\Delta r_d = K\frac{\mu}{\lambda}\cos\alpha$	1
Contrast in the image taken by an optical microscope is due to the _________ of light by the different grains of the specimen.	Reflection	Refraction	Absorption	Transmission	3
Moiré fringes are the results of the combination of the diffracted beam with _________ order beam.	zero	first	second	None of the above	1

If the two crystals have parallel diffracting planes with spacing d_1 & $d_{2,}$ the parallel Moiré spacing D will be given by _________.	$\frac{d_1-d_2}{d_1 d_2}$	$\frac{d_1}{d_1-d_2}$	$\frac{d_1 d_2}{d_1-d_2}$	$\frac{d_2}{d_1-d_2}$	3
LEED instrument in its basic design consists of an electron emitting source having negative voltage of about _________.	5-500 eV	5-500 KeV	50-500 KeV	50-500 eV	1
The depth of penetration of slow electron is about a few Å compared to about _________ for the HEED cases.	10-20 Å	10-15 Å	5-10 Å	None of the above	1
Decoration technique is used to investigate the effect of _________.	Surface topography	Micro structural feature	Etching of a crystal structure	Both a & b	3
Auger electron spectroscopy technique depends on _________.	Radiation less electron	Radiative electrons	Both a & b	None of these	1
Auger electron spectroscopy can be used for _________.	Imaging purpose	Analysis of organic compounds	Both a & b	None of these	1
Emitted Auger electrons are detected by _________.	Auger detector	Cylindrical mirror analyzer	Electron detector	None of these	2
Auger electrons come from layers ranging between _________ below the film surface.	30 to 50 Å	65 to 85 Å	100 to 200 Å	2 to 20 Å	4
Characteristics of an Auger electron are independent of _________.	Nature of material	Incident beam	Both of these	None of these	2
Auger electron spectroscopy was observed by _________.	Auger	Miller	Both a & b	None of these	1
In X-ray photo electron spectroscopy (XPES), binding energy of electrons is related to X-ray energy by _________.	$E_b = h\gamma - K_E + Q_s$	$E_b - h\gamma = K_E - Q_s$	$E_b + Q_s = h\gamma - K_E$	$E_b + h\gamma = Q_s - K_E$	1
ESCA technique is widely used for _________.	Analysis of organic material	Analysis of inorganic material	Both of these	None of the above	1
In ESCA, we use _________.	X-ray photon	Auger electron	Both of these	None of these	1
Radiationless emission of electron was observed by _________.	Auger	Miller	Raman	Both c & d	1

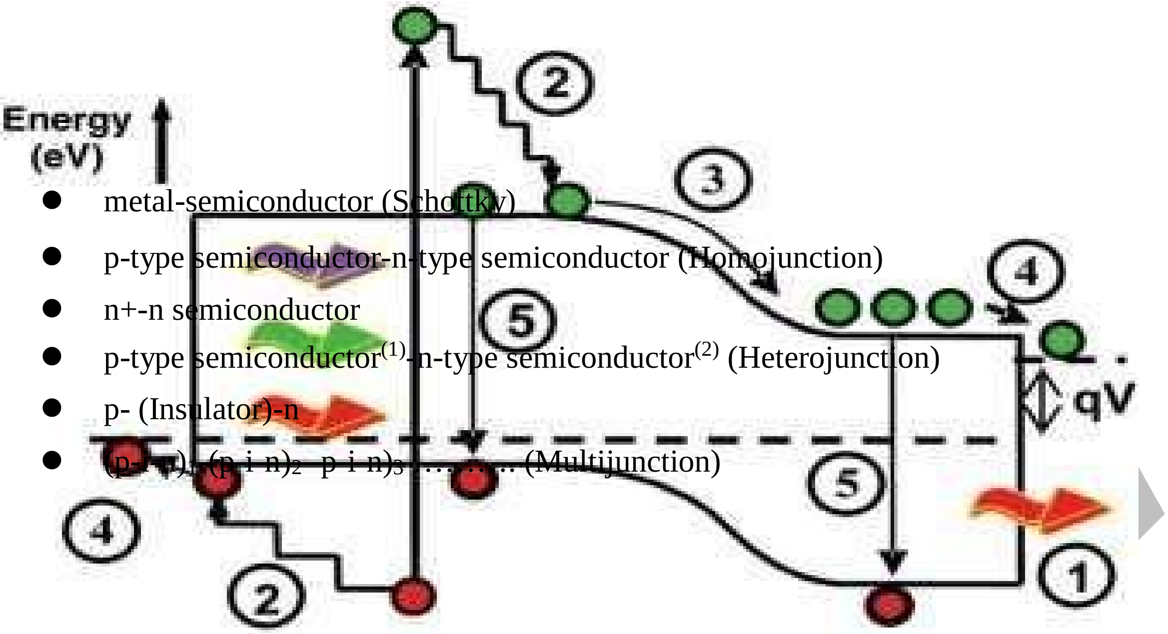
Optical properties of thin films and thin films solar cells:

Optical properties ofsolid emanate fromits interactionswith electromagneticwaves and are manifested in optical frequencies.The effect ofsuch interaction in opticalfrequencies results in optical behavior. Optical properties of filmhave been studiedextensively primarily because ofthere application in various optical and optoelectronicdevices. It has been found that there is considerable deviation of optical parameters fromthat of the bulk material. The optical study of a solid, concern not only with physicalphenomenon like reflection, refraction, absorption, transmission and interference of lightbut also on interaction of photon energy with matter and consequent change in thereelectronic states. The study of optical properties of solids helps in understanding ofelectronic and atomic structure of these materials. Absorption studies providesimple means for the evaluation of absorption edge, optical energy band, opticaltransition that may be direct orindirect,allowed or forbidden and also of the nature of the solid material. Asimple way to determine the opticalproperties ofsolid is by illuminating thesample with light and then measure the reflection, transmittance or absorbance as afunction of photon energy. Thiswas experimented by spectroscopic methods.

Thin Film Solar Cells

SOLAR Cell:PHOTOVOLTAICS

- Direct Conversion of light into electrical energy is called PHOTOVOLTAICS (PV)
- Photovoltaic devices which convert solar energy into electricity are called SOLAR CELLS
- Two electronically dissimilar materials (with different free electron densities) brought together to form a junction with a barrier form a PV device. Typical examples are :
    - metal$_1$-oxide-metal$_2$



- metal-semiconductor (Schottky)
- p-type semiconductor-n-type semiconductor (Homojunction)
- n+-n semiconductor
- p-type semiconductor$^{(1)}$-n-type semiconductor$^{(2)}$ (Heterojunction)
- p- (Insulator)-n
- $(p\text{-}i\text{-}n)_1$ $(p\ i\ n)_2$ $p\ i\ n)_3$ ……… (Multijunction)

SOLAR CELL

- Solar Cell operations depend on : o Absorption of light to create electron-hole pairs (carriers) o Diffusion of carriers o Separation of electrons and holes o Collection of carriers
- A Solar cell is a light driven battery with an open current voltage (V_{oc}), short circuit current (I_{sc}), maximum power point current and voltage (I_n, V_m), and a series and a parallel resistance (R_s, R_{sh}).
- Solar Cell Efficiency
  η – output = Im Vm = I siVIL FT input Σ nhv Σ nhv
  depends on quantum efficiency of creation of carriers, effectiveness of separation of carriers before recombination and collection of the separated carriers.
- Highest Theoretical Efficiency of known Jct Materials
  Homojunction ~ 30%

Heterojunction ~ 42%

36 Tandem Multigap Jctns 76%

What is required for an ideal Solar Cell ?

1.Cheap,Simple and Abundant Material
2.Integrated Large Scale Manufacturabilty
3.Cost (< 1$/watt)and Long Life
HIGH ABSORPTION COEFFICIENT > 10^5 cm^{-1} with direct band gap ~1.5 eV

JUNCTION FORMATION ABILITY
HIGH QUANTUM EFFICIENCY
LONG DIFFUSION LENGTH
LOW RECOMBINATION VELOCITY
ABUNDANT,CHEAP & ECO-FRIENDLY MATERIAL
· CONVENIENCE OF SHAPES AND SIZES
· SIMPLE AND INEXPENSIVE INTEGRATED PROCESSING/MANUFACTURABILITY
· MINIMUM MATERIAL / WATT
· MINIMUM ENERGY INPUT/ WATT
· ENERGY PAY BACK PERIOD < 2 YEARS
· HIGH STABILTY and LONG LIFE (> 20 Years) · COST (< 1$/Watt)

POSSIBLE Solar Cell Materials
Single Elements:

Si (epi, mc, nc, mixed)
Carbon (nanotubes, DLC)

Binary alloys / Compounds:

Cu_2S, Cu_2O Cu-C, CdTe, CdSe,

GaP, GaAs, InP,ZnP , a-Si : H, Dye coated TiO_2

Ternary (+) Alloys / Compounds:

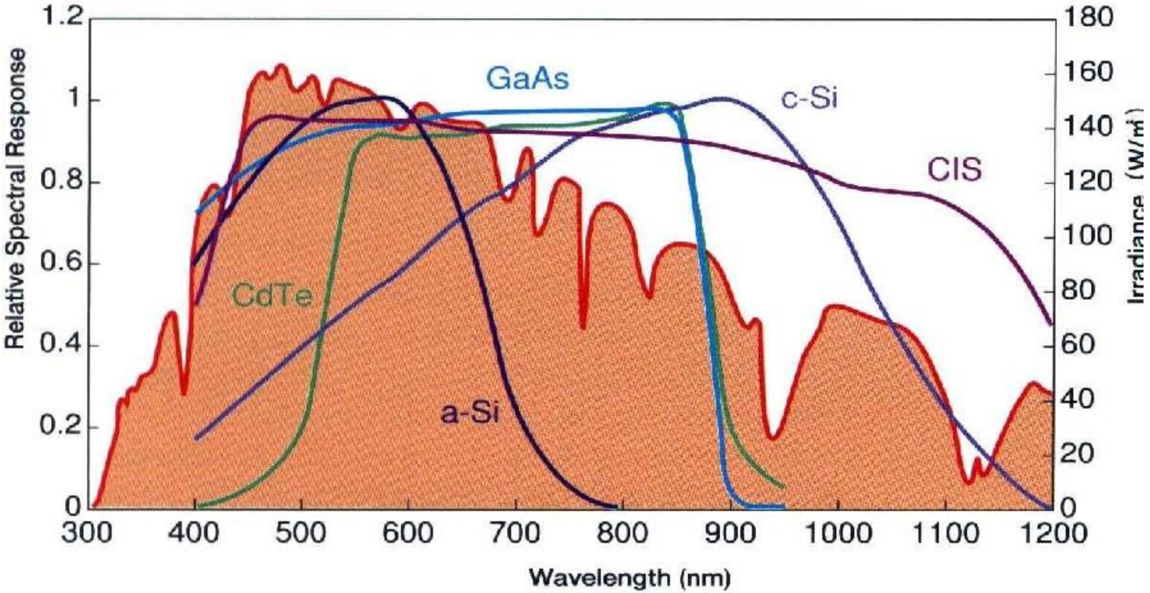
Cu-In-S, Cu-In-Se,Cu-Zn-S, CdZnSe , CdMnTe, Bi-Sb-S,

Cu-Bi-S, Cu-Al-Te, Cu-Ga-Se, Ag-In-S, Pb-Ca-S,
Ag-Ga-S, Ga-In-P, Ga-In-Sb ,and so on.

Organic Materials:

Semiconducting Organics / Polymers and Dyes

Spectral response of solar cells



Crystalline Silicon :Present Scenario

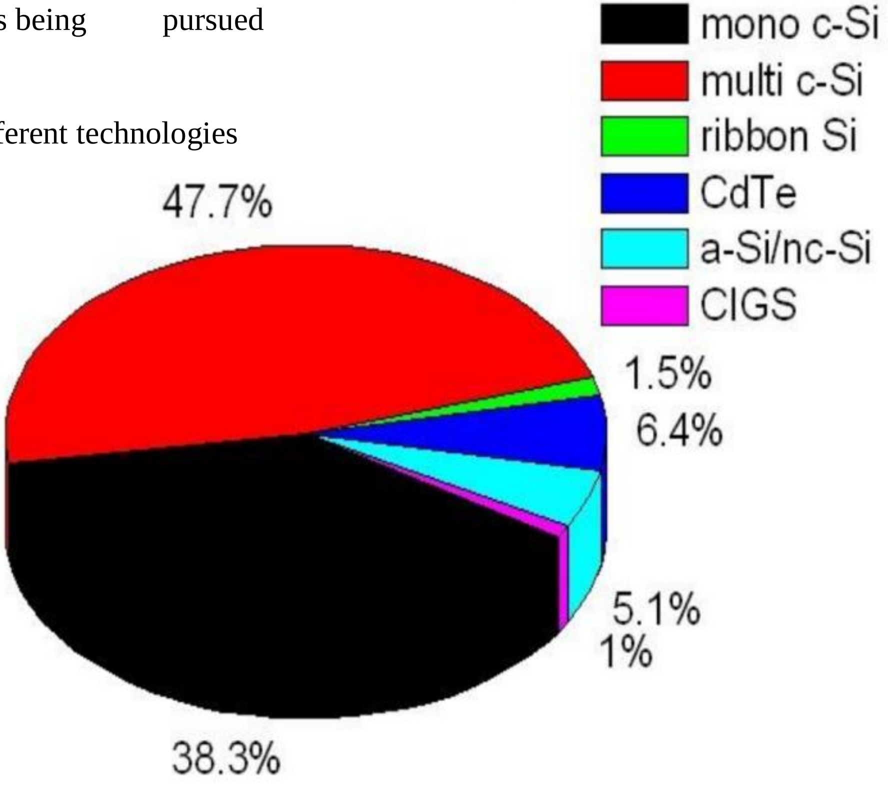
- Efficiency of single crystal Si cells (Laboratory) has been rising steadily to ~ 25% as a result of better understanding of the junction properties and innovations in cell design and fabrication technologies.
- Efficiency gap between best laboratory cells, submodules/modules, and mass produced modules varies with the maturity of technology and can be at least 10% lower at every step so that the manufactured cell may be as low as 50% of the efficiency of the best laboratory cell.
- The world PV production of ~ 7900 MW in FY 2009 is primarily (~ 93%) based on single, crystal and polycrystalline silicon.
- With increasing production of Si-PV from 200 kW in 1976 to 6900 MW in 2008, the cost of solar cells has decreased from $100 to about $3/Wp
- With the existing technology and the material cost, the cost of Si cells can not be decreased significantly unless major innovations in the production of appropriate quality silicon I thin sheets take place.
- Present day technology uses 8”or larger pseudo square of ~ 200μ m thickness, with an efficiency of ~ 15-16%. The energy (16-5 kWH/Wp) pay back period of such cells is ~3-

4 years.The module life is about 25 years

- Specially designed silicon solar cells with efficiency ~ 18-20% are being manufactured on a limited scale for special applications (e.g for concentration).

- Polycrystalline silicon solar cells with efficiency ~ 12-14% are being produced on large scale.
- Specially designed thin(~ 20 m) films silicon solar cells with efficiency ~ 12% have been fabricated on a lab scale . Production of hybrid thin film Si cells on MW scale is being pursued

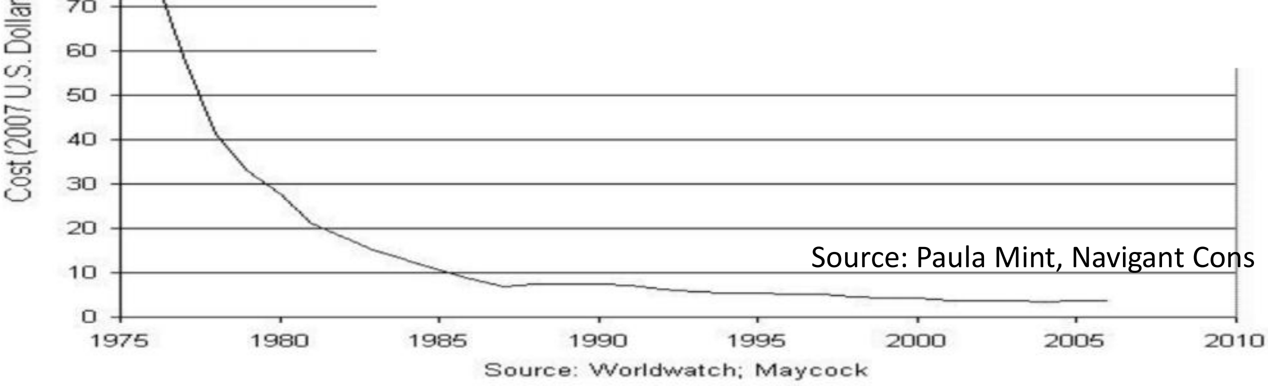
Solar module production for different technologies



CIGS is emerging with about 1% share CdTe is leading with over 6% share a-Si:H: About 5% share C- Si dominates with ~ 90% share

EPIA expects thin film shares will grow:

20% in 2010 with about 4 GW 25% in 2013 with about 9 GW



Source: Paula Mint, Navigant Cons lting

Source: Worldwatch; Maycock

WHY THIN FILM SOLAR CELLS ?

SMALL THICKNESS REQUIRED DUE TO HIGH ABSORPTION, SMALL DIFFUSION LENGTH & HIGH RECOMBINATION VELOCITY

MATERIALS ECONOMY, VERY LOW WEIGHT GHT PER UNIT POWER

□VARIOUS SIMPLE & SOPHISTICATED DEPOSITION TECHNIQUES

□A VARIETY OF STRUCTURES AVAILABLE : AMORPHOUS, PLOYCRYSTALLINE, EPITAXIAL

TOPOGRAPHY RANGING FROM VERY ROUGH TO ATOMICALLY SMOOTH

□DIFFERENT TYPES OF JUNCTIONS POSSIBLE –HOMO, HETERO, SCHOTTKY, PEC

□TANDEM AND MULTI JUNCTION CELLS POSSIBLE

□IN-SITU CELL INTEGRATION TO FORM MODULES

□COMPATIBILITY WITH SOLAR THERMAL DEVICES

- TAILORABILITY OF VARIOUS OPTO-ELECTRONIC PROPERTIES (e.g; Energy Gap ,Electron Affinity ,Work function ,Graded Gap ,etc)

Thin Film Cu_2S –CdS Cell

- One of the simplest solar cell to produce with simple chemical conversion technique
- Highest efficiency obtained ~10 %
- Large scale production of modules with ~5% efficiency demonstrated during 70’s
- Stability of cells due to cuprous-cupric conversion remained an issue
- Due to the emergence of higher efficiency Si cells, this cell lost the battle of survival
- Revival of this cell with suitable modifications is a possibility

Crystalline states of Si: Long range or short range order of atoms

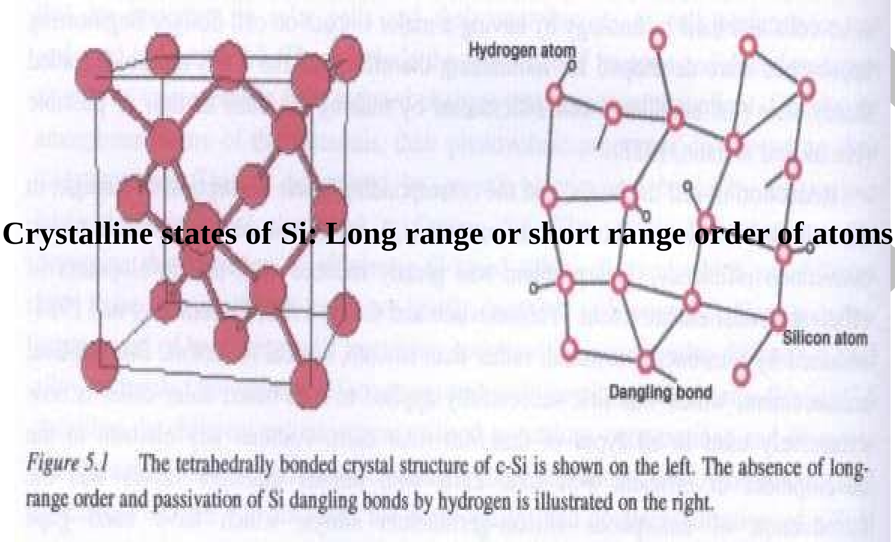
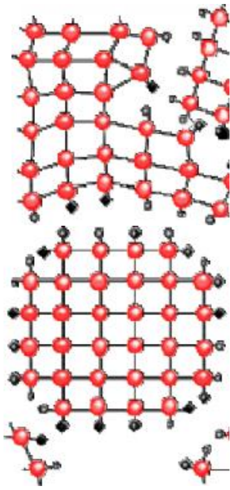


Figure 5.1 The tetrahedrally bonded crystal structure of c-Si is shown on the left. The absence of long-range order and passivation of Si dangling bonds by hydrogen is illustrated on the right.



Uncoordinated atoms and broken

c-Si & Poly-Si bonds (called **dangling bonds** are

characteristics of a-Si

a-Si **– amorphous Si**

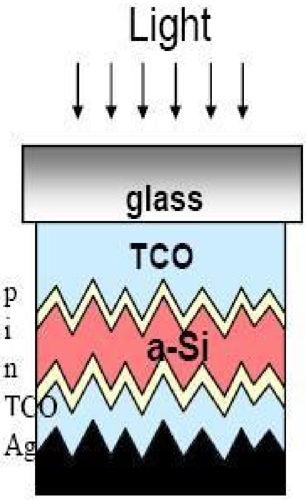
a-Si:H **– amorphous hydrogenated Si Hydrogen passivates the** uc-Si:H **–**
microcrystalline Si (hydrogenated)dangling bonds in a -Si:H. Almost

any impurity can be added to this open structure to obtain asuitable semiconducting behaviour

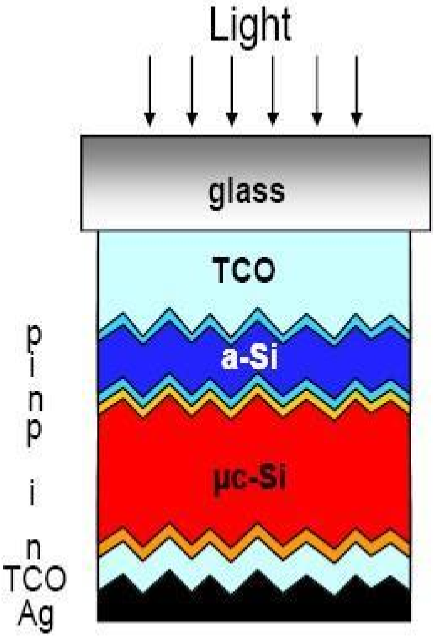
Absorption coefficient of Si can change with the crystalline state

Different Eg ▯▯ → Different optical properties

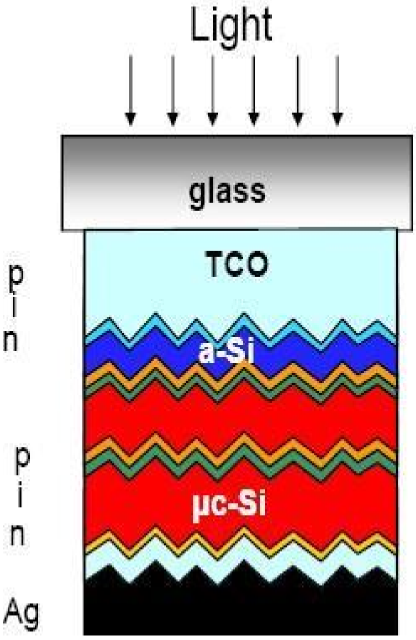
Why Amorphous Silicon as a Photovoltaic Material?



Single junction cell
Module eff. 5-7%



Tandem cell
Module eff. 7-10%



triple cell
Module eff. > 12%

> 10^5 cm^{-1})
tremely thin
l cost
iformly coat

hnique are
g process
eV) where

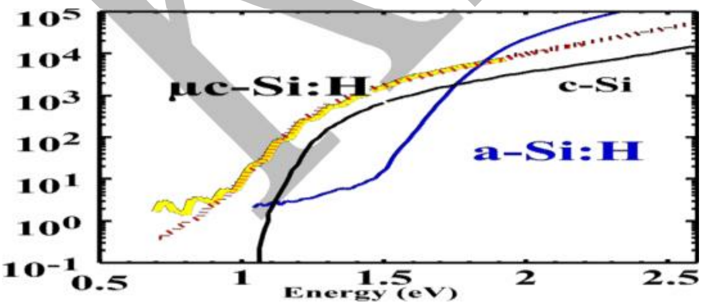
by selective

y efficiently)

le transport

properties for p-i-n type solar cells

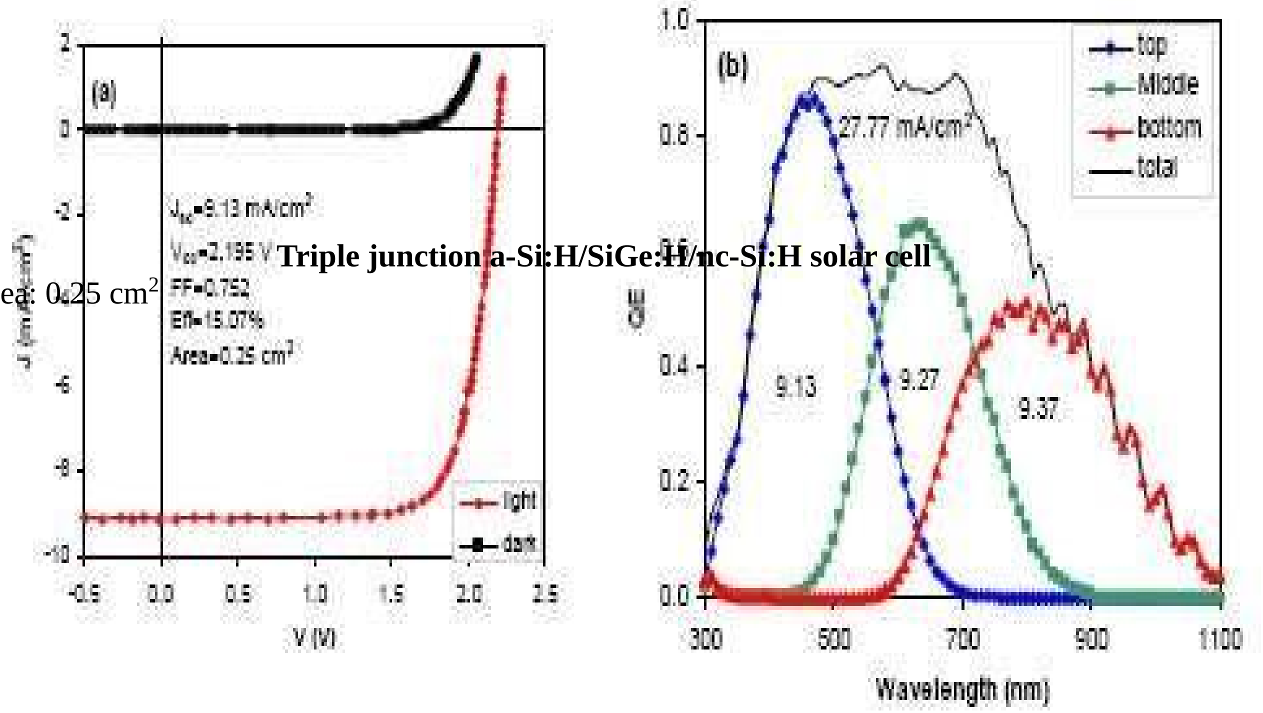
small areaeff ~15%



single/tandem/triple junction solar cells

Triple junction a-Si:H/SiGe:H/nc-Si:H solar cell

Area: 0.25 cm^2



Initial efficiency: 15.1%; Stable efficiency: 13.

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UNIT V

Extensive twinning is observed especially those having a _____	SCC	FCC	BCC	none of these	2
The additional 2-d (211) orientation of Ag on a (100) face of Na	Multitwinnin	Twinning	Epitaxial	None of the above	1
A direct electron microscope observation of multitwinned crysta	Twinning	Multiply twir	Epitaxy	Multitwinning	2
The twinning effect is observed in _________ pattern.	Transmission	Transmission	Transmission	Transmission-diffraction	4
The transformation of FCC structure material often to a h_{op} a vic	Metal	Chalcogenide	Non-metallic	None of the above	2
The SnS an orthorhombic structure about 250° changes to a ___	Rhombic ZnS	Cubic ZnS	Octahedral Z	Tetrahedral ZnS	2
The nickel sulphide develops into new phases confirming to FC	Twinning	Multitwinnin	Multiple twir	Epitaxial	4
The reversible phase transition takes place due to _________.	Heating cycle	Cooling cycle	Both a & b	None of the above	3
The new phase in metastable state is changed to stable by the pr	Thermal heat	Thermal evap	Thermal anne	Flash evaporation	3
Polymorphic cases are often observed in _________ films.	Metal	Non-metal	Chalcogenide	None of these	1
The theory of twinning was discussed by _________.	Goswami	Hall	Laud	Finchet	2
Phase transition change without any change of its _________.	Properties	Composition	Structure	Phase	2
Presence of pairs of dark and white lines or bands known as ___	Willion Lines	Kikuchi lines	Lane zone	None of these	2
The influence of the substrate decreases with the _________ of	Decreases	Increases	no change	None of the above	2
If the crystal surface is very rough, the diffraction patterns will _	Appear	Disappear	increase	none of these	2
The ordered structure of crystalline film can be examined by ___	Frequency di	Transmission	Impurity met	None of these	2
When the flake is extremely thin, then two dimensional lattice n	Different lane	Same lane zo	Wilman zone	None of these	1
The diffraction spots lie in hyperboles and their dispositions dep	Degree of fil	Degree of ber	Substrate ten	None of these	2
A crystal surface be made to a highly disordered state. Such surf	Beilby layer	Kikuchi layer	Wilman layer	None of these	1
The Beilby layer can be transformed to crystalline state by ____	Vapourizatio	Cooling	Thermal anne	Both a & b	3
In the diffraction rings, the line width of rings can be obtained fr	$t = \lambda B/L$	$t = L\lambda/B$	$t = L\lambda B$	$t = B/\lambda L$	2
The general expression for position of reflection spots for all typ	Wilman	Goswami	Evans Phillip	W.Straughen	1
In the epitaxial growth, with higher temperature atom mobility w	Decrease	Increase	no change	None of the above	2
The minimum epitaxial temperature is related to the deposition r	R ≥ A exp (-I	R ≥ A exp (-I	R ≤ A exp (-I	$R \leq A \exp(-E_D/KT_e)$	4
The epitaxy where the over growth and the substrate are of the s	Homotaxy	Heterotaxy	Both a & b	None of these	1
Epitaxy occurs only when both deposit and the substrate must be	Polycrystallin	Single crystal	Amorphous s	Both a & b	2
The difference between the network spacing, the substrate and t	100 (a-b)/b	b-a/100 a	100 (b-a)/a	100 a/(b-a)	3
Engel considered epitaxial orientation to be due to _________.	Coulombic fo	Nuclear force	Weak forces	Strong forces	1
According to monolayer theory the strain will be within the elas	10%	5%	15%	20%	2
Diffraction effects can be studied at a small grazing incident ang	Few Å to abc	Greater than	Greater than	None of the above	1
At a higher angle of incidence, the beam passes through ______	Thicker layer	Over the surf	Below the su	Thinner layers	1
At a lower angle of incidence, the beam passes through ______	Thicker layer	Over the surf	Below the su	Thinner layers	2
Initial orientations and film growth can be interpreted from the r	The surface c	Critical nucle	The substrate	All of the above	4
The effect of the curvature of the film can be illustrated from the	Bi_2Se_3 film	Na_2SO_3 film	Both a & b	none of these	1
The initial stage of epitaxial growth is _________.	Single layer	multi layer	mono layer	None of the above	3
The cathodic deposition and chemical displacement process hav	two	one	three	None of the above	3
Dissociations occur more often in compounds when the metal ic	different	same	either a or b	None of the above	1
_________ phenomenon as been observed during the vacuum de	Phase transiti	Dissociation	Twinning	Multi twinning	2
The vacuum deposited films need not necessarily have the ____	Different con	Same compos	Different con	none of these	2
The thicker deposits should generally develop _________ orient	1-d	2-d	3-d	none of these	1
In _________ stage the atomic arrangement of the deposit over	initial	intermediate	last stage	Both a & b	1
In _________ stage the deposits formed are no longer affected b	initial	intermediate	last stage	none of these	2
In _________ stage the 1-d orientation developed by the deposit	last stage	initial	intermediate	none of these	1
During the vacuum deposition process many compounds under t	low	very low	high	very high	3
With the increase of film thickness there is a change in the epita	Single twinni	Multiple twir	Both a & b	none of these	3
During the vacuum deposition process many compounds under t	low	very low	high	very high	1
In the case of cathodic deposition on _________ substrates, thic	Single crysta	Poly crystalli	both a & b	none of the above	2
In crystal growth process for neutral or amorphous substrate __	Nucleation	epitaxial	intermediate	final stage	2
In nucleation stage the atomic arrangement of the deposits at the	Critical nucle	Nobility of ac	Nucleation fr	Substrate surface atoms	4
In crystal growth process the orientation of 3-d micro crystals ar	Nucleation st	Epitaxial stag	Intermediate	Final stage	1
In epitaxial stage the deposited atoms becomes _________ micr	1-d	2-d	3-d	all	3
At the end of epitaxial stage the crystal becomes _________.	Micro crystal	Polycrystallin	Fresh layer	None of these	2
The intermediate stage _________ will not interfere on the grov	Dislocations	Substrate & c	Substrate & c	Substrate & associated grain boun	2
In intermediate stage the influence of substrate or over growth la	Fresh layer	Twinning	Deposition pa	Stacking faults	3
_________ is a deposition parameter.	Current densi	Twinning	Stacking faul	None of these	1

The initial step in the crystal growth is the formation of ______	Fresh layer	Nucleus	Micro crystal	Polycrystalline	2
Development of 1° orientation as well as shape and morphology	Twinning	Stacking faul	Deposition p	None of these	3
Identification of individual stage except final stage is done by _	Deposition p	Electron diffr	Current densi	Twinning	2
The process involved in the formation of embryo is _________.	Crystallizatio	Fusion	Nucleation	All	3