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Research Article

Review of Comparative Booster Performances of Semiconductor Optical Amplifier and Erbium-doped-fiber Amplifier for use in Future Long-haul Optical Networks

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Abstract: This study reviews the performance of the Semiconductor Optical Amplifier (SOA) photonic device with the classic Erbium-doped-fiber-amplifier (EDFA). In certain situations, we report that the SOA out-performs the EDFA, particularly in terms of gain and Q-factor and BER of the post-amplified received signal. This substantiates its potential as a viable replacement for the EDFA in future all-optical, long haul networks.

Keywords: Amplifier, BER, erbium, gain, Q factor, semiconductor

INTRODUCTION

The attenuation losses in long haul optical systems of the future can be improved by using all-optical amplification (Bogoni *et al*., 2004). Presently, electro-optic regenerators are quite cumbersome and expensive for WDM (wavelength- division multiplexed) systems (Fig. 1), requiring conversion into the electrical domain and then back into optical. Hence, all-optical amplifiers are better used to directly amplify the optical signals (Fig. 2) without the need for electrical conversion, thus decreasing attenuation.

The two types of optical amplifier most used at present are the Semiconductor Optical Amplifier (SOA) and the Optical Fiber Amplifier (OFA). The latter devices usually employ rare-earth doped fiber gain mediums, commonly erbium (Er^{3+}) and have tended to dominate conventional system applications for many years functioning only as in-line amplification to compensate for fiber losses. However, SOAs are increasingly becoming of interest, not only as basic amplifiers, but as more functional elements in optical communication networks capable of providing all-optical signal processing; such as high speed optical switching, optical gating, wavelength conversion and in-line detection. These functions, where there is no conversion of optical signals into the electrical domain, will be required in future transparent optical networks.

SOAs are compact, highly compatible devices which are easily installed into a communications link and can be a more favorable choice when compared to OFAs due to various attractive properties; such as fast switching speed, high on/off contrast ratio and the ability to be cascaded. It therefore follows that SOAs will no doubt become a more promising choice of amplifier in the near future by virtue of their intrinsic characteristics-high gain, low input power requirements, small size, capability for large-scale integration, very short response times and multi-functional capabilities (Bogoni *et al*., 2004).

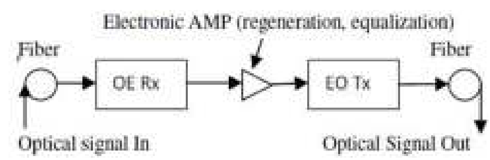

Fig. 1: EO regeneration (Bogoni *et al*., 2004)

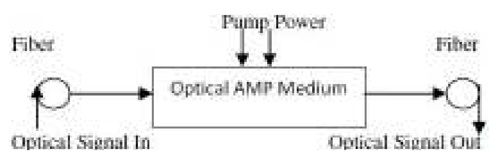

Fig. 2: All-optical regeneration (Huang, 2003)

The Erbium-Doped-Fiber-Amplifier (EDFA) is still at present the default choice of optical amplifier for boosting signals along the line. The basic working mechanism of this device can briefly be described as a pump laser coupled to an input light signal, which is then passedthrough a waveguide slightly doped (ppm)

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Table 1: Main features of EDFA and SOA (Sharaiha, 2004)

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 insensitive (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

with erbium ions. The pump laser excites the erbium ions, which in turn emit photons in phase with the input signal and this therefore amplifies the signal. The EDFA was one of the first widely adopted optical amplifiers in optical communication networks due to its impressive performance, which also helped revolutionize the optical telecommunications industry.

However, there remain some outstanding advantages of SOAs in comparison with fiber amplifiers-such as direct optical amplification through electronic injection without the need for optical pumping, compactness, lower power consumption, ability to be integrated easily with other semiconductor optoelectronic devices and low cost (Huang, 2003). Furthermore, a SOA consists of just a single component, therefore leading to a much smaller size and devices with very high gain are available both in the 1300 nm and 1550 nm wavelength regions where attenuation and material dispersion are at a minimal. Table 1 shows a summary comparison of both optical amplifier technologies.

However, the SOAs major disadvantage and fundamental difference to the fiber amplifier is its nonlinearity, due to a very short lifetime of the injected carriers (Stubkjaer *et al*., 1992). SOAs are also slightly polarization sensitive (about 1 dB). As a result, SOA devices will invariably require polarization matching. The polarization of the incident laser must match the polarization of the semiconductor (Johni *et al*., 2014). The interaction between gain and carrier density can be used in a number of sophisticated applications where the SOA serves not only as an amplifier but also as a multi-functional element.

This study will review a selection of recent work done on the comparative performances of SOAs and EDFAs, particularly in terms of gain and Q-factor and BER of post-amplified received signal.

REVIEW OF RECENT WORK

In recent work done by Singh *et al*. (2013), they transmitted 16 channels at 10 Gbps data rate using a NRZ data format which converts the logical signal to corresponding electrical signal. The logical signal is fed in to the external Mach-Zehnder modulator where the input signals from laser source are modulated through a carrier. Amplitude modulator is sine square with excess loss of 3 dB. After multiplexing the signals are launched into DS- anomalous fiber with reference frequency of 193.414 THz and attenuation of 2dB/km at different transmission distances. 16 transmitters were used by a source component.

The simulation set-up they used consisted of EDFA and SOA at different transmission distances and dispersion (Fig. 3). Optical power meters P1, P2, P3, optical probes O1, O2, O3 and splitters S1, S2, S3 were used for measuring the signal power and spectrum at different levels. The optical signal was transmitted over

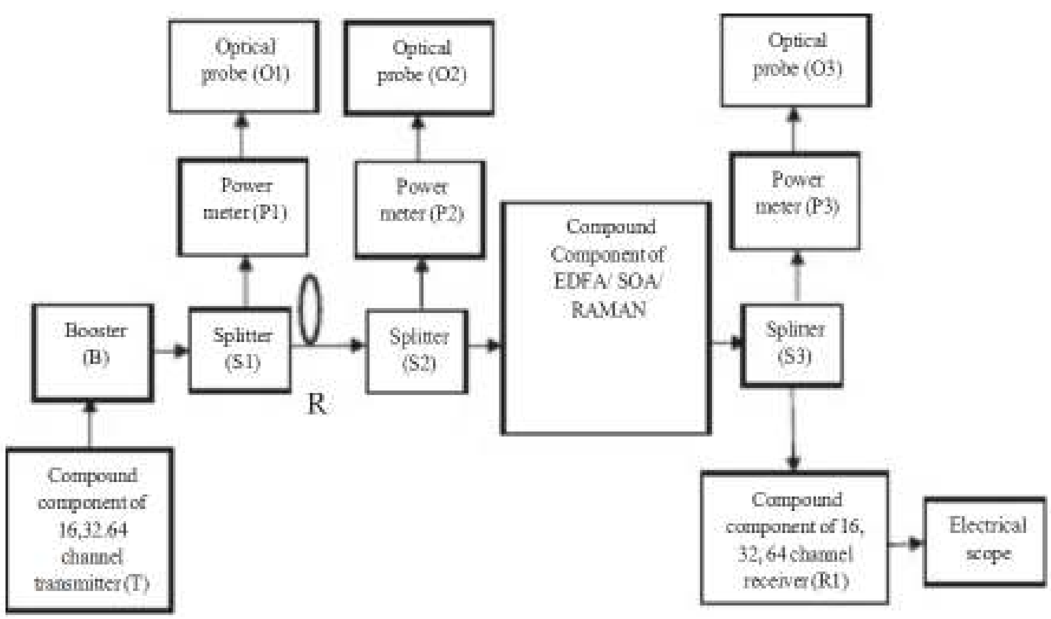

Fig. 3: Block diagram of simulation set-up used (Singh *et al*., 2013)

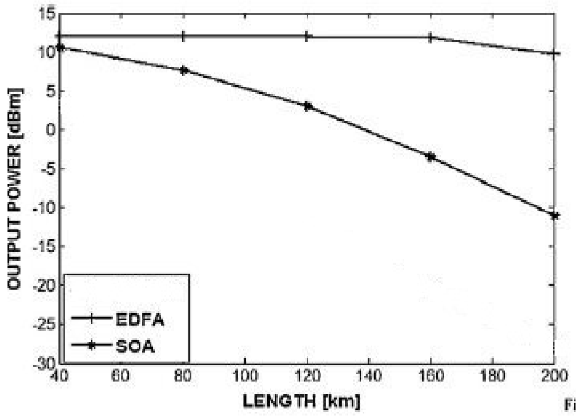

Fig. 4: Output power vs. length for 16 channels in the presence of nonlinearities (Singh *et al*., 2013)

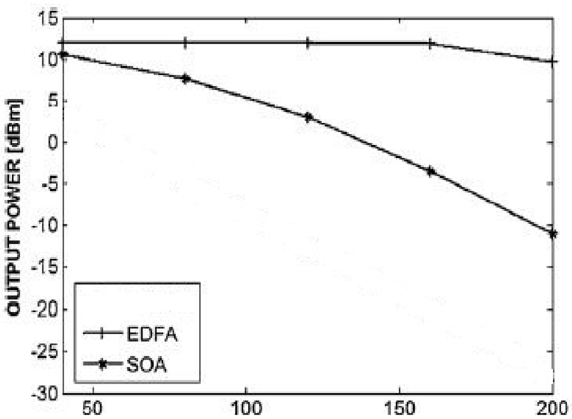

Fig. 5: Output power vs. length for 16 channels in the absence of nonlinearities (Singh *et al*., 2013)

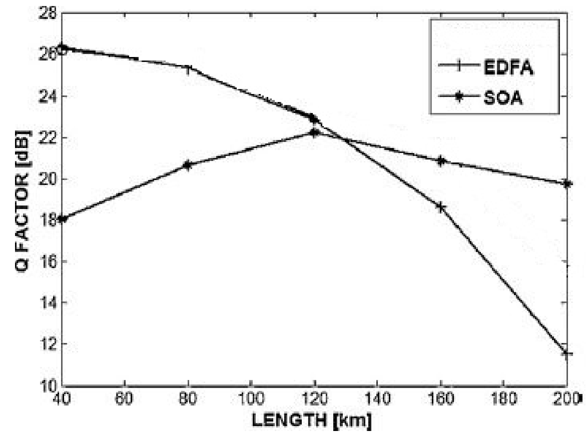

Fig. 6: Q-factor vs. length for 16 channels in the presence of nonlinearities (Singh *et al*., 2013)

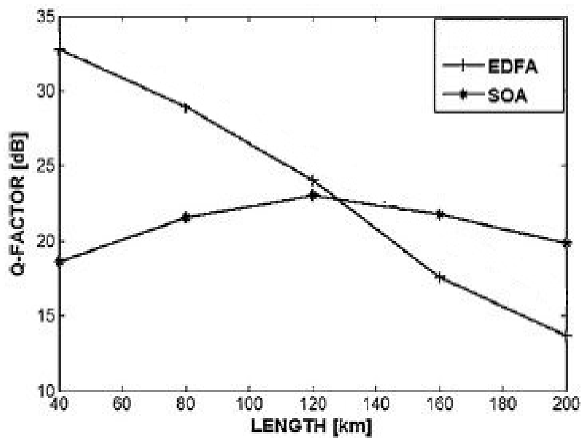

Fig. 7: Q-factor vs. length for 16 channels in the absence of nonlinearities (Singh *et al*., 2013)

different distances for 40, 80, 120, 160 and 200 km at 2ps/nm km dispersion. PIN photodiode and filters were used to convert modulated signal into original signal. A receiver (R1) was used to detect all 16 signals and convert these into electrical form. A fixed 12 dBm output power configuration EDFA, with flat shape gain and noise figure of 4.5 dB, was used in this study. Their results for EDFA and SOA were compared for 16 channels at 10 Gbps WDM system, in terms of received maximum output power (dBm), minimum BER and maximum Q-factor (dB) - varied from 40 to 200 km and dispersion varied from 2 to 10 ps/nm/km. Figure 4 and 5 shows the graphical presentation of output power in the presence and absence of nonlinearities, respectively. The output power decreases due to attenuation and nonlinearities. The variation of output power in the presence of nonlinearities for EDFA and SOA were 12.040 to 9.710 dBm and 10.627 to -11.079 dBm, respectively. Therefore better output power was provided by the EDFA amplifier. In the absence of nonlinearities, better output power was also provided by EDFA (12.043 dBm). The variation of output power in the absence of nonlinearities for EDFA and SOA were 12.043 to 9.689 dBm and 10.628 to -11.076 dBm, respectively.

Figure 6 and 7 show the graphical presentation of the Q-factor they obtained in the presence and absence of nonlinearities for EDFA and SOA, respectively. As it is shown here, in both cases, the better Q-factor was provided by the EDFA. The variation of Q-factor in the presence of nonlinearities for EDFA and SOA were 26.308 to 11.52 dB and 18.059 to 19.73 dB, respectively. Also at 120 km, the EDFA and SOA had almost the same Q-factor and at 200km the SOA had the highest Q-factor. In the absence of nonlinearities at 160km, the SOA had higher Q-factor than EDFA. The variations in Q-factor for EDFA and SOA in the absence of nonlinearities were 32.76 to 13.64 dB and 18.66 to 19.82 dB, respectively.

Figure 8 and 9 show the graphical representations of BER as a function of length in the presence and absence of nonlinearities for EDFA and SOA, respectively. In the former (Fig. 8), it was observed that

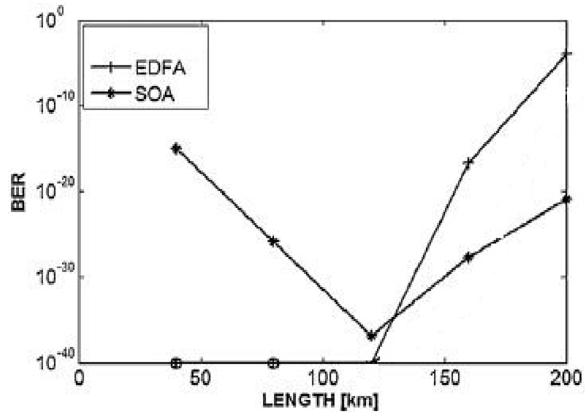

Fig. 8: BER vs. length for 16 channels in the presence of nonlinearities (Singh *et al*., 2013)

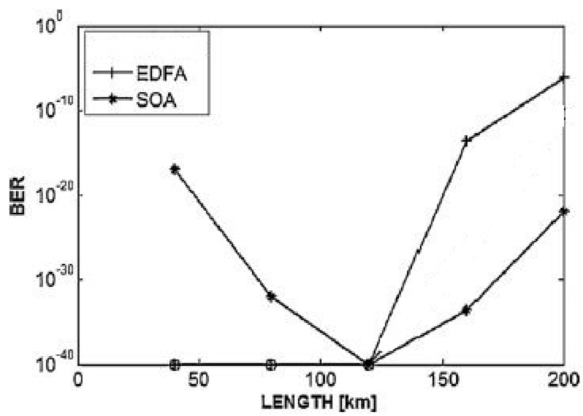

Fig. 9: BER vs. length for 16 channels in the absence of nonlinearities (Singh *et al*., 2013)

the SOA had high BER at 40 km and then it decreases linearly up to 120 km. At 120 km, the SOA had comparable BER with the EDFA. After 120 km, the BER of the EDFA and SOA increased up to 200 km. The variations in BER for EDFA and SOA were reported as 10^{-40} to 9.31×10^{-5} and 1.02×10^{-15} to 1.15×10^{-21} respectively. In the latter case, when they did not consider the nonlinearities, they found that better BER was provided by the SOA amplifier (Fig. 9).

From the Fig. 8 and 9 (Singh *et al*., 2013), we can see summarily that the performances of EDFA and SOA in a 10 Gbps WDM system with 16 channels, both in the presence and absence of nonlinearities, were compared in terms of BER, Q-factor and output power. The comparison was made by varying the transmission distance (40-200km) and dispersion (2-10 ps/nm/km). From this study, it was found that when the dispersion is 2ps/nm/km the SOA obtained better results. But when the dispersion was increased the EDFA had better results than the SOA.

In other recent work (Ibrahim and Abubaker, 2014), EDFAs and SOAs (including Raman amplifiers) were discussed with a view to applications suitable for low-cost, moderate performance application space. This study stressed that these amplifiers must be small in size and easy to control to allow their use in many places in future, long haul optical networks. They concluded that each technology has different properties making them suitable for a variety of applications.

In more recent work done (Hasegawa *et al*., 2011) the design of SOA structures was optimized using simulation techniques and prototypes were fabricated. The prototyped SOA had an output power of 5 dBm or higher and a Noise Figure (NF) of 4 dB or lower at 100 mA of current satisfying the requirements for a single-channel optical amplifier, whose characteristics were similar to those of an EDFA. It was established in this study that the SOA holds a considerable promise as an optical amplifier of compact size, low power consumption and low noise.

In other work done (Michie *et al*., 2009) it was emphasized that SOAs can amplify in both directions, as opposed to unidirectional EDFAs and also that the spectral width is around 200 nm for amplification. Currently used Passive optical networks (PON) are based on bidirectional transmission, so this was useful study.

CONCLUSION

This study has reviewed a selection of recent work done on the comparative performances of SOAs and EDFAs used as boosters, particularly in terms of gain and Q-factor and BER of post-amplified received signal. In certain situations, we report that the SOA out-performs the EDFA, giving useful information to designers. In many situations, increasingly being investigated by both industry and academia, the SOA continues to provide numerous efficient and cost-effective solutions as a tiny optoelectronic device, with tremendous potential for integration with a wide variety of other active and passive optical components. SOAs also have many non-linear functions, as opposed to the EDFA which only has gain and will therefore continue to generate new interest for a wide variety of applications in future all optical communication systems and may well become the default choice device to use.

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