CHAPTER 5

OPTICAL SOURCES AND FIBER OPTIC TRANSMITTERS

5.1 Introduction

A fiber optic transmitter is a hybrid electro-optic device converts electrical signals into optical signals and launches the optical signals into an optical fiber. A fiber optic transmitter consists of an **interface circuit**, a **source drive circuit**, and an **optical source**. The **interface circuit** accepts the incoming electrical signal and processes it to make it compatible with the source drive circuit. The **source drive circuit** intensity modulates the optical source by varying the current through the source. An **optical source converts** electrical energy (current) into optical energy (light). Light emitted by an optical source is launched, or coupled, into an optical fiber for transmission. Fiber optic data link performance depends on the amount of optical power (light) launched into the optical fiber.

Most light sources and detectors are electronic devices built from the same semiconductor materials as are used in transistors and integrated circuits. The design of these devices is a separate study and will not be considered here. Instead, our view will be restricted to the characteristics which are of interest to the user. This chapter attempts to provide an understanding of light-generating mechanisms within the main types of optical sources used in fiber optics.

Figure 5.1 shows the block diagram of an optical transmitter. It consists of an optical source, a modulator, and electronic circuits used to power and operate the two devices. Semiconductor lasers or light-emitting diodes are used as optical sources because of their compact nature and compatibility with optical fibers [15].

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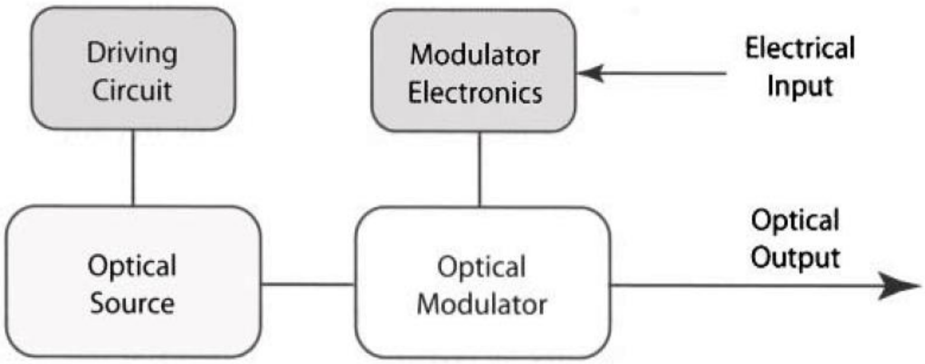

Figure 5.1: Block diagram of an optical transmitter [15].

The modulator uses the data in the form of an electrical signal to modulate the optical carrier. Although an external modulator is often needed at high bit rates, it can be dispensed with at low bit rates using a technique known as **direct modulation**. In this technique, the electrical signal representing information is applied directly to the driving circuit of the semiconductor optical source, resulting in the modulated source output. Such a scheme simplifies the transmitter design and is generally more cost-effective.

An important design parameter is the **average optical power** launched into the communication channel. Clearly, it should be as large as possible to enhance the signal-to-noise ratio (**SNR**) at the receiver end. However, the onset of various nonlinear effects limits how much power can be launched at the transmitter end. The launched power is often expressed in "**dBm**" units with 1 mW acting as the reference level.

$$P(dBm) = 10\log_{10}\left(\frac{P}{1\ mW}\right)$$

Thus, 1 mW is 0 dBm, but 1 μW corresponds to -30 dBm. The launched power is rather low (less than -10 dBm) for light-emitting diodes, but semiconductor lasers can launch power levels exceeding 5 dBm. Although light-emitting diodes are useful for some low-end applications related to local-area networking and computer-data transfer, most lightwave systems employ semiconductor lasers as optical sources. The bit rate of optical transmitters is often limited by electronically rather than by the semiconductor laser itself. With proper design, optical transmitters can be made to operate at a bit rate of up to 40 Gb/s.

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5.2 General Characteristics of Optical Sources

The development of efficient semiconductor optical sources, along with low-loss optical fibers, led to substantial improvements in fiber optic communications. Semiconductor optical sources have the physical characteristics and performance properties necessary for successful implementations of fiber optic systems. Two main types of optical light sources are available, these are:

a. Monochromatic incoherent sources light-emitting diodes (LEDs).
b. Monochromatic coherent sources laser diodes (LDs).

The fundamental requirements for Light Sources (**LED**, **LD**) in fiber optic applications are outlined below:

1. A size and configuration compatible with launching light into an optical fiber. Ideally, the light output should be highly directional.
2. Must accurately track the electrical input signal to minimize distortion and noise. Ideally, the source should be linear.
3. Should emit light at wavelengths where the fiber has low losses, low dispersion and where the detectors are efficient.
4. Must couple sufficient optical power to overcome attenuation in the fiber plus additional connector losses and leave adequate power to drive the detector.
5. Should have a very narrow spectral bandwidth (linewidth) in order to minimize dispersion in the fiber.
6. Must be capable of maintaining a stable optical output which is largely unaffected by changes in ambient conditions (e.g. temperature).

5.2.1 Materials

Semiconductor-based light sources are about the size of a grain of salt. This size allows efficient coupling of their light output into the small diameters of fibers. In addition, their **semiconductor structure** and **low-power dissipation** characteristics make them compatible with integrated-circuit electronics. To create a light-emitting device for use in the spectral transmission bands of optical fibers, material engineers fabricate layered structures consisting of different alloy mixtures.

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Table 5-1 lists some **LED** and laser diode material mixtures together with their operating wavelength range and approximate bandgap energies. Alloys consisting of three elements are called ternary compounds, and four-element alloys are known as quaternary compounds. A specific operating wavelength can be selected for AlGaAs, InGaAs, and InGaAsP devices by varying the proportions of the constituent atoms. This devices can be tailored to emit at a selected wavelength in the 780 nm to 850 nm band or in any of the other transmission bands ranging from 1280 to 1675 nm for glass fibers.

Table 5-1: Some LED and LD Material Mixtures and their Characteristics [14].

Material	Wavelength range nm	Bandgab energies eV
GaAs	900	1.4
GaAlAs	800–900	1.4–1.55
InGaAs	1000–1300	0.95–1.24
InGaAsP	900–1700	0.73–1.35

$h = 4.135 \times 10^{-15}$ c

$h = 6.626 \times 10^{-3}$ s . s

5.2.2 Light Generating Mechanism

The electrons in semiconductor materials are allowed to reside in only two specific energy bands, as shown in **Figure 5.2**. The two allowed bands are separated by a forbidden region, called an energy gap, in which electrons cannot reside. The energy difference between the top and bottom bands is referred to as the bandgap energy. In the upper band, called the conduction band, electrons are not bound to individual atoms and are free to move around in the material. The lower band is called the valence band. Here holes (which are vacancies in an atom that are not occupied by an electron) are free to move. The mobile electrons and holes set up a current flow when an external electric field is applied.

An electron sitting in the conduction band can drop down into a hole in the valence band, thereby returning an atom to its neutral state. This process is called recombination (**or electron-hole pair recombination**), since an electron recombines with a hole. This recombination process releases energy in the form of a photon and is the basis by which a source emits light.

The energy E emitted during such a recombination is related to a specific wavelength of light λ through the relationship $E = 1.240/\lambda$, where λ is given in micrometers and E is specified in electron volts. Since each type of material has a unique bandgap energy, electron-hole recombination in different materials results in different wavelengths being emitted.

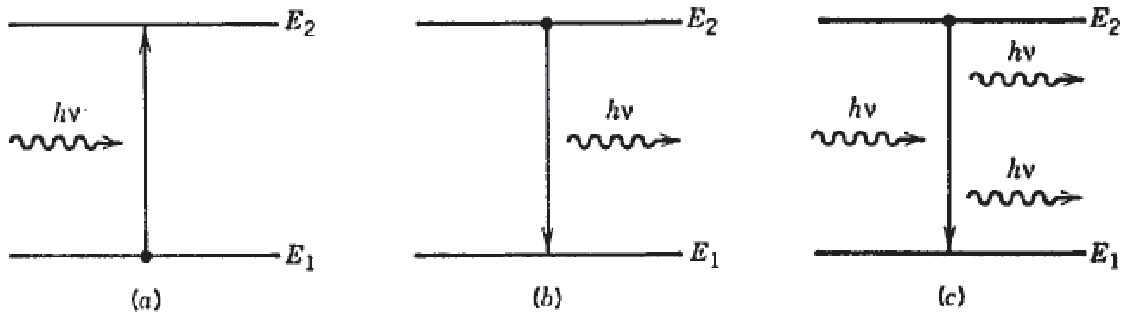

Figure 5.2: Three fundamental processes occurring between the two energy states of an atom: (a) absorption; (b) spontaneous emission; and (c) stimulated emission.

5.2.3 Spontaneous and Stimulated Emissions

If an atom is in the excited state, it eventually returns to its normal "ground" state and emits light in the process. The light emission can occur through two fundamental processes known as spontaneous emission and stimulated emission. Both are shown schematically in **Figure 5.2**. In the case of spontaneous emission, photons are emitted in random directions with no phase relationship among them. Stimulated emission, by contrast, is initiated by an existing photon.

The remarkable feature of stimulated emission is that the emitted photon matches the original photon not only in energy (**or in frequency**), but also in its other characteristics, such as the direction of propagation. All lasers, including semiconductor lasers, emit light through the process of stimulated emission and are said to emit coherent light. In contrast, **LEDs** emit light through the incoherent process of spontaneous emission.

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5.2.4 Direct and Indirect Bandgap Semiconductors

In order to encourage electroluminescence it is necessary to select an appropriate semiconductor material. The most useful materials for this purpose are direct bandgap semiconductors in which electrons and holes on either side of the forbidden energy gap have the same value of crystal momentum and thus direct recombination is possible. This process is illustrated in Figure 5.3 (a) with an energy–momentum diagram of a direct bandgap semiconductor. It may be observed that the maximum energy of the valence band occurs at the same (**or very nearly the same**) value of electron crystal momentum as the energy minimum of the conduction band. Hence, when electron–hole recombination occurs the momentum of the electron remains virtually constant and the energy released, which corresponds to the bandgap energy, E_g, may be emitted as light. This direct transition of an electron across the energy gap provides an efficient mechanism for photon emission and the average time that the minority carrier remains in a free state before recombination (**the minority carrier lifetime**) is short (**10^{-8} to 10^{-10} s**). Some commonly used direct bandgap semiconductor materials are shown in **Table 5-2**.

In indirect bandgap semiconductors, however, the maximum and minimum energies occur at different values of crystal momentum Figure 5.3 (b). For electron–hole recombination to take place it is essential that the electron loses momentum such that it has a value of momentum corresponding to the maximum energy of the valence band. The conservation of momentum requires the emission or absorption of a third particle, a phonon.

Table 5-2 Some direct and indirect bandgap semiconductors with calculated recombination coefficients

Semiconductor material	*Energy bandgap (eV)*	*Recombination coefficient B_r ($cm^3\ s^{-1}$)*
GaAs	Direct: 1.43	7.21×10^{-10}
CaSb	Direct: 0.73	2.39×10^{-10}
InAs	Direct: 0.35	8.5×10^{-11}
InSb	Direct: 0.18	4.58×10^{-11}
Si	Indirect: 1.12	1.79×10^{-15}
Ge	Indirect: 0.67	5.25×10^{-14}
GaP	Indirect: 2.26	5.37×10^{-14}

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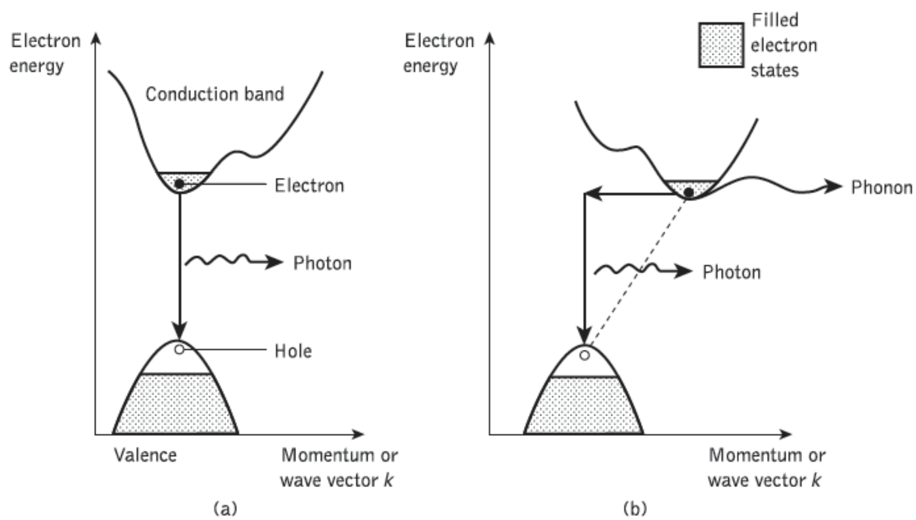

Figure 5.3: Energy–momentum diagrams showing the types of transition:
(a) Direct bandgap semiconductor; (b) indirect bandgap semiconductor

5.3 Light Emitting Diodes LEDs

A light-emitting diode (LED) **is a semiconductor device that emits incoherent light, through spontaneous emission, when a current is passed through it**. Typically LEDs for the **850 nm** region are fabricated using **GaAs** and **AlGaAs**. LEDs for the **1300 nm** and **1550 nm** regions are fabricated using an **InGaAsP** and **InP**. The basic LED types used in fiber optic communication systems are:

1. Surface-emitting LED (**SLED**).
2. Edge-emitting LED (**ELED**).

LED performance differences help link designers decide which device is appropriate for the intended application. For short-distance < **3 km**, **low-data-rate** fiber optic systems, **SLED**s and **ELED**s are the preferred optical source. Typically, **SLED**s operate efficiently for bit rates up to **250 Mb/s**. **Because SLEDs emit light over a wide area (wide far-field angle), they are almost exclusively used in multimode systems.** For medium-distance, medium-data-rate systems, ELEDs are preferred. ELEDs may be modulated at rates up to **400 Mb/s** and can be used for both single mode and multimode fiber systems.

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