Optimization of Ultra-long MQW Semiconductor Optical Amplifiers for All-optical 40-Gb/s Wavelength Conversion

Wenbin Zhao, Zhaoyang Hu, Vikrant Lal, Lavanya Rau, and Daniel J. Blumenthal
Department of Electrical & Computer Engineering, University of California, Santa Barbara, CA 93106
Tel: (805) 893-5614, Fax: (805) 893-5707, E-mail: wenbin_zhao@umail.ucsb.edu

Abstract: Detailed study of cross-phase modulation wavelength conversion based on ultra-long semiconductor optical amplifier is implemented to optimize the extinction ratio and pattern dependence. Error free 40Gb/s wavelength conversion is demonstrated.

©2005 Optical Society of America
OCIS codes: (190.5970) All optical wavelength conversion; (250.5980) UL-SOA

1. Introduction

All optical wavelength conversion (AOWC) is a key function for optical networks and packet switching approaches like optical label swapping [1]. Integration of MZI-SOA based wavelength conversion and tunable sample grating distributed Bragg reflector (SGDBR) laser has been demonstrated to work at 10-Gb/s [2]. This tunable all optical wavelength converter is very compact with large wavelength tunable range. However, due to slow gain recovering time of semiconductor optical amplifier (SOA), the bandwidth of this SOA based wavelength converter is limited. One of ways to increase bandwidth is to speed up gain recovery by increasing the length of SOA [3], or by injecting holding beam at transparency [4]. The other way is to reshape pulse shape by filter [5-7].

In this paper, a simple scheme of AOWC, consisting of an ultra-long SOA and a band-pass filter, is demonstrated based on cross-phase modulation (XPM) in SOA. Wavelength converter is operated at 40-Gb/s with error-free. The length of SOA is optimized to maximize the extinction ratio of converted signal, and to reduce the pattern effect. Probe power and signal power dynamic ranges are studied. SOA is fabricated on offset QW structure with capability to be integrated with SGDBR and other passive devices.

2. Operation principle of ultra-long SOA-based XPM wavelength converter

A set of SOA with active region lengths varying from 1mm to 3.5mm in 250um increments were fabricated on offset QW structure using offset QW processing [2]. The active QW above the passive waveguide is etched off by wet etching, following by 1.9um P-InP cladding layer re-growth. The SOA input and output facets are tilted at 7 degrees.

![Fig.1. (a) Experimental setup and (b) optical Spectra.](image_url)

To measure performance as a 40-Gb/s XPM wavelength converter, the setup in Fig.1 (a) was used. A fiber ring laser was used to generate a 10GHz RZ pulse train with 2ps width at 1558nm, which is modulated with PRBS data. Optical time domain multiplexer (OTDM) multiplexes 10Gb/s data to 40-Gb/s using a passive split and interleave
technique. The 40-Gb/s signals and probe CW wavelength are combined and coupled into UL-SOA with lens fiber. Data imposes a phase modulation onto the CW light basing on XPM effect in the SOA. The phase modulation broadens the probe CW signal and generates optical sidebands. A band-pass filter takes out one of its sidebands, and converts phase modulation to amplitude modulation by suppressing the probe CW carrier. Shown in Fig.1 (b) are the optical power spectra of phase modulated probe wavelength after the SOA and the amplitude-modulated signal after the optical filter at probe wavelength. The converted 40-Gb/s signals are de-multiplexed to four 10-Gb/s channels using an EAM for bit error rate (BER) testing. Computer simulations were used to optimize parameters, and are compared to experimental measurements. The SOA model is based on transfer matrix method. The converted signal after SOA is transformed to frequency domain by FFT, and a filter model is used to extract the converted signal, which is transformed back to time domain.

3. Optimization and experimental results of 40-Gb/s wavelength conversion
The variation of extinction ratio (ER) and peak power fluctuation (PPF) as a function of SOA length is shown in Fig.2. PPF is defined as peak power level variation with PRBS data in eye diagram, mainly due to the pattern effect. When the length of SOA increases above 2.5mm, the ER is saturated. However, the PPF decreases and minimized at 3.5mm, the pattern effect is decreased. Saturation of ER above 2.5mm is in agreement with the measurement of gain recovery time with bulk SOA length in [3]. Increasing SOA length does decrease gain recovering time, however there is limit due to ASE. Huge ASE in long SOA makes carrier density not uniform with uniform current injection, which induces the gain overshooting [3].

![Fig.2. Extinction ratio and peak power fluctuation with SOA Length.](image)

We simulated and measured the effect of probe CW power on the converted signal ER and Q-factor as shown in Fig.3 (a). The ER goes up with increasing of probe power, and closes to saturation. The CW is not only the new

![Fig.3. Extinction ratio and Q factor with (a) probe CW power, and (b) signal power.](image)
carrier wavelength, but also acts as a holding beam to suppress ASE. Strong ASE noise is reduced significantly due to the large probe power, which improve noise figure, and increase the ER. Strong probe beam is not able to increase stimulated emission rate much, and thus speedup gain recover time significantly. It is in agreement with the measurement of carrier lifetime in bulk SOA [3]. The CW power should be close to or less than the signal power in order to be efficiently modulated.

Fig.3 (b) shows the signal power dynamic range. ER and Q of converted signal reach maximum at about 2dBm signal power, and are almost flat in about 10dB range. From dropping of ER with signal power increasing furthermore, we can conclude that the phase modulation is induced not by field, but by carrier, although the field intensity is very large in 2ps pulse width. The numerical simulation is matched with the experimental results very well.

The 40Gb/s BER of the XPM wavelength converted signal is shown in Fig.4 (b). The device for BER measurement is offset QW SOA with length 2.5mm. The measured power penalty at BER=10^{-9} is between 1.8dB and 2.5dB for four channels. The power penalty arises from the OSNR degradation and pattern dependence.

4. Conclusion

Experimental and numerical simulations show that optimizing the length of SOA can improve the extinction ratio of converter, which is due to speeding up of gain recovery. Basing on the study of the XPM-based wavelength converter, the extinction ratio of converted signal is maximized, pattern effect is reduced and error-free 40Gbps wavelength conversion is obtained. Probe power and signal power dynamic ranges are also studied for the further integration with SGDBR and filter. This work is still going on. The authors acknowledge the funding support of the DARPA/MTO DOD-N program under the LASOR project award number W911NF-04-9-0001.

References