UNIT II

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SYLLABUS

OPTICAL SOURCES

- **LED:** Visible LED, Infrared LED, LED structure and configuration, Loss mechanism, Application of LED, operating Characteristics materials for Visible LED.

- **LASER:** Principle of LASER Action, Efficiency of LASER Diode, principles and structures, index guided and gains guided lasers, mode separation, quantum well laser, laser modulation.

LECTURE PLAN

S. NO	TOPIC	BOOK/PAGE
1	**LED:** Visible LED, Infrared LED, LED structure and configuration	2/296-297, 2/303-310
2	Operating Characteristics	2/310-320
3	Materials for Visible LED, Loss mechanism, Application of LED	1/143-147, 1/147-152
4	**LASER:** Principle of LASER Action Efficiency of LASER Diode	1/152-153, 2/264-265
5	principles and structures	2/245-262
6	index guided and gains guided lasers	1/162-167
7	mode separation, quantum well laser, laser modulation	1/167-168, 1/169-172

Introduction

- The main function of the optical source is to convert electrical energy (current) into optical energy (light).
- There are basically 2 kind of the optical sources, i.e.,

1. LED – incoherent source
2. LASER – coherent source

Requirement of the Optical Source

- The size and configuration of the source must be compatible with the optical fiber.
- The output of the light should be highly directional.
- Must be highly sensitive for the electrical signal in order to minimize distortion and noise.
- Ideally the source should be linear.

Cond...

- Must be able to couple the sufficient optical power in order to overcome attenuation in the fiber and losses in the connectors.
- Should have a very narrow spectral bandwidth in order to minimize the dispersion in the fiber.
- Must be able to maintain a stable output even in the variation in the ambient conditions.

Topics from Semiconductor Physics

- Energy Band
- Intrinsic and Extrinsic material
- PN Junction
- Direct and Indirect Band Gap
- Semiconductor Device Fabrication

LED

- The LED operates on lower current densities than LASER.
- The emitted photons from LED device have random phases, so the LED is an incoherent Optical Source.
- The LED supports many optical modes, so it is a multimode source.

Advantages of LED

a) Simpler fabrication
b) Reduced cost
c) Higher reliability
d) Less temperature dependence
e) Simpler drive circuitry
f) Linearity

Quantum Efficiency and LED Power

- The majority and minority charge carriers in a semiconductor material are equal in amount.
- The majority and minority charge carriers recombine in pairs in order to change neutrality in the crystal.
- The excess of e- and h+ in p type and n type material is created in semiconductor light source by carrier injection at the device contact.

Cond...

- When the carrier injection stops, the carrier density returns to its equilibrium state.
- In general, the carrier density decays exponentially with the time according to the relation: $n = n_0 e^{-\frac{t}{\tau}}$

Cond...

- n_0 is the initial injected excess electron density,
- τ is the carrier life time.
- If there is constant flow of current into an LED, then an equilibrium condition will be established.
- Equilibrium condition means that, the no of electrons and holes in n type and p type material is equal.

Cond...

- It is because the injected carriers are created and recombined in pairs so that the charge neutrality can be maintained within the LED.
- There are two rates at which the carriers are generated.

1. Rate due to Externally supplied carriers.
2. Rate due to thermally generated carriers.

Cond…

- So the total rate will be the sum of these two.
- So the total carrier generation rate will be:

$$\frac{dn}{dt} = \frac{J}{qd} - \frac{n}{\tau}$$

- At equilibrium state, the derivation will be zero. So the no of charge carriers will be;

$$n = \frac{J\tau}{qd}$$

Cond…

- The relation shows the steady state electron density in the active region when a constant current is flowing in it.
- The internal quantum efficiency in the active region is defined by the relation as:

$$\eta_{\text{int}} = \frac{R_r}{R_r + R_{nr}}$$

Cond…

- R_r is radiative recombination rate.
- R_{nr} is nonradiative recombination rate.

$$R_r = \frac{n}{\tau_r} \quad \& \quad R_{nr} = \frac{n}{\tau_{nr}}$$

- So, $$\eta_{\text{int}} = \frac{\dfrac{n}{\tau_r}}{\dfrac{n}{\tau_r} + \dfrac{n}{\tau_{nr}}} = \frac{\tau}{\tau_r} \quad where, \quad \frac{1}{\tau} = \frac{1}{\tau_r} + \frac{1}{\tau_{nr}}$$

Cond...

- In the current injected into LED is *I*, then the total no of recombinations per second will be:

$$R_r + R_{nr} = I/q$$

- So, we can say that,

$$R_r = \eta_{\text{int}} \frac{I}{q}$$

Cond...

- R_r is the total no of photons generated per second.
- Then optical power generated internally to the LED is, $P_{int} = \eta_{int} \frac{I}{q} h\nu = \eta_{int} \frac{I}{q} \frac{hc}{\lambda}$

Problems.

- Example 4.5, Keiser
- Example 7.1 Senior.

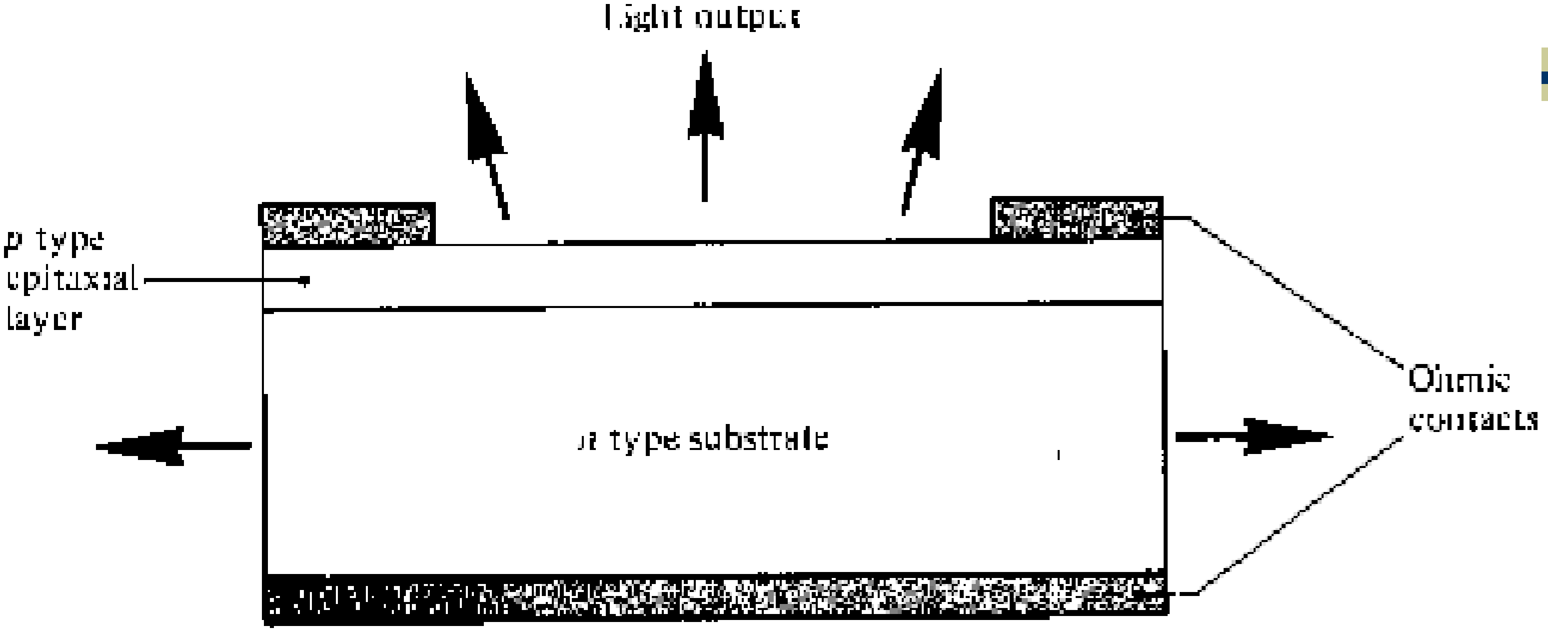
LED Structures

- There are basically four types of LED structures.

1. Planar LED
2. Dome LED
3. Surface Emitter LED
4. Edge Emitter LED

1. Planar LED

- It is the simplest structure.
- Can be fabricated either by LPE/VPE.
- The substrate usually is GaAs substrate.
- In this structure P type epitaxial layer is diffused into N type Substrate.
- The forward current flows through the junctions.

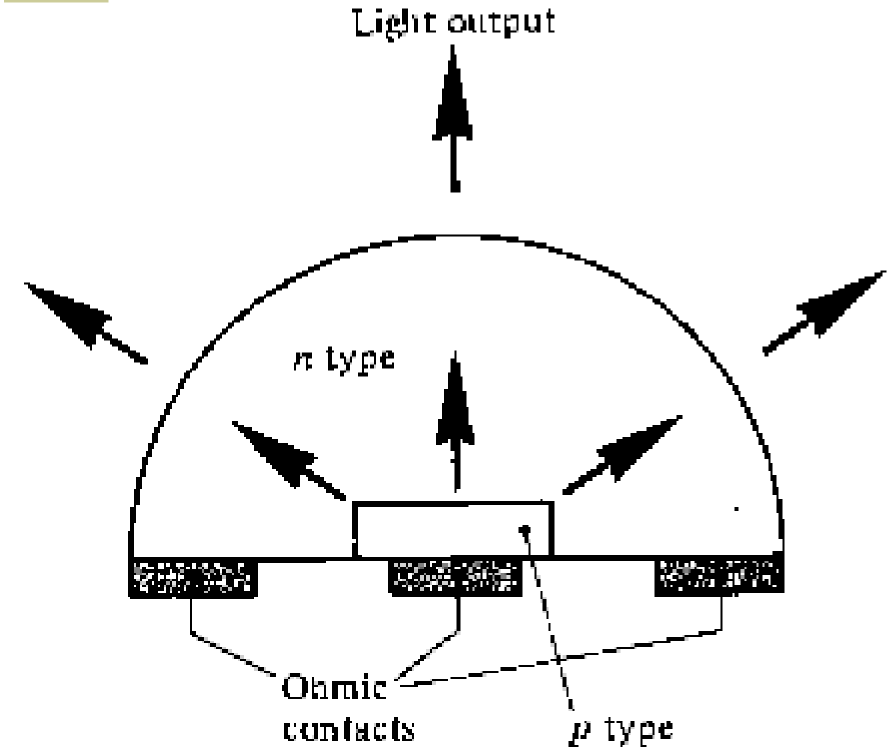

Light output
p type
epitaxial
layer
n type substrate
Ohmic
contacts

Cond…

- This structure emits light from all surfaces.
- Due to total internal reflection a small amount of light escapes from the device.

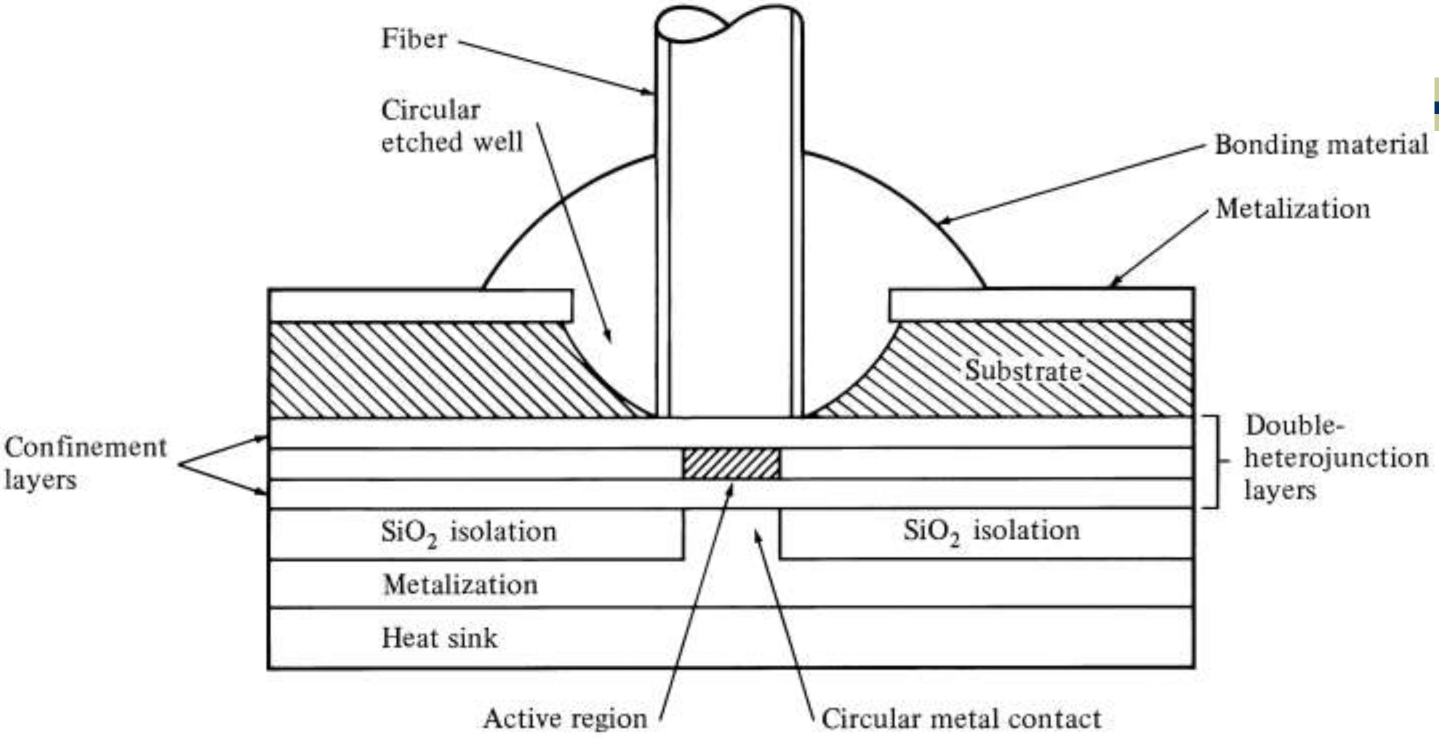
2. Dome LED

- In this structure, a hemisphere of n type GaAs is formed around a diffused p type region.
- This device has high external power efficiency.
- This is because of the hemisphere structure.
- In this structure dome is used to maximize the internal emission at the substrate – air interface.


Light output
n type
Ohmic
contacts
p type

3. Surface Emitter LED

- The surface-emitting LED is also known as the Burrus LED in honor of C. A. Burrus, its developer.
- In SLEDs, the size of the primary active region is limited to a small circular area of 20 μm to 50 μm in diameter.



Fiber
Circular
etched well
Bonding material
Metalization
Substrate
Confinement
layers
Double-
heterojunction
layers
SiO2 isolation
SiO2 isolation
Metalization
Heat sink
Active region
Circular metal contact

Cond...

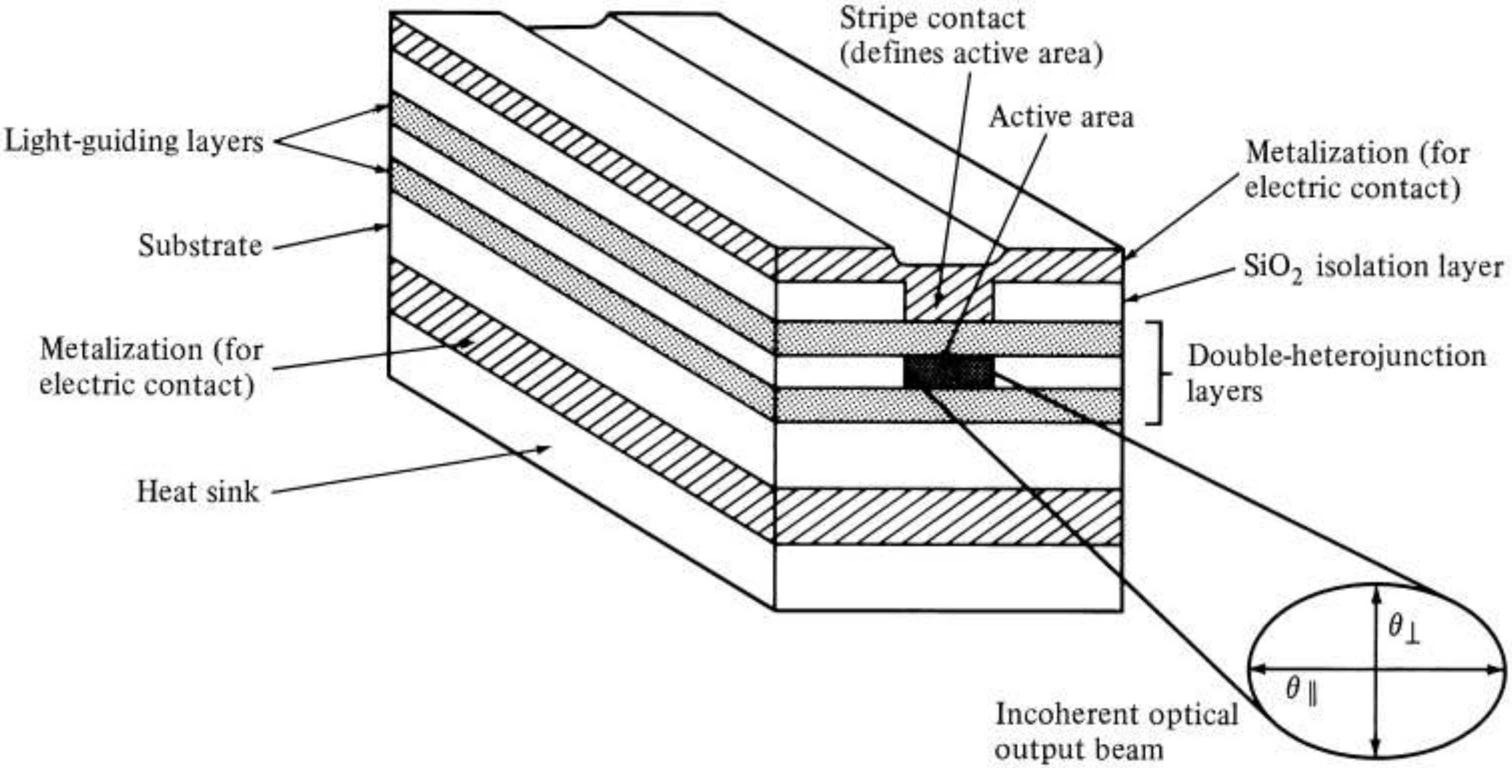
- The active region is the portion of the LED where photons are emitted.
- The primary active region is below the surface of the semiconductor substrate perpendicular to the axis of the fiber.

Cond...

- A well is etched into the substrate to allow direct coupling of the emitted light to the optical fiber.
- The etched well allows the optical fiber to come into close contact with the emitting surface.

4. Edge Emitter LED

- The active region is embedded into a waveguide structure so that the light is directed an edge
  - Larger active region
  - More directional radiation (similar to LASER)


Stripe contact
(defines active area)
Active area
Light-guiding layers
Metalization (for
electric contact)
Substrate
SiO2 isolation layer
Double-heterojunction
layers
Metalization (for
electric contact)
Heat sink
θ⊥
θ ∥
Incoherent optical
output beam

Modulation Bandwidth of an LED

- It is defined in either electrical or optical terms.
- The ratio of electrical power input to the power out is known as ***Electrical Bandwidth***.

Cond...

$$RE_{dB} = 10\log_{10}\frac{Electrical\ Power_{out}}{Electrical\ Power_{in}}$$

$$= 10\log_{10}\frac{P_{out}}{P_{in}}$$

$$= 10\log_{10}\frac{I^2{}_{out}/R_{out}}{I^2{}_{in}/R_{in}}$$

$$\alpha 10\log_{10}\left[\frac{I_{out}}{I_{in}}\right]^2$$

Cond...

$$\Rightarrow \left[\frac{I_{out}}{I_{in}}\right]^2 = \frac{1}{2}$$

$$\Rightarrow \frac{I_{out}}{I_{in}} = \frac{1}{\sqrt{2}} = 0.707$$

Cond...

- So, we see that, the electrical bandwidth is the frequency at which the output current has dropped as per previous equation 0.707 of the input current of the system.

Cond...

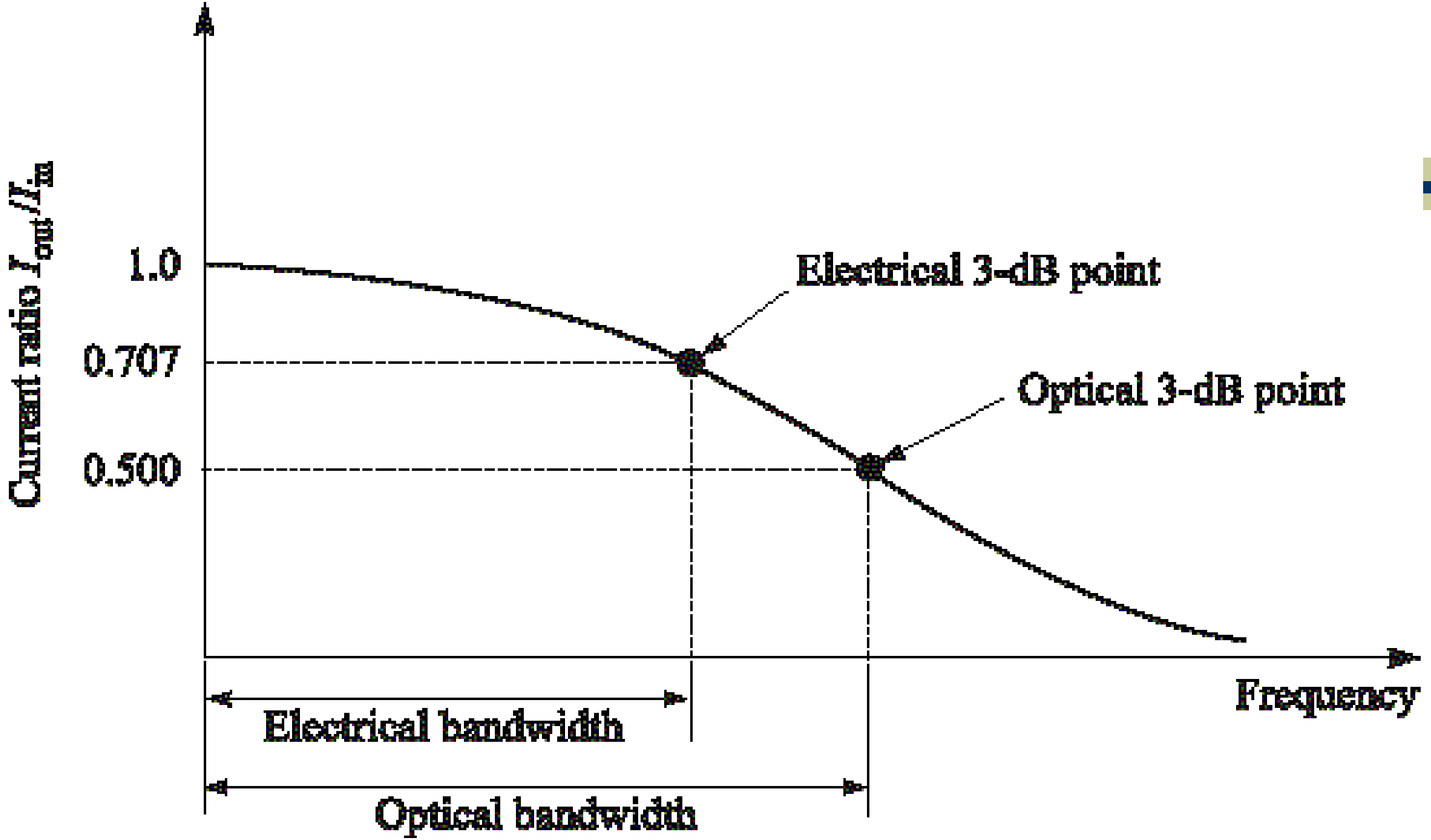
- The ratio of optical output power to the optical out power is known as ***Optical Bandwidth***.

Cond…

$$RE_{dB} = 10\log_{10}\frac{Optical\ Power_{out}}{Optical\ Power_{in}}$$

$$\Rightarrow \qquad \alpha 10\log_{10}\frac{I_{out}}{I_{in}}$$

$$\Rightarrow \frac{I_{out}}{I_{in}} = \frac{1}{2}$$


Current ratio I_{out}/I_{in}
1.0
0.707
0.500
Electrical 3-dB point
Optical 3-dB point
Frequency
Electrical bandwidth
Optical bandwidth

Cond…

- So,
- The electrical 3 dB point occur when the ratio of the currents is equal to 0.707.
- The optical 3 dB points occur when the ratio of the currents is equal to ½.

Cond…

- The *modulation Bandwidth* is the frequency range between zero and high frequency 3 dB point.
- If the 3 dB bandwidth of the modulated optical carrier is considered, we obtain increased value for the modulation bandwidth.

Cond…

- From the figure, the optical bandwidth is significantly greater than the electrical bandwidth.
- The modulation bandwidth of the LEDs is determined by these three mechanisms.

Cond...

1. The doping level in the active layer.
2. The reduction in radiative lifetime due to the injected carriers.
3. The parasitic capacitance of the device.

Cond...

- The speed at which an LED can be directly modulated is fundamentally limited by the recombination lifetime of the carriers.
- The optical output power of the device is;

Cond...

$$\frac{P_e(\omega)}{P_{dc}} = \frac{1}{\sqrt{1+(\omega\tau_i)^2}}$$

τ_i is the injected carrier lifetime in the recombination region

P_{dc} is the dc optical out power for the same drive circuit

LASER

Review Problems

- With the suitable diagram give the mechanism of light from an LED and its use as an optical source for communication. **[UPTU 2009-10]**
- Discuss the relationship between electrical and optical modulation bandwidth for an optical fiber communication system. Estimate the 3 dB optical bandwidth corresponding to a 3 dB electrical bandwidth of 50 MHz. **[UPTU 2009-10]**
- Discuss the semiconductor injection laser. How the efficiency of the laser is defined? How is injection laser coupled to a fiber? **[UPTU 2009-10]**
- What are the requirements of optical sources to be used in optical communication? Explain direct and indirect band gap semiconductors. **[UPTU 2010-11]**

Cond...

- What are the advantages and disadvantages of LED? Draw and explain double heterojunction layer structure of LED. **[UPTU 2010-11]**
- What are the advantages and disadvantages of LASER diode? Explain the principle of working of LASER diode. **[UPTU 2010-11]**
- Explain the principle of semiconductor lasers and draw the emission characteristics. **[UPTU 2011-12]**
- What are the stimulated and spontaneous emissions? Explain the principle of laser action. **[UTU 2011-12]**

Cond…

- Describe the mechanism of emission of light from light emitting diode. What are the types of structures of light emitting diode? Explain any one of them. **[UTU 2011-12]**
- What are the advantages of semiconductor injection lasers over light emitting diodes for communication? The total efficiency of an injection laser with a GaAs active region is 18%. The voltage applied to the device is 2.5 V and the band gap energy of GaAs is 1.43 eV. Calculate the external power efficiency of the device. **[UTU 2011-12]**
- Explain how the optical and electrical confinement is achieved in a LASER. **[UTU 2012-13]**

Cond...

- What is the difference between a surface emitting LED and edge emitting LED? An injection loss has a total efficiency in a GaAs active region as 20%. The volume applied to the device is 2.2 V and the band gap energy of GaAs is 1.43 eV. Find the external power efficiency of the device.**[UTU 2012-13]**
- Explain modulation bandwidth of an LED with the help of suitable frequency response curve, clearly marking optical and electrical bandwidth. **[UTU 2012-13]**
- How internal and external quantum efficiency is laser diode. Determine and describe Quantum well laser.**[UTU 2012-13]**

REFRENCES

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