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The Role of Optical Amplifiers in Soliton Communication System: A Review

Authors
Er. Ruchi Sharma, Er. Manpreet Kaur
Chandigarh Engineering College, Landran, Mohali, Punjab

Abstract

The soliton is an innovative area of research that deserves intense investigation in many branches of physics. Different class of soliton-bearing models has been proposed in many physical problems in various context of physical system and still continues to flourish as an area of intense research, but unfortunately when soliton pulses are used for long-haul applications, they shed their energy on their way and hence needs to be amplified periodically. Different optical amplifiers are used in the soliton model to amplify the soliton pulses so that they can propagate at the same shape.

An optical amplifier is a device that amplifies an optical signal directly, without the need to first convert it to an electrical signal. There are several different physical mechanisms that can be used to amplify a light signal, which correspond to the major types of optical amplifiers. In doped fiber amplifiers and bulk lasers, stimulated emission in the amplifier's gain medium causes amplification of incoming light. In semiconductor optical amplifiers (SOAs), electron-hole recombination occurs

Keywords: *EDFA, SOA, Soliton.*

I Introduction

The transmission distance of any fiber-optic communication system is limited by fiber losses. For long-haul systems, the loss limitation has traditionally been overcome using optoelectronic repeaters in which the optical signal is first converted into an electric current and then regenerated using a transmitter. Such regenerators become quite complex and expensive for wavelength-division multiplexed (WDM) light wave systems. An alternative approach to loss management makes use of optical amplifiers, which amplify the optical signal directly without requiring its conversion to the electric domain. Several kinds of optical amplifiers were developed during the 1980s, and the use of optical amplifiers for long-haul light wave systems became widespread during the 1990s. By 1996, optical amplifiers were a part of the fiber-optic cables laid across the Atlantic and Pacific oceans.

The current efforts of research and development are aiming at increasing the total capacity of medium and long haul optical transmission systems [1]. At the same time, deregulation of telecommunication markets and global success of the Internet has driven the demand for higher and higher system capacity. The transmission distance of any fiber-optic communication system is eventually limited by fiber losses. For long-haul systems, the loss limitation has traditionally been overcome using optoelectronic repeaters in which the optical signal is first converted into an electric current and then regenerated using a transmitter. Such regenerators become quite complex and expensive for wavelength-division multiplexed (WDM) Light wave systems. Currently the optical amplifiers are used which directly amplify the transmitter optical signal without conversionto electric forms asin-line amplifiers[1]. It amplifies the signals simultaneously and decreases the attenuation.

Fiber attenuation is the main reason behind power depletion of signal as it travels the distance. The fiber non-linearities are responsible for the signal power level depletion [1]. In 1990s the fourth generation of optical systems emerges, the main technology behind this is the invention of optical fiber amplifiers were developed using fiber amplifiers to increase the repeater spacing and bit rate.

EDFA has been used as booster and inline amplifier to transmit optical signals over thousands of kilometers [2]. EDFAs are having of low noise figure and have a good gain bandwidth and can amplify multichannel signals on different wavelengths simultaneously, so EDFA emerges as the implementing technology for WDM systems. It is also reported that under deeper saturation or having steeper saturation characteristic EDFA would result in less BER impairment [3]. Another option for amplifications is Semiconductor optical amplifier. SOA has ultra-wide band spectrum, low power consumption and low cost [5].

II Types Of Amplifiers Used In Soliton Transmission System

***Laser Amplifier*:**

Almost any laser active gain medium can be pumped to produce gain for light at the wavelength of a laser made with the same material as its gain medium. Such amplifiers are commonly used to produce high power laser systems. Special types such as regenerative amplifiers and chirped-pulse amplifiers are used to amplify ultra-short pulses.

Doped fiber amplifiers:

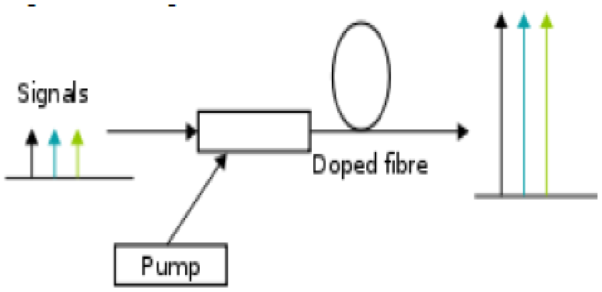

Fig. 1 Schematic diagram of a simple Doped Fiber Amplifier

Doped fiber amplifiers (DFAs) are optical amplifiers that use a doped optical fiber as a gain medium to amplify an optical signal. They are related to fiber lasers. The signal to be amplified and a pump laser are multiplexed into the doped fiber, and the signal is amplified through interaction with the doping ions. The most common example is the Erbium Doped Fiber Amplifier (EDFA), where the core of a silica fiber is doped with trivalent erbium ions and can be efficiently pumped with a laser at a wavelength of 980 nm or 1,480 nm, and exhibits gain in the 1,550 nm region.

An erbium-doped waveguide amplifier (EDWA) is an optical amplifier that uses a waveguide to boost an optical signal. Amplification is achieved by stimulated emission of photons from dopant ions in the doped fiber. The pump laser excites ions into a higher energy from where they can decay via stimulated emission of a photon at the signal wavelength back to a lower energy level. The excited ions can also decay spontaneously (spontaneous emission) or even through nonradioactive processes involving interactions with phonons of the glass matrix. These last two decay mechanisms compete with stimulated emission reducing the efficiency of light amplification. The amplification window of an optical amplifier is the range of optical wavelengths for which the amplifier yields a usable gain. The amplification window is determined by the spectroscopic properties of the dopant ions, the glass structure of the optical fiber, and the wavelength and power of the pump laser.

Although the electronic transitions of an isolated ion are very well defined, broadening of the energy levels occurs when the ions are incorporated into the glass of the optical fiber and thus the amplification window is also broadened.

1. Erbium Doped Fiber Amplifier

Relatively high-powered beam of light is mixed with the input signal using a wavelength selective coupler. The input signal and the excitation light must be at significantly different wavelengths. The mixed light is guided into a section of fiber with erbium ions included in the core. This high-powered light beam excites the erbium ions to their higher-energy state. When the photons belonging to the signal at a different wavelength from the pump light meet the excited erbium atoms, the erbium atoms give up some of their energy to the signal and return to their lower-energy state. A significant point is that the erbium gives up its energy in the form of additional photons which are exactly in the same phase and direction as the signal being amplified.

So the signal is amplified along its direction of travel only. This is not unusual - when an atom “lases” it always gives up its energy in the same direction and phase as the incoming light. Thus all of the additional signal power is guided in the same fiber mode as the incoming signal.There is usually an isolator placed at the output to prevent reflections returning from the attached fiber. Such reflections disrupt amplifier operation and in the extreme case can cause the amplifier to become a laser. The erbium doped amplifier is a high gain amplifier.

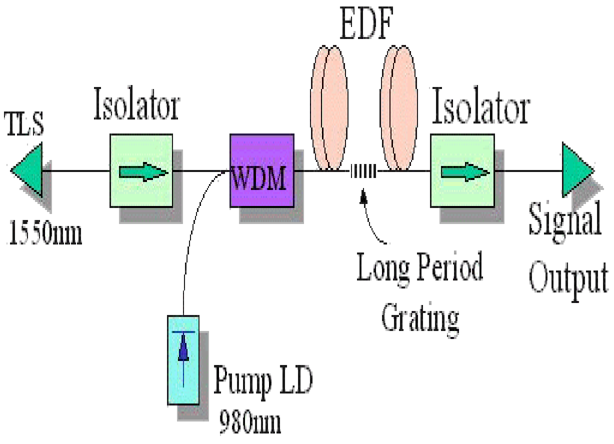

Fig. 2 Schematic Diagram of EDFA

A. Noise

The principal source of noise in DFAs is Amplified Spontaneous Emission (ASE), which has a spectrum approximately the same as the gain spectrum of the amplifier. Noise figure in an ideal DFA is 3 dB, while practical amplifiers can have noise figure as large as 6–8 db.

As well as decaying via stimulated emission, electrons in the upper energy level can also decay by spontaneous emission, which occurs at random, depending upon the glass structure and inversion level. Photons are emitted spontaneously in all directions, but a proportion of those will be emitted in a direction that falls within the numerical aperture of the fiber and are thus captured and guided by the fiber. Those photons captured may then interact with other dopant ions, and are thus amplified by stimulated emission. The initial spontaneous emission is therefore amplified in the same manner as the signals, hence the term *Amplified Spontaneous Emission*. ASE is emitted by the amplifier in both the forward and reverse directions, but only the forward ASE is a direct concern to system performance since that noise will co-propagate with the signal to the receiver where it degrades system performance. Counter-propagating ASE can, however, lead to degradation of the amplifier's performance since the ASE can deplete the inversion level and thereby reduce the gain of the amplifier.

B. Gain saturation

Gain is achieved in a DFA due to population inversion of the dopant ions. The inversion level of a DFA is set, primarily, by the power of the pump wavelength and the power at the amplified wavelengths. As the signal power increases, or the pump power decreases, the inversion level will reduce and thereby the gain of the amplifier will be reduced. This effect is known as gain saturation – as the signal level increases, the amplifier saturates and cannot produce any more output power, and therefore the gain reduces. Saturation is also commonly known as gain compression. To achieve optimum noise performance DFAs are operated under a significant amount of gain compression (10 dB typically), since that reduces the rate of spontaneous emission, thereby reducing ASE. Another advantage of operating the DFA in the gain saturation region is that small fluctuations in the input signal power are reduced in the output amplified signal: smaller input signal powers experience larger (less saturated) gain, while larger input powers see less gain.

The leading edge of the pulse is amplified, until the saturation energy of the gain medium is reached. In some condition, the width (FWHM) of the pulse is reduced.

C. Erbium-doped fiber amplifiers

The erbium-doped fiber amplifier (EDFA) is the most deployed fiber amplifier as its amplification window coincides with the third transmission window of silica-based optical fiber. Two bands have developed in the third transmission window – the *Conventional*, or C-band, from approximately 1525 nm – 1565 nm, and the *Long*, or L-band, from approximately 1570 nm to 1610 nm. Both of these bands can be amplified by EDFAs, but it is normal to use two different amplifiers, each optimized for one of the bands. The principal difference between C- and L-band amplifiers is that a longer length ofdoped fiber is used in L-band amplifiers. The longer length of fiber allows a lower inversion level to be used, thereby giving at longer wavelengths (due to the band-structure of Erbium in silica) while still providing a useful amount of gain. EDFAs have two commonly-used pumping bands – 980 nm and 1480 nm. The 980 nm band has a higher absorption cross-section and is generally used where low-noise performance is required. The absorption band is relatively narrow and so wavelength stabilized laser sources are typically needed. The 1480 nm band has a lower, but broader, absorption cross-section and is generally used for higher power amplifiers. A combination of 980 nm and 1480 nm pumping is generally utilized in amplifiers.

2. Semiconductor Optical Amplifier

Semiconductor optical amplifiers (SOAs) are amplifiers which use a semiconductor to provide the gain medium [4]. These amplifiers have a similar structure to Fabre – Perrotlaser diodes but with anti-reflection design elements at the end faces. Recent designs include anti-reflective coatings and tilted waveguide and window regions which can reduce endface reflection to less than 0.001%. Since this creates a loss of power from the cavity which is greater than the gain it prevents the amplifier from acting as a laser.

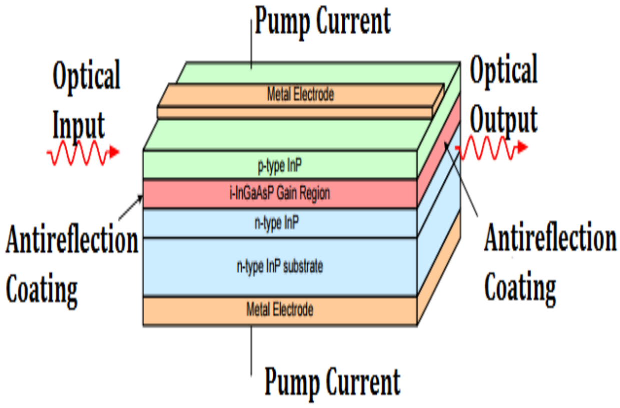

Fig. 3 Schematic Diagram of SOA

Semiconductor optical amplifiers are typically made from group III-V compound semiconductors such as GA As/AlGaAs, InP/Inga As, InP/InGaAsP and InP/InAlGaAs, though any direct band gap semiconductors such as II-VI could conceivably be used. Such amplifiers are often used in telecommunication systems in the form of fiber-pigtailed components, operating at signal wavelengths between 0.85 µm and 1.6 µm and generating gains of up to 30 db.

The semiconductor optical amplifier is of small size and electrically pumped. It can be potentially less expensive than the EDFA and can be integrated with semiconductor lasers, modulators, etc. However, the performance is still not comparable with the EDFA. The SOA has higher noise, lower gain, moderate polarization dependence and high nonlinearity with fast transient time. The main advantage of SOA is that all four types of nonlinear operations (cross gain modulation, cross phase modulation, wavelength conversion and four wave mixing) can be conducted. Furthermore, SOA can be run with a low power laser [5]. This originates from the short nanosecond or less upper state lifetime, so that the gain reacts rapidly to changes of pump or signal power and the changes of gain also cause phase changes which can distort the signals. This nonlinearity presents the most severe problem for optical communication applications. However, it provides the possibility for gain in different wavelength regions from the EDFA. "Linear optical amplifiers" using gain-clamping techniques have been developed. High optical nonlinearity makes semiconductor amplifiers attractive for all optical signal processing like all-optical switching and wavelength conversion. There has been much research on semiconductor optical amplifiers as elements for optical signal processing, wavelength conversion, clock recovery, signal demultiplexing, and pattern recognition.

III Conclusion

In long distance communications, whether going through wire, fiber or wave, the signal that carries the information needs to be amplified. In fiber optics communications, this can be done in several ways: by converting the optical signal into an electronic one by using an optical amplifier. By stimulated emission, one photon gives rise to another photon: the total is two photons. Each of these two photons can give rise to another photon: the total is then four photons. And it goes on and on. Semiconductor laser amplifiers are used; however, they are not free of problems. All amplifiers amplify an incoming signal but also add noise to the signal which is not desirable SLA’s have a poor noise performance: they add a lot of noise to the signal. The EDFA is an optical fiber doped with erbium. EDFA is a low noise light amplifier. Erbium is a rare-earth element which has some interesting properties for fiber optics communications.

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