Performance analysis of semiconductor optical amplifier using four wave mixing based wavelength Converter for all Optical networks.

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Abstract
In this paper, investigations are made on performance analysis of the semiconductor optical amplifier (SOA) using four wave mixing (FWM) based wavelength converter. This analysis is done at 10Gb/s in terms of shifted wavelength conversion efficiency, quality factor (Q-parameter) and bit error rate (BER) for up and down conversions. The investigations are carried out by varying the probe signal wavelength and bias current of SOA. From the numerical simulations it has been observed that down-conversion efficiency is more than Up-conversion efficiency and it starts decreases at larger wavelengths. It is found that maximum FWM conversion efficiency is around 27.3417 dB at current 160 mA and 28.5669 dB at current 160 mA for up and down conversion respectively for 10Gb/s.
Keywords: FWM, XGM, XPM, SOA, Wavelength conversion, Conversion efficiency..

I. Introduction

Optical wavelength converters have become the key components of the future broadcast optical networks. Optical wavelength converters remove wavelength blocking in optical cross connects in wavelength division multiplexed(WDM) networks and increase flexibility and capacity of network for fixed set of wavelength [1]. A wavelength converter is an optical device which is used for the purpose of converting an injected signal of light from one wavelength to the desired wavelength in a system or network. There are four main types of nonlinearity: cross-gain modulation (XGM), cross-phase modulation (XPM), self-phase modulation (SPM) and four-wave mixing (FWM). Wavelength conversion exploiting the SOA nonlinearities exhibits different advantages and disadvantages, depending on the operation. For example, the main advantages of XGM wavelength converters are their simplistic configurations, high conversion efficiencies and high bit rate capabilities (up to 40 Gb/s). However, XGM wavelength converter suffers from several drawbacks such as the required large input power to saturate the SOA, high noise figure, an inverted output signal in comparison to the input signal. Alternatively, the XPM method can be utilized in such a way to overcome the disadvantages of XGM, by placing one or more SOAs in an interferometric configuration [2]. Further XGM and, XPM does not offer transparency to bit rate and modulation format. In order to overcome these disadvantages of XGM, XPM, Four wave mixing (FWM) wavelength conversion technique can be used. Recently, four-wave mixing (FWM), nonlinearity based on semiconductor optical amplifier (SOA) has become one of the most favorable methods of wavelength conversion, offering numerous benefits to the system designer.
Unlike XGM and XPM wavelength converters, FWM offers transparency to bit rate and modulation format, and hence preserves both the phase and amplitude information. This is due to the non-changing nature of the optical properties of the information signal during the conversion process occurring within the SOA. The FWM-based wavelength converter in an SOA offers a high bit rate capability up to tens of gigabits per second (10Gb/s).

II. Theoretical analysis

When optical communication systems are operated at moderate power (a few milliwatts) and at bit rates up to about 2.5Gb/s, they can be assumed as linear systems.However, at higher bit rates such as 10Gb/s and above and/or at higher transmitted powers, it is important to consider the effect of nonlinearities. In case of WDM systems, nonlinear effects become important even at moderate powers and bit rates. Four-wave mixing is a nonlinear effect arising from third-order optical nonlinearity. It can occur if at least two different frequency components propagate together in a nonlinear medium such as an optical fiber. Fig.1. shows a simple principle of mixing of two waves at frequency ω_1 and ω_2 such that $\omega_2>\omega_1$. In effect, two new frequency components are generated: $\omega_2=\omega_1-(\omega_2-\omega_1)=2\omega_1-\omega_2$ and $\omega_4=\omega_2+(\omega_2-\omega_1)=2\omega_2-\omega_1$. Furthermore frequency ω_3 or ω_4 can be amplified.

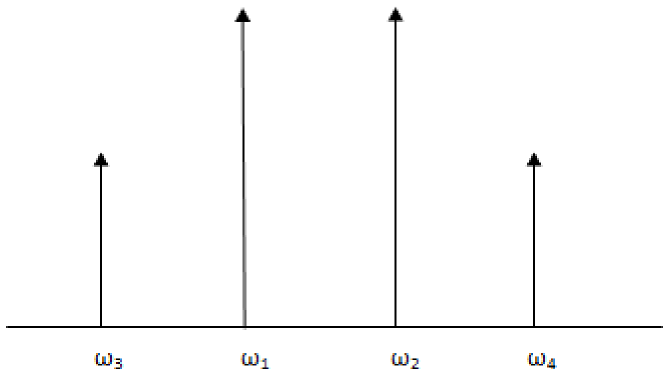

Fig.1. FWM of two wave ω1and ω2

In four wave mixing based frequency (wavelength) converter [4],

$$\nu_p = \frac{\nu_1}{2} + \frac{\nu_2}{2} \qquad (1)$$

the pump frequency is chosen such as where ν_1 and ν_2 are the frequencies of input signal and the converted signal respectively. Conversion efficiency (η) of a FWM wavelength converter is

$$\eta = 10 \log \frac{P_{out}\,(\lambda_{converted\ \ signal})}{P_{in}\,(\lambda_{probe\ \ signal})} \qquad (2)$$

Bit error rate (BER) is defined as

$$\mathrm{BER} = \frac{1}{2}\mathrm{erfc}(\frac{Q}{\sqrt{2}}) \qquad (3)$$

III. Simulation Setup

The simulation are genrated by setup as shown in Fig.2.The powers of pump and probe CW lasers are set to be fixed as shown in Table 1.The probe signal is modulated by NRZ electrical driver at a data rate 10Gb/s.The probe CW laser wavelength is varied accordingly.The polarizer1 and polarizer2 is used to match the phase state of pump and probe signals. It is a necessary condition to ensure efficient FWM occur in SOA before being combined by the 3dB coupler. These combined signals are amplified by Erbium dopped fiber amplifier (EDFA) having the fixed gain 10dB and noise figure of 4.2dB.The EDFA is used to increase the combined signal power such that it can saturate the SOA amplifier. A low pass filter of 0.4nm bandwidth is connected just after the EDFA in order to supress the any additional ASE noise.The bias current of SOA is varied and coressponding converted wavelengths are notified.

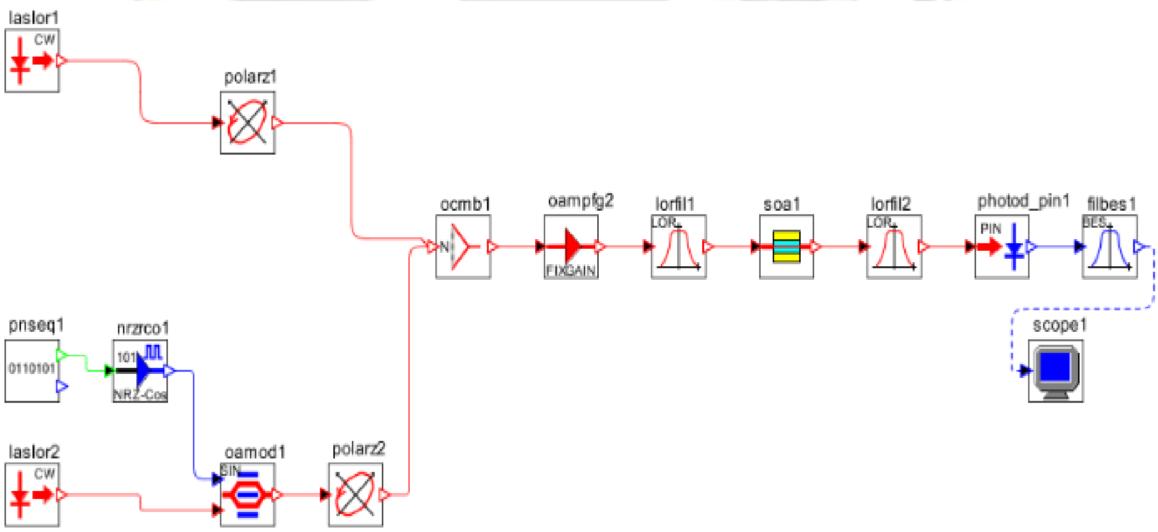

Fig.2:Simulation setup of FWM wavelength converter.

Table 1: Simulation Parameters

Parameter Type	Values
Pump CW laser wavelength	1550 nm
Pump CW laser power	5dBm
Probe CW laser power	3dBm

IV. Results and discussions

The simulation has been carried out for the setup shown in Fig.1. The converted signal power obtained as a function of wavelength shift. The pump signal wavelength is fixed at 1550 nm, however the probe signal wavelength is varied in the range of 1551–1555 nm for down-conversion and 1545–1549 nm for up-conversion. Fig.3,4 shows the variation of BER, Q with respect to variation of current of SOA from 100 mA to 200 mA respectively. From the fig.3,4.it is seen that the BER values is very high at low current but as we increase the bias current BER value continuously decreases because at higher currents SOA goes in saturation mode which is further responsible for FWM process.SOA goes in saturation mode when current of SOA reached at 130 mA. As shown table 2, maximum observed value of Q is 32.454 at wavelength 1545 nm and at current 200mA.In table 3, minimum observed value of BER is $3.15x10^{-40}$ at 1548 nm and at 180 mA. As shown in table 2, maximum value of Q 23.3447 is observed at wavelength 1554 nm and at current 200 mA. In table 3, minimum value of BER $1x10^{-40}$ is observed at 1555 nm and at 180 mA.

It is observed that with the increase in probe signal wavelength conversion efficiency decreases while converted signal power increases. Farah Diana [3] investigated the four wave mixing SOA based wavelength converter system for data rate of 2.5Gb/s but in this paper we investigate the system for data rate of 10Gb/s.Fig.5. shows the optical spectrum of converted FWM wavelength for down conversion.

Table 2: Q factor analysis when pump wavelength (λ_{pump}) is 1550 nm and varying SOA bias current

S. No.	λ_{probe} (nm)	Q- factor (Up-conversion) SOA drive current (mA) (100)	(120)	(140)	(160)	(180)	(200)
1	1545	6.02060	6.02060	6.02060	6.02060	6.02060	32.454
2	1546	17.2029	17.7193	18.9232	20.4826	22.2110	23.3132
3	1547	17.2638	17.7668	18.9716	20.5434	22.2898	23.377
4	1548	17.3582	17.8398	19.0503	20.6521	22.4555	23.4885
5	1549	17.7194	18.1379	19.3665	21.0395	22.9556	23.7913
S. No.	λ_{probe} (nm)	Q- factor (Down conversion) SOA bias current (mA) (100)	(120)	(140)	(160)	(180)	(200)
1	1551	17.5270	17.6721	18.6735	20.1394	21.8445	22.3621
2	1552	17.3489	17.7627	18.9232	20.4755	22.2132	23.1988

3	1553	17.2611	17.7436	18.9352	20.4967	22.2402	23.3046
4	1554	17.2289	17.7385	18.9418	20.5073	22.2457	23.3447
5	1555	17.1866	17.7088	18.9141	20.4729	22.1979	23.3108

Table 3: BER analysis when pump wavelength (λ_{pump}) is 1550 nm and varying SOA drive current

S. No.	λ_{probe} (nm)	BER (Up-conversion) SOA bias current (mA)					
		(100)	(120)	(140)	(160)	(180)	(200)
1	1545	$2.275x10^{-2}$	$2.275x10^{-2}$	$2.275x10^{-2}$	$2.275x10^{-2}$	$2.275x10^{-2}$	$1x10^{-40}$
2	1546	$1.98x10^{-13}$	$2.47x10^{-14}$	$1.23x10^{-18}$	$5.43x10^{-26}$	$1.24x10^{-37}$	$1x10^{-40}$
3	1547	$1.19x10^{-13}$	$1.48x10^{-14}$	$2.33x10^{-19}$	$1.43x10^{-25}$	$1.79x10^{-38}$	$1x10^{-40}$
4	1548	$5.25x10^{-14}$	$5.88x10^{-15}$	$6.57x10^{-19}$	$1.83x10^{-27}$	$3.15x10^{-40}$	$1x10^{-40}$
5	1549	$2.29x10^{-14}$	$1.28x10^{-15}$	$1.38x10^{-20}$	$1.3x10^{-29}$	$1x10^{-40}$	$1x10^{-40}$
S. No.	λ_{probe} (nm)	BER (Down conversion) SOA bias current (mA)					
		(100)	(120)	(140)	(160)	(180)	(200)
1	1551	$6.39x10^{-14}$	$9.08x10^{-15}$	$3.25x10^{-17}$	$3.21x10^{-23}$	$2.56x10^{-35}$	$1.55x10^{-39}$
2	1552	$7.04x10^{-14}$	$9.32x10^{-15}$	$1.38x10^{-18}$	$6.49x10^{-25}$	$4.67x10^{-36}$	$1x10^{-40}$
3	1553	$1.14x10^{-13}$	$1.65x10^{-14}$	$3.23x10^{-19}$	$1.90x10^{-25}$	$5.27x10^{-38}$	$1x10^{-40}$
4	1554	$1.62x10^{-13}$	$2.03x10^{-14}$	$9.46x10^{-19}$	$3.51x10^{-26}$	$5.97x10^{-38}$	$1x10^{-40}$
5	1555	$2.35x10^{-13}$	$2.44x10^{-14}$	$1.50x10^{-18}$	$7.30x10^{-26}$	$2.06x10^{-37}$	$1x10^{-40}$

Fig.6. shows the down conversion performance of Q due to the variation of wavelength at different currents.Fig7 performance of BER due to the variation of wavelength at different currents. Maximum FWM conversion efficiency is around 27.3417 dB at current 160 mA and 28.5669 dB at current 160 mA for up and down conversion respectively 10Gb/s. Fig.8. shows the increase in conversion efficiency for down conversion at different currents. Fig.9. shows the optical spectrum of converted FWM wavelength for up conversion. Fig.10,11 shows the up conversion performance of Q and BER due to the variation of wavelength at different currents respectively. Fig.12 shows the conversion efficiency for up conversion at different currents. Down conversion provides better performance as compared to up-conversion. This is due to the phase interference between the FWM mechanisms [3].

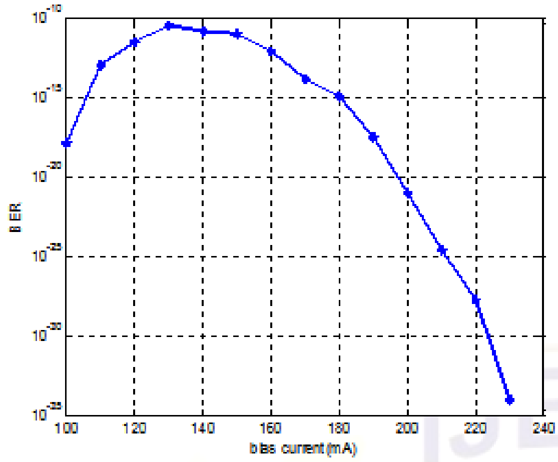

Fig.3. BER versus bias current of SOA

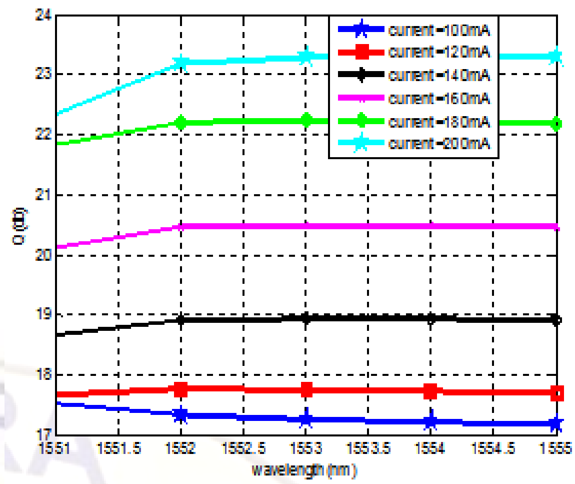

Fig.6. Q Quality factor versus wavelength for variation of current of SOA

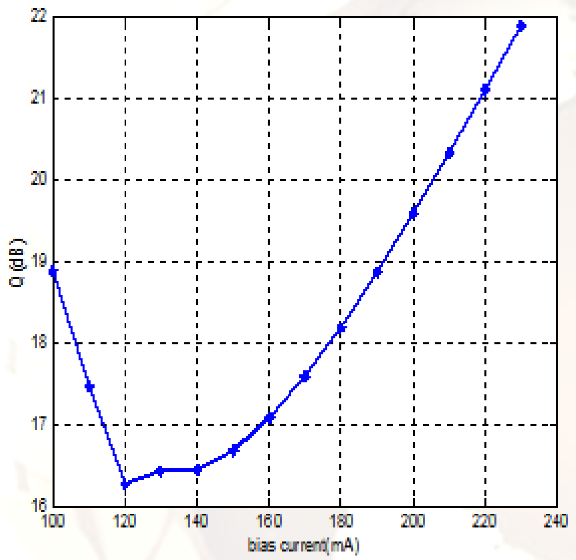

Fig..4. Q Quality factor versus bias current of SOA

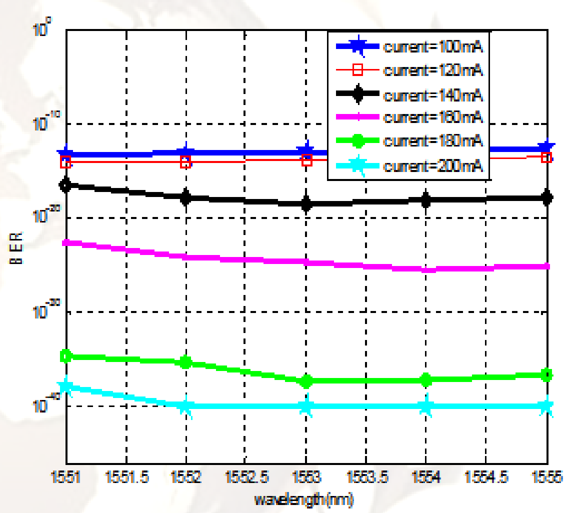

Fig.7. BER versus wavelength for variation of current of SOA

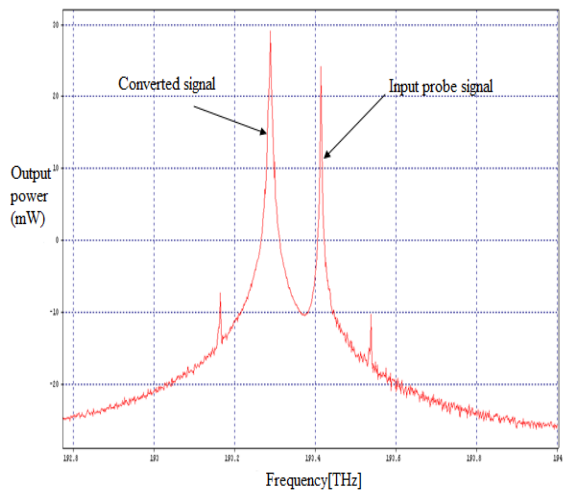

Fig.5. Optical spectra of Down- converted signal vaires with frequency

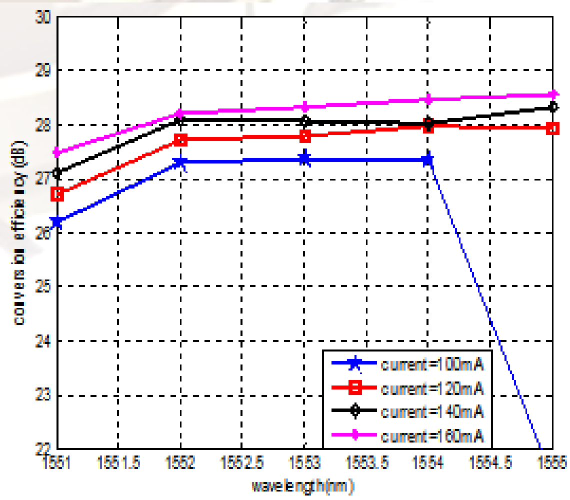

Fig.8.Down- Conversion efficiency versus wavelength for variation of current of SOA

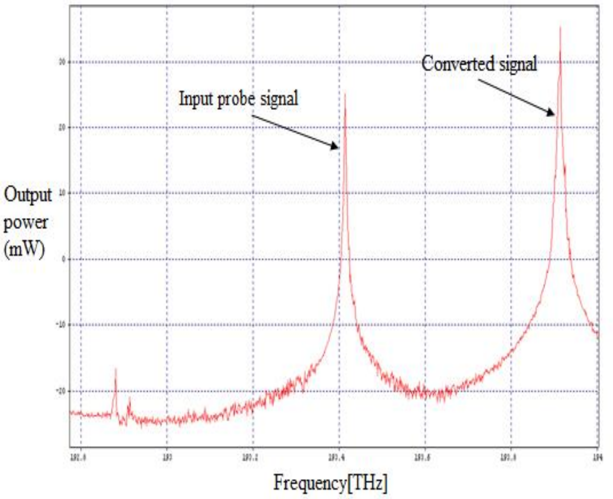

Fig.9. Optical spectra of Up-converted signal vaires with frequency

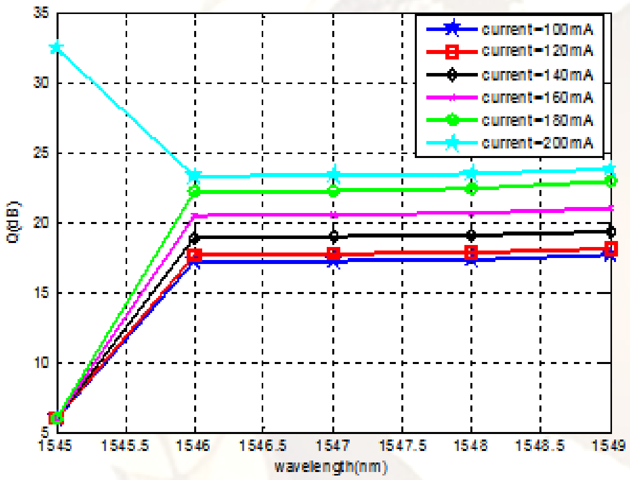

Fig.10. Q Quality factor versus wavelength for variation of current of SOA

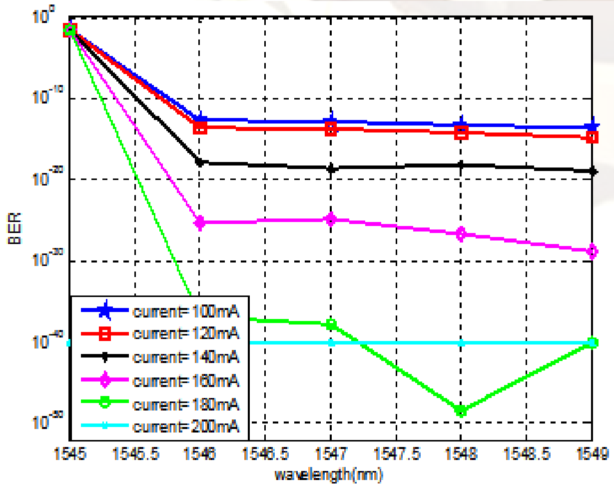

Fig.11. BER versus wavelength for variation of current of SOA

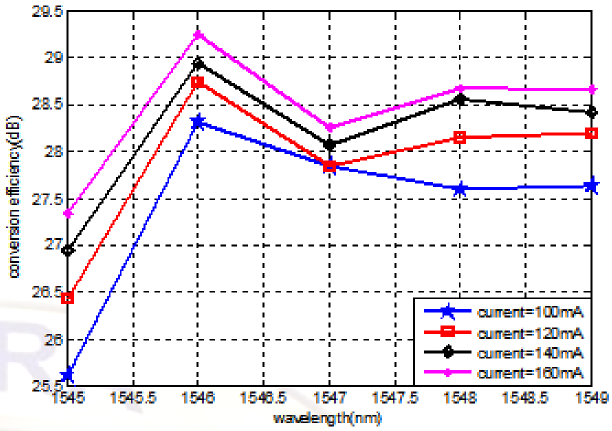

Fig.12.Up- Conversion efficiency versus wavelength for variation of current of SOA

V. CONCLUSION

We have simulated and 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 and current of SOA amplifier. Farah Diana [3] investigated the four wave mixing SOA based wavelength converter system for data rate of 2.5Gb/s but in this paper we have investigated the system for data rate of 10Gb/s. The conversion efficiency (η), quality factor (Q) and bit error rate (BER) have been analyzed for 10Gb/s. It is found that down-conversion is better than up conversion. Maximum FWM conversion efficiency is around 27.3417 dB at current 160mA and 28.5669 dB at current 160mA for up and down conversion respectively for 10Gb/s.

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