Chapter 1

INTRODUCTION

1.1 Fiber Communication

Fiber optics has gained prominence in telecommunications, instrumentation, cable television networks, and data transmission and distribution. Development of fibers and devices for optical communications began in the early 1960's [1] and continues to be established as one of the most promising technologies today.

Four important developments or inventions have contributed to this progress:

- The invention of the LASER (Light Amplification by the Stimulated Emission of Radiation) in the late 1950's.
- The development of low loss optical fiber in 1970's.
- The invention of the optical fiber amplifier in 1980's.
- The invention of the in-fiber Bragg grating in 1990's.

The continuing development of semiconductor technology imposes large impact on optical communication systems. The availability of laser sources has stimulated research into optical communication. Two types of sources commonly used as transmitters in optical fiber system are semiconductor light-emitting diodes (LEDs), which are incoherent sources, and laser diodes (LDs). Besides that, laser diodes also play a key role as pump sources for solid-state lasers in optoelectronic devices such as optical amplifiers.

The first fiber optical amplifiers for telecommunication were demonstrated in 1987. An optical amplifier is a device that amplifies the optical signal directly without changing it to electricity, in which the light itself is amplified. The recent advent of practical optical amplifiers has revolutionized optical communication.

The basic components of an optical communication system are shown in Figure 1.1.

- A modulator encodes the data in serial bit stream in electrical form for fiber transmission.
- Modulator drives the light source (laser or LED) so that the light is focused into the fiber.
- The light travels along the fiber in which it may experience dispersion and loss of strength.
- At the receiver end, the light is converted to electrical form by a detector.
- The signal is then amplified by an optical amplifier and fed to another detector.
- The detector then decodes the sequence of state changes and reconstructs the original bit stream.
- The received timed bit stream then is fed to a using device.

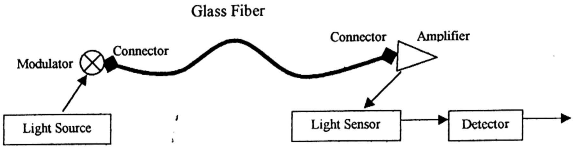

Figure 1.1 Schematic Optical Transmission

1.2 Erbium Doped Fiber Amplifiers (EDFAs)

There are many possible types of optical amplifiers. An optical amplifier is a device that amplifies the optical signal directly without changing it to electricity. The light itself is amplified. The most important type of amplifier is the erbium doped fiber amplifier (EDFA). In 1985, a research group at the University of Southampton in the United Kingdom succeeded in developing an optical amplifier that took the form of laser-diode-pumped erbium-doped fibers, activated or pumped with low power of visible light . This is the dominant type of optical amplifier because of its high gain, large bandwidth and low noise. It can amplify signal up to 1000 times (30 dB) along a short length of fiber. An EDFA consists of a short section of fiber doped with ion of the rare earth element erbium (Er^{3+}) is shown in Figure 1.2 .

The laser diode in the diagram generates a high-powered (10 – 20 mW) beam of light at a wavelength such that the pumping light is absorbed by the erbium ions, raising them to excited states and causing population inversion. The most efficient pumping bands are around 980 nm and 1480 nm. When an erbium ion is in an excited state, a photon will stimulate it to give up some of its energy in the form of photon and return to a lower-energy state. This is the principle of "stimulated emission".

The basic operations of the EDFA are as follows:

a) The input signal (1530 –1570 nm) is mixed with the pumped signal (980 or 1480 nm) using a wavelength multiplexer (WM).

b) The mixed light is guided into a section of fiber doped with erbium ions in the core, in which the pump signal excites the erbium ions to their higher-energy state.

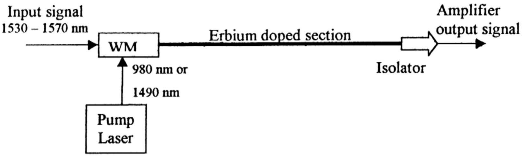

Figure 1.2 Erbium Doped Optical Fiber Amplifier

c) The input signal which is at different wavelength from the pump signal meets the excited erbium ions, the ions give up part of their energy to the signal and return to their lower-energy state.

d) The significance is that the erbium ions give up their energy in photons that are exactly in the same phase and direction as the input signal. The signal is amplified along its traveling direction only in the fiber core.

e) An isolator is placed at the output to prevent reflections, which disrupt amplifier operation, from returning to the erbium-doped fiber.

1.3 The Most Efficient Pump Light Source – 980 nm

There are many possible scenarios for pumping operation of an EDFA. The laser diode pump sources used in EDFA applications can be classified into three main categories:

a) InGaAsP and multi-quantum well InGaAs at 1480 nm

b) Strained quantum well InGaAs at 980 nm

c) GaAlAs at 820 nm

A wavelength of 980 nm is identified as being the most efficient pump light source where:

- 980 nm is almost twice as efficient as a pump wavelength than 1480 nm. This is because there is no excited state absorption exists.
- Amplifiers pumped at 980 nm are relatively insensitive to ambient temperature changes, and thus maintaining temperature stability.
- It is easier to obtain and maintain an population inversion in the three-level system operation at 980 nm (as explained in Figure 1.3) than a two-level laser system pumped at 1480 nm.
- This pump wavelength yields high power emission. It provides high coupling efficiency to the single mode optical fiber and high reliability.

A disadvantage of 980 nm pumping is that the pump bandwidth to which the erbium will respond is quite narrow. The wavelength of the pump within a relatively narrow range needs to be controlled for optimal power transfer. Furthermore, lasers at 980 nm were not easily available where there were no reliable proven data for this wavelength.

We can investigate the 980 nm pumping operation from the "Fermi-Dirac Distribution" of energy states of erbium, as illustrate in Figure 1.3[1]. The energy bands are centered around a specific energy state represented by horizontal lines: $I_{15/2}$ band, $I_{13/2}$ band, $I_{11/2}$ band and $I_{9/2}$ band. A photon with wavelength 980 nm interacts with an electron in the $I_{15/2}$ state. The photon releases energy to electron, which transfers into the $I_{13/2}$ band. Electrons in $I_{13/2}$ band is unstable and decay into the $I_{11/2}$ band with a half-life of around one microsecond.

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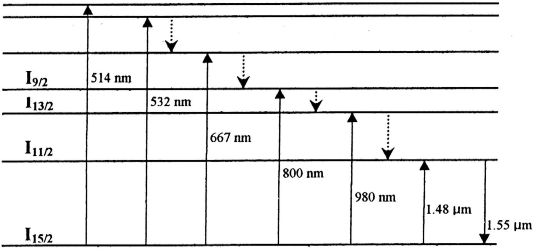

Figure 1.3 Energy Level States of Erbium

The energy given off is absorbed into lattice vibrations in the form of phonons. In the $I_{11/2}$ state, electron are metastable, electrons can stay for a long time (with a half-life of 11 miliseconds) in this state. When an electron decays spontaneously from the $I_{11/2}$ state to the $I_{15/2}$ state, it will emit a photon with wavelength in the range of 1550 nm. The incoming photon of input signal interacts with the excited electron in the $I_{11/2}$ band, this will result the electron jumps to the ground state. It gives out a photon in exactly the same phase and direction and exactly the same wavelength as the photon which caused the interaction. For significant amplification to occur, population inversion of erbium ions needs to be present. There must be more erbium ions in the excited state than in the ground state. The probability that an incoming photon of input signal encountering an excited erbium ion must be greater than that it will encounter a ground state erbium ion and be absorbed.

1.4 Summary

Building a good semiconductor laser pump is a very considerable challenge. An EDFA works in the way that a constant beam of pump light at the right wavelength to excite erbium atoms is mixed with the input signal through a wavelength selective coupler. This pump light constantly keeps the erbium ions in an excited state. The signal light picks up energy from excited erbium ions as it passes through the section of doped fiber and is amplified. The significance is that erbium only absorbs light and is excited if the pump light is at one of a very specific set of wavelengths (820nm, 980 nm and 1480 nm). Light in the range of wavelengths between about 1525 nm and 1570 nm will cause the excited erbium to undergo stimulated emission and hence the signal will be amplified. Light at other wavelengths will pass through the device unaffected. The best pump source is at a wavelength of 980 nm. In view of this, a strained quantum well laser diode lasing at 980 nm is studied and simulated in this project.