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| **UNIT – 5** |
| **LASER AND FIBRE OPTICS** |
| **Unit-05/Lecture-01** |
| **Introduction & Definition [RGPV/ June 2011,Dec2012 (14)]**  An atom consists of an electron cloud revolving around the central nucleus having protons and neutrons. The atoms are constantly in motion, they vibrate, move and rotate. Also they are in different states of excitation and hence have different energies. If some external energy in the form of light, heat, or electricity is supplied to an atom, the electrons from low energy level called ground state may jump to higher energy level  called excited state. The electrons in the higher energy orbit cannot stay there for a long time. Therefore they return to the ground state spontaneously releasing the absorbed energy in the form of radiations.  **LASER**  The term LASER stands for Light Amplification by Stimulated Emission of Radiation. The LASER is a device which amplifies light waves similar to the transistor which amplifies electric current. The laser is a powerful source of light.  **Principle of LASER**  Laser works on the principle of quantum theory of radiation. When an atom in the lower energy E1 absorbs the photon energy of incident radiation, it is excited to the higher energy level of energy E2. This process is called absorption. The number of absorption transition take place perunit time per unit volume is directly proportional to the number of atoms in the lower energy level and the number of photons in the incident radiation.  The energy difference E2- E1 is called excitation energy and it is equal to the energy of the photon absorbed by the atom. In higher energy level (E2), the atom cannot remain long time, since it has a tendency to drop 2energy. So the atom jumps to the lower energy level (E1). At that time, the energy difference E2- E1 is emitted in the form of radiation as photon. The energy of the photon released, E2- E1 =hν, where ν is the frequency of the radiation and h, the Planck's constant.    **Definitions [RGPV/ June 2011,Dec2012 (14)]**  **Spontaneous emission**  Spontaneous emission is the process of photon emission takes place immediately without any inducement during the transition of atoms from higher energy levels to lower energy levels. This is a random process in which the photons are emitted at different time. So, in the emitted radiation each photon has different phase and are incoherent. The number of spontaneous transition (Nsp ) taking place per unit sp time per unit volume is directly proportional to the number of atoms in the higher energy level (N2) is.  Nsp α N2  Nsp = A21 N2  where A21 is a constant known as the probability of spontaneous transition per unit time. Also it is called Einstein's co-efficient of spontaneous emission.    **Stimulated emission**  Einstein found a new process called stimulated emission to increase the number of transition of atoms from higher energy levels to lower energy levels.  Stimulated emission is the process of photon emissions takes place by an inducement given by another photon incident on the atoms in higher energy levels. The energy of the photon emitted is equal to the energy of the photon incident.  Consider an atom in the higher energy level (E2 ). When an external radiation of photon energy E2- E1 is incident on the excited atom, the photon stimulates the atom to make transition from higher to lower energy level. As a result the same photon energy E2- E1 is emitted in the form of radiation. During this process, the stimulating photon and the photon emitted by the excited atom are emitted simultaneously in the same direction. Hence they are identical in phase, direction and frequency and are coherent. This process of stimulated emission is used to produce laser beam.  The number of stimulated transition (Nst) taking place per unit time per volume is directly to  1) the number of atoms in the higher energy level (N2)  2) The energy density Eν in the frequency range ν and ν+d ν.  ie Nst α N2 Eν  Nst = B21 N2 Eν  Where B21 is a constant known as the probability of stimulated transition per unit time. Also it is called Einstein's co-efficient of stimulated emission.    **Population inversion**  Population inversion is the establishment of the situation to make more number of atoms in the excited state required for the chain reaction of stimulated emission.  For achieving the population inversion, the number of atoms must be raised continuously to the excited state. When a sufficient energy is given to the atoms in the ground state, they are excited to the higher energy levels. This process is called **pumping**. If the atoms in the ground state are brought to the excited state by means of light energy, the process is called **optical pumping.**   |  |  |  |  | | --- | --- | --- | --- | | S.NO | RGPV QUESTIONS | Year | Marks | | Q.1 | Difference between spontaneous emission and stimulated emission | June2011 | 7 | | Q.2 | Explain the spontaneous emission and stimulated emission, population inversion, pumping | DEC 2012 | 14 | |

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| **Unit-05/Lecture-02** |
| **Einstein’s coefficient A & B [RGPV/ Dec2013 (7)]**  **Consider a ststem of atoms having ground state energy and excited state energy** E1 and E2 with the number of densities N1 andN2 respectively. If the photons of frequency    are incident on the system of atoms, there will be induced absorption. The rate of absorption of photons will be proportional to the number densities N1 and energy density Eν in the frequency range ν and ν+d ν in the incident radiation.  Rate of absorption α N1 Eν  Ra = B12 N1 Eν  Where B12 is a constant known as the probability of stimulated absorption per unit time. Also it is called Einstein's co-efficient of stimulated absorption.  **Atoms in the excited state** E2 can come down either through Spontaneous emission or stimulated emission of radiation.  In case of Spontaneous emission the rate of transition of atoms from E2 to E1 does not depend on the energy density of atoms and is proportional to the number densities N2 in the excited state  Rate of Spontaneous emission α N2  Rsp **= A21**N2  where A21 is a constant known as the probability of spontaneous transition per unit time. Also it is called Einstein's co-efficient of spontaneous emission.  In case of stimulated emission the rate of transition of atoms from E2 to E1 will be proportional to the number densities N2 and energy density Eν in the frequency range ν and ν+d ν in the incident radiation.  Rate of Spontaneous emission α N2 Eν  Rst = B21 N2 Eν  Where B21 is a constant known as the probability of stimulated transition per unit time. Also it is called Einstein's co-efficient of stimulated emission.  In thermal equilibrium, the rate of transition of atoms from E1 to E2 must be equal to the rate of transition of atoms from E2 to E1. Thus  Rate of absorption = Rate of Spontaneous emission + Rate of stimulated emission  B12 N1 Eν  = **A21**N2 + B21 N2 Eν  B12 N1 Eν  - B21 N2 Eν = **A21**N2    From Maxwell distribution  From Plank’s law  On comparing the eq.  Thus, the probability of induced absorption is equal to the probability of stimulated emission  **And**  **i.e. the ratio of** Einstein's co-efficient of spontaneous emission to the Einstein's co-efficient of stimulated emission is directly proportional to the cube of frequency.       |  |  |  |  | | --- | --- | --- | --- | | S.NO | RGPV QUESTIONS | Year | Marks | | Q.1 | Obtain the relation between the transition probability of **Einstein’s coefficient A & B** | Dec 2013 | 7 | | Q.2 |  |  |  | | Q.3 |  |  |  | |
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| **Unit-05/Lecture-03** |
| **Main components of laser system [RGPV/ June 2012 (7)]**  There are three main components of laser system   1. Active medium 2. Energy source 3. Optical resonator   **Active medium**:  When active medium is excited, it achieves population inversion. The active medium may be solid, liquid or gas. Depending on the active medium we have different type of lasers i.e. solid state lase, liquid laser or gas lasers.  **Energy source:**  The energy source raises the system to an excited state.  **Optical resonator**  The optical resonator consists of two mirrors facing each other. The active medium is enclosed by this cavity. Out of the two mirrors, one is fully reflective while the other is partially reflective. The function of the optical resonator is to increase the intensity of laser beam.  **Action of optical resonator**   1. Initially the active centres are in non excited state. 2. Using a suitable pumping process, the material is taken into the population inversion state. For this purpose, the energy source is used. 3. At the initial stage, the spontaneous photons are emitted in all directions. The photons that travel in specific direction are selected while others are rejected. 4. The stimulated photons are to be made through medium constituting the resonator source the directional selectivity, the photons are travelling in random directions are lost. On reaching the partially reflective mirror, some photons are transmitted out while the remaining are reflected back. 5. The reflected photons de-excite more and more atoms. At fully reflective mirror, some photons are absorbed while a major number of photons are reflected. The beam is not amplified. 6. The amplified beam undergoes multiple reflections at the mirrors and gain in strength. 7. When the amount of amplified light beam equal to the total amount of light lost the laser beam oscillations begins. 8. When the oscillator build -up to enough intensity then they emerge out through the front mirror as highly collimated intense beam i.e. laser light.   **Characteristics of LASER**  Laser radiation is different from normal light radiation. The characteristics of laser are given below:  1. Laser radiation is monochromatic. It contains only one particular wavelength (colour) of light. The wavelength is determined by the amount of energy released.  2. Laser radiation is coherent. In emitted radiation all the photons are having the same phase and amplitude.  3. Laser radiation is highly directional. Laser beam of light can travel very long distance, without much divergence.  4. Laser radiation is very intense. The intensity and hence the brightness of the laser radiation is high.  The radiation having single wavelength, same amplitude and same phase is called ‘coherent radiation’.  **Coherence**  Coherence between two sources of light concerns with the existence of a constant phase relation between them. This is of following types.   1. **Temporal coherence** 2. **Spatial coherence**   **Temporal coherence**  Temporal coherence is the measure of the average correlation between the value of a wave and itself delayed by τ, at any pair of times. Temporal coherence tells us how monochromatic a source is. In other words, it characterizes how well a wave can interfere with itself at a different time. The delay over which the phase or amplitude wanders by a significant amount (and hence the correlation decreases by significant amount) is defined as the [coherence time](http://en.wikipedia.org/wiki/Coherence_time) *τc*. At τ=0 the degree of coherence is perfect whereas it drops significantly by delay *τc*. The [coherence length](http://en.wikipedia.org/wiki/Coherence_length) *Lc* is defined as the distance the wave travels in time τc.  **Spatial Coherence**  In some systems, such as water waves or optics, wave-like states can extend over one or two dimensions. Spatial coherence describes the ability for two points in space, *x1* and *x2*, in the extent of a wave to interfere, when averaged over time. More precisely, the spatial coherence is the [cross-correlation](http://en.wikipedia.org/wiki/Cross-correlation) between two points in a wave for all times. If a wave has only 1 value of amplitude over an infinite length, it is perfectly spatially coherent. The range of separation between the two points over which there is significant interference is called the coherence area, *Ac*   |  |  |  |  | | --- | --- | --- | --- | | S.NO | RGPV QUESTIONS | Year | Marks | | Q.1 | **Write a short note on coherence, optical resonator** | June 2012 | 7 | |

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| **Unit-05/Lecture-04** |
| **Ruby laser. [RGPV/ JUNE 2012(14), JUNE 2011 (7)]**  The first working laser was built in 1960 by Maiman, using a ruby crytal and so called the Ruby laser.  Ruby belongs to the family of gems consisting of Al2O3 with various types of impurities. For example pink Ruby contains 0.05% Cr atoms. The schematic diagram of ruby laser can be drawn as:  Ruby Lazer  **Construction of Ruby Laser**  The ruby lazer consists of a ruby rod . which is made of chromium doped ruby material. At the opposite ends of this rod there are two silver polished mirrors. Whose one is fully polished and other is partially polished. A spring is attached to the rod with fully polished end for adjustment of wave length of the lazer light. Around the ruby rod a flash light is kept for the pump input. The whole assembly is kept in the glass tube. Around the neck of the glass tube the R.F source and switching control is designed in order to switch on and off the flash light for desired intervals.  **Operation of Ruby Laser:**  When we switch on the circuit the R.F operates. As a result the flash of light is obtained around the ruby rod. This flash causes the electrons within ruby rod to move from lower energy band towards higher energy band. The population inversion takes place at high energy band and electrons starts back to travel towards the lower energy band. During this movement the electron emits the laser light. This emitted light travels between the two mirrors where cross reflection takes place of this light. The stimulated laser light now escapes from partially polished mirror in shape of laser beam.  The spring attached with the fully polished mirror is used to adjust the wave length equal to λ/2 of laser light for optimum laser beam. The switching control of the R.F source is used to switch on and off the flash light so that excessive heat should not be generated due to very high frequency of the movement of the electron.  **Energy Level Diagram for Ruby Laser**  Energy level diagram for the Ruby Laser  The above three level energy diagram show that in ruby lasers the absorption occurs in a rather broad range in the green part of the spectrum. This makes raise the electrons from ground state E1 to the band of level E3 higher than E1. At E3 these excited levels are highly unstable and so the electrons decays rapidly to the level of E2. This transition occurs with energy difference (E1 – E2) given up as heat (radiation less transmission). The level E2 is very important for stimulated emission process and is known as Meta stable state. Electrons in this level have an average life time of about 5m.s before they fall to ground state. After this the population inversion can be established between E2 and E1. The population inversion is obtained by optical pumping of the ruby rod with a flash lamp. A common type of the flash lamp is a glass tube wrapped around the ruby rod and filled with xenon gas. When the flash lamp intensity becomes large enough to create population inversion, then stimulated emission from the Meta stable level to the ground level occurs which result in the laser output. Once the population inversion begins, the Meta stable level is depopulated very quickly. Thus the laser output consists of an intense spike lasting from a few Nano sec to µsec. after stimulated emission spike, population inversion builds up again and a 2nd spike results. This process continues as long as the flash lamp intensity is enough to create the population inversion.  **Advantages of Ruby Lasers**   * From cost point of view, the ruby lasers are economical. * Beam diameter of the ruby laser is comparatively less than CO2 gas lasers. * Output power of Ruby laser is not as less as in He-Ne gas lasers. * Since the ruby is in solid form therefore there is no chance of wasting material of active medium. * Construction and function of ruby laser is self explanatory.   **Disadvantages of Ruby Laser**   * In ruby lasers no significant stimulated emission occurs, until at least half of the ground state electrons have been excited to the Meta stable state. * Efficiency of ruby laser is comparatively low. * Optical cavity of ruby laser is short as compared to other lasers, which may be considered a disadvantage.   **Applications of ruby Laser**   * Due to low output power they are class-I lasers and so may used as toys for children’s. * It can be used in schools, colleges, universities for science programs. * It can be used as decoration piece & artistic display.   **Nd:YAG Laser**  **Nd:YAG** (**neodymium-doped yttrium aluminum garnet**; **Nd:Y3Al5O12**) is a crystal that is used as a lasing medium for solid-state lasers. The dopant, triply ionized neodymium, Nd(III), typically replaces a small fraction (1%) of the [yttrium](http://en.wikipedia.org/wiki/Yttrium) ions in the host crystal structure of the yttrium aluminium garnet (YAG), since the two ions are of similar size. It is the neodymium ion which provides the lasing activity in the crystal, in the same fashion as red chromium ion in ruby lasers.  Construction and Working  Nd:YAG lasers are optically pumped using a flashtube or laser diodes. These are one of the most common types of laser, and are used for many different applications. Nd:YAG lasers typically emit light with a wavelength of 1064 nm, in the infrared. However, there are also transitions near 940, 1120, 1320, and 1440 nm. Nd:YAG lasers operate in both pulsed and continuous mode. Pulsed Nd:YAG lasers are typically operated in the so-called Q-switching mode: An optical switch is inserted in the laser cavity waiting for a maximum population inversion in the neodymium ions before it opens. Then the light wave can run through the cavity, depopulating the excited laser medium at maximum population inversion. In this Q-switched mode, output powers of 250 megawatts and pulse durations of 10 to 25 nanoseconds have been achieved.The high-intensity pulses may be efficiently frequency doubled to generate laser light at 532 nm, or higher harmonics at 355 and 266 nm.  Nd:YAG absorbs mostly in the bands between 730–760 nm and 790–820 nm. At low current densities krypton flashlamps have higher output in those bands than do the more common xenon lamps, which produce more light at around 900 nm. The former are therefore more efficient for pumping Nd:YAG lasers.      As can be seen from the energy level diagram, Nd lasers are four level lasers. Nd ions have two absorption band, and excitation is done by optical pumping, either by flash lamps for pulsed lasers, or by arc lamps for continuous wave lasers. From these excited energy levels, the Nd ions are transferring into the upper laser level by a non radiative transition. The stimulated emission is from the upper laser level to the lower laser level, and the wavelengths of the emitted photons are around 1.06 [mm]. From the lower laser level, a non-radiative transition to the ground level. |

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| S.NO | RGPV QUESTIONS | Year | Marks |
| Q.1 | Discuss the principle construction and working of Ruby laser. | JUNE 2012 JUNE 2011 | 14  7 |

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| **Unit-02/Lecture-05** |
| **He-Ne Lasers [RGPV/ JUNE 2011(10), DEC 2012 (10)]**  He-Ne stands for Helium-Neon. The He-Ne laser active medium consists of two gases which do not interact form a molecule. Therefore He-Ne laser is one type of atomic gas lasers.  **Construction of He-Ne Lasers**  The construction of typical He-Ne laser plasma tube can be shown as:  Helium Neon Laser Consturction  The tube where the lasing action takes place consists of a glass envelop with a narrow capillary tube through the center. The capillary tube is designed to direct the electrical discharge through its small bore to produce very high current densities in the gas.  The output coupler and the HR (high reflective) mirror are located at the opposite ends of the plasma tube. To make laser tubes more economical and durable manufacturers often attach the mirror s directly to the ends of the capillary tube as shown above. This is very common with small low power lasers. With high power tubes or when optically polarized output is desired, the capillary tubes ends are cut at an angle and sealed with glass planes called Brewster windows. When this is done then the mirrors mush be mounted in mechanically stable but adjustable mounts. This allows the operator to align the mirror surfaces parallel to each other but perpendicular to the axis of the capillary tube.  The plasma tube has a large cylindrical metallic cathode and a smaller metallic anode. The current is directed from cathode to anode.  **Working of  He-Ne Laser**  In the He-Ne laser the light is produced by atomic transitions within the Neon atom. The Helium does not directly produce laser light but it acts as a buffer gas, the purpose of which is to assist/help the atoms of the other gas to produce lasing in as manner.  When energy from the pumping source is applied He-Ne gas mixture then some of the energy is observed by the Helium atoms. In other words we can say that helium atoms achieve an excited state. Now when the Helium atoms move within the laser tube, they collide with the Neon atoms. At each collision some of the energy within the helium atom is transferred to the Neon atom and so raising it to an excited meta-stable state. When a sufficient number of Neon atoms reach to this state then population inversion occurs and hence the lasing can take place.  This can be shown by simplified energy level diagram as:  Energy level diagram of He-Ne lasers  Here upward transition shows the absorption of energy from the pumping source by Helium atom. While down ward transition shows the emission of energy / light or lasing present in the Neon atom only.  In diagram above there are 3 down word energy transitions for Neon that produce lasing. If transition occurs at the relatively small energy step from E5 to E4 then low energy infrared photon is released with a wavelength of 3.391 microns. If transition occurs at E5 to E2 which is much larger energy step then it produces short wavelength more energetic photon at 632.8nm. This gives the red light which is most desirable for He-Ne laser applications.  E3 to E2 then it produces a laser output at 1.152microns in infrared portion of the spectrum.  **Characteristics of He-Ne Laser**  The He-Ne laser is a relatively low power device with an output in the visible red portion of the spectrum. The most common wavelength produced by He-Ne lasers is 632.8nm, although two lower power (1.152µm and 3.391µm) infrared wavelengths can be produced if desired. Majority of He-Ne lasers generate less than 10m watt of power, but some can be obtained commercially with up to 50m watts of power. For He-Ne lasers the typical laser tube is from 10 to 100 cm in length and the life time of such a tube can be as high as 20,000 hours.  **Applications / Uses of He-Ne Laser**  The Helium-Neon gas laser is one of the most commonly used laser today because of the following applications.   * He-Ne lasers are produced in large quantities from many years. * Many schools / colleges / universities use this type of laser in their science programs and experiments. * He-Ne lasers also used in super market checkout counters to read bar codes and QR codes. * The He-Ne lasers also used by newspapers for reproducing transmitted photographs. * He-Ne lasers can be use as an alignment tool. * It is also used in Guns for targeting.   **Advantages of He-Ne Laser**   * He-Ne laser has very good coherence property * He-Ne laser can produce three wavelengths that are 1.152µm, 3.391 µm and 632.8nm, in which the 632.8nm is most common because it is visible usually in red color. * He-Ne laser tube has very small length approximately from 10 to 100cm and best life time of 20.000 hours. * Cost of He-Ne laser is less from most of other lasers. * Construction of He-Ne laser is also not very complex. * He-Ne laser provide inherent safety due to low power output.   **Disadvantages of He-Ne Laser**  The weak points of He-Ne laser are   * It is relatively low power device means its output power is low. * He-Ne laser is low gain system/ device. * To obtain single wavelength laser light, the other two wavelengths of laser need suppression, which is done by many techniques and devices. So it requires extra technical skill and increases the cast also. * High voltage requirement can be considered its disadvantage. * Escaping of gas from laser plasma tube is also its disadvantage   **CO2 laser [RGPV/ JUNE 2011(10), DEC 2012 (10)]**  The CO2 laser (carbon dioxide laser) is a laser based on a gas mixture as the [gain medium](http://www.rp-photonics.com/gain_media.html), which contains carbon dioxide (CO2), helium (He), nitrogen (N2), and possibly some hydrogen (H2), water vapor and/or xenon (Xe). Such a laser is electrically pumped via a gas discharge, which can be operated with DC current, with AC current (e.g. 20–50 kHz) or in the radio frequency (RF) domain. Nitrogen molecules are excited by the discharge into a [metastable](http://www.rp-photonics.com/metastable_states.html) vibrational level and transfer their excitation energy to the CO2 molecules when colliding with them. Helium serves to depopulate the lower laser level and to remove the heat. Other constituents such as hydrogen or water vapor can help (particularly in sealed-tube lasers) to reoxidize carbon monoxide (formed in the discharge) to carbon dioxide.    CO2 lasers typically emit at a wavelength of 10.6 μm, but there are other lines in the region of 9–11 μm (particularly at 9.6 μm). In most cases, average powers are between some tens of watts and many kilowatts.  The filling gas within the discharge tube consists primarily of:   * [Carbon dioxide](http://en.wikipedia.org/wiki/Carbon_dioxide) (CO2) (around 10–20%) * [Nitrogen](http://en.wikipedia.org/wiki/Nitrogen) (N2) (around 10–20%) * [Helium](http://en.wikipedia.org/wiki/Helium) (He) (The remainder of the gas mixture)   The specific proportions vary according to the particular laser.  The [population inversion](http://en.wikipedia.org/wiki/Population_inversion) in the laser is achieved by the following sequence:   1. [Electron](http://en.wikipedia.org/wiki/Electron) impact excites vibrational motion of the nitrogen. Because nitrogen is a [homonuclear molecule](http://en.wikipedia.org/wiki/Homonuclear_molecule), it cannot lose this energy by [photon](http://en.wikipedia.org/wiki/Photon) emission, and its excited vibrational levels are therefore [metastable](http://en.wikipedia.org/wiki/Metastability) and live for a long time. 2. Collisional energy transfer between the nitrogen and the carbon dioxide molecule causes vibrational excitation of the carbon dioxide, with sufficient efficiency to lead to the desired population inversion necessary for laser operation. 3. The nitrogen molecules are left in a lower excited state. Their transition to ground state takes place by collision with cold helium atoms. The resulting hot helium atoms must be cooled in order to sustain the ability to produce a population inversion in the carbon dioxide molecules. In sealed lasers, this takes place as the helium atoms strike the walls of the container. In flow-through lasers, a continuous stream of CO2 and nitrogen is excited by the plasma discharge and the hot gas mixture is exhausted from the resonator by pumps.   Lasing transition in CO2 laser  Lasing transitions in CO2 laser occur when the molecule is going from higher energy level of the asymmetric mode into one of the other two, as can be seen in fig..   1. The transition to the symmetric stretching mode correspond to the wavelength of 10.6 [mm]. 2. The transition to the bending mode correspond to the wavelength of 9.6 [mm].     Applications  CO2 lasers are widely used for material processing, in particular for   * cutting plastic materials, wood, die boards, etc., exhibiting high absorption at 10.6 μm, and requiring moderate power levels of 20–200 W * cutting and welding metals such as stainless steel, aluminum or copper, applying multi-kilowatt powers * [laser marking](http://www.rp-photonics.com/laser_marking.html) of various materials. |

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| S.NO | RGPV QUESTIONS | Year | Marks |
| Q.1 | How laser light is different from ordinary light. Describe the principle, construction and working of He – Ne Laser or CO2 laser. Write any two characteristics of laser light. | June 2011  Dec 2012 | 10  7 |
| Q.2 | Define the principle, construction and working of any one Laser. | DEC 2013 | 7 |
| **UNIT 5/LECTURE 6** | | | |
| **OPTICAL FIBRE [RGPV/ JUNE 2012(7)]**    Optical fibers are fine transparent glass or plastic fibers which can propagate light. They work under the principle of total internal reflection from diametrically opposite walls. In this way light can be taken anywhere because fibers have enough flexibility. This property makes them suitable for data communication, design of fine endoscopes, micro sized microscopes etc. An optic fiber consists of a core that is surrounded by a cladding which are normally made of silica glass or plastic. The core  ransmits an optical signal while the  cladding  guides the light within the core. Since  light is guided through the fiber it is sometimes called an optical wave guide.    A ray of light, incident upon the *interface* between two transparent optical materials having different indices of refraction, will be totally internally reflected (rather  than refracted) if  (1) the ray is incident upon the interface from the direction of the more dense material and  (2) the angle made by the ray with the normal to the interface is greater than some critical angle, the latter being dependent only on the indices of refraction of the media.    **Construction of optical fibre**  Basically optical fibers consist of two parts   1. Core and Cladding: these are made from fused silica glass (SiO2) and are optically transparent. 2. Coating:   The central portion of the optical fibers is called the core; it is this part in which light rays are guided. That portion which surrounds the core is called cladding. The refractive index of the core is always slightly greater than the refractive index of the cladding. Due to this difference in the refractive indices of the core and cladding, the light rays are always kept within the core of the optical fibers.  During manufacturing of the optical fibers, protective layers of plastic are uniformly applied to the entire length of the fiber. The refractive index of the coating is higher than that of cladding and core, to attenuate any undesirable light in the cladding. This coating can be removed when desired, i.e. (for jointing etc). The coating gives protection to the fibers from external influences and absorbs shear forces. These coatings are usually colored to identify individual fibers in a multi-fibers cable.    **Types Of Optical Fiber**  A mode is a stable propagation state in optical fibers. When light rays travel along certain paths through the optic fibers, the electromagnetic fields in the light waves support each other to form a stable field distribution. Thus light travels in the fibers. These stable operating points (standing waves) are called modes. If the light follows other paths then a stable wave will not propagate through the fiber and hence there will be no mode.  The optical fibers are typed according to the following modes:  **1.Single-mode Fiber**  In this, the light propagates in a single or fundamental mode in the core. Such fibers with only one mode are called single-mode fiber. It allows a single light path, and typically used with LASER signaling. The single mode fibers can allow greater bandwidth and cable runs than that of multimode but it is more expansive. The single mode fiber has the best characteristics of highest data rates and least attenuation. The single mode fiber is of very small size. It has the core of approximatly 5 to 10 micro meter in diameters.  Single-mode fiber allows for a higher capacity to transmit information because it can retain the fidelity of each light pulse over longer distances, and it exhibits no dispersion caused by multiple modes. Single-mode fiber also enjoys lower fiber attenuation than multimode fiber. Thus, more information can be transmitted per unit of time. Like multimode fiber, early single-mode fiber was generally characterized as step-index fiber meaning the refractive index of the fiber core is a step above that of the cladding rather than graduated as it is in graded-index fiber. Modern single-mode fibers have evolved into more complex designs such as matched clad, depressed clad and other exotic structures.  Single-mode Fiber  Single-mode fiber has disadvantages. The smaller core diameter makes coupling light into the core more difficult. The tolerances for single-mode connectors and splices are also much more demanding.  **2.MULTI-MODE**  It is further divided into:   * **STEP-INDEX** * **GRADED-INDE**   **STEP-INDEX MULTIMODE FIBERS**  This fiber works in a very simplified way. The word step-index is used because the refractive index suddenly changes at the interface between core and cladding. The refractive index of the core is slightly greater than that of the cladding, thus confining the light to the core, by the principle of total internal reflection. The step-index multi mode fibers collect light easily but have a limited bandwidth.  Total Internal Reflection in Multimode Step-index fiber  **GRADED-INDEX FIBERS**  These are called graded-index fibers because in these fibers the refractive index changes gradually from the core to the cladding and at the boundary between the core and cladding, the change is abrupt. The refractive index decreases gradually from the center of the core to the edge of the cladding. Graded-index multi mode fibers collect light better than small core single mode fibers and have broader bandwidth than step-index multi mode fibers.  Multimode Graded-index Fiber   |  |  |  |  | | --- | --- | --- | --- | | S.NO | RGPV QUESTION | YEAR | MARKS | | Q.1 | What are optical fibres? Explain how glass fibre guides light from one end to the other? | June 2012 | 7 | | Q.2 |  |  |  | | | | |

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| **UNIT 5/LECTURE 7** |
| **Acceptance angle [RGPV/DEC 2011 (7)]**  Consider a light ray (i) entering the core at a point A , travelling through the core until it reaches the core cladding boundary at point B. As long as the light ray intersects the core-cladding boundary at a small  angles, the ray will be reflected back in to the core to travel on to point C where the process of reflection is repeated .ie., total internal reflection takes place. Total internal reflection occurs only when the angle of incidence is greater than the critical angle.  If a ray enters an optic fiber at a steep angle(ii), when this ray intersects the core-cladding boundary, the angle of intersection is too large. So, reflection back in to the core does not take place and the light ray is lost in the cladding. This means that to be guided through an optic fibre, a light ray must enter the core with an angle less than a particular angle called the acceptance angle of the fibre. A ray which enters the fiber with an angle greater than the acceptance angle will be lost in the cladding.    Consider an optical fibre having a core  of refractive index n1 and cladding of refractive index n2. let the incident light makes an angle i with the core axis as shown in figure (a). Then the light gets refracted at an angle θ and fall on the core-cladding interface at an angle where,  http://amrita.vlab.co.in/userfiles/image026%20%282%29.png...................... (1)  By Snell’s law at the point of entrance of light in to the optical fiber we get,      ....................... (2)  Where n0 is refractive index of medium outside the fiber. For air n0 =1.     The largest value of θ = im  occurs when       When light travels from core to cladding it moves from denser to rarer medium and so it may be totally reflected back to the core medium if θ' exceeds the critical angle θ'c. The critical angle is that angle of incidence in denser medium (n1) for which angle of refraction become 90°. Using Snell’s laws at core cladding interface,   For air    Thus, **acceptance angle** is defined as the maximum angle from the fibre axis at which the light may enter the fibre so that it will propogate in the core by the total internal reflection.  **Acceptance cone**  It is the cone in which the light incident at acceptance angle or less than the acceptance angle and then the light can propagate through the fiber after total internal reflection.    **Numerical Aperture [RGPV/ DEC 2012(4)]**  The significance of NA is that light entering in the cone of semi vertical angle im only propagate through the fibre. The higher the value of im or NA more is the light collected for propagation in the fibre. Numerical aperture is thus considered as a light gathering capacity of an optical fibre. It is also known as figure of merit.  Numerical Aperture is defined as the Sine of angle of acceptance.  It may also be evaluated in terms of relative refractive index difference is defined as        is very small, the term is negligible  **V-Number [RGPV/ DEC 2012(4)]**  In an [optical fiber](http://en.wikipedia.org/wiki/Optical_fiber), the **normalized frequency**, *V* (also called the **V number**), is given by  V = {2 \pi a \over \lambda} \sqrt{{n_1}^2 - {n_2}^2}\quad = {2 \pi a \over \lambda} \mathrm{NA},  where *a* is the [core](http://en.wikipedia.org/wiki/Fiber_optics#Principle_of_operation) radius,  λ is the wavelength in vacuum,  *n*1 is the maximum refractive index of the core,  *n*2 is the refractive index of the homogeneous cladding,  and applying the usual definition of the numerical aperture *NA*.  **Significance of V number:**  If V is less than 2.405 then the fiber is mono mode but if V is greater than 2.405 then fiber is multimode.  V number is also related with the number of modes is the fiber as:  N = V2/ 2 for step index fiber and  Number of modes for graded index fiber is N = V2/ 4.   |  |  |  |  | | --- | --- | --- | --- | | S.NO | RGPV QUESTION | YEAR | MARKS | | Q.1 | What is meant by acceptance angle of optical fibre? Derive an expression for it? | Dec2011 | 7 | | Q.2 | Define following terms of optical fibre. 1.normalized frequency  2.numerical aperture | Dec2012 | 4 | |

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| **UNIT 5/LECTURE 8** |
| **Attenuation [RGPV/ DEC 2013 (4)]**  It is defined as the reduction in amplitude (or power) and intensity of a signal as it is guided throughout optical fibre.  The fiber loss mean's wasting of energy (power) in fiber. If Pin is the input power and Pout is the output power of fiber, than fiber loss is defined methematically as:  Loss = Pout / Pin  ---------(1)  In decibels (logrithmic unit) the (1) can be  Lossdb = 10 X log(Pout / Pin)  ---------- (2)  The unit uses for less will be "decibels per kilometer" because the loss is increases mostly with fiber length.  **LOSSES IN FIBERS**: **[RGPV/ DEC 2013 (7)]**  There are many reasons which contribute to losses in optical fibers. The main sources of losses are summarized below:  (i) **Absorption loss:**  Absorption due to impurities present in the fiber are a major source of fiber loss. Normal glass is relatively impure with copper, iron and manganese being the common contaminants. The absorption loss due to these impurities varies with the wavelength being used. Also presence of hydroxyl ions(OH) add to loss. In order to manufacture low loss fibers, the impurity level must be brought down to the barest minimum.  ii) **Intrinsic absorption**:  Even if all the impurities are eliminated from the optical fiber materials, absorpotion loss will still occur. This happens because pure glass has its own absorption loss at some wavelengths like ultra violate and infrared, which is used in optical communication.  iii) **Rayleigh scattering**:  It is the scattering of light due to micro-irregularities the dielectric medium through which electromagnetic wave propagates. The Rayleigh scattering varies inversely as the wave length. So higher scattering occurs at lower wavelength and gradually diminishes at larger wavelength. Small defects such as hubbies in the fibre cause localized scattering.    **Rayleigh scattering**  (iv) **Microbending:**  Even slight deformation of the fiber axis cause the optical power to he redistributed among the rays. Such loss, referred to as Microbending loss, may he minimised by either decreasing the core size or increasing the refractive index difference along the fiber axis.    **microbending**  (v) **Bend or Curnature loss:**  Bending a fiber causes radiation of previously guided rays. The loss resulting from this radiation depends on he angle and radius of bending. Generally bending radius of a few cms or more arc not hazardous.    **macrobending**  (vi) **Cladding effects**:  The loss due to absorption In the cladding material also add to The total loss. In a multimode fiber, almost entire power is cofined to the core and therefore the effect of lossy cladding is not much felt. However, as the core is much smaller dimension in monomode fibers, there is much more power in the cladding. As such the purity of cladding is very important.  **DISPERSION IN FIBERS*.* [RGPV/ DEC 2013 (4)]**  Dispersion is the broadening of light pulses as it propagates through the fiber. It increases with length of the fiber. Excessive dispersion causes over-lapping of adjacent pulses or inter symbol interference. So dispersion has a negative effect on the bandwidth of a fiber. The higher the dispersion, lie lower will he bandwidth of the system. Dispersion also decreases the peak optical power of the pulse and therefore increases the effective attenuation of a fiber,  Dispersion may be classified into two categories depending on the cause. These are  (I) Modal and (ii) Material dispersion.  (I) **Modal dispersion:**  These are dominant in multimode fibers where the optical rays propagate in different modes. Thus the path lengths are different for different modes and consequently propagation time is different for different rays, This results in broadening or dispersion of light pulses.  In order to solve this problem, graded index fibers have been discovered where the refractive index varies accross he cross-section of the fiber. Therefore the speed of optical rays arc different for different modes. The refractive index profile is so designed that the propagation lime is almost the same for different modes.  Another solution to tie problem of modal dispersion is to reduce the core diameter to such an extent that only a single mode of propagation is possible. Such a fiber is called the monomode fiber. With the introduction of this type of fiber it has been possible to virtually eliminate modal dispersion. The fiber bandwidth, therefore, is much greater now a days.  (ii) **Material dispersion:**  The refraction index of a optical material varies with the wavelength of operation. The variation pattern is shown below:  It can be seen from the above figure that the refractive index decreases with the increasing lengths. Practical optical sources have a non-zero spectral width. So, there is a difference in refractive index and, consequently, speeds of light rays are different for this non-zero spectral width. This results in broadening or dispersion of optical signals. The LED source has a much larger spectral line width and thereby material dispersion is much higher. Later on LASER diode sources have been developed with much less spectral line width and higher optical output power. Thus it has been possible to reduce the material dispersion to a great extent. The unit of material dispersion is ps/nm/km (Pico seconds per manometer of source spectral line width per kilometer of fiber)  **RESULTANT BANDWIDTH**  Dispersion is the major factor which limits the bandwidth of a fiber, Overall or total dispersion may he obtained from the following relationship:  (Total dispersion)2 = (Modal dispersion) 2 + (material dispersion)2  The bandwidth of system may be calculated from the following empirical relation:  BW= l80/T GHz km  Where T is total dispersion expressed in ps/km.     |  |  |  |  | | --- | --- | --- | --- | | S.NO | RGPV QUESTION | YEAR | MARKS | | Q.1 | Write a short note on different loss mechanism in an optical fibre | Dec 2013 | 7 | | Q.2 | Discuss the attenuation and dispersion in optical fibre. | Dec 2013 | 4 | | Q.3 |  |  |  | |

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| **UNIT 5/LECTURE 9** |
| **Calculation of dispersion**  Consider a ray of light OA be incident at an angle on the entrance aperture of the fibre. The ray is refracted into the core along AB an angle with the axis of the core. Now the ray strikes at the upper core cladding at B. After this the ray is totally internally reflected back inside the core. Further it strikes at point C of lower cladding and after reflection it again strikes the upper interface at D. let t be the time taken by the light ray to cover the distance B to C and then from C to D with velocity v.    Then  If be the refractive index of core and c is the speed of light in vacuum , then  From fig.  Substituting the values from eq (2) and (3) in eq (1), we get   As the ray in the fibre propagates by a series of total internal reflections ar the interface, the time taken by the ray I traversing an axial length l of the fibre will be  Now, we consider that all the light rays lying between angle 0 and angle are present. The time taken by rays making 0 angle with the fibre axis will be minimum. This is given by putting in eq. (5), i.e.,  The minimum time is given by  The maximum time rate is given by  The time interval △τ at the output is  Where  We know that, the numerical aperture  So , in terms of NA, delay difference △τ is given by  Expressions (8) and (9) are employed to estimate the maximum pulse broadening.     |  |  |  |  | | --- | --- | --- | --- | | S.NO | RGPV QUESTION | YEAR | MARKS | | Q.1 | What is meant by inter modal dispersion? Derive an expression for the time delay difference in the step index fibre? | May 2014 | 7 | |  |  |  |  | |

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| **UNIT 5/LECTURE 10** |
| The refractive indices of core and cladding materials of a step index fibre are 1.48 and 1.45, respectively. Calculate: (i) numerical aperture, (ii) acceptance angle, and (iii) the critical angle at the core-cladding interface and (iv) fractional refractive indices change.  **Sol:** Let the refractive index of core, *n*1 = 1.48  and the refractive index of cladding , *n*2 = 1.45   1. Numerical aperture (NA)      1. Let *θ*0 be the acceptance angle      1. *n*2 sin 90 = *n*1 sin *θc* [*θc* = critical angle]      1. The fractional refractive indices change,     [Q2. Calculate the number of allowed modes in a multimode step index fiber, a = 100 μm, core index of 1.468 and a cladding index of 1.447 at the wavelength of 850nm.](https://www.rgpvonline.com/)  Solution: |

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| **UNIT 5/LECTURE 11/ADDITIONAL TOPICS** |
| **Optical Fiber Transmitter**  Optical Fiber Transmitter Block Diagram  **Explanation**  Optical transmitter is a device that generates the signal sent through optical fibers. The basic elements of optical fiber transmitter are shown in above Fig:  **Electronic Interface**  There is wires standard electronic connection or pins energizing the transmitter. They provide power Electronic I/P and Optical O/P signals.  **Optical Interface**  There are actually the connectors between the light source and fiber may have different forms.  **Drive CKT**  This depends on application, requirements, data format and the light source.  **Electronic Processing**  In some transmitters the I/P Electrical signals are electronically processed to put them into of suitable from to drive the light source.  **Optical Monitor**  It Monitors the O/P of the LASER and provides feedback to the drive CKT so that the O/P power remains stable.  **Temperature Monitor**  The characteristic of semi-conductor LASER changes in temperature. The life time of LASER decreases with increase in operating temp and the O/P power also decrease which produce some change in 0/p wave length of the light, to keep the operating temp stable the Thermo-electric coolers are used in optical fiber transmitters these coolers control the temp of LASER.  **Attenuation**  The optical fiber transmitters should produce some standard level of power and this level should not desired for the receivers, to handle the receiver I/P power, the attenuator is used in the transmitter to reduce the O/P level of the transmitter to a safe value for the receivers.  **External modulator**  The external modulation means modulation of light source by on external device in order to prevent spreading of wave-length range of light emitted by LASER.  **Optical Fiber Receiver**  Optical Fiber Analog Reciver block Diagram  This is a device that converts the optical signal received through the fiber into Electrical from for the use of other devices as an I/P signals; the basic elements of optical receiver either analog or digital are shown below.  **Detector**  The 1st stage of optical fiber receiver is a detector, which converts the received signal into an Electrical from.  **Amplification Stages**  In the amplification stages there are 2, stage of amplifier are used which amplifies the converted signal, for further processing.  **De modulator or Decision CKT**  It reproduces the original Electrical signal from modulated incoming signals. |