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SEMICONDUCTOR OPTICAL AMPLIFIERS AND THEIR IMPORTANCE IN OPTICAL SIGNALS PROCESSING

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Abstract. This article reviews the semiconductor optical amplifier photonic device used in modern optical communication networks. The device is described and compared with other types of amplifiers, including the popular fiber optic amplifier. The operation of the semiconductor optical amplifier is explained and other types of semiconductor optical amplifiers that are widely studied for optical network communication systems are described. The inherent nonlinearities of semiconductor optical amplifiers are also reviewed and how they can be used for various wavelength conversion schemes are discussed.

Keywords: SOA - semiconductor optical amplifier, EDFA, EDWA, LOA - linear optical amplifier

Today, there is an increase in the use of fiber-optic communication networks, which is mainly due to the use of the enormous bandwidth of optical fiber, which creates the opportunity to develop new optoelectronic technologies. Today, systems operate at bit rates exceeding 100 Gb/s. Optical technology is the main carrier of global information and is also central to the implementation of future networks with the capabilities required by a growing society. These capabilities include almost unlimited bandwidth for the provision of almost any type of communication service, including full transparency, which allows flexible routing of channels. Most of these advances in optical communication networks are realized using optical amplifiers.

As the recent increase in data rates is largely due to new photonics technologies that allow the use of the enormous potential of optical fiber, next-generation optical networks require advanced photonics subsystems for high-speed all-optical signal processing of narrow (picosecond) optical pulses. Semiconductor optical amplifier-based subsystems have been proven to be capable of implementing many all-optical signal processing functions, and therefore the technology has broad commercial value and high future potential in optical fiber communication systems.

Currently, there are two types of optical amplifiers in common use - semiconductor and fiber optic amplifiers. The latter devices typically use fiber materials doped with the rare earth element erbium (Er3+) and have tended to dominate traditional system applications for many years, acting only as linear amplifiers to compensate for fiber losses. However, semiconductor optical amplifiers are increasingly gaining interest not only as basic amplifiers but also as functional elements in optical communication networks capable of providing all-optical signal processing, such as high-speed optical switching and wavelength conversion. Such functions are required in future transparent optical networks, even if optical signals cannot be converted to the electrical domain.

SOAs are compact, highly compatible devices that can be easily integrated into the communication network and may be a more convenient choice compared to OTC due to

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various features such as switching speed, high on-off, contrast ratio and cascadability. It follows that SOAs may become a more promising amplifier choice in the near future due to their high gain, low input power requirements, small size, large-scale integration capability, very short response times and multifunctionality.

The erbium-doped fiber amplifier (EDFA) is still the standard choice of optical amplifier for amplifying signals along a line. The basic working mechanism of this device can be briefly described as a pump laser coupled to an input light signal, which is then passed through a waveguide slightly doped with erbium ions. The pump laser excites the erbium ions, which in turn emit photons in phase with the input signal, amplifying this signal. Due to its impressive performance, the EDFA was one of the first widely used optical amplifiers in optical communication networks, which also helped revolutionize the optical telecommunications industry. However, some outstanding advantages of SOAs compared to fiber amplifiers remain - for example, direct optical amplification by electron injection without the need for optical pumping, compactness, low power consumption, the ability to easily integrate with other semiconductor optoelectronic devices, and low cost. In addition, SOAs consist of only one component, resulting in a much smaller size, and very high-gain devices are available in the 1300 nm and 1550 nm wavelength regions, where attenuation and material dispersion are minimal. Table 1 shows a comparison of optical amplifier technologies.

Comparison of Optical Amplifiers

Type	Raman	EDFA	EDWA	SOA	LOA
Size	200x	100x	20x	1x	1x
Power Consumption	High	Medium	Low	Low	Low
Integratable on single chip	No	No	No	Yes	Yes
Linear:					
Switched-network: Capable	No	No	No	No	Yes
Crosstalk-free: Data rate	Yes	Yes	Yes	No	Yes
Crosstalk-free: Channels	Yes	Yes	Yes	No	Yes

EDFA – Erbium-doped Fiber Amplifier
EDWA – Erbium-doped Wavelength Amplifier
SOA – Semiconductor Optical Amplifier
LOA – Linear Optical Amplifier

However, the main disadvantage of SOA and its difference from fiber amplifier is its nonlinearity, since the carrier lifetime is very short, and it is slightly polarization sensitive (about 1 dB). As a result, SOA devices always require polarization matching.
Table 2 compares the main characteristics of EDFA and SOA.

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Feature	EDFA	SOA
Noise figure (dB)	3-5	7-12
Insertion loss (dB)	0.1-2.0	6-10
Maximum internal gain (dB)	30-50	30-35
Polarization sensitive (dB)	No	<2
Saturation output (dBm)	10-20	5-7
-3dB gain bandwidth (nm)	30	30-50
Pump source	Optical	Electrical
Integration	No	Yes
Non-linear effects	Negligible	Yes
Functional device possibility	No	Yes

The SOA is basically optoelectronic in operation. A schematic diagram of a typical SOA is shown in Fig. 1(b). The device is driven by an electrical current (bias mA) to amplify the input light signal. The concept is that of a laser diode (LD) operated around threshold bias, except that the SOA has an internal anti-reflection coating to reduce its reflectivity to almost zero. Fig.1 shows a comparison between a LD and a SOA. However, polarization independence is an important factor for the SOA, which is usually not the case for a laser. For this reason, waveguides in amplifiers are normally designed to have polarization insensitive gain as well as high coupling efficiencies to optical fibres.

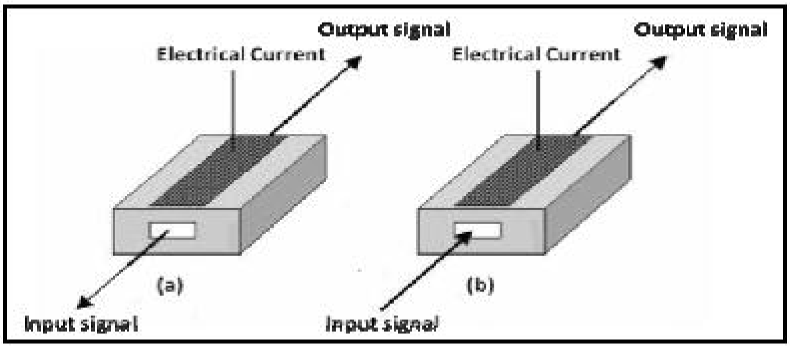

Fig. 1: Comparison schematic diagram of LD (a) and SOA (b)

However, polarization independence is an important factor for SOAs, which is usually not the case for lasers. Therefore, amplifiers are designed to have polarization-insensitive input and output capabilities, as well as to provide high coupling efficiency to optical fibers.

The active region of the SOA provides amplification for the input signal through stimulated emission, as shown in Figure 2.

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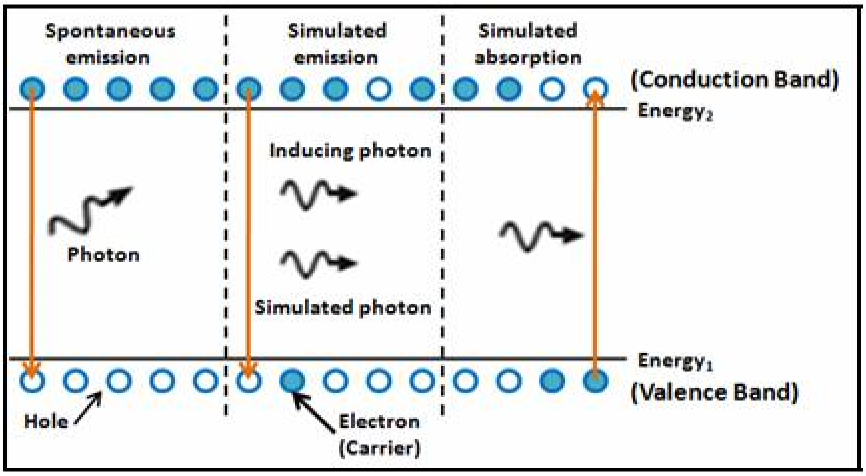

Fig. 2: Spontaneous and stimulated process

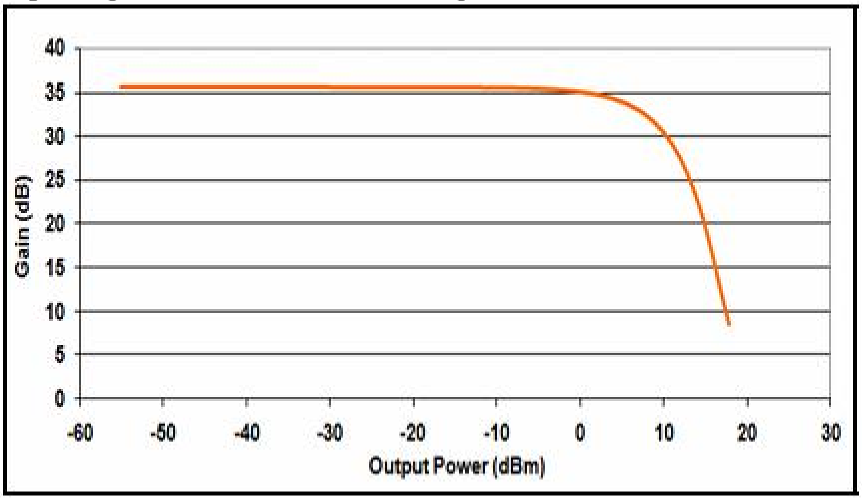

Fig. 3: SOA gain characteristics

This fading can cause significant signal degradation and can also limit the fading capability of the SOA when used as a multi-channel amplifier in spectral division multiplexing (WDM) systems.

With the development of optical fiber communication networks and the increase in data transmission speed, optical amplifiers are playing an important role. In particular, there are comparisons between erbium-doped fiber amplifiers (EDFA) and semiconductor optical amplifiers (SOA), and their advantages and disadvantages are identified. EDFA has a wide spectrum, but it has high noise level and noise attenuation problems, and is widely used. SOA, on the other hand, is important for its small size, integration ability and low cost, but has disadvantages such as polarization sensitivity, noise and spectral limitations. At present, SOA may play an even more important role in the future due to its compactness, speed and low power requirements. In general, optical amplifiers and their new generation technologies are becoming a central element in the creation of high-speed, reliable and wide-area optical communication networks.

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