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Role of Diodes and Amplifiers in the Optic Fiber Communication Systems

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ABSTRACT *Hetero-junction LEDs and lasers are mostly used as the optical sources in optical fiber communication so that threshold current density is drastically reduced and also produces continuous wave operation, high efficiency, high coherence, high directionality and high efficiency and high power output.*

KEYWORDS : Diode, power and wavelength.

1.1.1: INTRODUCTION AND DISCUSSION:

Optical sources

Heterojunction LEDs and lasers are mostly used as the optical sources in optical fiber communication. Heterojunction means that a p-n junction is formed by a single crystal such that the material on one side of the junction differs from that on the other side of the junction. In the modern GaAs diode lasers, a hetero junction is formed between GaAs and GaAlAs. This type of p-n junction diode laser or LED is used at 0.8 mm wavelength. At longer wavelengths, InP-InGaAsP heterojunction laser diodes are used.

Heterojunction lasers or LEDs are superior to conventional homojunction lasers or LEDs. Generally heterojunction lasers and LEDs have minimum threshold current density (10 A/mm2), high output power (10 mW) even with low operating current (<500 mA), high coherence and high monochromaticity, high stability and longer life[4].

For example in the case of a double hetero structure stripe laser, the active junction re-gion is few microns. So the threshold current density is drastically reduced. The stripe geometry provides stability with longer lifetime for the diode. Thus it gives high power output, continuous wave operation, high efficiency, high coherence and high directionality[6]. By means of the heterojunction formed by two different materials, both the carriers and the optical field are confined in the central active layer. The bandgap differences of adjacent layers confine the charge carriers while the step change in the indices of refraction of adjoining layers confines the optical field to the central active layer and provides an efficient waveguide structure. This dual confinement leads to both high efficiency and high power output.

1.1.2: Optical detectors

Semiconductor based photodiodes are used as optical detectors in the optical fiber commu-nication systems. They have small size, high sensitivity and fast response. There are two types of photodiodes:

p-i-n photodiodes and (ii) Avalanche photodiodes (APD)

p-i-n photodiodes: A positive-intrinsic-negative (p-i-n) photodiode consists of p and n regions separated by a very lightly n doped intrinsic region. Silicon p-i-n photodiodes are used at 0.8 mm wavelength and InGaAs p-i-n photodiodes are used at 1.3 mm and 1.55 mm wavelengths. In normal operation, the p-i-n photodiode is under high reverse bias voltage. So the intrinsic region of the diode is fully depleted of carriers. When an incident photon has energy greater than or equal to the bandgap energy of the photodiode material, the electron-hole pair is created due to the absorption of photon. Such photon-generated carriers in the depleted intrinsic region where most of the incident light photons are absorbed, are separated by the high electric field present in the depletion region and collected across the reverse biased junction[2]. This gives rise to a photocurrent flow in the external circuit. The p-i-n photodiode acts as a linear device such that I = RP = photo current; P = incident optical power; R = responsivity of the photodiode

Here η = quantum efficiency of the diode; hv = energy of the incident photon; q = charge of electron.

The responsivity of the photodiode depends on the bandgap of the material, operating wavelength, the doping and the thickness of the p, i and n regions of the diode. For example to get high quantum efficiency and hence the maximum sensitivity, the thickness of the depletion layer should be increased so that the absorption of photons will be maximum. But it reduces the response speed of the photodiode. In the wavelength 1.33 mm and 1.55 mm, InGaAs p-i-n photodiodes have high quantum efficiency and high responsivity.

(ii) Avalanche photodiodes (APDs): It consists of four regions p + i p n+ in order to develop a very high electric field in the intrinsic region as well as to impart more energy to photoelectrons to produce new electron-hole pairs by impact ionization. This impact ionization leads to avalanche breakdown in the reverse biased diode. So the APDs have high sensitivity and high responsivity over p-i-n diodes due to the avalanche multiplication. The responsivity of APD is given by

R = hq M hv

where M is called avalanche multiplication which is greater than 50. APDs are made from silicon or germanium having operating wavelength 0.8 mm and from InGaAs having operating wavelength 1.55 mm[1].

1.1.3: Optical amplifiers

In the long distance optical fiber communication systems, the repeaters are situated at an equal distance of 100 km. These are used to receive and amplify the transmitted signal to its original intensity and then it is passed on to the main fiber[7]. Previously it was done by conversion of optical energy into electrical energy and amplification by electrical amplifiers and then reconversion of electrical energy into optical energy. Such methods not only increase the cost and complexity of the optical communication system but also reduce the operational bandwidth of the system. But today it is done by erbium doped optical fiber amplifiers in an elegant manner by inserting a length of 10 m fiber amplifier for every 100 km length of main fiber. By this, the signal to noise ratio is greatly improved due to optical domain operation only [8,9].

Further there is a large reduction in the cost of laying and maintaining the optical am-plifier, due to its simple design which is in the form of fiber coupler, and easy fabrication. It is found that optical amplifiers can simultaneously amplify multiple wavelength division multiplexed optical signals.

Initially optical amplifiers were designed utilizing stimulated Raman scattering and Brillouin scattering. By injecting a high power laser beam as a pumping radiation into an un-doped relatively long length fiber (10 km) or a doped short length fiber (10 m), the laser action is achieved through the nonlinear effects produced within the fiber and can provide optical amplification. Generally Raman gain is very small. It is found that higher Raman gain is achieved in large length fibers, ultra low loss fibers and small diameter fibers. For high-speed communications, the narrow gain-bandwidth of Raman amplifiers or Brillouin amplifiers are not suitable. Further there is no possibility to increase the band-width or gain in these amplifiers[3].

Meanwhile Mollenauer designed an erbium doped silica fiber laser amplifier. It has high gain even in a short length fiber. In erbium doped silica fiber, the erbium ions concentration is about 1025 ions/m3. For an optical signal amplification at wavelength of 1.55 mm, InGaAsP laser diode operating at a wavelength of 1.48 mm is used as a pumping source. The erbium ions in the ground level `E1' absorb this radiation and get excited to the broadened upper level E2. The energy level E2 is broadened into a band due to the electric field of adjacent ions (i.e. energy level splitting by Stark effect) and due to the amorphous nature of silica glass.

In erbium doped silica fiber, only the transition between E_2 and E_1 is 100% radiative and all other transitions are non-radiative. Due to the rapid thermalization of E_3r+ ions in the energy band E2, even though the absorption wavelength is at 1.48 mm, the emission wavelength is at 1.55 mm from the bottom of the energy band E 2. For low pump powers even though the erbium ions are excited to the E2 level, population inversion is not there due to predominant spontaneous emission. In such a case the optical signal at 1.55 mm will get attenuation. As the pump power increases, the rate of excitation increases. Hence at some threshold pump power level, population inversion may exist. Stimulation of the erbium ions in the energy level E2 by the incoming signal photons gives laser action such that the emitted photon and stimulating photon are having the same energy and same phase[5].

Thus the signal is amplified. When the signal travels down the optical fiber amplifier, the pump power can be gradually decreased since the signal is amplified and reabsorbed. Thus there is an optimum length for the fiber amplifier to get maximum gain. When the initial pump power is 5 mW, the optimum length of the fiber amplifier is about 7m.

ONCLUSION:

Heterojunction lasers or LEDs are superior to conventional homojunction lasers or LEDs in the wavelength 1.33 mm and 1.55 mm and InGaAs p-i-n photodiodes have high quantum efficiency and high responsivity. Erbium doped optical fiber amplifiers increses the signal to noise ratio due to optical domain operation.

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