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Research Article

# THE WORKING PRINCIPLE OF OPTICAL AMPLIFIERS AND THEIR TYPES

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## ABSTRACT

One of the most important components of optical communication systems is optical amplifiers. By improving the performance of optical amplifiers, we will be able to achieve the optimality of the entire network. This article describes optical amplifiers and their types.

## KEYWORDS

Optical amplifiers, SOA - Semiconductor Optical Amplifiers, EDFA – Erbium Doped Fiber Amplifier

## INTRODUCTION

An optical amplifier is a device that amplifies an optical signal 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 [1,2,3,4]. Optical amplifiers are important in optical communication and laser physics. They are used as optical repeaters in the long distance fiber-optic cables which carry much of the world's telecommunication links.

The main part

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. In Raman amplifiers, Raman scattering of incoming light with phonons in the lattice of the gain medium produces photons coherent with the incoming photons [5,6,7]. 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 ultrashort pulses.

Solid-state amplifiers are optical amplifiers that uses a wide range of doped solid-state materials (Nd: Yb:YAG, Ti:Sa) and different geometries (disk, slab, rod) to amplify optical signals. The variety of materials allows the amplification of different wavelength while the shape of the medium can distinguish between more suitable for energy of average power scaling. Beside their use in fundamental research from gravitational wave detection[11] to high energy physics at the National Ignition Facility they can also be found in many of today's ultra short pulsed lasers.

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.

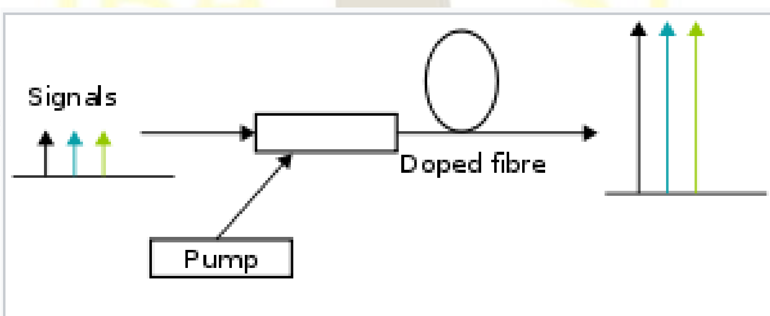


**Fig. 1. Schematic diagram of a simple Doped Fiber Amplifier**

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 nonradiative processes involving interactions with phonons of the glass matrix. These last two decay mechanisms compete with stimulated emission reducing the efficiency of light amplification [9,10,11,12]. 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. A relatively high-powered beam of light is mixed with the input signal using a wavelength selective coupler (WSC). 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 ions, the erbium ions 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. An optical isolator is usually 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. 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

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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 and increase the noise produced relative to the desired signal gain.

Semiconductor optical amplifiers (SOAs) are amplifiers which use a semiconductor to provide the gain medium. These amplifiers have a similar structure to Fabry–Perot laser diodes but with anti-reflection design elements at the end faces. Recent designs include anti-reflective coatings and tilted wave guide and window regions which can reduce end face 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. Another type of SOA consists of two regions. One part has a structure of a Fabry-Perot laser diode and the other has a tapered geometry in order to reduce the power density on the output facet. Semiconductor optical amplifiers are typically made from group III-V compound semiconductors such as GaAs/AlGaAs, InP/InGaAs, 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 850 nm and 1600 nm and generating gains of up to 30 dB.

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