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Performance Analysis of SOA Using XPM Based Wavelength Converter for All Optical Networks

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ABSTRACT: Wavelength converter plays an important role for increasing the capacity and flexibility of future broadcast network. The cross phase modulation (XPM) based converter has high conversion efficiency at low input powers. In this paper, investigations are made on performance analysis of the semiconductor optical amplifier (SOA) using cross phase modulation based wavelength converter. This analysis is done at 10Gb/s in terms of shifted wavelength conversion efficiency and quality factor for up and down conversions. The investigations are carried out by varying the probe signal wavelength and bias current of SOA. It has been observed that down-conversion efficiency is more than up-conversion efficiency and it starts decreasing at larger wavelengths. It is found that maximum XPM conversion efficiency is around 0.53dB and 9.09dB at 1550.1nm and 1530nm for up and down conversion respectively for 10Gb/s. The XPM using SOA based wavelength converter is improved by increasing the active region length and bias current of SOA.

KEYWORDS: XPM, SOA, FWM, XGM, SOA-MZI.

I.INTRODUCTION

Optical wavelength converters are the key components for multi wavelength optical transfer networks and offer wavelength conversion in optical domain without deformation of input signals [1]. Wavelength converters increase the flexibility and ability of networks for a permanent set of wavelengths. The electro-optic converter support wavelength conversion, But has limitations such as large power consumption and complexity. Wavelength converters based on SOA and semiconductor lasers have been focusing on research during the last few years [1, 2]. SOA used in cross gain modulation (XGM), cross phase modulation (XPM) and four wave mixing (FWM) mode for wavelength conversions. Seo et al. [3] reported that all optical up conversion used XGM based SOA with high conversion efficiency. But, it requires a large input optical power to saturate the gain of the SOA.

Wavelength conversion exploiting the SOA nonlinearities exhibits different advantages and disadvantages, depending on the process. For example, the main advantages of XGM wavelength converters are their simplistic configurations, high conversion efficiencies and high bit rate capabilities. However, XGM wavelength converter suffers from several limitations such as requirement of large input power to saturate the SOA, high noise figure, an inverted output signal in contrast to the input signal. On the other hand, the XPM method can be utilized in such a way to overcome the limitations of XGM, by placing one or more SOAs in a design [4]. Further XGM and XPM do not offer flexibility to bit rate and modulation format. FWM provides transparency to the bit rate and modulation format and hence preserves both the phase and amplitude information. FWM based SOA is the only method with apparent optical properties of the information signal during the conversion process occurring within a SOA [5, 6]. But conversion efficiency for this scheme is not very high. So it is hard to retain a larger optical signal-to-noise ratio (OSNR) for converted signal in cascaded wavelength converters. So, to overcome the problems of XGM and FWM scheme, SOA converters can be used in XPM mode. This scheme is based on the dependency of refractive index of carrier density in the active region of SOA. Therefore, received signals deplete the carrier density and modulate the refractive index and thus phase modulation of continuous wave (CW) signal is multiplexed into the converter. The phase modulated CW signal can be demultiplexed subsequently in the receiver [7].

Majumder et al. [8] reported XPM based SOA Mach-Zehnder interferometer (SOA-MZI) wavelength converter. They optimized the bias current, optical filter bandwidth and pump intensity in SOA-MZI provision to achieve high OSNR. This wavelength conversion can be achieved for up and down conversions up to 2nm for non-return to zero (NRZ) signal at 10Gb/s [9]. Song et al. [11] reported the maximum up conversion efficiency of 7dB, but this can be possible at very low optical power. In this paper the effort has been made to extend the wavelength for up and down wavelength conversion range and improvement in conversion efficiency.

Studies on XPM-based wavelength converters in SOAs have been undertaken in much previous work. For example, Ye et al. [12] claimed that the performance of the converted signal depends on both the phase arm bias current and its operation. In other work, Singh et al. [13] improved the conversion efficiency and wideband conversion range by increasing the active region length and bias current of the SOA. They found that at high active region length and bias current, the converter provides a conversion band more than 15 nm, for both up and down conversions, while exhibiting conversion efficiency of more than 8 dB. The formula of conversion efficiency is given by

$$\eta = P_{out}/P_{in}$$

where P_{out} is output power of converted probe and P_{in} is input power of pump signal

It is apparent from the above literature that the methods to reduce the congestion level by the use of SOA based wavelength converter in the optical communication system have been comprehensively studied in the past decade. However, the techniques to preserve the pattern of XPM based SOA for wavelength converter application is still being explored and accessed quantitatively.

In this paper, they optimized the bias current, optical filter bandwidth and pump intensity by using two channels in SOA-MZI provision to achieve high OSNR. This wavelength conversion can be achieved for up and down conversion at 10Gb/s. Further, the work has been extended by using 4 channels XPM in SOA based wavelength converter for improving the conversion efficiency. After introduction in Section 1, Section 2 presents the wavelength converter set-up based on XPM and system description. The optimization of SOA parameters are explained in Section 3.The results are discussed in Section 4 and conclusions are summarized in Section 5.

II. WAVELENGTH CONVERTER SET-UP BASED ON XPM

The model of four channels wavelength converter is shown in Fig.1. The optical pulse generated signal is formed by encoding CW signal with wavelength into the amplitude modulator. The signal with wavelength 1550nm is sent to lower port of SOA and pump is applied at upper port with desired wavelength, which is vital at the output. To generate the SOA-MZI configuration, wavelength division multiplexer (WDM) is used. The formation of the SOA-MZI configuration is optimized so that maximum XPM produces the requirement inside the SOA-MZI. The upper semiconductor optical amplifier represented by SOA_1 and lower is represented by SOA_2.

The output of the SOA-MZI configuration is applied to the raised cosine band pass filter with optimized bandwidth of 0.4nm. Output is then detected by PIN photodiode at converted wavelength. The responsivity and dark current of the receiver is 1A/W and 10nA respectively. The simulation is carried out at center frequency of 193.1THz. The time domain simulation bandwidth is different according to the conversion range.

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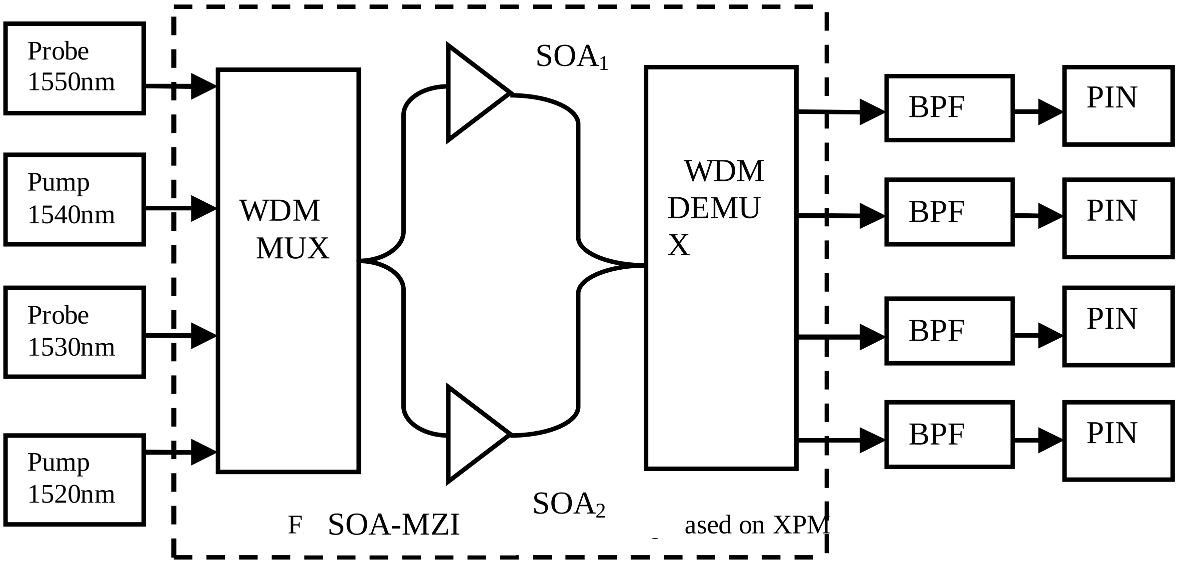

III. OPTIMIZATION OF SOA PARAMETERS FOR ENHANCEMENT OF XPM

SOA-MZI configuration has been shown in Fig. 1, where SOA_2 is taken as ordinary practical and another SOA_1 structure is optimized for improvement of the XPM in SOA-MZI configuration.

Table1.Variation in active length of SOA_1 due to Q-factor and P_{in} for converted signal wavelength of 1550nm.

Active region length (µm)	Q-factor at different signal input power (dBm)			
	-8dBm (dB)	-5dBm (dB)	-3dBm (dB)	0dBm (dB)
500	20.31	20.82	20.80	20.36
600	20.29	20.80	20.77	20.34
700	20.28	20.82	20.80	20.38
800	20.32	20.86	20.85	20.45
1000	18.93	19.11	19.08	18.93

For input wavelength 1550nm, XPM down converted wavelength obtained is 1540nm for the support of SOA_1. The simulation set-up is shown in Fig. 1 is used to verify the parameters of SOA_1, for enhancing the performance of XPM. Table 1 shows that as we enhance the active region length of SOA_1, Q-factor goes on decreasing up to saturation power of SOA_1. Also, it is observed that variation in Q-factor is insignificant for the variation of the input signal and the active region length of SOA_1 is 1000µm which shows the minimum Q-factor.

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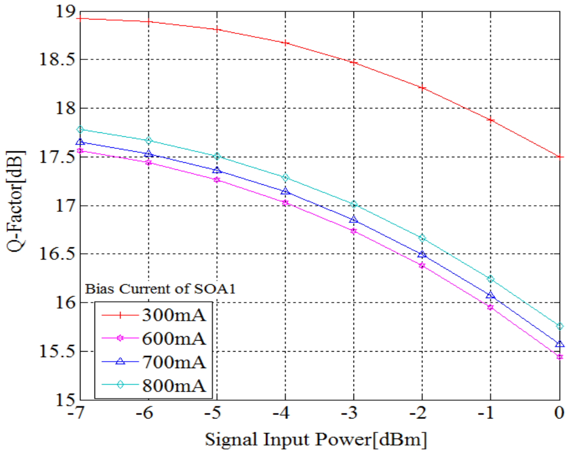

Fig.2. Q-factor variation with signal input power for different bias current.

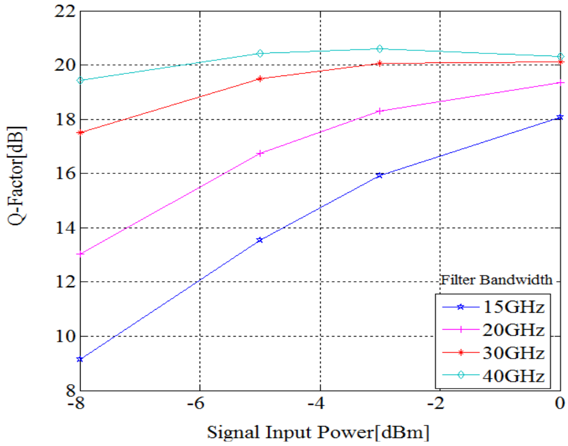

Fig.3. Q-factor variation with signal input power for different filter bandwidth.

Table 2. Optical filter bandwidth variation with input signal for converted wavelength of 1550nm

Optical filter bandwidth (GHz)	Q-factor at different P_{in} (dBm)			
	-8dBm (dB)	-5dBm (dB)	-3dBm (dB)	0dBm (dB)
15	9.14	13.53	15.92	18.08
20	13.02	16.75	18.31	19.36
30	17.52	19.50	20.07	20.12
40	19.44	20.44	20.60	20.30

Optimization of the bias current of SOA_1 is also done for boosting the XPM. As shown in Fig. 2, by enhancing the bias current from 300 to 600mA, the Q-factor continuously declines [9, 10]. It is clearly seen that minimum Q-factor is observed at 700mA bias current, before the saturation of SOA_1. If there is further raise the bias current, then large Q-factor is obtained. Table 2 shows the optimized optical filter bandwidth by using optimum bias current 700mA and length 500µm of SOA_1.

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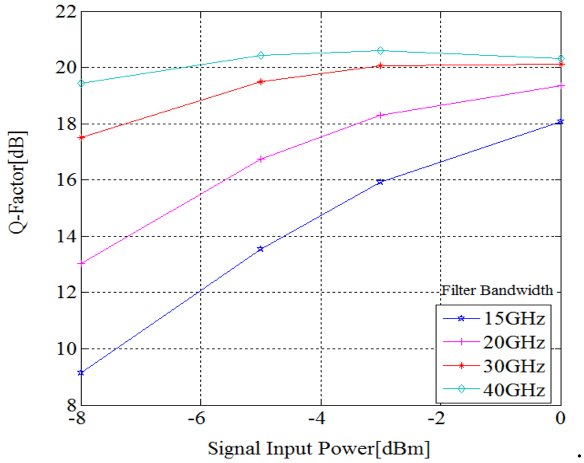

Fig. 3 Q-factor variation with signal input power for different filter bandwidth.

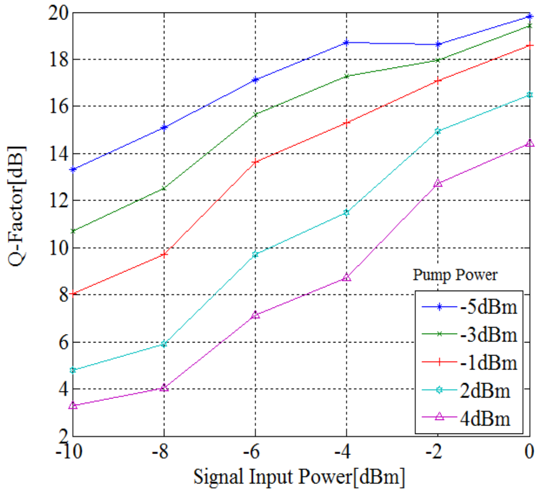

Fig.4 Q-factor variation with signal input power for different pump power.

At 40GHz, optical filter bandwidth of the raised cosine filter shows maximum Q-factor for all input signals. Table 3 shows the optimized parameters of the SOA-MZI for wavelength converters based on the XPM. It is observed that longer length of active region and high bias current of the SOA leads to faster response and small gain variation of SOA device [11]. Higher bias current of the SOA provides the best gain by wider spectrum bandwidth of the SOA [14].

V. RESULT AND DISCUSSION

In order to examine the performance of wavelength converter, the Q-factor verses signal input power for different pump power as shown in Fig.4. The input signal wavelength 1550nm is converted to 1540nm. The Q-factor goes on diminishing with the increase in the pump power. This shows good agreement with result reported Ref. [14]. At 4dBm pump power, the minimum Q-factor is 3.29dB. It is also observed that as we enhance the input signal power, Q-factor is decreased up to saturation of the SOA_1. After saturation power of the SOA_1, Q-factor goes on increasing. The converter set-up shown in Fig. 1 is also used for up and down conversion with large bandwidth. The time domain simulations bandwidth increases according to conversion ranges.

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Table3. Parameters of the SOA-MZI for wavelength converter based on XPM

Parameters	SOA_1	SOA_2
Bias current (mA)	250	500
Length of active region (μm)	500	300
Width of active region (μm)	3	1.5
Thickness of active region (μm)	0.08	0.15
Confinement factor	0.3	0.3
Transparency carrier density (m^3)	$1.4x10^{24}$	$1x10^{24}$
Line enhancement factor	3	3
Input & output coupling loss	0	0

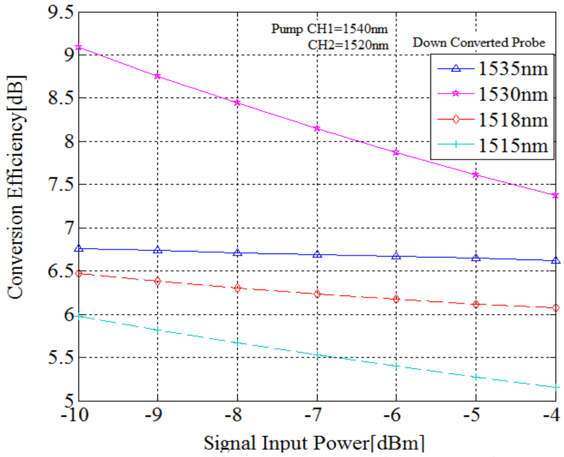

Fig. 5 Conversion efficiency as the function of signal input power for down conversion wavelengths.

It shows that highest value of conversion efficiency is just about 9 for down conversion and 0.62dB.The efficiency of down converted signal is high as compared to up conversion efficiency. The best result is examined at low pump power of 4dB. This shows an upgrading over results reported in Ref. [15]. The conversion efficiency goes on decreasing with the increase in signal input power for both up and down conversion. The optical power spectrums versus conversion range for both up and down conversions are shown in Fig. 7. The apparent eye patterns are also observed at converted signal wavelength 1530 to 1560nm.

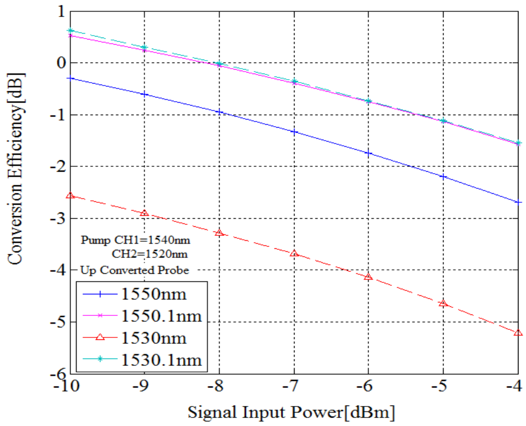

Fig. 6 Conversion efficiency as function of signal input power for up conversion.

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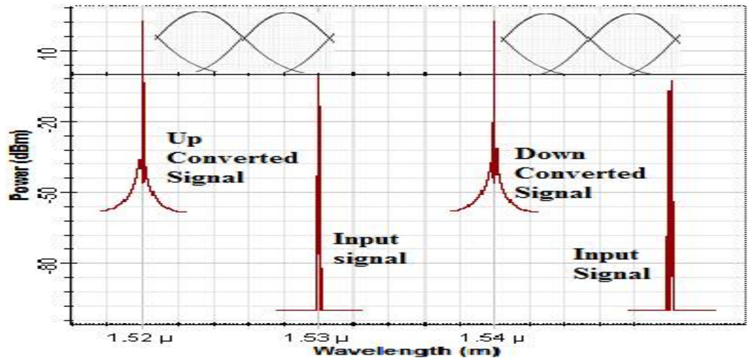

Fig. 7 Optical power spectrum for up converted and down converted signals.

VI.CONCLUSION

The wavelength conversion using XPM in SOA-MZI configuration with large band of up and down conversion. It is observed that high active region length and bias current in the SOA leads to XPM in SOA-MZI configuration. For this, low pump power of 4dB observed is best. The efficiency of down converted signal is high as compare to up converted signal. This wavelength converter provides conversion band additional than 15nm for both up and down conversions. This wavelength conversion increases the ability of future optical network.

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