SESSION :03

- Manufacturing Process and Applications of LED
- Solving problems

APPLICATIONS

- Indicator lights on our stereos
- Automobile dashboards
- Microwave ovens.
- Numeric displays on clock radios
- Digital watches
- Calculators are composed of bars of LEDs.
- LEDs also find applications in telecommunications for short range optical signal transmission such as TV remote controls.

RAW MATERIALS

- Diodes are made of very thin layers of semiconductor material one layer will have an excess of electrons, while the next will have a deficit of electrons.
- This difference causes electrons to move from one layer to another, thereby generating light.
- Thickness is thin as .5 micron or less (1 micron = 1 ten-thousandth of an inch).
- Impurities within the semiconductor are used to create the required electron density.
- A semiconductor is a crystalline material that conducts electricity only when there is a high density of impurities in it.
- The slice, or wafer, of semiconductor is a single uniform crystal, and the impurities are introduced later during the manufacturing process.

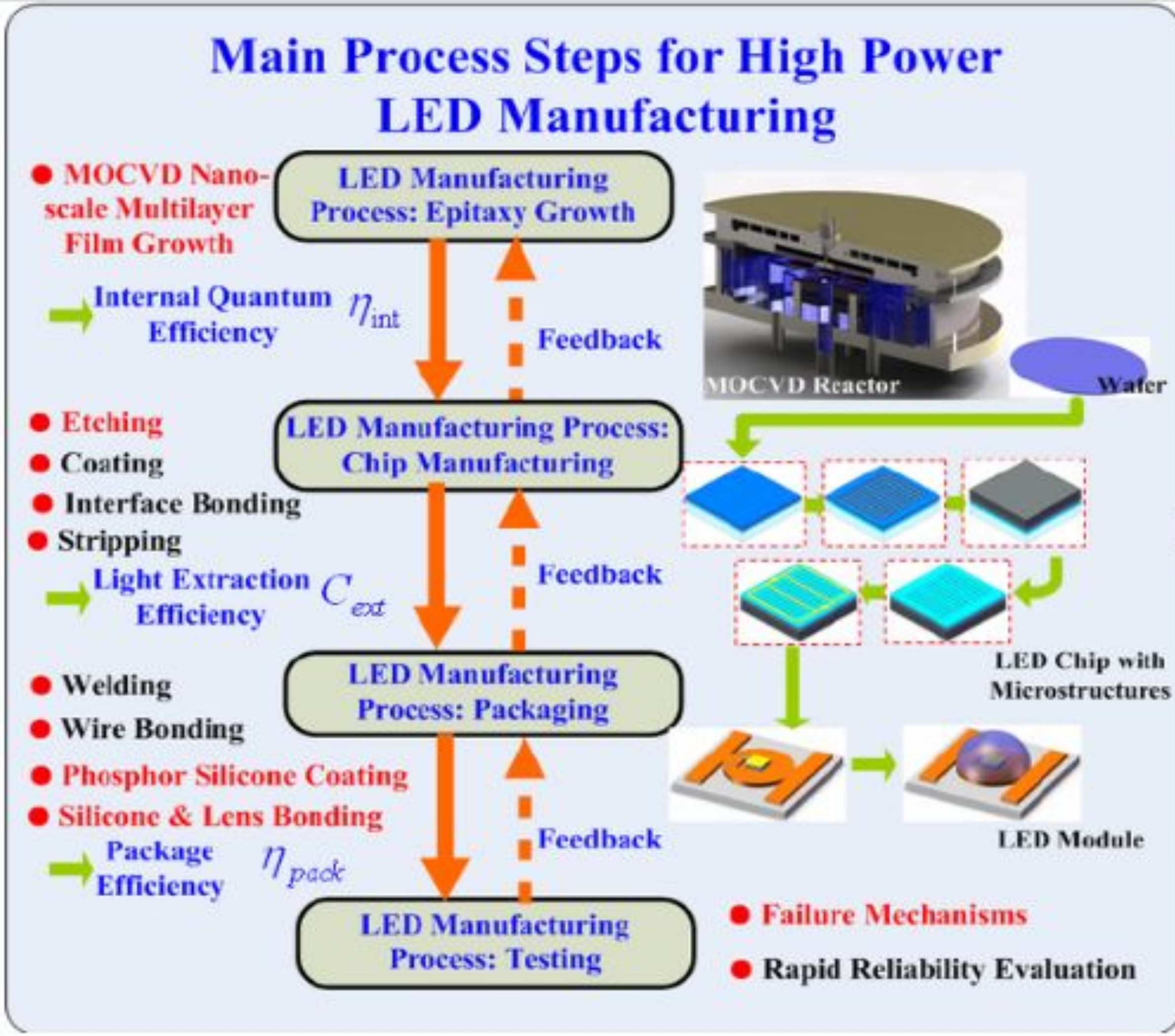
- The particular semiconductors used for LED manufacture are gallium arsenide (GaAs), gallium phosphide (GaP), or gallium arsenide phosphide (GaAsP).

- The impurities commonly added are zinc or nitrogen, but silicon, germanium, and tellurium have also been used.

- wires must be attached onto the substrate. These wires must stick well to the semiconductor and be strong enough to withstand subsequent processing such as soldering and heating.

- **Gold** and silver compounds are most commonly used for this purpose, because they form a chemical bond with the gallium at the surface of the wafer.

LED MANUFACTURING STEPS



$$\eta_{total} = \eta_{int} \cdot C_{ext} \cdot \eta_{pack}$$

Having a Combined Effect on High Power LEDs on :

- Light Output Efficiency
- Heat Resitance
- Reliability

Main process steps for high power LED manufacturing.

THE MANUFACTURING PROCESS

Making semiconductor wafers

STEP:1 First, a semiconductor wafer is made.

- The particular material composition—GaAs, GaP, or something in between—is determined by the color of LED being fabricated. The crystalline semiconductor is grown in a high temperature, high pressure chamber.
- Gallium, arsenic, and/or phosphor are purified and mixed together in the chamber. The heat and pressure liquify and press the components together so that they are forced into a solution.
- To keep them from escaping into the pressurized gas in the chamber, they are often covered with a layer of liquid boron oxide, which seals them off so that they must "stick together." This is known as *liquid encapsulation,* or the *Czochralski crystal growth method.*
- After the elements are mixed in a uniform solution, a rod is dipped into the solution and pulled out slowly. The solution cools and crystallizes on the end of the rod as it is lifted out of the chamber, forming a long, cylindrical crystal ingot (or *boule)* of GaAs, GaP, or GaAsP.

STEP 2. The boule is then sliced into very thin wafers of semiconductor, approximately 10 mils thick, or about as thick as a garbage bag.

- The wafers are polished until the surfaces are very smooth, so that they will readily accept more layers of semiconductor on their surface.
- The principle is similar to sanding a table before painting it. Each wafer should be a single crystal of material of uniform composition.
- Unfortunately, there will sometimes be imperfections in the crystals that make the LED function poorly.
- Imperfections can also result from the polishing process; such imperfections also degrade device performance.
- The more imperfections, the less the wafer behaves like a single crystal; without a regular crystalline structure, the material will not function as a semiconductor.

STEP 3: The wafers are cleaned through a rigorous chemical and ultrasonic process using various solvents.

- This process removes dirt, dust, or organic matter that may have settled on the polished wafer surface.
- The cleaner the processing, the better the resulting LED will be.

Adding epitaxial layers

STEP 4: Additional layers of semiconductor crystal are grown on the surface of the wafer.

- This is one way to add impurities, or dopants, to the crystal. The crystal layers are grown this time by a process called *Liquid Phase Epitaxy* (LPE).
- In this technique, epitaxial layers—semiconductor layers that have the same crystalline orientation as the substrate below—are deposited on a wafer while it is drawn under reservoirs of molten GaAsP.
- The reservoirs have appropriate dopants mixed through them. The wafer rests on a graphite slide, which is pushed through a channel under a container holding the molten liquid (or *melt,* as it is called).
- Different dopants can be added in sequential melts, or several in the same melt, creating layers of material with different electronic densities.
- The deposited layers will become a continuation of the wafer's crystal structure.LPE creates an exceptionally uniform layer of material, which makes it a preferred growth and doping technique. The layers formed are several microns thick.

STEP 5: After depositing epitaxial layers, it may be necessary to add additional dopants to alter the characteristics of the diode for color or efficiency.

- If additional doping is done, the wafer is again placed in a high temperature furnace tube, where it is immersed in a gaseous atmosphere containing the dopants—nitrogen or zinc ammonium are the most common.
- Nitrogen is often added to the top layer of the diode to make the light more yellow or green.

Adding metal contacts

STEP 6: Metal contacts are then defined on the wafer.

- The contact pattern is determined in the design stage and depends on whether the diodes are to be used singly or in combination.
- Contact patterns are reproduced in photoresist, a light-sensitive compound; the liquid resist is deposited in drops while the wafer spins, distributing it over the surface.
- The resist is hardened by a brief, low temperature baking (about 215 degrees Fahrenheit or 100 degrees Celsius).
- Next, the master pattern, or mask, is duplicated on the photoresist by placing it over the wafer and exposing the resist with ultraviolet light (the same way a photograph is made from a negative).
- Exposed areas of the resist are washed away with developer, and unexposed areas remain, covering the semiconductor layers.

STEP 7: Contact metal is now evaporated onto the pattern, filling in the exposed areas.

- Evaporation takes place in another high temperature chamber, this time vacuum sealed.
- A chunk of metal is heated to temperatures that cause it to vaporize. It condenses and sticks to the exposed semiconductor wafer, much like steam will fog a cold window.
- The photoresist can then be washed away with acetone, leaving only the metal contacts behind. Depending on the final mounting scheme for the LED, an additional layer of metal may be evaporated on the back side of the wafer.
- Any deposited metal must undergo an annealing process, in which the wafer is heated to several hundred degrees and allowed to remain in a furnace (with an inert atmosphere of hydrogen or nitrogen flowing through it) for periods up to several hours.
- During this time, the metal and the semiconductor bond together chemically so the contacts don't flake off.

STEP 8: A single 2 inch-diameter wafer produced in this manner will have the same pattern repeated up to 6000 times on it

- This gives an indication of the size of the finished diodes.
- The diodes are cut apart either by cleaving (snapping the wafer along a crystal plane) or by sawing with a diamond saw.
- Each small segment cut from the wafer is called a die.
- A difficult and error prone process, cutting results in far less than 6000 total useable LEDs and is one of the biggest challenges in limiting production costs of semiconductor devices.

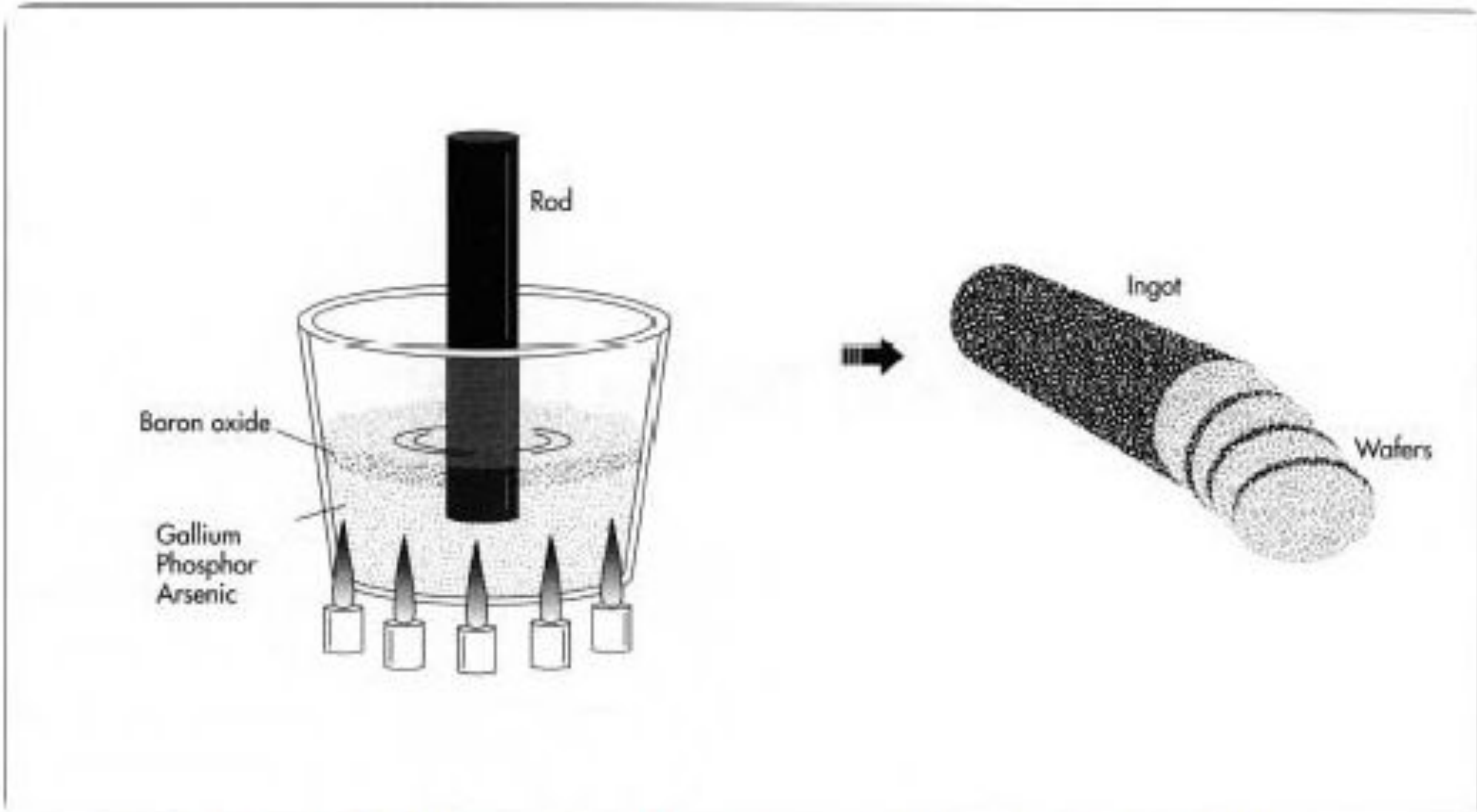
Mounting and packaging

STEP 9: Individual dies are mounted on the appropriate package.

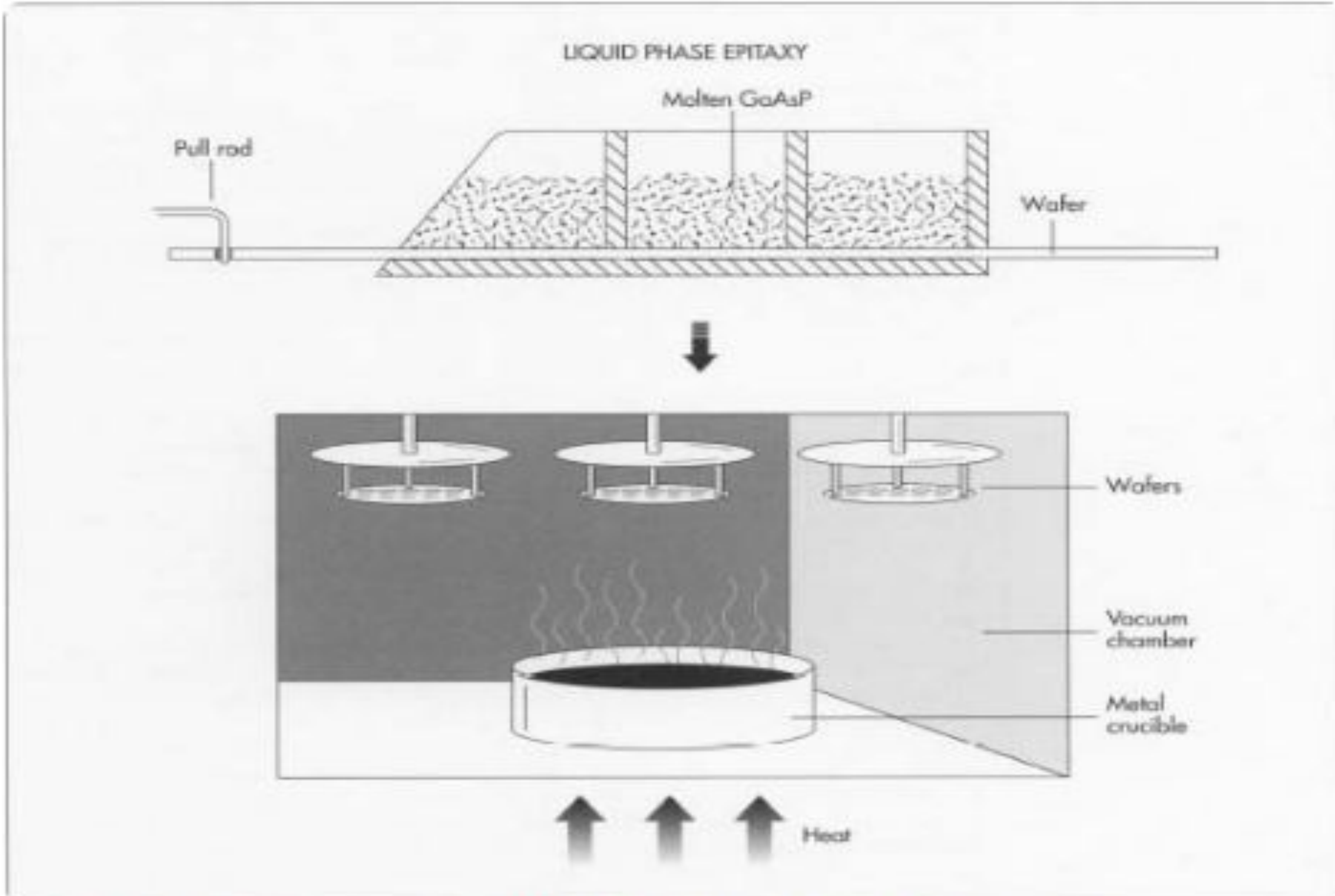
- If the diode will be used by itself as an indicator light for example, it is mounted on two metal leads about two inches long.
- Usually, in this case, the back of the wafer is coated with metal and forms an electrical contact with the lead it rests on.
- A tiny gold wire is soldered to the other lead and wire-bonded to the patterned contacts on the surface of the die. In wire bonding, the end of the wire is pressed down on the contact metal with a very fine needle.
- The gold is soft enough to deform and stick to a like metal surface.

STEP 10: Finally, the entire assembly is sealed in plastic.

- The wires and die are suspended inside a mold that is shaped according A typical LED indicator light shows how small the actual LED is.
- Although the average lifetime of a small light bulb is 5-10 years, a modern LED should last 100 years or more before it fails.
- To the optical requirements of the package (with a lens or connector at the end), and the mold is filled with liquid plastic or epoxy.
- The epoxy is cured, and the package is complete.



To make the semiconductor wafers, gallium, arsenic, and/or phosphor are first mixed together in a chamber and forced into a solution. To keep them from escaping into the pressurized gas in the chamber, they are often covered with a layer of liquid boron oxide. Next, a rod is dipped into the solution and pulled out slowly. The solution cools and crystallizes on the end of the rod as it is lifted out of the chamber, forming a long, cylindrical crystal ingot. The ingot is then sliced into wafers.



One way to add the necessary impurities to the semiconductor crystal is to grow additional layers of crystal onto the wafer surface. In this process, known as "Liquid Phase Epitaxy," the wafer is put on a graphite slide and passed underneath reservoirs of molten GaAsP.

Contact patterns are exposed on the wafer's surface using photoresist, after which the wafers are put into a heated vacuum chamber. Here, molten metal is evaporated onto the contact pattern on the wafer surface.

Problem :01

- A GaAs LED radiates at 900 nm. If the forward current in the LED is 20 mA, calculate the power output, assuming an internal quantum efficiency of 2%.

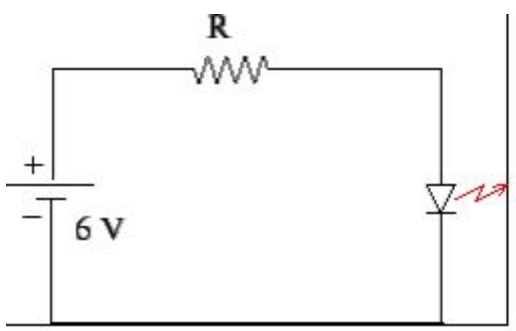
The energy of the photon (in eV) is

$$\frac{hc}{e\lambda} = \frac{6.62 \times 10^{34} \times 3 \times 10^{8}}{1.6 \times 10^{-19} \times 9 \times 10^{-7}} = 1.38$$

Thus the power output is $P = 0.02 \times 1.38 \times 20 = 0.55\text{mW}$.

Problem :02

- In the circuit shown, the forward biased LED has a voltage drop of 1.5 volts. If the battery voltage is 6 V, calculate the resistance to be connected to the circuit, if the current through the LED is 15 mA. How much power is dissipated in the resistor ?



Solution :02

If r is the internal resistance of the LED he current through the resistors is $V/(R+r) = 0.015$which gives $R+r = 6/0.015 = 400\,\Omega$. As the drop across LED is 1.6 V, the internal resistance r is $1.5/0.015 = 100\,\Omega$. The external resistance to be connected is $R = 400 - 100 = 300\,\Omega$. The power rating of the resistor should at least be $RI^2 = 300 \times 2.25 \times 10^{-4} = 77.5$mW.

Problem:03

The working voltage of an LED is 1.8 volts. If the desired current flow is 15 mA, how much power is dissipated in a resistor that must be connected to an LED circuit operated on a d.c. voltage of 12 V.

Ans: 0.153 W

PROBLEM :04

- The change in the emitted wavelength of a GaAs LED is 3 nm when the temperature is changed from 300 K to 310 K. Assuming a linear variation with temperature, find the change in the band gap energy of GaAs, if the gap at 300 K is 1.420 eV.

Ans: 5 meV

PROBLEM :05

For the theoretical spectrum shown, calculate the linewidth $\Delta\lambda$at half the maximum intensity for $\lambda = 870$nm at room temperature.

Solution :

As $\lambda = hc/E$, on differentiating, we get

$$\Delta\lambda = \frac{hc}{E^2}\Delta E = \frac{\lambda^2}{hc} \times 1.8kT$$

Substituting $\lambda = 870$nm and $T = 300$K, $\Delta\lambda = 28.4$nm.

PROBLEM :06

A surface emitting LED of large surface area is coupled to a step index fiber of core radius 25 μm. If the luminance of the LED is 10^4 W/m ^{2}-sr, how much power is coupled to a fiber of numerical aperture 0.2 ?

ANS: 2.4 Microwatts