High Speed wavelength preserved 2R Regeneration Based on Filtering and Cross-Gain Compression in Semiconductor Optical Amplifiers

Liang Wang(1 ,2), Bo Huang(1 ,2), Zhixue He(1 ,2), Yaoxiong Liang(1 ,2), Hongxin Liu(1 , 2), Xue Wang(1 , 2), Dexiu Huang(1 , 2), Nan Chi(1)

1: School of Information Science and Engineering, Fudan University, Shanghai 200433, China , E-mail:nanchi@fudan.edu.cn

2: Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology,
Wuhan 430074, China

ABSTRACT

We propose a novel scheme employing phase to amplitude modulation conversion and cross-gain compression in Semiconductor Optical Amplifiers (SOAs) to implement 2R regeneration at 40Gb/s. The resilience on the pumping power and filtering are analyzed.

Keywords: Cross-Gain Compression(XGC), Cross-Gain Modulation(XGM), Semiconductor Optical Amplifier(SOA)

I INTRODUCTION

Next generation transparent optical networks will require the regeneration of very high-bit rate degraded signals directly in the optical domain. To achieve this goal, several techniques for all-optical(2R and 3R) regeneration have been reported recently. Most of these schemes exploit wavelength converters. One of the methods to achieve wavelength conversion is using the cross-gain modulation(XGM) in SOAs.

The Cross-Gain Modulation in semiconcuctor optical amplifiers(SOAs) has been largely studied in the past for its possible application to all-optical signal processing. In XGM, a strong pump light co- or counterpropagates in an SOA with a weak continuous wave(CW light). The strong light saturates the SOA, producing the gain saturation effect which the CW light experiences, so this process transfers the information included in pump light to the CW light. Thus the wavelength conversion has been achieved.The XGM scheme based on SOAs can be polarization independent, has a large conversion range [1], and a high input power dynamic range .There are, however, also some shortcomings related

Optical Transmission, Switching, and Subsystems VI, edited by Ken-ichi Kitayama, Pierpaolo C. Ghiggino, Kim Roberts, Yikai Su, Proc. of SPIE Vol. 7136, 71361E · © 2008 SPIE · CCC code: 0277-786X/08/$18 · doi: 10.1117/12.803893

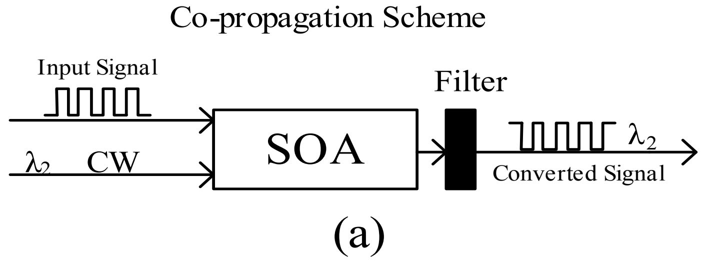
to XGM. The degradation of the extinction ratio of the converted signal may accumulate along the optical path and consequently impair the cascadability. Their speed is ultimately limited by the gain recovery time. Moreover, to change the wavelength of the regenerated signals is sometime a highly undesired feature, thus finding reasonable methods to solve these problems is necessary.

In this paper, we proposed a novel scheme to realize ultra high speed 2R regeneration simulaneously maintaining the wavelength based on Cross-Gain Modulation(XGM) and subsequent phase modulation to amplitude modulation conversion, and Cross-Gain Compression(XGC) in two cascaded semiconductor optical amplifiers. It uses cross saturation effects between two complementary signals(i.e. input signal plus its inverted copy)propagating in a highly saturated semiconductor optical amplifier(SOA). In our scheme, we use an SOA to get a distorted signal as our orginal signal, then the inverted signal is produced by using XGM in the second SOA. After the process of optimizing converted signal with the help of Bragg Grating Filter or Delayed Interference Signal wavelength Converter(DISC), the orginal signal and the inverted signal are injected simultaneously to the third SOA in which they share the XGC effect. The limiting amplification in the SOA, due to gain saturation, and the spectral modulation of the gain, due to inter-band relaxations, provide noise compression on both logical “1s” and “0s”, respectively[2]. Controlling the power of the two signals and consequently setting the condition of overall constant power in SOA propagation, we exploit both effects avoiding pattern distortions in the SOA and the related chirp.

This paper is organized as follows. First, in Section Ⅱ, we do the analysis in theoretical ways. In Section Ⅲ, we described the principle our scheme. Then in Section Ⅳ, we do the numerical simulation and give results on it. Finally, in Section Ⅴ, we make report on this high speed wavelength preserved 2R regeneration based on filtering and Cross-Gain Compression in semiconductor optical amplifiers.

Ⅱ THEORETICAL ANALYSIS

Fig.1. shows the principle of XGM in SOA. In XGM, a strong modulated-pump signal co- or counterpropagates in an SOA with a weaker continuous-wave(CW) probe. The pump modulates the SOA gain, the gain variations are experienced by the probe light, and this transfers the information encoded in the pump to the probe.



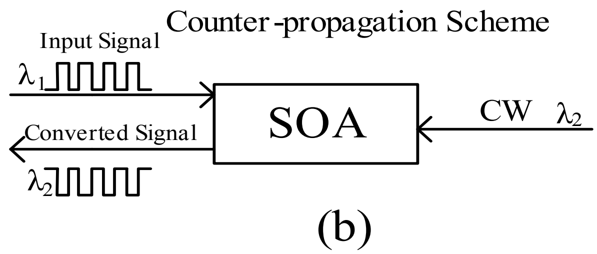


Figure.1. Principle of XGM in SOA

Take the ideal SOA into account. When optical pulses are propagating in the SOA, the longitudinal carrier density, photon density and refractive index are changing . Therefore, in order to simulate the internal process of wavelength conversion accurately, we divide the SOA into several sections. In SOAs, carrier density N and optical power P meet the following equations:

$$\frac{\partial N_j(z,T)}{\partial T}=\frac{I}{qV}-\frac{N_j}{\tau_c}-\sum_w \frac{\Gamma g_{w,j}(N(z,T))}{h\omega_w A_{cross}}\overline{P_{w,j}} \qquad (1)$$

$$\frac{\partial P_w(z,T)}{\partial z}=\Gamma(g_w(N(z,T))-\alpha_{\mathrm{int}})P_w(z,t) \qquad (2)$$

in equation (1) and (2) j stands for different sections of SOA, and T = t-z/V_g (V_g is group velocity), I refers to the injection current , v is the volume for each section of SOA, q is electronic charge, τ_c is the photon lifetime of spontaneous emission, and τ_c^{-1} = A+BN+CN^2, where A is the nonradiative coefficient due to recombination at defects or traps, B is the spontaneou radiative recombination coefficient, and C is the Auger coefficient. w is referred to signal light or probe light, Γ is the confinement factor, hω stands for the energy of photon, A_{cross} is the cross-sectional area of the active layer, α_{int} is the internal loss, P $_{w,j}$ is the average optical power of the jth section, and its format is described in equation (3)

$$\overline{P_{w,j}}=\frac{1}{\Delta L}\int_{(j-1)\Delta L}^{j\Delta L} P_{w,j-1}e^{(\Gamma g_w(N)-\alpha_{in})z}dz=\frac{G_j-1}{\ln(G_j)}P_{w,j-1} \qquad (3)$$

where $G_j = e^{(\Gamma g_w(N) - \alpha_{in})\Delta L}$, ΔL is the length of each section, $P_{w,j-1}$ is the output power of the (j-1)th section, $g_w(N)$ is the material gain, and it can be expressed as follows

$$g_w(N)=a_1(N-N_0)-a_2(\lambda-\lambda_N)^2+a_3(\lambda-\lambda_N)^3 \qquad (4)$$

where a_1 differential gain, a_2、 a_3 are gain coefficients, N_0 is the transparent carrier density, λ_N is gain peak wavelength written as$\lambda_N = \lambda_0 - k_0 (N- N_0)$, where$\lambda_0$ is the transparent gain peak wavelength, k_0 is a constant.

III PRINCIPLE

Fig.2. shows the XGC working principle. Two signals at diffenent wavelengths are coupled and synchronized, then they are injected in the SOA. The total power is high enough so as to make the SOA deep saturated. Moreover, controlling the relative power of the two signals, it is set quite constant to prevent the pattern effects. In this scheme, a logical "1"(or logical "0") is propagating with a logical "0"(or logical "1") at the same time due to the inverted signals, so they are sharing the saturated gain in the SOA. During the progagation , saturation and dynamical effects affect the shape of signals. The saturated gain act as power equalizer on the logical "1s" amplitude. The overall effect is similar to a high-pass filter with around 1-GHz cut off frequency. At the same time, the logical "0s" experience the compressed gain when coprogagating with logical "1s". The XGC between opposite symbols can lead to noise compression of both logical "1"and logcial "0" levels.

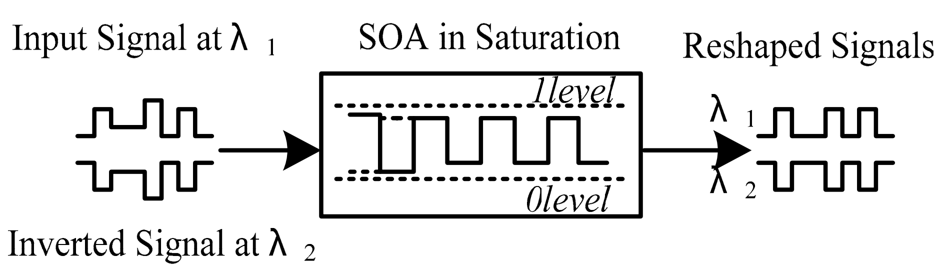


Figure.2. XGC working principle

In our scheme, we use the XGM method to generate an inverted signal at a different wavelength from the input. And a Bragg Grating Filter or a Mach–Zehnder interferometer integrated with the first SOA to form so called delayed interference signal wavelength converter (DISC) is used to improve the quality of the output signal. The advantages of the two devices are described as follows

(1) Bragg grating filter: The converted signal with large chirping could be suppressed by the steep edge of the grating and an improvement of the cascadability could be obtained. A simple linear approximation of the transmission function of the grating shows the possibility of extinction ratio

improvement of signals since the grating can result in frequency to intensity modulation conversion.

(2) DISC: The remarkable advantage of the DISC scheme is its capability to preserve the RZ format during the conversion process; this is achieved by choosing a shorter delay loop. When the delay is less than one bit interval, the output pulse width can be shortened at the expense of a power penalty.

After the first stage, the original signal and the inverted signal are injected into the second SOA. The two lightwaves co-propagate in a saturated SOA, sharing the gain compression. The limiting amplification in the SOA, due to gain saturation, and the spectral modulation of the gain, due to inter-band relaxations, provide noise compression on both logical "1s" and "0s",respectively [2]. Controlling the power of the two signals and consequently setting the condition of overall constant power in SOA propagation, we exploit both effects avoiding pattern distortions in the SOA and the related chirp.

NUMERICAL SIMULATION AND RESULTS

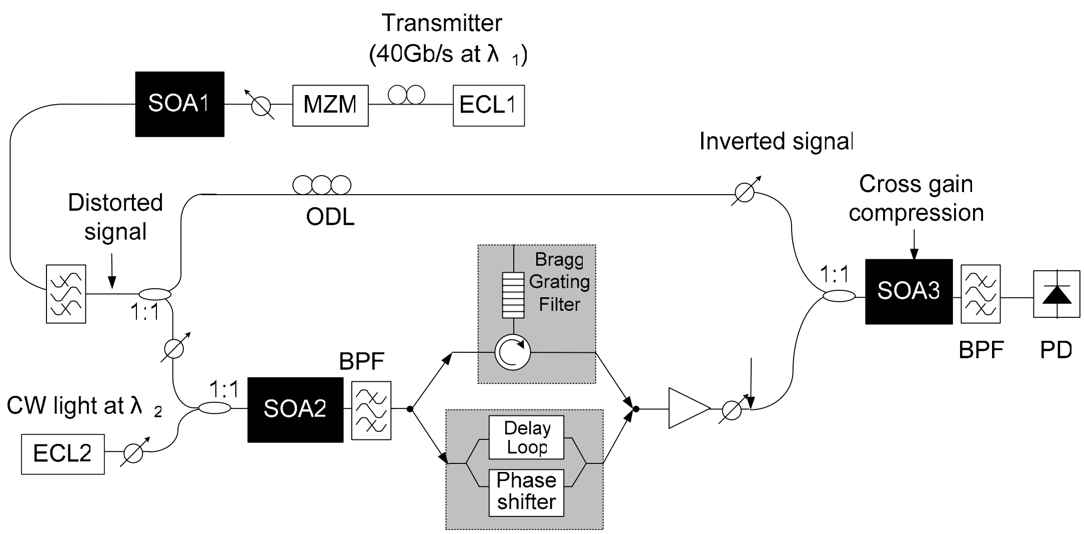


Figure.3. Numerical setup of 40Gb/s 2R Regeneration Based on Cross-Gain Compression in Semiconductor Optical Amplifiers

Fig.3. shows the setup of this scheme. The input signal was generated by using a laser ECL1 at λ_1 = 1554nm modulated by 40Gb/s NRZ signal through Mach–Zehnder modulator. SOA1 was used to get a distorted signal as our original signal in the experiment. Then the signal was split into two parts, one was sent to the XGM-based signal inverter in which we used a tunable laser at λ_2=1551nm as the pump to do wavelength conversion. During the conversion the signal in λ_1 transferred to λ_2; the other one was synchronized through an optical delay line with the wavelength-converted and inverted copy. The two waveforms were then coupled and sent to SOA3 in which the cross-gain compression has been achieved.

Fig.4. shows the eye diagrams of different stages in the experiment. As shown in Fig.4.(a), original signal is deteriorated due to the pattern effect in SOA. In Fig.4.(b) due to the effect of Bragg Grating Filter the quality of the signal has been improved but inverted. Finally a very clean eye diagram can be

obtained after 2R regeneration as shown in Fig.4.(c). From the evolution of the eye diagrams we see the beneficial effect of the 2R regeneration.

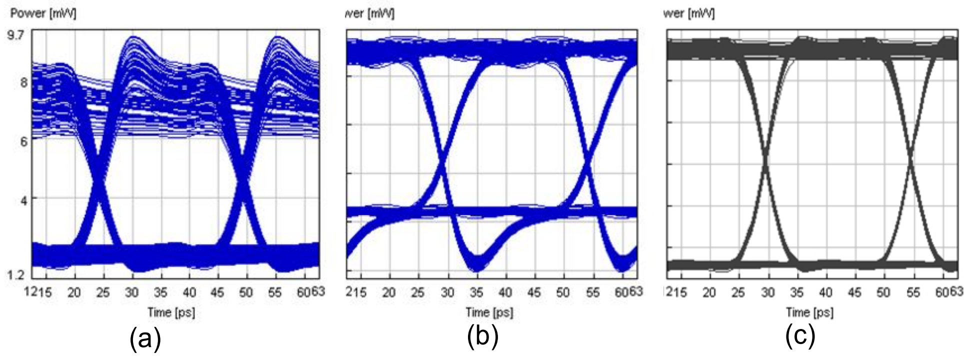


Figure.4. Obtained eye diagrams for the (a) original(distorted) signals(b)signals after Bragg Grating Filter (c)signals after 2R regeneration

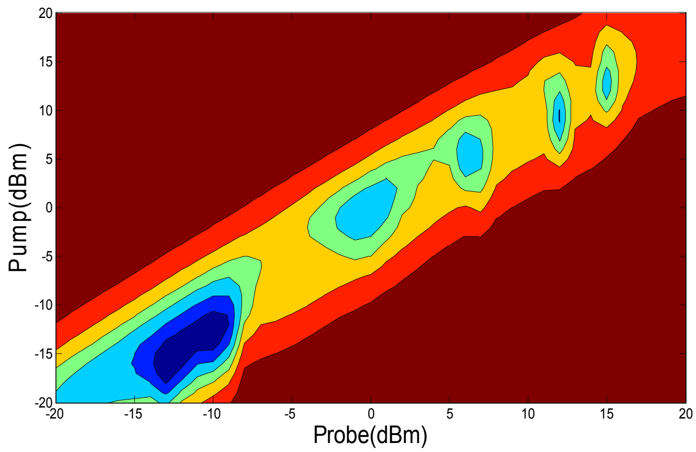


Figure.5. Bit-Error-Rate(BER) versus both of the change in pump light power and probe light power

From Fig.5. , it is obvious that there is a pair of optimal value for pump power and probe power to make BER the lowest. And we find the optimal value for the pump is about -13dBm and for probe -16dBm.

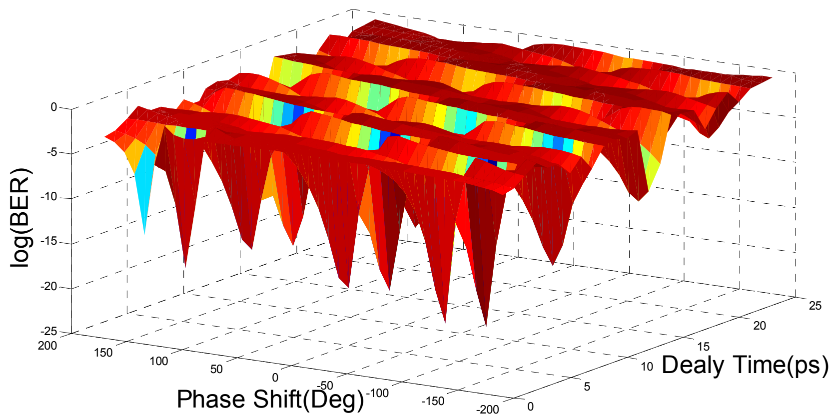


Figure.6. Bit-Error-Rate(BER) versus both of the change in delay time and phase shift of Mach–Zehnder interferometer

We also evaluated the delay time with phase shift in DISC vs BER. Fig.6. shows the BER as a function of phase shift and delay time in three-dimensional axis. The figure indicates that there should be optimal combination of phase shift and delay time for the lowest BER.

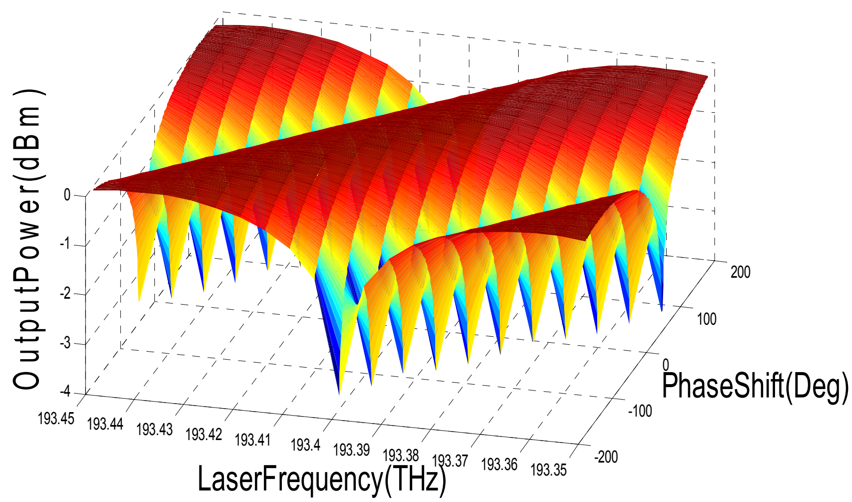


Figure.7. Output power versus both of the change in phase shift of Mach–Zehnder interferometer and laser frequency

From Fig.7. we can see that the output power is changing as the phase shift and laser frequency are changing. Obviously , there are several pairs of values for phase shift and laser frequency making the output power get the largest value.

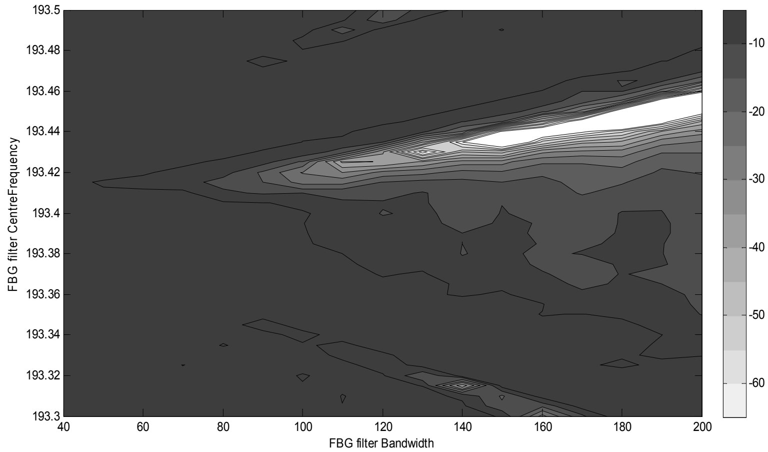


Figure.8. Bit-Error-Rate(BER) versus both of the change in bandwidth and center frequency of Bragg Grating Filter

In Fig.8. we know the relationship among BER and bandwidth and center frequency of Bragg Grating Filter. As the results above, there is also an optimal combination of bandwidth and center frequency of Bragg Grating Filter for the lowest BER.

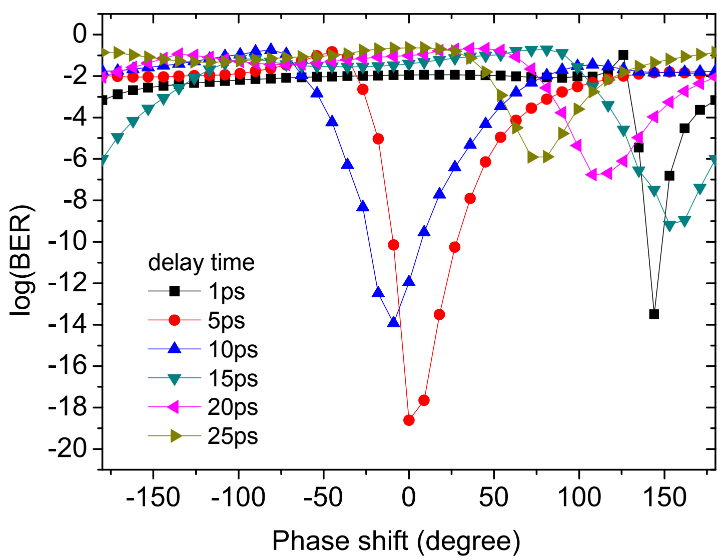


Figure.9. BER versus phase shift with different delay time in Mach–Zehnder interferometer

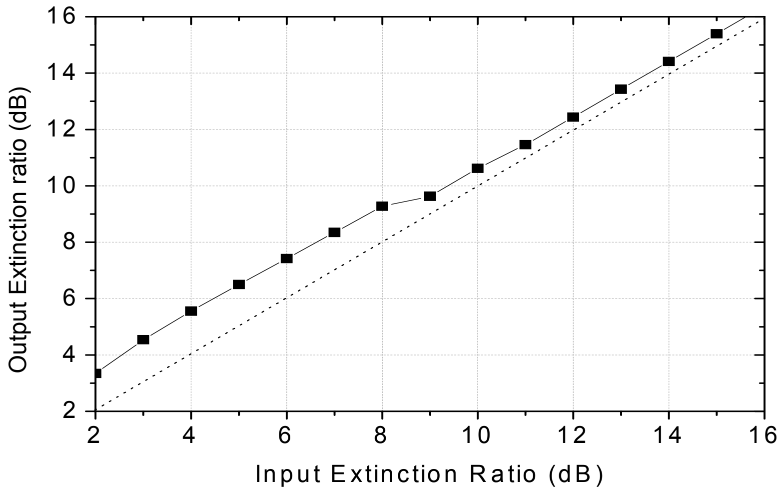


Figure.10. Output Extinction Ratio as a function of the input Extinction Ratio

Finally, we give the improvement of ER as a result of 2R regeneration. Fig.10. shows that the ER of original signal has increased by about 2dB after 2R regeneration. The ER is absolutely enhanced by XGC.

□ CONCLUSION

We have proposed a novel scheme that can achieve wavelength-preserving signal reshaping in 40Gb/s. The fundamental principles are XGM and XGC in SOAs. For the first stage(cross-gain modulation), owing to the use of Bragg Grating Filter or DISC the scheme can overcome the slow response of SOA, managing to high speed performance. The cross-gain compression can greatly improve the quality of the signal, increasing the output ER, and strongly reduce the waveform distortions related to pattern effect. Furthermore, this scheme has the potential to be used in a higher speed performance such as 100Gb/s.

ACKNOWLEDGEMENT

This work is funded by the Hi-Tech Research and Development Program of China (No. 2007AA01Z260, 2006AA01Z251), National National Natural Science Foundation of China (No. 60777010), OCLT foundation project and Program for New Century Excellent Talents.

REFERENCE

1. Joergen, IEEE J.Select. Topics Quantum Electron, vol. 3 (1997), pp. 1168-1180
2. G.Contestabile et al., “Cross-Gain Compression in semiconductor Optical Amplifiers”, J.Lightwave Technol., vol. 25 (2007), pp. 915-921
3. G.Contestabile et al., “40Gb/s Wavelength Preserving 2R Regeneration for Both RZ and NRZ Signals”,OFC2008, paper OWK1

4. J.Leuthold et al., “Compact and Fully Packaged Wavelength Converter with Integrated Delay Loop for 40Gbit/s RZ Signals”, OFC2000, paper PD17

5. Hanlim Lee, Hyunjae Yoon, et al., “Theoretical Study of Frequency Chirping and Extinction Ratio of Wavelength-converted Optical Signals by XGM and XPM using SOA’s”, IEEE Joural of quantum electronics, vol. 35, NO. 8, AUGUST 1999

6. Yoshiyasu Ueno et al., “3.8-THz Wavelength Conversion of Picosecond Pulses Using a Semiconductor Delayed-Interference Signal-Wavelength Converter(DISC)”, IEEE Photonics Technology Letters, vol. 10, No.3, 1998