SYED AMMAL ENGINEERING COLLEGE

(Approved by the AICTE, New Delhi, Govt. of Tamilnadu and Affiliated to Anna University, Chennai)

Established in 1998 - An ISO 9001:2008 Certified Institution

Dr. E.M.Abdullah Campus,Lanthai,Ramanathapuram – 623 502.

Phone: 304000, 304222, 304 101 (04567) Fax: 304123(04567)

Web: www.syedengg.ac.in E.mail:saec@syedengg.ac.in

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

(ACCREDITED BY NBA)

EC6016 Opto Electronic Devices

Unit I

TWO marks questions

1. What is meant by wave function?

 Wave function is the probability amplitude of finding the electron in an energy state of the solid. It is a complex displacement of matter wave (electron wave) and we can`t measure it.

2. Define wave-front.

In the plane waves and in other forms of wave there are surfaces of constant phases, which are referred to as wave surfaces or wave fronts. The propagation of a light wave can be predicted by assuming that each point on the wave front acts as a source of secondary wavelets which spread out in all direction. The envelope of these secondary wavelets after a small interval of time is the new wave front.

3. Differentiate Brewster angle and Critical angle.

 At Brewster angle the incident light at an interface between two media of refractive index n_1 and n_2, the followings are occurred, 1. The parallel component's reflectance is zero 2. The parallel component is fully transmitted 3. Only the perpendicular component is fully reflected.

 $\tan\theta_B = n_2/n_1$; $\theta_B = \tan^{-1}\left(\frac{n2}{n1}\right)$

 At Critical angle, the incident light at an interface between two media of RI n_1 and n_2, (n_1 is denser than n_2) there is no transmitted light and the total light is reflected, (called total internal reflection).

 $\sin\theta_c = n_2/n_1$; $\theta_c = \sin^{-1}\left(\frac{n2}{n1}\right)$

4. Define interference fringes.

The coherent waves from different sources maintain constant phase relationships. When an area is illuminated simultaneously by these sources, the irradiance usually varies from point to point giving rise to **interference fringes**.

5. Define Diffraction and Polarization.

   Diffraction: The light emerges from a small aperture or narrow slit is observed to spread out, this failure of light to travel in straight lines is called diffraction.

   Polarization: If the EF vector of an EMW propagating in free space vibrates in a specified plane, the wave is said to be plane polarized. The light beams characterized by highly oriented EFs and such light are referred to as being polarized.

6. Define Phase Velocity and Group Velocity.

   Phase velocity: The wave fronts are having constant phase and they move through space with a velocity, called phase velocity. The phase velocity occurs in single frequency component.

   Group velocity : A group of waves of closely similar wavelength is moving such that their resultant forms a packet. This packet moves with the group velocity.

7. Define Black body source.

   The opaque bodies or hot dense gases which radiate at virtually all wave lengths. The rate at which energy is emitted is proportional to the fourth power of the absolute temperature, that is $W = \sigma T^4$. σ is Stefan's constant

8. Define Line source.

   Line sources radiate at discrete wavelengths. In excited gases there is little interaction between the individual atoms, ions or molecules, the electromagnetic radiation is emitted at well defined wave lengths. This can be understood easily by Bohr model.

9. Write Einstein's equation of photoelectric concept.

   $E_{max} = hf - e\phi$, where h – plank's constant, ϕ is work function, constant, eϕ : represents the energy required to free electron from the surface.

10. Draw E-k relationship for electron given by Kronig-Penney model.

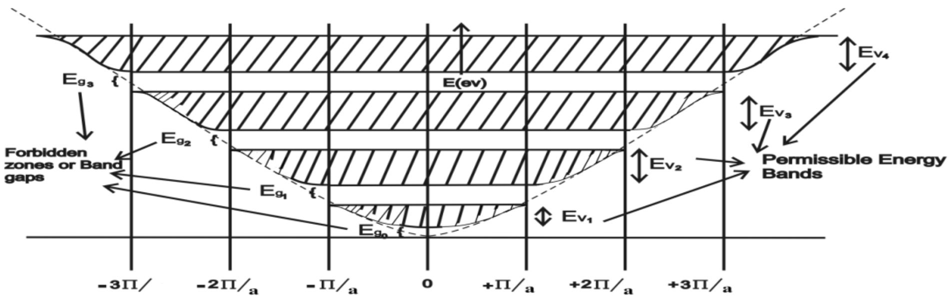


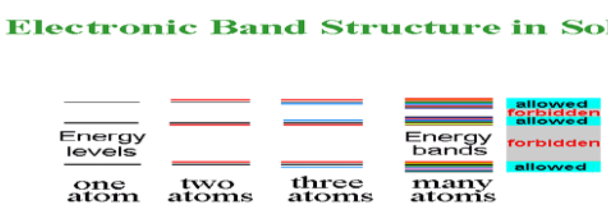
Fig 1.49 Energy Band Diagram of electrons in a crystal solid -the interruption of E-k diagram due to Bragg Reflection

11. Differentiate direct band gap and indirect band gap.

Direct band gap : The band gap is called "direct" if the momentum of electrons and holes is the same in both the conduction band and the valence band; an electron can directly emit a photon. Eg.,GaAs

Indirect band gap :. In an "indirect" gap, a photon cannot be emitted, the momentum of electrons and holes is not the same in both the conduction band and the valence band, the electron must pass through an intermediate state and transfer momentum to the crystal lattice. Eg., Si.

12. Draw the Schematic representation of energy bands in solids.



13. Define electrical conductivity.

The electrical conductivity is obtained by applying external voltage. The electric field creates a force on the electrons. The electrical conductivity is denoted by the symbol 'σ '.

$\sigma = ne\mu_e$; n : no. of electrons, e : electron charge, μ_e : electron mobility

14. Write current density equation of semiconductor.

$$J = J_n + J_p = en\mu_n E + ep\mu_p E = (n\mu_n + p\mu_p)\, eE$$

$J = \sigma E$; J_n – current density of electron, J_p – current density of holes, μ_n – mobility of electrons, μ_p – mobility of holes, σ – conductivity , E – electric field.

15. Define Phonon and Photon.

Phonon : lattice vibration of crystal

Photon : either incident light on device or light radiated by recombination.

16. Explain Excitons.

The Coulombic attraction of an electron for a hole can result in that both being bound together. A bound electron – hole pair is called an exciton. The Excitons are orbiting about their common center of gravity. The effective mass of the electron and hole reduces.

17. Define work function and electron affinity.

Work function : The minimum energy required to enable an electron to escape from the surface of the solid is called work function.

In semiconductor the work function is defined as the energy difference between the Fermi level and vacuum level.

Electron Affinity : is the energy difference between the bottom of the conduction band and vacuum level or

The electron affinity of an atom or molecule is defined as the amount of energy released or spent when an electron is added to a neutral atom or molecule in the gaseous state to form a negative ion.

18. What is the result obtained for the excess carriers in semiconductor?

The excess minority carrier concentration that entering both sides of the junction of semiconductor decreases exponentially with distance.

19. Define Diffusion Coefficients of semiconductor.

Diffusion coefficient is the ease (or easiness) of the carrier motion through the crystal lattice. It is related to the mobilities.

$$D_n = \mu_n \frac{kT}{q} = \mu_n V_t \quad , \quad D_p = \mu_p \frac{kT}{q} = \mu_p V_t$$

BIG questions

1. Derive an expression of wave nature of light starting with the Maxwell's equation. (16)
2. Explain the Young's double slit interference. (8)
3. Explain Diffraction. (8)
4. Explain about Polarization. (8)
5. Explain the formation of energy bands in various materials. (8)
6. Derive an expression for electrical conductivity in solids. (8)
7. Explain the principles of superposition and hence derive an expression for maximum irradiance resulting from four coherence sources. (10)
8. With a neat diagram explain the interference effects in a thin film of refractive index 'n'. (6)
9. Explain in details about the excess carriers in semiconductors and hence derive the expression for the variation of excess carriers concentration with distance and time. (12)
10. Discuss about drift and diffusion of carriers with relevant mathematical expression. (10)
11. From the Schrödinger equation explain the formation of energy bands in solids. (16)
12. Derive the expression for concentration of electrons and holes in an intrinsic and extrinsic semiconductor with relevant diagrams. (16)

Unit II

TWO marks questions

1. Define Photoluminescence and Electroluminescence.

   Photoluminescence : excitation arises from the absorption of photons

   Electroluminescence: excitation results from the application of an electric field which may be either ac or dc
2. Define Stokes shift.

In photoluminescence, the absorption energy and emission energy are same, the wave length of both absorption and emission would be identical. In fact it is not same; the peak emission wave length is invariably shifted towards the red end of the spectrum compared to the peak of the absorption spectrum. It is called as Stokes shift. This is caused by the effect of crystal vibration.

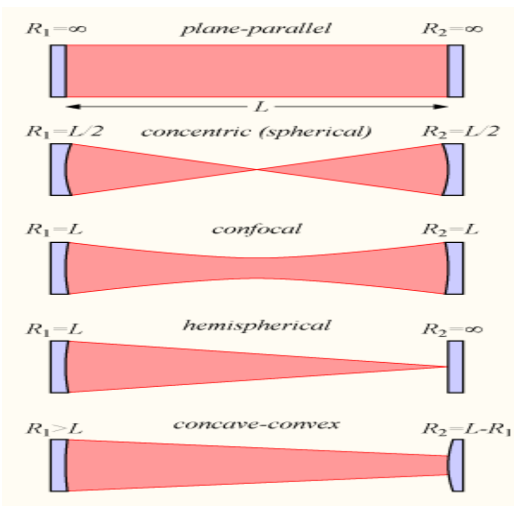
3. What are the radiative recombination processes?

1. Inter-band transitions 2. Recombination via impurity centers and 3. Exciton recombination

4. What is Population Inversion?

The excitation of more electrons from lower level to the higher level is called population inversion. The excitation process is called pumping.

5. Draw the commonly used laser cavity configuration.



6. Define line shaping function.

The spectral lines have a finite wavelength spread , that is they have a spectral width. This can be in both emission and absorption.

7. Define mode locking.

Mode locking is a technique for producing periodic, high power, short duration laser pulses. The different modes of signal have to maintain the same relative phase to one another.

8. Discuss electron trapping.

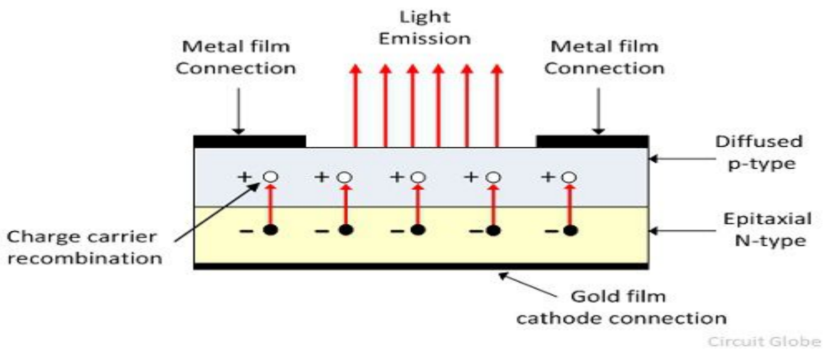
On a semiconductor there are many kinds of defects which are generated as a cause of the fabrication processes involved. Pits, Polishing dimples, scratches, metal residue are all defects found.

Traps: The impurities, point defects, surface states, dangling bonds, and also localized stresses can act as trapping centres in a semiconductor material. Trapping center means it can attract an electron and then hole and act as recombination centre.

9. Mention some important LED materials.

1. Gallium arsenide 2. Gallium Phosphide 3. Gallium arsenide phosphide 4. Gallium aluminium arsenide

10. Draw the typical construction of LED.



11. Mention the laser losses.

1. Transmission at the mirrors
2. Absorption and scattering at the mirrors
3. Absorption in the laser medium
4. Scattering at optical inhomogeneities in the laser medium
5. Diffraction losses at the mirrors

BIG questions

1. Explain photoluminescence and electroluminescence. (8)
2. Explain the operation of active and passive matrix LCD in details. (16)
3. Explain electroluminescence and discuss radiative recombination process. (16)
4. Explain absorption of radiation by using Einstein's relations. (10)
5. Discuss the theory of population inversion and threshold condition in 2 level laser system. Also explain with diagram, the various transitions involved in a 4 level system. (16)
6. Discuss the theory of laser emission and population inversion. (8)
7. Explain LED construction and discuss method followed to reduce reflection losses. (10)
8. Discuss the theory of mode locking in Laser with neat diagrams and hence devise an expression for irradiance. (12)

Unit III

TWO marks questions

1. What is temperature coefficient of resistance?

   In the Bolometer the incident radiation heats a fine wire or metallic strip causing a change in its electrical resistance. This is called temperature coefficient of resistance.

   Two types: positive and negative temperature coefficient

   Positive temp coefficient: Increasing temp increases the resistance, eg., Platinum and nickel

   Negative temp coefficient: Increasing temp decreases the resistance, eg Oxide of manganese, cobalt or nickel.

2. Define quantum yield or quantum efficiency.

   The ratio of the number of emitted electrons to the number of absorbed photons is called the quantum yield or quantum efficiency.

3. Define work function.

   The minimum energy required to enable an electron to escape from the surface of the solid is called work function.

   In semiconductor, the work function is defined as the energy difference between the Fermi level and vacuum level.

4. What is negative electron affinity?

The electron affinity of an atom or molecule is defined as the amount of energy released or spent when an electron is added to a neutral atom or molecule in the gaseous state to form a negative ion.

When an electron is added to a neutral atom (i.e., first electron affinity) energy is released; thus, the first electron affinities are **negative**. However, more energy is required to add an electron to a negative ion.

5. Discuss speed of response of photo multipliers.

The electrons take finite time to traverse the dynamic chain from cathode to anode. In fact this time will not be the same for all the electrons. There are two reasons for the spread of transit time.

1. The electrons have a spread in velocities when they are ejected from the cathode and subsequent dynodes. 2. They traverse slightly different paths through the photo-multiplier.

6. Define Dark Current.

Even when no radiation is falling onto the photocathode surface, thermionic emission gives rise to a dark current, which often constitutes the main source of noise in photo-emissive devices.

7. What is shot noise?

It is encountered whenever there is current flow and arises directly from the discrete nature of the electronic charge. The electrons will fluctuate slightly and gives rise to fluctuations in the current flow.

8. Differentiate between photo-conductive and photo-voltaic.

photo-conductive : Incident light produces a potential, no external bias required.

photo-voltaic: Incident light produces a potential, it needs a reverse bias.

9. What is flicker noise?

At frequencies less than 1 KHz a relatively little understood source of noise known as **flicker or 1/f noise** becomes predominant. It is present in most semiconductor devices and although the cause has been established. There is some definite links with trap distributions.

The rms noise current due to flicker noise is : Δi_f (flicker) = $i\,(B\,\Delta f/f)^{1/2}$ **, B is** constant.

10. What is generation and recombination noise?

The main source of noise in photoconductive detectors arises from fluctuations in the rates of generation and recombination of electron – hole pairs. Both optical and thermal excitation processes contribute to generation noise.

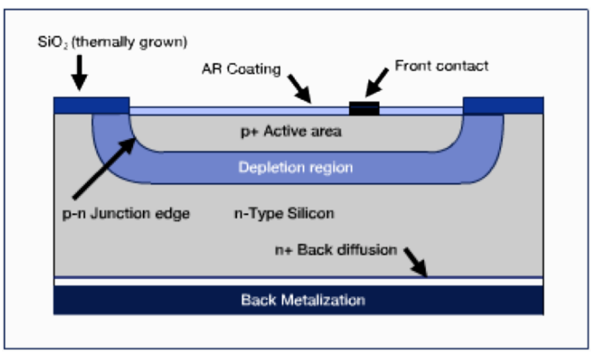
11. What is solar cell?

It is p-n junction detector operated under conditions such that it can deliver power into an external load.

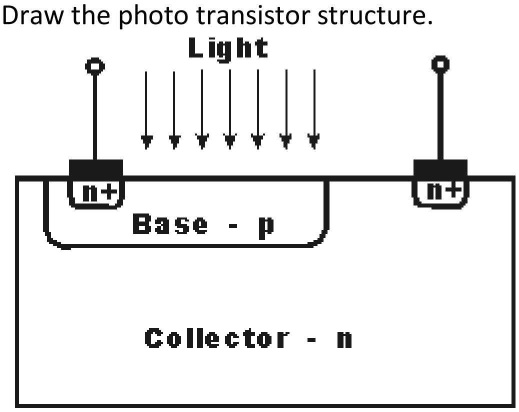
Or

A solar cell or photovoltaic cell is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect. Its electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Solar cells are the building blocks of photovoltaic modules.

12. Draw the typical Si photo diode structure.



13. Draw the photo transistor structure.



14. What is photo current?

Photocurrent is the electric current through a photosensitive device, such as a photodiode, as the result of exposure to radiant power. The photocurrent may occur as a result of the photoelectric, photo-emissive, or photovoltaic effect.

15. What are junction capacitance effects?

    A diode under reverse bias exhibits a voltage dependent capacitance caused by the variation in stored charge at the junction. The capacitance decreases with increasing reverse voltage. At high frequencies the diode capacitance acts as a shunt across the output resistance network and reduces the output. High junction capacitance reduces the bandwidth.

16. What are the advantages of Schottky photo diode?

    Schottky photo-diode has the surface metal layer made with sufficiently thin to transmit blue and near ultra – violet radiation, thus giving an enhanced sensitivity in this region.

17. What is noise equivalent power?

    Noise equivalent power is an indication of the size of the minimum detectable signal. It is defined as the power of sinusoidally modulated monochromatic radiation which would result in the same rms output signal in an ideal noise –free detector as the noise signal encountered in the real detector.

18. Calculate the maximum frequency of operation of a thermal detectors with thermal time constant of **1 ms**.

    τ_H, thermal time constant = 1 ms

    $\tau_H << 1/2\pi f \rightarrow f << 1/2\pi\tau_H << 159Hz$

19. What are the limitations of Germanium based photo diodes?

    The Germanium photo diode has low quantum efficiency and has high leakage currents. The high leakage current produces high noise current.

BIG questions

1. Explain the general concepts of Thermal detectors. (8)

2. Explain the Thermoelectric detectors. (16)
3. Discuss the photon devices. (16)
4. Describe the noises in photo multipliers. (8)
5. Discuss the design issues of APD. (16)
6. Draw and explain the equivalent circuit of a photo diode. (8)
7. Explain the operation of a Solar Cell. (8)
8. Explain the principle, construction and working of a pyro electric detector. (10)
9. Brief about photo emissive devices. (6)
10. Explain the principle of operation of photo transistor. (8)
11. Discuss the construction and working of a Vidicon type imaging tube. (8)

Unit IV

TWO marks questions

1. List the advantages of digital modulation.

   Digital modulation is more suited for large bandwidth optical transmission and reception.

   It is relatively free from noise or distortion.

2. Compare analog and digital modulation.

   Analog modulation: 1. The information signal or wave varies the light from the source, or high frequency signal, in a continuous manner. 2. Thus both could be sinusoidal. 3. There is always one-to-one correspondence between the information signal and the magnitude of the modulated carrier. 4. It requires high signal to noise at receiver. 5. More suited for low modulation frequencies.

   Digital modulation: 1. discrete change in the intensity of the carrier is caused by the information signal. 2. The information is transmitted by the high frequency signal as a series of discrete pulses. 3. More suited for large BW optical transmission and reception. 4. Relatively free from noise and distortion.

3. What is Electro optic modulator?

   Electro-optic modulator is an optical device in which a signal-controlled element exhibiting the electro-optic effect is used to modulate a beam of light. The modulation may be imposed on the phase, frequency, amplitude, or polarization of the beam. The electro-optic effect is the change in the refractive index of a material resulting from the application of a DC or low-frequency electric field. This is caused by forces that distort the position, orientation, or shape of the molecules constituting the material.

4. Define Electro optic effect.

When an electric field is applied across an optical medium the distribution of electrons within it is distorted so that the polarizability and hence the refractive index of the medium changes anisotropically. This effect may be to introduce new optic axes into naturally doubly refracting crystals.

5. What is Quantum Confined Stark Effect (QCSE)?

In a quantum well hetero-structure, there will be a strong interaction of the EF with the optical wave. Close to the sub-band transition energies the absorption is dominated by excitonic effects and the electro-absorption is greatly enhanced. This is described as the quantum confined Stark effect, which is a quadratic effect with respect to EF.

6. Determine the change in RI due to Pockel's effect in a **10mm** wide KD*P crystal for an applied voltage of **4KV**, the electro optic coefficient and Refractive Index of the material are **$26.4X10^{-12}$** m/V and **1.51** respectively.

$E = V/t = 4000/10^{-2}$ V/m

We can use the formulae

$n_x' = n_0 + (n_0^3/2)\, r_{63}\, E_z$ or

$n_y' = n_0 - n_0^3/2\, r_{6'3}\, E_z$ or both

$n - n_0 = \pm (n_0^3/2)\, r_{63}\, E_z = [(1.21)^2/2\,] x\ 26.4x10^{-12} \ x\ 4000/10^{-2} = 1.8x10^{-5}$.

7. Define Bi-refringence.

An electric field applied to an anisotropic crystal, produces electric polarization. The speed of propagation of a light wave in such crystals depends on the direction of propagation and the polarization of the light. That is the refractive index of the crystal varies with direction in the crystal. These crystals are said to birefringent or doubly refracting. Birefringence produces two waves, one is called ordinary wave and the second one is called extra ordinary wave.

8. Define Pockel effect and Kerr effect in crystal.

   The change in refractive index as a function of the applied field can be obtained from the equation

   $\Delta(1/n^2) = r\mathcal{E} + P\mathcal{E}^2$

   In solids the linear variation in the RI associated with $r\mathcal{E}$ is known as the Pockels effect.

   The variation in RI arising from the quadratic term is called the Kerr effect.

9. Define Half Wave voltage.

   Half wave voltages cause the two waves polarized parallel to the principal axes to acquire a relative spatial displacement of $\lambda/2$, which is equivalent to a phase difference of π and produces a 90 rotation. This voltage allows maximum transmission.

10. What is acosto optic effect?

    The acosto-optic effect is the change in the refractive index of a medium caused by the mechanical strains accompanying the passage of an acoustic wave through the medium.

11. What is the difference between Raman-Nath regime and Bragg regime.

    Raman-Nath regime: The acoustic diffraction grating is so thin that the diffracted light suffers no further redistribution before leaving the modulator. The light is diffracted as from the simple plane grating.

    Bragg regime: The light diffracted from the incident beam is extremely re-diffracted before leaving a acoustic field. The acoustic field acts very much like a thick diffraction grating i.e., a grating made up of planes rather than lines.

12. Define Bragg Cell.

    An acousto-optic modulator also called a Bragg cell, uses the acousto-optic effect to diffract and shift the frequency of light using sound waves. They are used in lasers for Q-switching, telecommunications for signal modulation, and in spectroscopy for frequency control. A piezoelectric transducer is attached to a material such as glass. An oscillating electric signal drives the transducer to vibrate, which creates sound waves in the material. These can be thought of as moving periodic planes of expansion and compression that change the index of refraction.

BIG questions

1. Explain the concept of external modulation and compare with direct modulation. (6)
2. Explain the concept of Bi-refringence in Uniaxial crystal with necessary diagrams. (8)
3. Derive the expression for retardation between two waves due to applied voltage in electro optic material. (8)
4. Discuss in detail the principle and operation of QCSE based optical switching device. (10)
5. Explain the significances fro Multiple Quantum Wells in opto electronic devices. (6)
6. Explain with a neat diagram of construction of electro optic effect based external modulation; also deduce the expression of modulated light. (10)
7. Discuss in detail the principle of operation of a photonic switch based on Self Electro Optic Device (SEED). (10)
8. Explain the concept of Bipolar controller modulator. (6)
9. Explain the principle of magneto optic devices. (10)
10. Explain the operating principles of Switching and logic devices. (16)
11. Explain the operation of a three input threshold logic gates with output characteristics curve. (10)
12. Write short notes on optical cross bar switch. (6)
13. Explain with a neat diagram, the construction of electro optic effect based modulator. (16)

Unit V

TWO marks questions

1. What are the major differences in characteristic of Opto electronic ICs when compared to conventional electronic ICs?

   Conventional electronic ICs characteristics: input-output isolation, packaging density is very high, very high quality, proper impedance matching, reliable, more parasitic etc.,

   Opto electronic ICs characteristics : high speed, high sensitivity, compactness, reliable, less packaging density, less impedance matching, less parasitic, etc.,

2. What are the advantages of Hybrid opto electronic Integration?

   In hybrid integration, discrete functional blocks or chips are connected using electronic (leads) or optical (fiber) interconnects.

   Advantages: which has the possibility of using high performance discrete devices as components.

3. List the factors that dictate the half wave voltage in an active wave guide device.

   Proportional to wave length and thickness of the wave guide and inversely proportional to active length , third power of refractive index and linear variation in the RI ('r'- Pockels effect).

4. What is Lithography?

   Photolithography, also termed optical lithography or UV lithography, is a process used in micro fabrication to pattern parts of a thin film or the bulk of a substrate. It uses light to transfer a geometric pattern from a photo mask to a light-sensitive chemical "photo resist", or simply "resist," on the substrate. A series of chemical treatments then either engraves the exposure pattern into, or enables deposition of a new material in the desired pattern upon the material underneath the photo resist. For example, in complex integrated circuits, a modern CMOS wafer will go through the photolithographic cycle up to 50 times.

5. What is Plasma etching?

   Plasma etching is a form of plasma processing used to fabricate integrated circuits. It involves a high-speed stream of glow discharge (plasma) of an appropriate gas mixture being shot (in pulses) at a sample. The plasma source, known as etch species, can be either charged (ions) or neutral (atoms and radicals). During the process, the plasma generates volatile etch products at room temperature from the chemical reactions between the elements of the material etched and the reactive species generated by the plasma. Eventually the atoms of the shot element embed themselves at or just below the surface of the target, thus modifying the physical properties of the target.

6. Give the condition for complete power transfer from one guide to another in an optical waveguide directional coupler.

   For proper energy exchange requires that the light propagating in both guides have the same velocity and propagation vector.

7. What are the advantages of Monolithic Opto electronic integration?

   All active and passive components are fabricated on the same chip. The OEIC has hetero-structures and the processing steps of the different component. **OEIC has reduced size, reduction of parasitic and the consequent achievement of higher circuit speed and bandwidth**.

8. Define the parameters eye closer and jitter used in eye diagram.

   Percentage eye closer = $(1-\frac{V1}{V2})$x100

   Percentage jitter = $\Delta t/t_c$ x100

9. Write down the fabrication complexity of OEIC transmitter compared to photo receiver.
   1. The laser structure is nearly 4 µm high, which makes the processing steps for integration with an incompatible heterostructure for the electronic device very difficult.
   2. The optical cavity in an edge-emitting laser needs to be defined by two end mirrors.
   3. Electrical and optical confinement needs to be achieved in the lateral dimension.
   4. The operation of the laser necessitates efficient heat sinking of the whole chip.

10. Name the techniques for fabricating waveguides.
    1. Ridge wave guide 2. Buried channel guide by implantation 3. Strip loaded guide and 4. Disordered MQW

BIG questions

1. What is the need for integration of Opto electronic devices and also draw the block diagram of essential elements of an OEIC. (8)
2. Explain the application of Opto electronic integrated circuits. (8)
3. Write a note on Hybrid integration OEIC fabrication. (6)
4. Brief about the principal forms of opto electronic integration with their merits and demerits.
5. Explain PIN diode and MODFET combination of photo diode. (8)
6. Draw the diagram of a PIN diode and HBT integration front end Photo receiver and explain its operation. (8)
7. Discuss the noise performance in Integrated Photo receivers. (8)
8. Explain the OEIC transmitter with fabrication diagram. (12)
9. Explain the principle and operation of wave guides and couplers in detail. (16)
10. Explain the principle and operation of
    1) Waveguide coupler (4)
    2) Waveguide interferometer (6)
    3) Active directional coupler switch. (6)