Chapter 3

OPTICAL SOURCES AND DETECTORS
3. Optical sources and Detectors

3.1 Introduction:

The success of light wave communications and optical fiber sensors is due to the result of two technological breakthroughs. The first of these was the development of glass fibers with low optical attenuation. The second was the development of efficient semiconductor sources whose light output can be coupled to and transmitted in these fibers. In the present chapter some of the semiconductors sources such as lasers and light emitting diodes (LEDs) are presented which are very often used in optical fiber communications and optical fiber sensors.

The receiver is the most critical part of a fiber optic communication system, since it determines the overall system performance in most situations. The function of the receiver is to detect the optical power transmitted through the fiber to the photo-detector and to extract the transmitted information. In an analog fiber optic system the receiver demodulates the detected signal to obtain the transmitted information. In a digital fiber optic system the receiver output consists of the regenerated data and, normally, the recovered clock signal as well. A key system performance parameter is the receiver sensitivity, which determines the minimum incident optical power required at the receiver to satisfy a specified value of bit error rate. A good receiver needs to have a large input dynamic range capability to accept unrestricted data format, fast acquisition time, multiple bit rate operation, low power consumption and finally low cost.

Conversion of the received light to an electronic signal is accomplished by means of a photo detector. The commonly used photo detectors in fiber optic system are 'PIN' photo diodes and avalanche photo-diodes (APDS). Photo-
conductors, phototransistors and other types of detectors have been used for special applications. Some of these are discussed in detail in the present chapter.

3.2 Optical sources:

The principal light sources used for fiber optic communications is heterojunction structures, semiconductor laser diodes and light emitting diodes. The hetero-junction consists of two adjoining semi-conducting materials with different band gap energies. These devices are suitable for fiber transmission systems, because they have adequate power output for a wide range of applications. Varying input current to the device can directly modulate their optical power output. They have high efficiency and their dimensional characteristics are compatible with those of the optical fibers.

The light emitting regions of both light emitting diodes and laser diodes consists of P-N junction constructed of direct band gap semiconductor materials. When the junction is forward biased, electrons and holes are injected into the P and N regions respectively. These injected minority carriers can recombine either radiatively, in which case a photon of energy $h\nu$ is emitted; or non-radiatively, where upon the recombination energy is dissipated in the form of heat. This P-N junction is known as the active or recombination region.

A major difference between light emitting diodes and the Laser diodes is that, the optical output from a light emitting diodes is incoherent, whereas that from a laser diode is coherent.

In a coherent source the optical energy is produced in an optical resonant cavity. The optical energy released from this cavity has spatial and temporal coherence, which means it is highly monochromatic and the output beam is highly directional.

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In an incoherence light emitting diodes source no optical cavity exists for wavelength selectivity. The output radiation has a broad spectral width. Since the emitted photon energies range over the energy distribution of the recombining electrons and holes, which usually lie between 1 KT and 2 KT (Where K is the Boltzman’s constant and T is absolute temperature at the P-N junction). In addition the incoherent energy is emitted into a hemisphere, according to a cosine power distribution and thus has large beam divergence.

3.2.1 Light emitting diodes:

Optical communication system requires bit rates less than approximately 50 μb / second. Semiconductor light emitting diodes are usually the best light sources. Light emitting diodes require less complex drive circulatory than Laser diodes. Since no thermal or optical stabilization circuits are needed and these can be fabricate less expensively with higher yields.

3.2.2 Laser diodes:

For optical fiber systems the laser sources used almost are semiconductor laser diodes. For optical fiber communication system requiring bandwidths greater than approximately 50 MHz, the semiconductor injection laser diodes are preferred over the light emitting diodes. Laser diodes typically have response time less than one nano-second, have optical bandwidth of 2 nm or less and in general are capable of coupling several milliwatt of useful luminescent power into optical fibers with small cores and small numerical apertures. Virtually all laser diodes used at present are multi layered hetero-junction devices. Stimulated emission in semiconductor lasers arises from optical transmissions between distribution of energy states in the valence band and covalent band. Lasing is the condition at which the light amplification becomes possible in the Laser diode. The requirement for lasing is that a population inversion be achieved.
3.3 Photo-detectors:

Some of the common Photo detectors used are

A) PIN photo-detector
B) Avalanche photo-detector

3.3.1 P-N and PIN photo-detectors:

Silicon photo-detectors, which respond to radiation to visible and near infrared spectrum, are commercially available. The structures in fabrication of these devices have reached an advanced stage of development. The three important types of structures are P-N junction photo-diode. P-N photo diodes, which respond from 0.8 to 1.7 μm have been used in the longer wavelength region. Hetero-junction PIN photo-diodes are made of GaAs / GaAlAs material system for 0.8 – 0.9 μm wavelength operation and the InGaAs / InP material system 1 to 1.6 μm wavelength operation are readily available.[7]

Both P-N junction and PIN photo-detectors are normally operated in the reverse biased or short circuit mode. A strong electric field exists in the junction where the photo generated electron-hole pairs are separated and produces a photo current in the external circuits. The electron-hole pairs that are generated with the depletion region are separated by the electric field and contribute to the photocurrent directly outside the depletion region. Some of the photo-generated electron hole pairs recombine, but minority carriers separated within the diffusion length from the edges of the depletion region are collected. They are subsequently swept across the depletion region by the electric field and contribute to the photocurrent.
3.3.2 Avalanche photo-detectors:

The Avalanche photo-detector is a photo-detector, which contains a region of high electric field and exhibits avalanche multiplication of photogenerated carriers. The multiplication mechanism is based on the impact ionization effect in semiconductors where free carriers created by photo-absorption are accelerated by a strong electric field until they gain sufficient energy, and upon collision produce mere electron hole pairs, giving rise to gain the photo-detectors. Avalanche photo-detectors require a higher biased voltage than PIN diodes to maintain a high electric field. The internal current gain is not a linear function of the applied voltage and very sensitive to temperature. The Avalanche process introduces extra noise because of the current amplification in the device. This excess noise depends upon the material, devised structure, gain and illumination condition and is the factor, which ultimately limits the useful gain of the APDINP Lattice, matched materials (In Ga As) and (InGaAsP) are used for APD applications in 1 to 1.6 µm wave-length region. The un-doped InGaAs layer constitutes in absorption layer and a low doped InP layer is the high field layer for Avalanche application. Since the incident light is absorbed only in the InGaAs layer and not in a multiplication layer, this structure is referred to as a SAMAPD[8] (separate absorption and multiplication APD).