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The Role of Optical Amplifiers in Optical Fiber Communication

B.Bala Subbanna, L.P.Divya Meenakshi

Abstarct:An optical amplifier is a device that amplifies an opticalsignal directly, without the need to first convert it to an electrical signal. An optical amplifier may be thought of as a laser without an optical cavity, or one in which feedback from the cavity is suppressed. Optical amplifiers are important in optical communication and laser physics. 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-holerecombination occurs. In Raman amplifiers, Raman scattering of incoming light with phonons in the lattice of the gain medium produces photons coherent with the incoming photons. Parametric amplifiers use parametric amplification. 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.

Keywords: Amolifier, EDFA, SOA

I. INTRODUCTION

An order to transmit signals over long distances (>100 km) it is necessary to compensate for *attenuation losses* within the fiber. Initially this was accomplished with an optoelectronic module consisting of an optical receiver, regeneration and equalization system, and an optical transmitter to send the data.

Although functional this arrangement is limited by the optical to electrical and electrical to optical conversions Several types of *optical amplifiers* have replaced theOE – electronic regeneration systems. These systems eliminate the need for E-O and O-E conversions.

This is one of the main reasons for the success of today's optical communications systems.

A. *Amplifier*:

When the signal becomes weak, then we need to amplify the signal to increase the strength of the weak signal.

B. *Repeater:*

It converts weak optical signal to electronic form,

C. *Regenerator*:

It removes noise and distortion, and reproduces original signal.

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***** Correspondence Author (s)
B.Bala Subbanna, M.E, (Ph.D), Assistant Professor, Debremarkos University,Ethiopia.
L.P.Divya Meenakshi, (M.Tech), Assistant Professor, Mits, Madanapalli.Andhrapradesh.

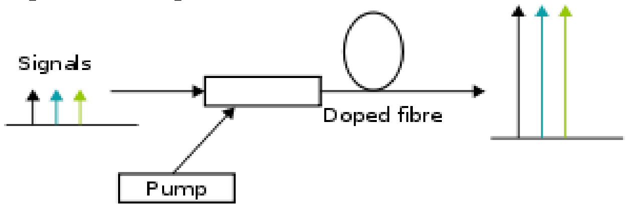
II. DIFFERENT TYPES OF OPTICAL AMPLIFIER

Laser amplifiers, : Doped fiber amplifiers,

A. *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:



Schematic diagram of a simple Doped Fiber Amplifier

Doped fiber amplifiers (DFAs) are optical amplifiers that use a dopedoptical 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. This broadening is both homogeneous (all ions exhibit the same broadened spectrum) and inhomogeneous (different ions in different glass locations exhibit different spectra). Homogeneous broadening arises from the interactions with phonons of the glass, while inhomogeneous broadening is caused by differences in the glass sites where different ions are hosted. Different sites expose ions to different local electric fields, which shifts the energy levels via the Stark effect. In addition, the Stark effect also removes the degeneracy of energy states having the same total angular momentum (specified by the quantum number J). Thus, for example, the trivalent erbium ion (Er^{+3}) has a ground state with J = 15/2, and in the presence of an electric field splits into J + 1/2 = 8 sublevels with slightly different energies. The first excited state has J = 13/2 and therefore a Stark manifold with 7 sublevels. Transitions from the J = 13/2 excited state to the J= 15/2 ground state are responsible for the gain at 1.5 µm wavelength. The gain spectrum of the EDFA has several peaks that are smeared by the above broadening mechanisms. The net result is a very broad spectrum (30 nm in silica, typically). The broad gain-bandwidth of fiber amplifiers make them particularly useful in wavelength-division multiplexed communications systems as a single amplifier can be utilized to amplify all signals being carried on a fiber and whose wavelengths fall within the gain window.

III. BASIC PRINCIPLE OF EDFA

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.

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.

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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.

D. Doped fiber amplifiers for other wavelength ranges

Thulium doped fiber amplifiers have been used in the S-band (1450–1490 nm) and Praseodymium doped amplifiers in the 1300 nm region. However, those regions have not seen any significant commercial use so far and so those amplifiers have not been the subject of as much development as the EDFA. However, Ytterbium doped fiber lasers and amplifiers, operating near 1 micrometer wavelength, have many applications in industrial processing of materials, as these devices can be made with extremely high output power (tens of kilowatts).

IV. 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.

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.

E. Raman amplifier:

In a Raman amplifier, the signal is intensified by Raman amplification. Unlike the EDFA and SOA the amplification effect is achieved by a nonlinear interaction between the signal and a pump laser within an optical fiber. There are two types of Raman amplifier: distributed and lumped. A distributed Raman amplifier is one in which the transmission fiber is utilized as the gain medium by multiplexing a pump wavelength with signal wavelength, while a lumped Raman amplifier utilizes a dedicated, shorter length of fiber to provide amplification. In the case of a lumped Raman amplifier highly nonlinear fiber with a small core is utilized to increase the interaction between signal and pump wavelengths and thereby reduce the length of fiber required.

The pump light may be coupled into the transmission fiber in the same direction as the signal (co-directional pumping), in the opposite direction (contra-directional pumping) or both. Contra-directional pumping is more common as the transfer of noise from the pump to the signal is reduced.

The pump power required for Raman amplification is higher than that required by the EDFA, with in excess of 500 mw being required to achieve useful levels of gain in a distributed amplifier. Lumped amplifiers, where the pump light can be safely contained to avoid safety implications of high optical powers, may use over 1W of optical power.

The principal advantage of Raman amplification is its ability to provide distributed amplification within the transmission fiber, thereby increasing the length of spans between amplifier and regeneration sites. The amplification bandwidth of Raman amplifiers is defined by the pump wavelengths utilized and so amplification can be provided over wider, and different, regions than may be possible with other amplifier types which rely on dopants and device design to define the amplification 'window'.

V. 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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B.BALA SUBBANNA, M.E,(Ph.D), Assistant professor, Dept. of Electrical Engineering,DebreMarkos University, Ethiopia,

L.P.DIVYA MEENAKSHI, (M.Tech), Assistant professor, MITS,Madanapalli.Andhrapradesh.