CHAPTER 2

LITERATURE RIVIEW

2.1 Laser and its Application

A laser is a device that emits (electromagnetic radiation) through a process called stimulated emission. Laser is actually an acronym for Light Amplification by Stimulated Emission of Radiation. Laser light is usually spatially coherent, which means that the light either is emitted in a narrow, low-divergence beam, or can be converted into one with the help of optical components such as lenses. Typically, lasers are emitting light with a narrow wavelength spectrum ("monochromatic" light). This is not all apply to type of lasers; however some emit light with a broad spectrum, while others emit light at multiple distinct wavelengths simultaneously. The coherence of typical laser emission is distinctive. Most of the light sources emit incoherent light, which has a phase that varies randomly with time and position.

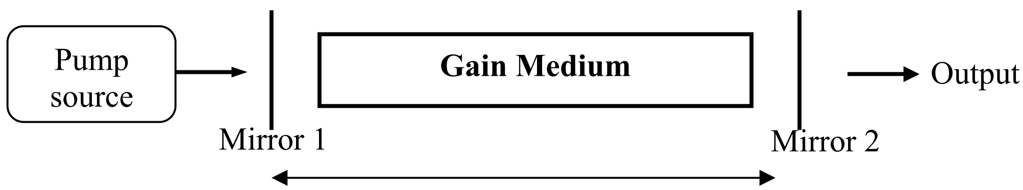
The first working laser was demonstrated on 16 May 1960 by Theodore Maiman at Hughes Research Laboratories [16]. Since then, lasers have become a big advancement in industry. The most effective application of lasers is in an optical storage devices such as compact discs and DVD players in which a semiconductor laser less than a millimeter wide scans the surface of the disc. The second-largest application is in the fiber-optic communications. Other common applications of lasers are bar code readers, laser printers and laser pointers.

In manufacturing, lasers were used for cutting, bending, and welding metal and other materials. In science, lasers were used for many applications. One of the more common is laser spectroscopy, which typically takes advantage of the laser's well-defined wavelength or the possibility of generating very short pulses of light. Lasers are used by the military for range-finding, target designation, and illumination. Lasers also have begun to be used as directed-energy weapons. Lasers are widely used in medicine for surgery, diagnostics, and therapeutic application.

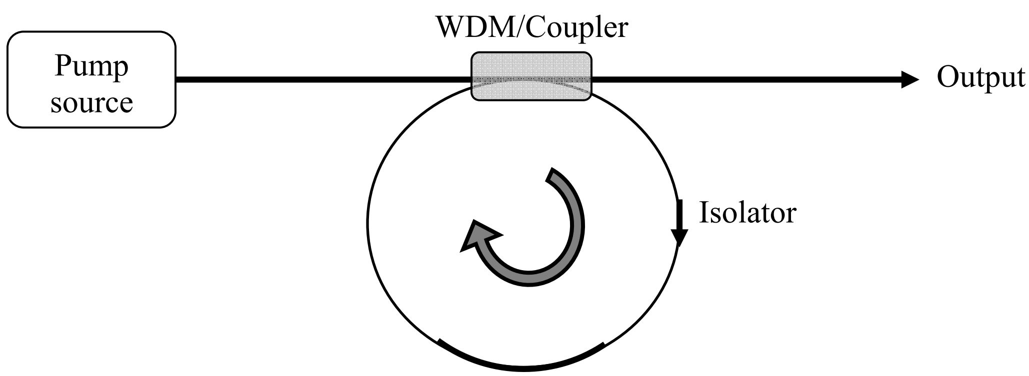
2.2 Fiber Laser

Fiber laser can be designed with a variety of choices for the laser cavity. The most common type of laser cavity is the Fabry-Perot (linear) cavity and ring cavity. All types of fiber lasers contain three essential elements which are the pump source, gain medium and oscillation cavity [18]. In most cases, the gain medium is a fiber doped with rare earth ions such as erbium (Er^{3+}), neodymium (Nd^{3+}), ytterbium (Yb^{3+}), thulium (Tm^{3+}), or praseodymium (Pr^{3+}), and one or several laser diodes are used for pumping.

The Fabry-Perot cavity from figure 2.1(a) below uses the reflection of light by two mirrors as a gain medium in the fiber laser system. With a free space between mirror 1 and mirror 2, light wave reflections between them lead to constructive and destructive interference of these waves within the cavity. Waves reflected from mirror 1 traveling towards the right interfere with waves reflected from mirror 2 travelling towards the left. The result is a series that allowed stationary or standing EM waves in the cavity [26]. Due to the reflection between the two mirrors, the optical cavity is reduced effectively, and provides optical gain in the medium. As the wave propagates, the power is increased. However, there are a few numbers of losses in the cavity medium acting against the stimulated emission gain such as light scattering of defects and inhomogenities, absorption by impurities, absorption by free carries and other loss phenomena.



(a) Fabry-Perot (linear) Cavity



(b) Ring Cavity

Figure 2.1: (a) Fabry-perot linear cavity design. (b) Ring cavity design

The Ring cavity shown in figure 2.1(b) designed as a ring laser which work as resonator in a form of a ring. It is also consists of an isolator to ensure a unidirectional operation. A length of fiber used as a gain medium which put inside the ring cavity and pumped by a laser diode as a source of pump light. Fiber lasers show several advantages such as high efficiency. A group of researchers have demonstrated up to 39% electrical-to-optical efficiency, an order of magnitude higher than conventional solid-state lasers with high gain around 50dB and low threshold operation. Fiber laser systems also can cover a broad wavelength region in the near-IR by selection of various rare-earth dopants by pumping with low cost.

2.3 Optical Fiber Amplifier

In various stages of an optical fiber communication system, the utilization of an amplifier is absolutely essential. The two types of amplifier used in optical communications systems are electronic amplifier and optical amplifier. Optical amplifiers differ from their conventional counterparts in that they do not require conversion from photon to electronic signals, but directly amplify the photons and transmit them to the next point of amplification through the optical fiber [15]. Optical amplifiers are produced by the process of stimulated emission induced by a population inversion in a lasing medium, or stimulated scattering due to non-linear scattering in the optical fiber.

Optical signals may require amplification at different points in communication systems. Optical amplifiers are used as post-amplifiers after the optical transmitter to increase the strength of the signal being sent through a length of fiber. Post-amplifiers can also generate powerful signals that can be split among many separate outputs if a single transmitter is distributing signals to many points. In-line amplifiers are used along the optical fiber transmission path for repeating and amplify a weak signal sufficiently to send it through the next segment of fiber. These generally are required in long telecommunication system but may be used in some networks where many branching points reduce transmitted power and the last one is pre-amplifiers used to amplify a weak optical signal before it enters an optical receiver for improving optical receiver sensitivity and stretching transmission distances [31,32].

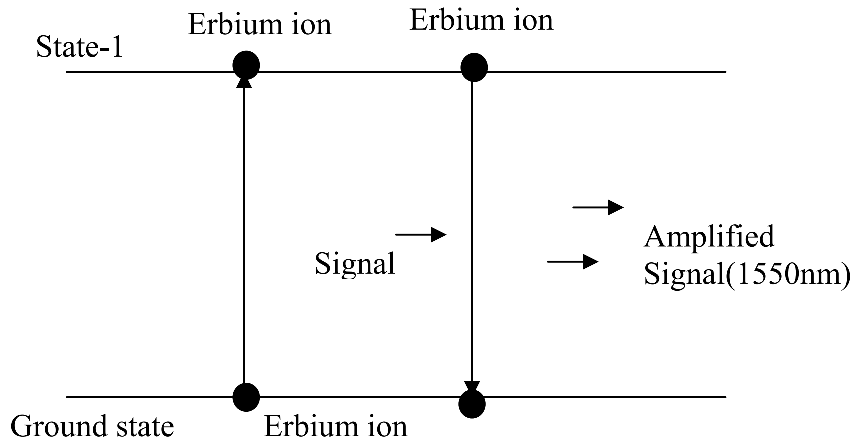
An important class of fiber amplifiers makes use of rare-earth elements as a gain medium by doping the fiber core during the manufacturing process. Although doped fiber amplifiers were studied as early as 1964 [19,20], their use became practical only 24 years later, after the fabrication and characterization techniques were improved. Amplifier properties such as operating wavelength and the gain bandwidth are determined by dopants rather than by the silica fiber. Many different rare-earth elements, such as erbium, holmium, neodymium, samarium, thulium, and ytterbium can be used to realize fiber amplifiers operating at different wavelengths in the range 0.5-3.5μm. Erbium-doped fiber amplifiers (EDFA) has attracts the most attention because of their operation in the wavelength region near 1.55μm [34]. Their deployment in WDM systems after 1995 revolutioned the field of fiber-optic communications and led to lightwave systems with capacities exceeding to 1 Tb/s.

Pumping at a suitable wavelength provides gain through population inversion. The gain spectrum depends on the pumping scheme as well as on the presence of other dopant. Many transitions can be used to pump an EDFA. Early experiments used the visible radiation emitted from argon-ion, Nd:YAG, or dye lasers even though such pumping schemes are relatively inefficient. Most EDFAs use 980-nm pump lasers as such lasers are commercially available and can provide more than 100mW of pump power. Pumping at 1480nm requires longer fibers and higher powers because it uses the tail of the absorption band.

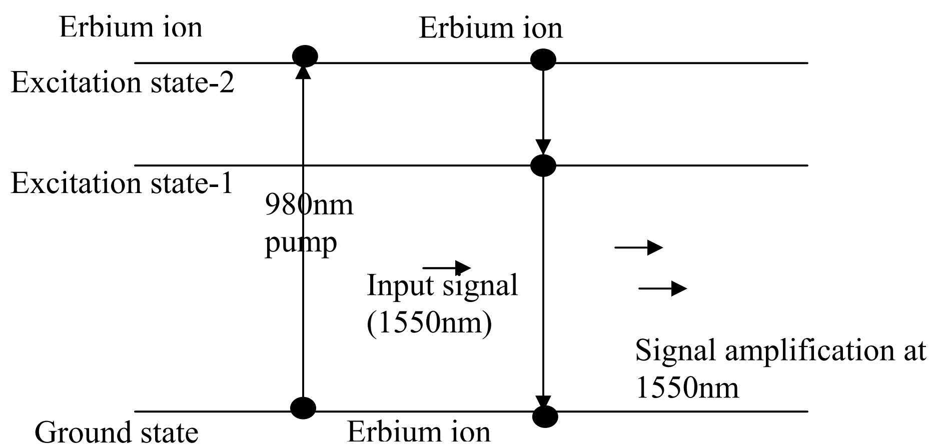
2.3.1 Principle of EDFA

This section briefly describes the working principles of erbium-doped fiber amplifiers. Erbium ions incorporated into a silica fiber are activated by pump light to create a population inversion, thus making stimulated amplification possible. Initially, the erbium ions are at ground state level, as shown in figure 2.2(a). If a laser operating at the 1480nm wavelength is used as a pump, the erbium ions from ground state level are excited to state-1 in Figure 2.2(a)). These ions will eventually falls to ground level and at the same time, release a photon. This process is referred to as spontaneous emission, and the accumulation of photons contributes to the process referred to as amplified spontaneous emission (ASE). ASE is an undesirable condition that adds noise to the optical amplifier.

Figure 2.2(b) shows the excitation process when a laser pump that operates at the 980nm wavelength is used to excite erbium ions to state-2. Since the lifetime of erbium ion is very short at state 2, the erbium ion is rapidly drop to the metastable level, state 1 without emits any photons. While an optical signal of 1550nm wavelength is applied at the input, the erbium ions fall from state-1 to ground will release a photon of the same wavelength as the applied signal, thus adding to the signal strength. This process referred to as a signal amplification process through stimulated emission described in figure 2.2(b)[15]. Actually, the level state -1 and ground state are respectively split into seven and eight sub-levels due to the Stark effects caused by the crystal lines field giving a total of 56 transitions that contributes to light emission. Accordingly, the emission spectrum is relatively broad because of the overlapping of line spectra [30].



(a) Population inversion process by 1480nm pumping



(b) Population inversion process by 980nm pumping

Figure 2.2: Spontaneous stimulated emission process fiber for optical amplification

2.3.2 Literature Review on Bismuth Oxide-Based Erbium-Doped Glass

In the last ten years, the researchers were interested to extend the telecommunication windows in order to keep up with the rapid growth of data streaming in telecommunication networks. In order to fill up this requirement, the wavelength division multiplexing (WDM) technique was applied in the region of 1.55μm which has lowest loss wavelength of silica glass fibers [6,7]. Erbium doped fiber amplifier (EDFA) is the effective solution to provide a broadband amplification in this wavelength region.

In recent years, an ultra broadband near infra red emission from Bi-doped glasses has been extensively studied [11,12] and optical amplification at the 1.3 μm wavelength was used with a 800nm excitation of bismuth-doped silica and silicate glass[10,11,12]. Through several results from other researchers, bismuth oxide (Bi_2O_3) based EDFAs (Bi-EDFAs) was found to be a promising candidates for such wideband amplifications to extend L-band amplification from 1530 to 1620nm with shorter fibers length [13]. The bismuth oxide fiber can be highly doped with Erbium ions without suffering from the ion-quenching and clustering effects commonly encountered in the conventional erbium doped fibers (EDFs). Therefore, only very short lengths of fiber are required to provide gains equivalent to that of much longer conventional SiO2-based EDFA. The short length of fiber implies a short interaction length and hence much lower accumulated dispersion and nonlinearity [14].

2.3.3 Characteristics of EDFA

2.3.3.1 Amplified Spontaneous Emission (ASE)

ASE or amplified spontaneous emission is a phenomena produced by spontaneous emission that has been optically amplified by the process of stimulated emission in a gain medium when it is pumped. Stimulated emission can be occurred at any wavelength/frequency within the fluorescence spectrum when it excites ions spontaneously falls from the upper level at a metastable situation to the ground state level and emit photons that are uncorrelated with the signal photons [29].

The calculation of ASE output for single transverse mode fibers with two independent mode polarizations at a frequency υ, the noise power in the bandwidth Δυ, corresponding to spontaneous emission is given by

$$P^{0}{}_{ASE} = 2hv\Delta v \tag{2.1 }$$

Where each mode is made up of a wave traveling in the forward direction and a wave traveling in the backward direction. The total noise power is then double the noise power traveling in one direction. The total ASE power at point z along the fiber is the sum of the ASE power P_{ASE} from level 2 to level 1 and the local noise power, $P^{0}{}_{ASE}$. The local noise power is stimulated by the emission of photons from excited erbium ions, and it is proportional to the product $\sigma^{(e)}(\upsilon)N_2$ where $\sigma^{(e)}$ is the stimulated emission cross section at frequency υ. The propagation of ASE power is given by:

$$\frac{dP_{ASE}(v)}{d_2} = [N_2\sigma^{(e)}(v) - N_1\sigma^{(a)}(v)]P_{ASE}(v) + P^{0}{}_{ASE}(v)N_2{}^{(e)}(v) \tag{ 2.2}$$

ASE depends on the light intensity of the signal pump power and can be measured using an OSA.

2.3.3.2 Gain and Noise Figure

The performance of the EDFA or doped fiber amplifier is describe by its gain and noise figure, which is defined as the ratio between beat-noise limited input signal-to-noise ratio (SNR_{in}) and the signal spontaneous beat-noise limited output signal-to-noise ratio (out). The gain of the EDFA is limited by the fact that there are a limited number of Erbium ions in the core. Increasing the pump power beyond the point where all ions are excited cannot produce more gain and thus saturation occurs. The gain of an erbium-doped fiber with a length of L is the ratio of the signal power at the fiber output to the signal power injected at the fiber input:

$$G = \frac{P_s(L)}{P_s(0)} \qquad (2.3)$$

One of the most important factors limiting the transmission distance in a fiber optical communication system is the optical power loss caused by scattering and absorption mechanisms in the optical fiber. ASE noise generated during amplification process is added to the signal leading to a decrease in signal to noise ratio (SNR) at the amplifier output. SNR reduction ratio from input to output of the amplifier is defined as Noise Figure (NF), which is also used for electronic amplifiers:

$$NF = \frac{SNR_{in}}{SNR_{out}} \qquad (2.4)$$

Noise Figure can also be expressed in terms of gain and spontaneous emission factor (n_{sp}) (or population inversion factor):

$$NF = \frac{2n_{sp}(G-1)}{G} \sim 2n_{sp} \quad (2.5)$$

$$n_{sp} = \frac{n_2}{n_2 - n_1} \quad (2.6)$$

The power spectral density of spontaneous emission induced noise $S_{sp}(v)$ is a function of frequency and follows the emission spectrum of Er^{3+} ions :

$$S_{sp}(v) = (G-1)n_{sp}hv \quad (2.7)$$

$$S_{sp}(v) = \frac{Pa^{+}}{\Delta\nu} \quad (2.8)$$

Using equation (2.5), EDFA noise figures can be expressed in terms of forward propagating ASE power (P+*a*) [4] :

$$NF = \frac{2Pa^{+}}{\mathrm{Gh\nu\Delta\nu}} \quad (2.9)$$

Here, $\Delta\nu$ is the bandwidth of the optical bandpass filter and $h\nu$ is the photon energy. As it can be seen from Eq.2.9 the EDFA noise figure depends directly on forward ASE power and gain. Noise Figure increases with increasing ASE power and decreases with increasing gain [32].

2.4 Introduction to Photonic Crystal Fiber (PCF)

Photonics Crystal Fibers (PCF), are also called as a microstructure fibers or holey fibers (HF) are a silica optical fiber with high nonlinearity and low loss. They have recently been placed under active research and are now possible to be manufactured, which is very useful for many applications. It was coined by Philip Russell in 1995-1997. Holey fibers or PCF have been important in the research community since the first working demonstration in 1996 [2,9], because of the additional degrees of freedom offered in the design of their optical properties such as nonlinearities, dispersion and polarization [2,4]. More specific categories of PCF include photonic-bandgap fibers (PCFs that confine light by band gap effects), holey fiber (PCFs using air holes in their cross-sections), hole-assisted fibers (PCFs guiding light by a conventional higher-index core modified by the presence of air holes), and Bragg fibers (photonic-bandgap fiber formed by concentric rings of multilayer films).

PCFs consist of an array of microscopic air holes running along the entire length [2,40]. The guidance properties of the PCF are determined by the size and pattern of the air holes and the solid silica regions rather than by the properties of the optical glass [2]. Nonlinear PCFs are of the high index guiding type. They are designed with a small core to get a high nonlinear coefficient with low effective area (A_{eff})[42]. A high index difference between the silica core and the air holes cladding enables tight mode confinement resulting in a low effective area and makes PCFs allow much stronger mode confinement and provides much higher nonlinearities [42]. Designs with large air-filling fractions and hole-to-hole spacing larger than 1μm are advantageous both in terms of achieving high nonlinearity and low confinement loss [42]. Effective mode areas as small as 1.3μm^2 in silica PCFs was achieved at 1550nm wavelength, corresponding to a nonlinear coefficient, γ around $70W^{-1}km^{-1}$, more than 70 times of the standard single mode fiber [2]. In addition, PCFs allow a more flexible tailoring of the high dispersion properties, simply by changing the structural dimensions which are crucial for many applications of nonlinear effects [2,41].

The discrete Raman amplifier is an attractive option to extend optical transmission systems into the optical communication bands outside the conventional erbium doped fiber amplifier (EDFA). In earlier work, a high gain discrete Raman L-band amplifier was demonstrated using a relatively short highly nonlinear HF [2]. Figure 2.3 shows the microstructure in the PCF which was obtained from SEM scanning. The structure of the PCF or holey fiber is changing dramatically along the length, which has different modal index values along the entire length [2,3].

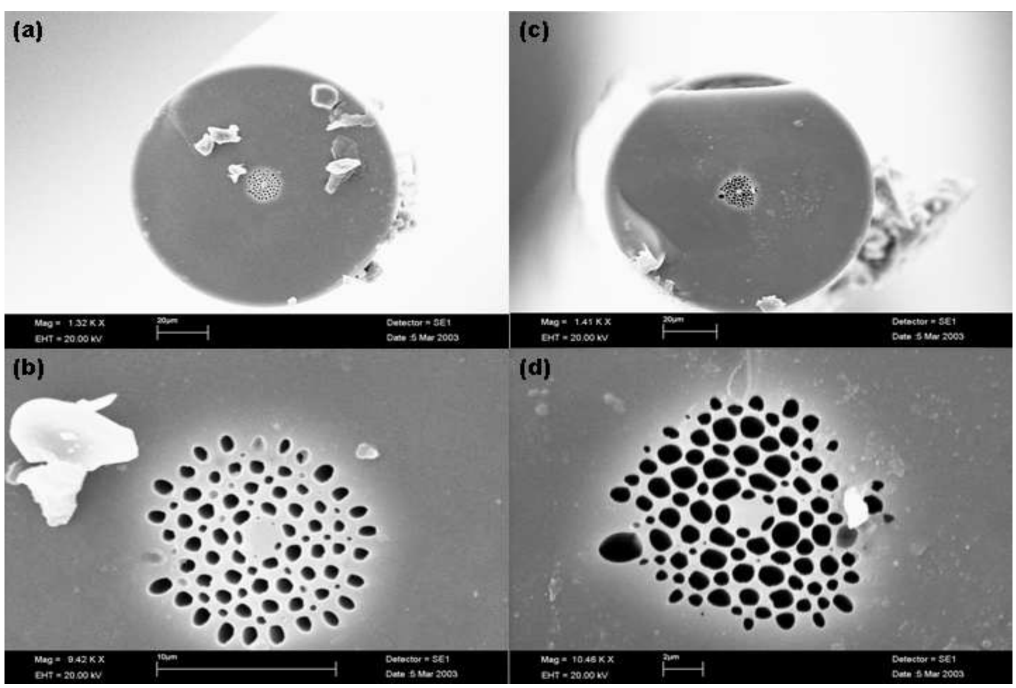


Figure 2.3: Microstructure of PCF/holey fiber

2.4.1 Application of PCF

Depending on the structure of its cross-section, PCFs have various properties such as single mode condition of propagation, a wide spectral band, depending on the situation, small area of mode field for nonlinear effects, low or high losses on curving, high nonlinearity for generation of harmonics and a supercontinuum, precisely controlled polarization, group speed dispersion, spectrum capacities and two-refraction.

PCFs are designed to satisfy many application needs. For example, it can support large or small mode field diameters, it can be single mode over an extremely broad wavelength range and it can produce highly birefringence resulting in improved polarization control [1,42]. It also can be used in spectroscopy, metrology, biomedicine, imaging, telecommunications, industrial machining and military [2].

2.4.2 Nonlinearity effects

Nonlinear effects have become significant at high optical power and have become even more important since the development of EDFA and WDM systems. The origin of nonlinearities is the refractive index of the optical fiber, which can be varied with the intensity of the optical signal. The combination of high total optical power and large number of channels in closely spaced wavelengths is a source for many kinds of nonlinear interactions [23]. The earliest measurements of a nonlinear refractive index in silica fibers were carried out in 1978 [23]. The importance of nonlinear effects in optical communication systems revived interest in the measurements of the nonlinear refractive index during 1990s.

The nonlinear effects can be divided into two categories. The first category is arise due to the interaction of light waves and phonons, leading to two important nonlinear scattering effects, Stimulated Raman Scattering (SRS) and Stimulated Brillouin scattering (SBS). The second type arise due to the effect that is related to the Kerr effect such as self-phase modulation (SPM), cross-phase modulation (XPM) and four wave mixing (FWM). For this type, there is an intensity dependence on the nonlinear refractive index of optical fiber [23].

In this dissertation, we studied the SBS phenomena in fiber laser application by using a piece of PCF as gain medium in fiber laser system. In the previous reports, BFLs have been achieved using more than 70m long PCF as a gain medium [44,45]. In the other previous research report from Ailng Zhang et.al [46], they use also 20m of PCF in set-up of ring laser to produce a comb of multiwavelength fiber laser with saturation output power of the EDFA is about +27 dBm. However, in this dissertation, a comb multiwavelength fiber laser was produced by using 20m of PCF by using output power of Bi-Si-EDFA is about 20dBm. The setup configuration and result explanation of BFL with using 20m length of PCF have been discussed in chapter 3,4 and 5.

Nonlinear properties of glass fibers mainly arise from the third order susceptibility, χ_3 which is the 1st nonlinear term in an isotropic medium. On the fundamental level, the origin of the nonlinear response is related to anharmonic motion of bound electrons under the influence of an applied field. As a result the total polarization **P** induced by electric dipoles is not linear in the electric field **E**, but satisfies to more general relation.

$$\mathbf{P} = \varepsilon_0 \left(\chi^{(1)} . \mathrm{E} + \chi^{(2)} : \mathbf{EE} + \chi^{(3)} : \mathbf{EEE} + \ldots\right) \tag{2.10}$$

where ε_0 is the vacuum permittivity and $\chi^{(j)}$ (j= 1.2,…) is the j-th order susceptibility. The linear susceptibility $\chi^{(1)}$ represent the dominant contribution to **P**. The second order susceptibility $\chi^{(2)}$ is responsible for such nonlinear effects as the second-harmonic generation and sum frequency generation. Most of the nonlinear effects in optical fibers arise from nonlinear refraction, a phenomenon referring to the intensity dependence of the refractive index. The relation between the refractive index *n*, intensity *I* and power *P* is

$$n = n_0 + n_2 I = n_0 + (n_2 / A_{eff})P \tag{2.11}$$

where n_0 is the wavelength- dependent part of the refractive index and A_{eff} is effective area of the optical fiber or in the case at hand, the PCF. The electric-quadrupole and magnetic-dipole moments can generate weak second-order nonlinear effects. The nonlinear coefficient is defined as $\mathbf{n_2/A_{eff}}$. In the literature, the nonlinear coefficient has two different notations. The relation between the often applied nonlinear parameter, γ, and nonlinear refractive index, n_2 is

$$\gamma = \frac{\omega_0 n_2}{C_o A_{eff}} = \frac{2\pi n_2}{\lambda_0 A_{eff}} \tag{2.12 }$$

where ω_0 represent the angular frequency of the light wave, C_0 is speed of light in vacuum. λ_0 is the wavelength in vacuum and A_{eff} is the effective area of the optical fiber. Typically, the nonlinear refractive index n_2 are found to vary in the range 2.2-3.9×10^{-20} m^2 / W for silica [8, 24].

2.4.2.1 Stimulated Brillouin Scattering (SBS)

Stimulated scattering is defined as "*transferring energy from the incident wave to another scattered wave at lower frequency or longer wavelength with the small energy difference being released in the form of phonons*" [17]. Phonons are an elementary particle analogous to photons but differ from the fact that a photon has quantum particle properties. Nonlinear stimulated scattering contain two important phenomena caused by interaction of light with phonons as explained in the previous section. The first one is SRS and the second one is SBS and both phenomena are related to excitation modes of the silica and transfer energy from the optical field in the nonlinear fiber. Brillouin effects were seen for the first time in 1922 by Leon Brillouin [21]. SBS is similar to SRS in as much as it manifests through the generation of Stokes waves.

However, a major difference exists between SBS and SRS. The Stokes wave propagates in the backward direction when SBS occurs in a single mode fiber, in contrast to SRS that can occur in both directions. The Stokes shift can be as small as ~10GHz, three orders of magnitude smaller for SBS compared with that of SRS [8,25]. On the other hand, the Brillouin gain g_B appears to be larger than the Raman gain and is also independent of the wavelength.

2.4.2.2 Physical Process of Stimulated Brillouin Scattering

SBS can occur when interactions happen between incident light and scattered waves through acoustic waves. The incident light can be seen as a kind of pump wave (from BP) while the scattered wave can be called "Stokes wave". The pump field generates an acoustic wave through the process of electrostriction [8]. It can be explained by the fact that when a narrow linewidth from a BP with high power signal propagates in an optical fiber, acoustic waves are generated and travels in the same direction as the pump light [18]. Acoustic phonons which have much lower energy resulted in frequency downshift due to it can modulate the refractive index of the medium. This pump induced index grating scatters the pump light through Bragg diffraction. The downshift in frequency of scattered light is because of the Doppler shift associated with the grating moving at the acoustic velocity V_A.

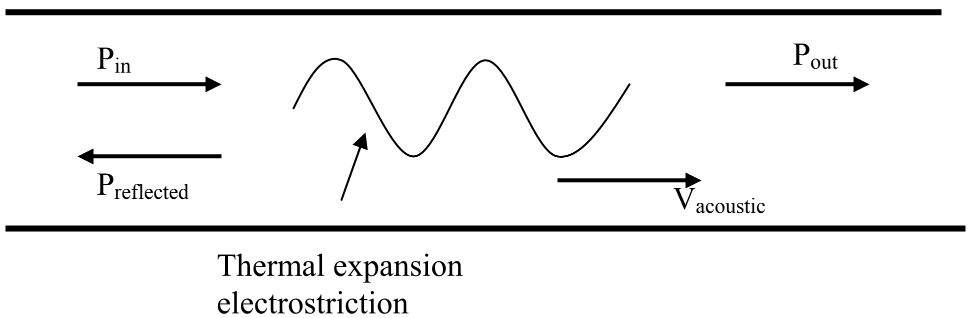


Figure 2.4 : Illustration of SBS phenomena

In this process, phonons may either be created or absorbed resulting in Stokes or anti-Stokes scattered waves. Using the conservation of energy theorem:

$$\boldsymbol{v_P = v_S + v_A} \tag{2.13}$$

$$\boldsymbol{v_P + v_A = v_{AS}} \tag{2.14}$$

V_P, V_A, V_S and V_{AS} are the frequency of the pump, acoustic phonon, Stokes wave and anti-Stokes wave respectively.

The magnitude of the Brillouin shift is given by:

$$v_B = \frac{2v_A n}{\lambda_P} \tag{2.15}$$

Brillouin frequency shift depends on the acoustic velocity and the fiber modal index. These two quantities depend on both the intrinsic characteristic of the fiber as well as environmental factors such as temperature and strain.

2.4.3 Brillouin Threshold for Brillouin Fiber Laser

Although SBS generation can be detrimental in coherent optical communication systems [33], it does serve a useful purpose for instance in producing Brillouin fiber laser(BFLs). BFLs are highly coherent light sources and have generated increasing interest for a number of applications such as in gyroscopes and sensors due to their extremely narrow linewidth [33,35]. SBS is characterized by three major parameters which are threshold power,P_{th} , gain,g, and range of frequency,Δf. P_{th} can be defined as the power of incident light at which the loss due to stimulated scattering is 3dB or half over the fiber length, L. The intensity of the scattering light grows exponentially when the power of incident light exceeds P_{th}. Gain, *g* refer to the peak gain of the stimulated scattering at the given wavelength [17].

The Brillouin threshold P_{th} can be defined as the critical pump power at which the Brilouin Stokes power is equal to the input light power at z = 0. For estimating the

Brillouin threshold, using $I_p(z) = I_p(0)e^{-\alpha z}$ and integrating it over the fiber length L, gives the Brillouin Stokes intensity that grow exponentially in the backward direction as:

$$I_s(0) = I_s(L)\exp\frac{g_B P_0 L_{eff}}{A_{eff} - \sigma L} \tag{2.16}$$

where $I_s(0)$ is the incident pump intensity at fiber position z=0, $P_0 I_p 0) A_{eff}$ is the input pump power, A_{eff} is the effective core area. The effective interaction length is given by

$$L_{eff} = \frac{1-\exp(-\sigma L)}{\sigma} \tag{2.17}$$

where $\boldsymbol{\alpha}$ is the absorption coefficient. Equation 2.17 shows how a Brillouin Stokes signal incident at z = L grows in the backward direction caused by Brillouin amplification occurring as a result of SBS. The Brillouin threshold occurs at the critical pump power P_{CR} can be obtained from this equation:

$$\frac{g_B P_{CR} L_{eff}}{A_{eff}} \approx 21 \tag{2.18}$$

where $\boldsymbol{g_B}$ is the peak value of the Brillouin gain. The threshold value predicted from equation 2.18 is only approximate as the effective Brillouin gain can be reduced by many factors such as impurities and inhomogeneties of the material. Variation of doping levels along the entire length of the fiber can lead to different acoustic velocities. The Brillouin threshold is given by:

$$P_{th} \approx \frac{21 A_{eff}}{g_B L_{eff}} \tag{2.19}$$

2.4.4 Polarization and Polarization Controller

Another characteristic of PCFs is their strong birefringence characteristic, which is set by the size and arrangement of the air holes. It does suggest optical components with better polarization maintaining characteristics. A theoretical analysis [27] and experiments, [28] showed high birefringence of the order of 1×10^{-3}, three times larger than that of conventional polarization maintaining fibers and so optical components with better polarization maintaining characteristics are expected.

Polarization is a property of waves that describes the orientation of their oscillation in the plane perpendicular to the wave's direction of travel. Polarization is used in areas of science and technology dealing with wave propagation, such as optics, seismology, and telecommunications. In studying polarization, light can split in two situations; single electromagnetic waves caused by the superposition of multiple waves. Light is a transverse electromagnetic wave, with the electric field and the magnetic field oscillating at right angles to each other and the direction of propagation.

The electric field of a light beam has a direction. One of these is the direction of travel with regard to phase shift, wavelength, velocity, and attenuation of the propagating wave. The other direction is that of the electric-field vector itself. Figure 2.5 shows the relationship between the vector E and the direction of travel for a simple plane wave. The wave travel in the z direction and the electric field vector points in the x-direction. An electric field that points in just one direction is said to be linearly polarized.

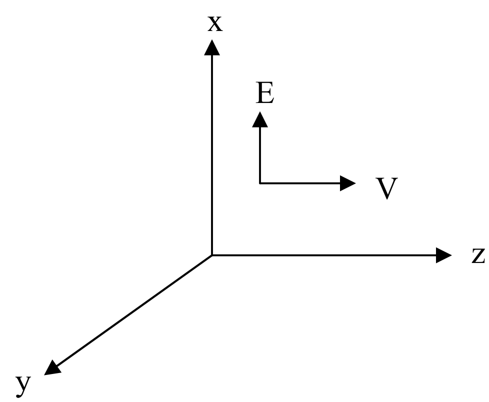


Figure 2.5: Wave travelling in the z direction having its electric field polarized in the x direction

The electric vector is always perpendicular to the direction of wave travel for a plane wave in an unbounded medium. This being so, the field in figure 2.5 could also point in the y-direction while traveling in the z-direction. Polarization of light source and polarization sensitive elements can determine the actual direction of polarization. It is also possible for two waves to travel in the z-direction simultaneously, one polarized in the x direction and one polarized in the y direction. These two waves would be independent for each other because of their orthogonal polarization. The term ‘mode’ refers to the different ways a wave can travel in a given direction. These two independent waves are the two plane wave-modes of an unbounded medium. It might be occured that other modes are possible, having polarizations in the xy plane at some angle to the x or y axis. Any electric field vector can be decomposed into its x and y components so that such a field is the combination of the two modes. In the optic fiber, many modes can exist. Polarization is just one of the differences among modes in a waveguide. Modes play an extremely important part in determining the design and capabilities of an optical communication system.

The polarization controller is a fiber device for producing a desired state of polarization. Although most fiber systems are independent of the state of polarization of the optical beam, coherent detection system and interferometer sensors are very much dependent upon the state of polarization of the optical signal.

A simple polarization controller is constructed by winding the fiber around a disk with a diameter in the order of one centimeter [5]. Usually, two or three of these fiber disks are connected in series. Rotating the disk about the axis of the transmission fiber produces a differential change in the refractive index of the two orthogonally polarized beams traversing the fiber. Any desired polarization state can be obtained with the appropriate rotation of the disks.

2.4.4.1 Optical Isolator

An optical isolator is composed of a magnetic garnet crystal employing a Faraday Effect, a permanent magnet for applying a designated magnetic and polarizing element which permits only forward light to pass while shutting out backward light. For this reason, optical isolators are indispensable devices for eliminating the adverse effect of return beams in high-speed optical fiber transmittance routes and amplifiers. By focusing on optical isolators with their operation wavelengths in the 1.30-1.55μm, range that been used widely in optical communication.

Using an optical isolator will ensure a low level of return to the laser diode. An optical isolator is a one-way transmission line [36]. That is, it will allow propagation in only one direction along the fiber. The most isolators make use of the Faraday effects which govern the rotation of the plane of polarization of an optical beam in the presence of a magnetic field [37]. The magnetic field, B, applied to the Faraday rotator causes a rotation in the polarization of the light due to the Faraday Effect. The angle of rotation, β is given by,

$$\boldsymbol{B = vBd} \tag{4.20}$$

Where ν is the verdet constant of the material, a measure of the strength of the Faraday Effect, d is the length of the rotator. Verdet constantfor most material is extremelly small and depending on wavelength [38,39].

The basic structure of such a device is shown in Figure 2.6. It consists of three parts, an input polarizer (vertically polarizer), a 45^0 Faraday rotator and output polarizer which is polarized at 45^0. A beam of light incident from the left is vertically polarized by the input polarizer and the resultant wave passes through the rotator. Generally, a Faraday rotator rotates the direction of linear polarization of an incident beam which rotates a plane of light polarization by 45^0. Thus the beam emerging from the rotator is linearly polarized at the vertical. The faraday rotator turns the plane of this polarization another 45^0, allows passage of this wave. The analyzer or output polarizer then enables the light to be transmitted through the isolator [35,36,37].

Now consider a beam travelling from right to left. This means the wave is polarized at 45^0 by P_R as it enters the isolator. It is rotated further by another 45^0 by the faraday device, so that it is horizontally polarized as it exits the left side of the rotator as shown on the figure. The polarizer will block passage of this horizontally polarized beam. We conclude that no light can travel from the right to the left through the isolator. It should be emphasized that the Faraday rotation is nonreciprocal[36,38]. In this thesis, an optical isolator is used in the BFL set-up to ensure unidirectional operation of the laser.

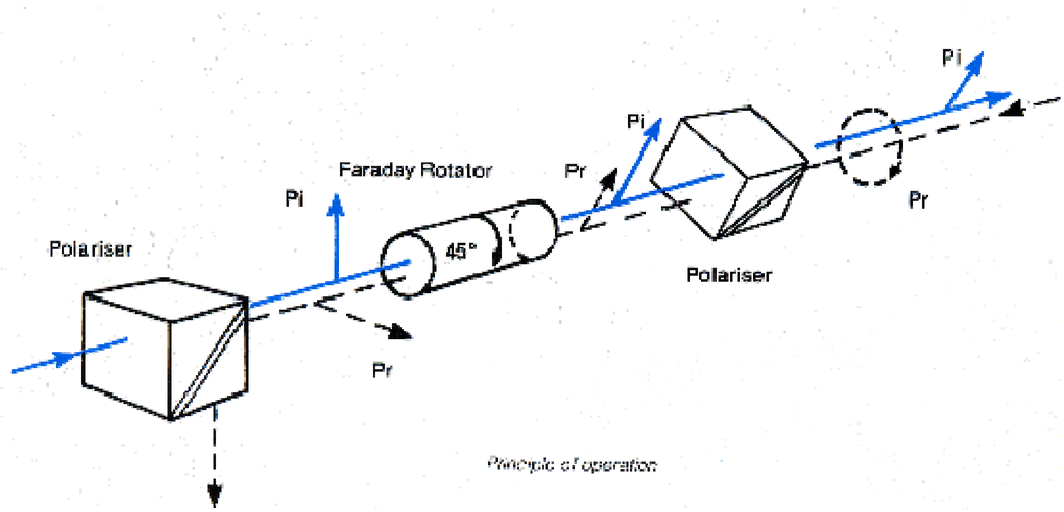


Figure 2.6 : Faraday rotator with a polarizer and an analyzer

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