To Investigate the Characteristics Parameters of Semiconductor Optical Amplifier based on Wavelength Converters for all Optical Networks

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ABSTRACT
All optical wavelength converters are key devices for all optical networks. Wavelength conversion employing semiconductor optical amplifiers (SOAs) has become an important component in WDM networks. This paper investigates the performance of a 20 Gb/s SOA-based FWM wavelength converter system. For this we have optimized the SOA parameters to achieve adequate quality factor and enhancement in four wave mixing effect so as to improve the converted signal power. This will be done in such a manner that the SOA never saturates and generate maximum four-wave mixing signals with minimum gain fluctuations. Performance is analyzed in terms of converted signal power, converted optical signal-to-noise ratio (OSNR) and Q factor for both up and down conversions with respect to wavelength shifted up to 10nm. It was found that the conversion efficiency and OSNR of the converted signal are 1dB and 45 dBm resp.

Keywords
Wavelength converter, WDM, SOA, FWM

1. INTRODUCTION
Optical networks are high capacity telecommunication networks based on optical technologies and components that provide routing and wavelength based services. Optical wavelength converters have become the key components of the future broadcast optical networks. Wavelength converter is final element in optical networks. Wavelength division multiplexing (WDM) systems are currently the optical multiplexing techniques of choice that is to be implemented due to recent exponential increase of data traffic. The use of wavelength division multiplexing in optical networks can increase system capacity, enhance network flexibility and provide for better management of current time division multiplexed systems. The most important use of wavelength converters will be for avoidance of wavelength blocking in optical cross connects in wavelength division multiplexed networks. Wavelength conversion is a technique to convert data signal from an original wavelength λ_1 to a different required wavelength λ_2 without changing the information of data [4]. Wavelength conversion can be used in WDM networks to improve efficiency. In WDM systems the number of available wavelength is limited and probability that two data channels try to access the same routing path at same time with the same wavelength increases with the traffic. So in order to avoid data re transmission due to routing conflicts wavelength converters are used. The all-optical wavelength converters proposed would allow the network to fulfill the requirement of flexibility, maintaining the transparency of the optical communication. Many technologies exist for the implementation of wavelength conversion Optoelectronic, cross-gain modulation, and cross-phase modulation [3]. Wavelength converters are candidate technologies that offer excellent performance in WDM systems [1]. Among these different methods of wavelength conversion, FWM provides an interesting approach due to its simplicity and unique characteristics of providing the preservation of amplitude and phase, data format and bit rate transparencies[3]. The wave mixing process results from the nonlinear properties of the medium in which, more than one waves are injected. Generally, the new waves generated by the mixing process have intensities proportional to the interacting wave intensities and frequencies and phases which are linear combinations of those of the interacting waves.

Studies on FWM-based wavelength converters utilizing SOAs have been proposed in much previous works, due to the numerous advantages offered by the nonlinearities of SOA. Hsu et al. [7] claimed that higher conversion efficiency and wider conversion range can be achieved by applying an assisted holding beam into the SOA. The assisted beam, which was used to saturate the SOA, can improve the conversion efficiency and signal to- background ratio. D'Ottavi et al. [9] proved that the use of a long SOA could improve the performance of the conversion at a data rate of 10 Gb/s. M. A. Summerfield [6] reported bit-error-rate measurements which show that there is a trade-off between maximizing the output SNR and minimizing intersymbol interference in the SOA. Consequently, the power penalty incurred in the frequency conversion can be minimized by careful selection of the input signal power. N.A. Awang et al. resulted the conversion efficiency −43 dB with a novel configuration of a wavelength converter by using a dual wavelength bi-erbium-doped fiber laser that uses an Arrayed Waveguide Grating (AWG) [11]. Farah Diana Mahad et al. [10] investigates the performance of a 2.5 Gb/s SOA-based FWM wavelength converter system, in terms of its shifted wavelength conversion efficiency -11dB and optical signal-to-noise ratio (OSNR) 22dB, for both up and down conversions at 2nm. Earlier work on wavelength converters using FWM in SOA was limited to 20 nm wavelength conversion with converted signal power of -8dBm at probe power of 3 dB [8]. We have extended the work [10] for wide-band conversion at 20 Gb/s by using simulations. Optimization of SOA parameters had been done with respect to signal and pump powers [12]. We have also optimized the parameters of the semiconductor optical amplifier, to achieve minimum gain fluctuations with enhanced four-wave mixing with respect to wavelength shifted. In Section 2, the Theoretical analysis has been reported. In Section 3, the setup for wavelength converter has been discussed. In Sections 4 and 5, results and conclusions are reported.

2. THEORETICAL ANALYSIS

The four-wave mixing phenomenon that occurs because of nonlinearities in the transmission medium can also be utilized to realize wavelength conversion. The scheme is inherently fast for both fiber and semiconductor nonlinear elements. Conversion efficiency and optical signal-to-noise ratio are usually the two most important figures of merit for the converted wave, and both need to be highly considered in the design of any wavelength converter. Conversion efficiency is defined as the ratio of the converted signal power to the probe signal power (dB).

$$\eta = 10\ \log\frac{P_{out}}{P_{in}}$$

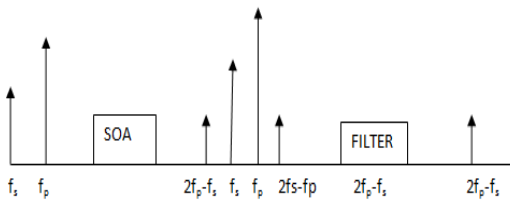

Fig 1: Four Wave Mixing (FWM) SOA Converter

η is Conversion efficiency, p_{out} is converted signal power and p_{in} is input signal power. Both the conversion efficiency and converted OSNR decreased at large detuning wavelengths, due to the frequency response of the nonlinear process. The efficiency in the case of up wavelength conversion is smaller than the efficiency in the case of down wavelength conversion due to destructive interference among the several nonlinearities of the gain medium, which is responsible for the generation of the two sidebands. FWM process is polarization sensitive. This feature can cause significant degradation to the performance of the optical nodes in which the FWM based converter is going to be used. The dual pump scheme is used to overcome these drawbacks to some extent [2].

Typical value of CE is -20 db, so optical power levels of ~10dBm have to be used for the pump of SOA converters while "10-20dBm" is needed for fiber based converters. Because of the low conversion efficiencies the signal-to noise ratio for the converted signals needs attention, especially if converters have to be cascaded [5].

3. SIMULATION SET UP

This wavelength converter is based on four-wave mixing in an SOA. We performed a series of simulations in order to optimize the SOA parameters. A simplified schematic diagram of the simulation setup with different blocks is shown in Fig. 2. The pump and probe laser sources are used with input powers of 5dBm and 3 dBm resp. The wavelength of pump laser source is fixed at 1550 nm. For probe signal wavelength is varied according to up and down conversion. Starting a probe signal with a wavelength from 1549 to 1545, the converter is characterized as up converter describes wavelength shifted that is 2nm to 10nm. Beginning a probe signal with a wavelength from 1551 to 1555, the converter is characterized as down converter describes wavelength shifted that is 2nm to 10nm.

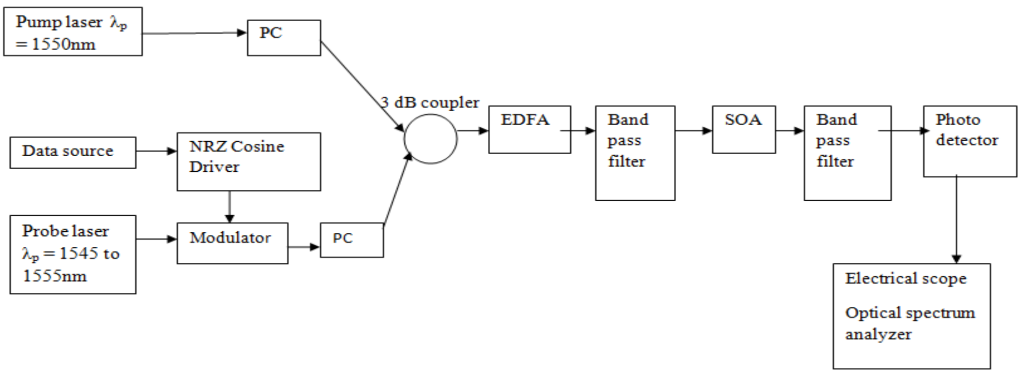

Fig 2: Schematic diagram of single stage up and down wavelength converter based on FWM

The probe signal is modulated by a raised cosine NRZ electrical driver, at a bit rate of 20 Gb/s. The pump and probe waves each pass through individual polarization controllers (PC's) before being combined by 3 dB coupler in order to match the state of polarization between them. After that erbium doped fiber amplifier (EDFA) is used to amplify the combined signal in order to saturate the SOA, having a fixed gain of 25 dB and 4.2 dB. Following amplification, the signals pass through a band pass filter (BPF) in order that this filter increases the OSNR of the converted signal by subdue the amplified spontaneous emission (ASE) contributed by the high-power EDFA in the spectral region of the converted signal as described in [10]. Later this, these signals are coupled into the SOA where FWM generates the converted signal. SOA parameters are optimized for the improvement of FWM signal. Following optimization salient parameters are shown in table 1. The input and output coupling losses of SOAs are taken as 3 dB.

Table 1. Optimized SOA Parameters

Parameter	Unit
Bias current	500mA
Cavity Length	300 µm
Cavity Width	1.5 µm
Thickness	.15 µm
Confinement factor	.35
Linewidth enhancement factor	6

The Spontaneous carrier lifetime is .3ns, transparent carrier density is 10^{18} cm-3 and saturation power is 9.51mW. just after SOA, BPF is used with center wavelength of converted signal wavelength, so that converted signal is captured by dismissing the probe and pump signal. Later photo detector is used to get electrical signal for measurements of Q factor, eye opening and bit error rate of converted signal.

4. RESULTS & DISCUSSIONS

The simulation has been carried out for the optimization of SOA parameters with the set-up shown in Fig. 2. In this simulation we use variable bandwidth simulation (VBS) technique. The Optimization of SOA parameters is done to improve the converted signal power of wavelength converter. The overall amplitude error is 0.3 dB and the overall group delay error is 1.2 ps. The optimization is done for up conversion by taking concern of various factors like converted signal power, Q factor and converted OSNR. All these results are taken with respect to wavelength shifted.

For optimization of bias current results shows that with increase in the current the converted signal power level is also increases. Fig 3. depicts that at a low value of bias current 200 mA, less converted signal power measured that is -10.0239 dBm at 2nm and -21.75 dBm at 10 nm wavelength shifted . As the current increases converted signal power increases. But for a high current of 600 mA or more, there is more unsteadiness in gain. Therefore, gain saturation occurs in the SOA and a poor eye opening is observed for this current. At a bias current of 500 mA, sufficient quality factor is observed 23.355dB with sufficient converted signal power -2.4775dBm and converted OSNR is 45.23 dBm as shown in table 2.

Table 2. Quality, converted signal power and converted OSNR at different bias current of SOA

Bias current(mA)	**200**	**300**	**400**	**500**	**600**
Q factor(dB)	16.991	14.992	15.24	23.355	24.11
Converted signal power(dBm)	-10.0239	-6.18	-3.72	-2.47	-4.49
Converted OSNR(dBm)	45.07	45.11	45.20	45.23	44.84

Table 3. Quality, converted signal power and converted OSNR at different confinement factor of SOA

Confinement factor	**.3**	**.35**	**.4**
Q factor(dB)	15.807	23.355	24.49
Converted signal power(dBm)	-3.07	-2.4775	-4.3
Converted OSNR(dBm)	45.22	45.23	44.75

Table 4. Quality, converted signal power and converted OSNR at different cavity length of SOA

Cavity Length (µm)	**200**	**300**	**400**
Q factor(dB)	23.90	23.355	24.49
Converted signal power(dBm)	-3	-2.4775	-2.7
Converted OSNR(dBm)	45	45.23	45.1

Table 5. Quality, converted signal power and converted OSNR at different cavity thickness of SOA

Thickness (µm)	**.12**	**.15**	**.2**
Q factor(dB)	24.42	23.355	15.98
Converted signal power(dBm)	-7.108	-2.4775	-3.99
Converted OSNR(dBm)	44.67	45.23	45.16

We also optimized the confinement factor as the results drawn in Fig. 4. for converted signal power versus wavelength shifted. Now we use optimized bias current 500mA. As the detuning frequency increases converted signal power degrades. When confinement factor is 0.3 or less, the FWM is low and the quality of detected signal is poor. But when confinement factor is 0.35, high quality is observed with relevant bit error rate at the receiver. It is noticed that with the increase in the confinement factor, the four-wave mixing effect is articulated due to gain variations in the SOA. We further observed that, the SOA-induced crosstalk increases, which produces gain saturation if we increase the confinement factor to 0.4. Hence, gain saturation increases in FWM signals and less converted signal power is observed at the output. As shown in Table 3, the highest *Q*-factor (23.355dB) and converted OSNR 45.23 dBm are noticed for converted FWM signals at confinement factor 0.35.

Following the optimization of confinement factor, now the length of SOA is varied to get sufficient converted signal. Observed from the table 4, if length is 200 µm the FWM less. At high length 400 µm Q factor and converted signal power degrades. So the optimized length considered is 300 µm which gives necessary values of converted signal power and quality.

The results are shown in Fig. 5. for optimization of thickness parameter of SOA. Considering thickness as 1 µm, no FWM does not occure. As we increase values of the active region thickness to .12 µm FWM signals are pronounced due to gain variations in SOA, noise is produced, causing a poor eye opening for the converted signal. Later when we increase the thickness of the active region of SOA, the gain unsteadiness decrease. The FWM effect is reduced for a high thickness of 0.2 µm and the quality of the detected signal is also poor. But for the thickness of 0.15 µm, a clear eye opening is observed with good FWM signals. Although we got maximum quality factor at .12 µm but we have to take maximum converted signal power with necessary Q factor. So At 0.15 µm cavity thickness of SOA, sufficient quality of 23.355 dB with good converted power and converted OSNR of 45.23 dBm is observed for the FWM signals as shown in Table 5.

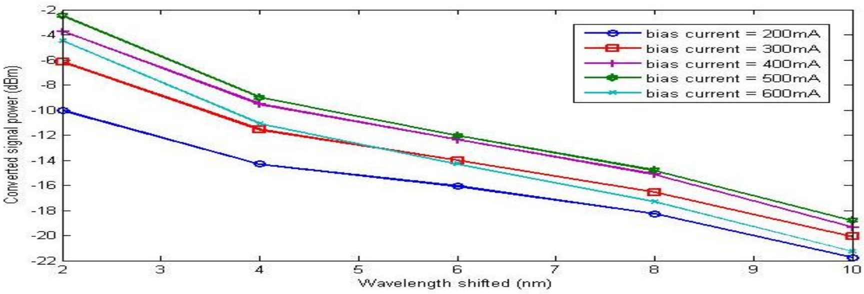

Fig 3: Converted signal power as a function of wavelength shifted at different bias current of SOA

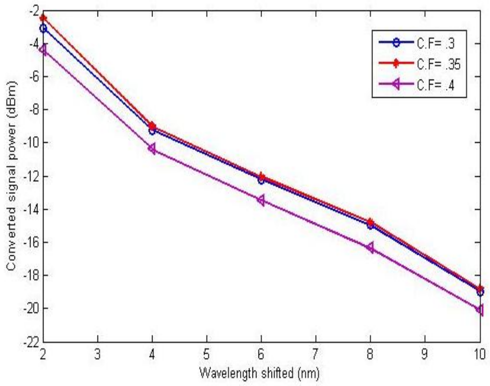

Fig 4: Converted signal power as a function of wavelength shifted at different confinement factor (C.F) of SOA By taking optimized bias current

In order to investigate the performance of up and down wavelength converter, the most important performance that are converted signal power, Quality factor, conversion efficiency and converted signal power have been measured. This analysis is done with the distance 1 Km, fiber is used before photodetector in simulation setup for this purpose. This simulation set up has been used all optimized parameters as shown in table 1. All the performance factors are given in table 6 for up and down conversion for wavelength shifted. Converted signal power and converted OSNR are two most prominent factors for performance of wavelength converter.

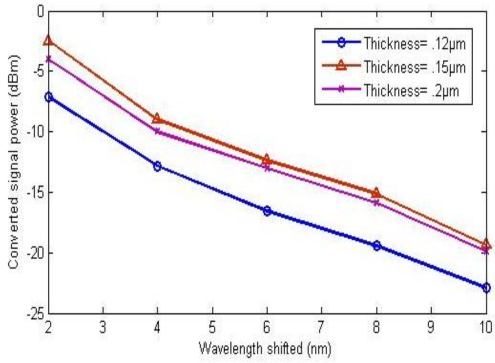

Fig 5: Converted signal power as the function of wavelength shifted for different active region thickness of SOA. Taking optimized confinement factor, bias current and width

Table 6. Performance analysis for up and down wavelength converter for different wavelength shifted

UP conversion analysis				
Wavelength shifted(nm)	**Q factor (dB)**	**Converted signal power(dBm)**	**Converted OSNR(dBm)**	**BER**
2nm	23.41	1.674	45.27	10^{-40}
4nm	22.71	-3.8843	44.04	10^{-40}
6nm	21.12	-6.44	43.95	$3.77*10^{-35}$
8nm	19.49	-10.3667	41.34	$5.15*10^{-32}$
10nm	18.22	-12.92	38.802	$8.77*10^{-16}$
DOWN conversion analysis				
Wavelength shifted(nm)	**Q factor (dB)**	**Converted signal power(dBm)**	**Converted OSNR(dBm)**	**BER**
2nm	23.72	1.31	45.90	10^{-40}
4nm	22.8	-3.79	45.203	$8.086*10^{-39}$
6nm	21.84	-6.762	44.29	$1.124*10^{-33}$
8nm	20.5	-9.908	43.66	$6.23*10^{-30}$
10nm	19.45	-11.277	41.354	$3.51*10^{-17}$

Fig.6. shows the up and down conversion performance with quality factor due to the variation of wavelength shifted. Maximum and minimum Q factor for up conversion is 23.41 and 18.22 dB respectively. Q factor for down conversion is better than up conversion at large detuning wavelength. Fig. 7 shows the conversion efficiency for both down and up conversions. The conversion efficiency decrease at large detuning wavelengths, due to the frequency response of the non-linear process. As the conversion efficiency is defined as converted signal power divided by input signal power. It can also be seen, that up conversions experience a conversion efficiency decrease from 1 to −14.6 dB. The converted OSNR decreased from 45.27dBm to 38.802 dBm up to 10 nm wavelength shift as shown in fig. 8. Both down and up conversions give almost similar results at lower wavelength shifted. There is small difference observed between up and down conversion at high wavelength shifted. The downconversion give better performance compared to up-conversion. This is due to the partially destructive or constructive phase interference between the FWM mechanisms.

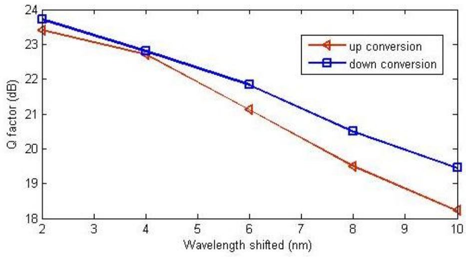

Fig 6: Q factor for down and up conversions.

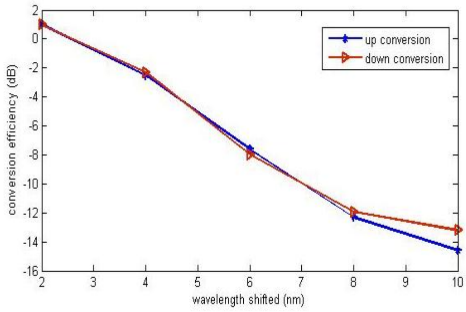

Fig 7: Conversion efficiency for down and up conversions

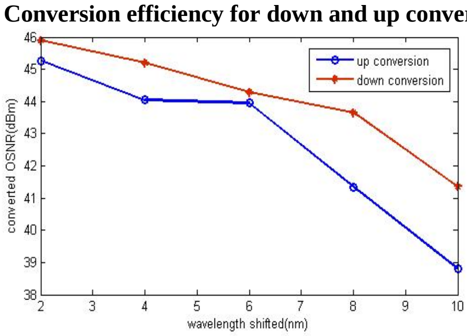

Fig 8: Converted OSNR for down and up conversions.

5. CONCLUSION

In this paper we have optimized the various parameters of SOA. We have decreased the gain unsteadiness by selecting suitable parameters of SOA to achieve sufficient quality with enhancement in four-wave mixing signals. We have also investigated various effects of FWM wavelength conversion process that are occurring within SOA medium. The analysis has done by varying the wavelength of probe signal that depends for up and down conversion. Farah Diana [10] investigated the four wave mixing SOA based wavelength converter system for data rate of 2.5Gb/s but in this research we have investigated the system for data rate of 20Gb/s with improved conversion efficiency and converted signal power. The conversion efficiency (η), quality factor (Q) and converted OSNR has been analyzed for 20Gb/s. It is found that down-conversion is better than up conversion. Maximum FWM conversion efficiency is around 1 dB and .98 dB for up and down conversion respectively for 20Gb/s.

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