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利用单支半导体光放大器和光带通滤波器实现40 Gbps归零码到非归零码的全光转换

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摘 要:为了解决全光码型转换中结构复杂和速率限制的问题,提出了应用于全光网络,利用半导体光放大器的非线性效应和光带通滤波器滤出特定光谱成分来实现全归零码到非归零码的全光转换方案.基于超快半导体光放大器模型,进行了40 Gbps归零码到非归零码全光转换的仿真与实验验证.实验结果表明:40 Gbps归零码到非归零码全光转换的功率损耗约为2 dB,与仿真结果高度吻合,验证了该方案的可行性与有效性.

关键词:光通信;码型变换;非线性光学;归零码;非归零码;半导体光放大器;光带通滤波器

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40 Gbps Data Format Conversion From RZ to NRZ Using Single SOA Assisted by Optical Band-pass Filter

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Abstract: To solve the problems of complicated structure and rate limiting in conventional format conversion system, 40 Gbps all-optical format conversion from return-to-zero to non-return-to-zero modulation format converter was proposed and demonstrated with a single semiconductor optical amplifier and an optical band-pass filter. The format converter consists of a single semiconductor optical amplifier which is acted as a nonlinear element to broaden the spectrum of input signal and the optical band-pass filter which is used to extract the special spectrum from the broadened spectrum. By adopting the ultra-fast semiconductor optical amplifier model, the 40 Gbps return-to-zero to non-return-to-zero format conversion was demonstrated with simulation. The proof of the principle experiment at 40 Gbps was demonstrated by using the test semiconductor optical amplifier and optical band-pass filter converter. Experimental results show that the power penalty induced by the pattern converter is about 2 dB, which is well coincidence with simulated results. The proposed scheme is robust and potential for applications in future optical networks.

Key words: Optical communication; Format conversion; Nonlinear optics; Return-to-zero; Non-return-to-zero; Semiconductor optical amplifier; Optical bandpass filter

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0 Introduction

All optical networks will become a key technology meeting with the explosive bandwidth requirements of modern communication networks. The evolving trends in optical network propelled by the ever-increasing bandwidth demands indicate a future leaning toward dense wavelength tributaries, increased line rates (>40 Gbps), longer transparency length, and improved flexibility[1-3]. Future all-optical networks are likely to be a hybrid of Wavelength Division Multiplexing (WDM) and Optical Time Division Multiplexting (OTDM). Nonreturn-to-Zero (NRZ) format is preferred in WDM networks due to its high spectral efficiency and timing-jitter tolerance, while the Return-to-Zero (RZ) format is widely used in OTDM systems for its tolerance to fiber nonlinearities in spite of the dispersion-induced effect[4-7]. Therefore, all-optical format conversion which is one of the significant all-optical signal processing techniques may play an important role in future optical network. Format conversion from RZ to NRZ signals is an essential example for interfacing different parts of the future optical network. Over the past few years, numerous format conversion schemes have been proposed and demonstrated. Among these schemes, RZ-to-NRZ format conversion may find some usages in transparent interconnection of future optical link or node. Significant efforts have been made for RZ-to-NRZ conversion schemes relying either on Kerr-based nonlinearities, active elements, or linear configurations[8-17]. These effects are generated in different nonlinear media, including nonlinear optical fiber, photonic crystal fiber, waveguide or others. Semiconductor Optical Amplifiers (SOAs) are also promising candidates for such optical format conversion because they can provide a smaller footprint, lower switching operation, and higher integration ability as compared to other nonlinear devices. Previously, various types of SOA-based optical format conversion using such as Cross-Phase Modulation (XPM), Cross-Gain Modulation (XGM), and Four-Wave Mixing (FWM) have been developed [18-20]. Hitherto, a Delay Interferometer (DI) is used in all most SOA-based format conversion approaches. In this DI, one arm is temperature controlled to change the refractive index, the other arm has a time delay, thus change the phase difference. This control is difficult.

In this paper, we experimentally demonstrate an optical format conversion based on a SOA at 40 Gbps. The proposed scheme is robust and potential for applications in future optical networks.

1 Principle of operation

In this experiment, a duplicator and a wavelength converter is used to realize the data format conversion from RZ to NRZ. The input RZ pulses with 1.5 ps width are duplicated within one period, thus expanding the time scale of each input bit. Then, the duplicated RZ pulses are converted to NRZ signal by using a wavelength converter. In the scheme, the number of copies of the RZ pulses is decided by the working speed of the wavelength converter[19-21]. For high-speed format conversion, a fast wavelength converter is a necessary device; meanwhile, selecting appropriate number of copies of the RZ optical pulses is also very important.

Fig. 1 is a schematic diagram of our experimental setup. Thereinto, dashed line: optical path; solid line: electronic path; EDFA: erbium doped fiber amplifier; Mod: modulator; SOA: semiconductor optical amplifier; OBPF: optical band pass filter; PD: photoelectric detector; CW: continuous waveform; ODL: optical delay line; VA: variable attenuator; ODL: optical delay line; OSA: optical spectrum analyzer; OSC: digital oscilloscope. The system consists of a 40 Gbps optical signal generation unit and a format conversion unit. In this experiment, A tunable picoseconds laser source (U2t TMLL 1 550) is employed for signal sources. The laser is driven by an ultra-low-noise and high-accuracy current source (ILX-Lightwave LDC-3724B), by which the laser temperature can also be controlled. To generate 40 Gbps data signals, one of the 10 GHz picoseconds laser source was modulated by a $LiNbO_3$ Modulator (LNM) which is driven by a Pulse Pattern Generator (PPG) with a $2^{31}-1$ Pseudorandom Bit Sequence (PRBS) data. The 10 Gbps data signal with a 1.5 ps pulse width was multiplexed to generate 40 Gbps data signals using the optical multiplexer (MUX). The 40 Gbps data signals is preprocessed by the system formed by one power splitter, one power combiner, and two ODLs. The preprocessing system has a time delay about 12.5 ps in each arm corresponding to about 2.625 mm fiber length difference. The signal power can be controlled by the followed Variable Attenuator (VA). The signal pulse and the probe light whose central wavelength is 1556.12 nm pass the power combiner, and then are launched into the SOA. The RZ signal and the probe light achieve sufficiently, the XGM and the XPM effect induce spectral broadening. The input power of the signal and probe light can be adjusted by the EDFA and the VA. The the principle is XPM and the resultant NRZ signal's bit pattern. The subsequent OBF then extracts the sideband spectrum with its central wavelength about 1556 nm. The signals are simultaneously observed optically and electronically using an Optical Spectrum Analyzer (OSA, Ando AQ6317C), an electronic detected system composed of a PD (U2t XPDV3120 with 75 GHz bandwidth) and a digital oscilloscope (OSC, Agilent 86100D with 80 GHz bandwidth).

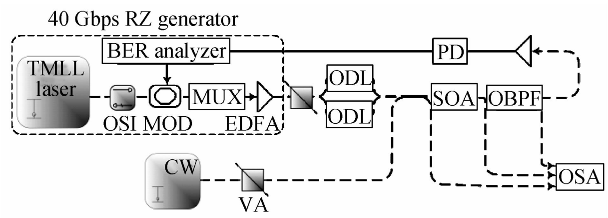

Fig. 1 Schematic diagram of the experimental setup

2 Results and discussion

In 40 Gbps optical format conversion simulation and experiment, the parameters are listed in Table 1. According to the previous analysis, we use the parameters as shown in Table 1 to simulate the optical format conversion. As shown in Fig. 2(a), the optical signal is a 40 Gbps pulse train at 1 550 nm with 1.5 ps pulse-width. To realize the format conversion, the format conversion system as shown in Fig. 1 is used to convert RZ to NRZ at 40 Gbps. The eye diagram of NRZ signal is shown in Fig. 2(b). As shown in Fig. 2, using the simulation scheme can realize the optical format conversion from RZ to NRZ.

Table 1 The parameters used in experiment

Parameter	Value
Wavelength of signal pulse/nm	1 562.57
Wavelength of probe light/nm	1 556.12
Bit rate/(Gb • s^{-1})	40
Injected current I/mA	320
Bandwidth of the fliter/nm	0.3
Small signal gain/dB	30
Saturation output/dBm	6
Gain peak wavelength/nm	1 560
3dB spectrum bandwidth/nm	50
Saturated gain recovery time/ps	25
The carrier recovery time/ps	53

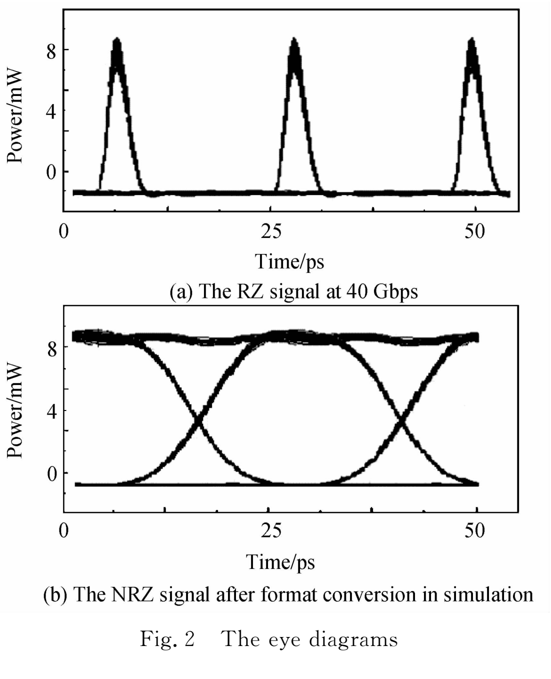

Fig. 2 The eye diagrams

To further study optical format conversion, the experimental setup which is shown in Fig. 1 is used to test and prove the simulation results. Fig. 3 presents the experimental results of the format conversion. Fig. 3(a) shows the eye diagram of the RZ signal at 40 Gbps. In our experiment, the RZ signal is 40 Gbps pulse train at 1 562.57 nm with 1.5 ps pulse-width. Then the 40 Gbps optical RZ signal and the probe light whose central wavelength is 1 556.12 nm pass the power combiner, and then are launched into the SOA. The RZ signal and the probe light achieve sufficiently, the XGM and the XPM effect induce spectral broadening. The input power of the signal and probe light can be adjusted by the EDFA and the VA. The subsequent OBPF then extract the spectrum with its central wavelength about 1 556 nm. The eye diagram of the NRZ is shown in Fig. 3(b). The converted NRZ signals show clear and open eyes, with some little ripples on the ground, which are caused by the carrier recovery process. No additional noise and pattern effect can be found.

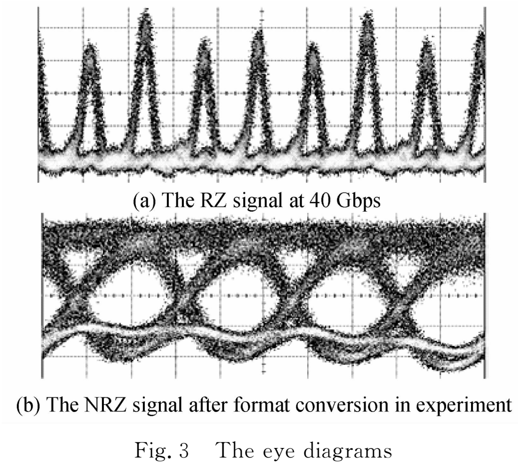

Fig. 3 The eye diagrams

The spectra of the input RZ signal and the converted NRZ signal are shown and analyzed in Fig. 4. Fig. 4(a) are spectra of the input RZ signal whose central wavelength is 1 562.57 nm and probe light whose central wavelength is 1 556.12 nm. From these spectra, we can see the spacing of the two wavelengths is 6.35 nm. When 40 Gbps RZ signal and probe light lunched into the SOA, the spectrum of the probe light will be broaden due to the XPM and XGM effects, as shown in Fig. 4(b). Then we adjust the center wavelength of the filter to 1 556 nm. Thus, the NRZ spectrum can be observed.

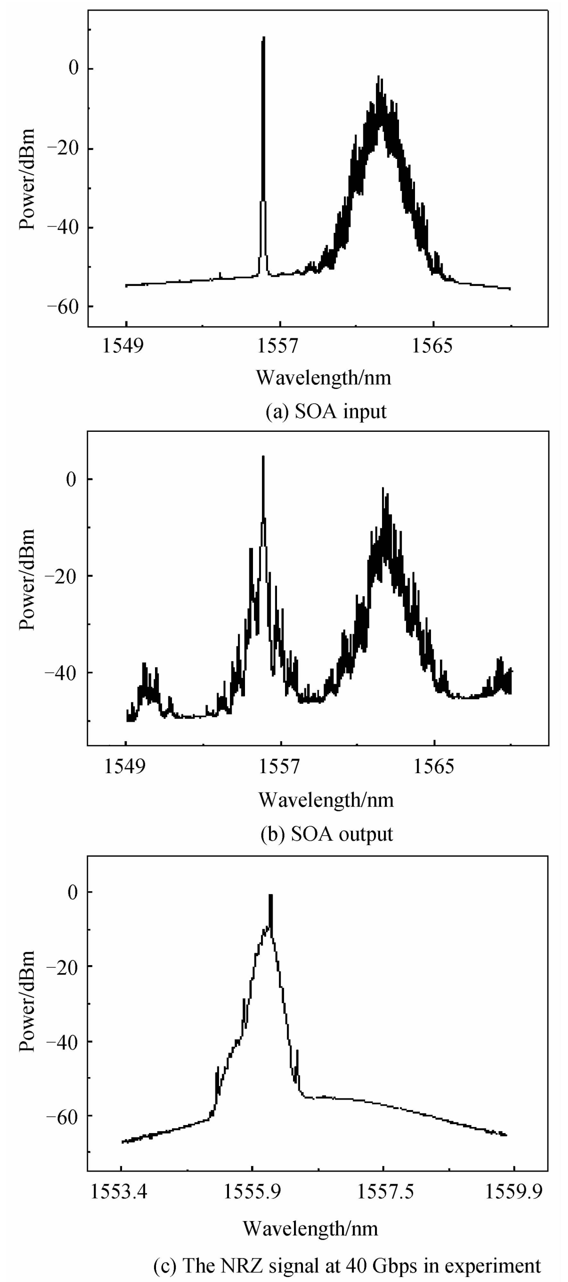

Fig. 4 The optical spectra

Fig. 5 shows the Bit Error Rate (BER) characteristics of the back to back and the optical conversion . Result shows that the power penalty

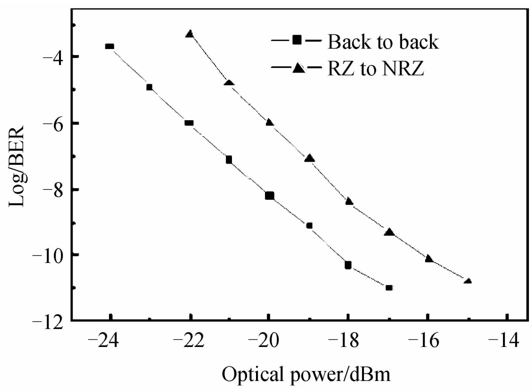

Fig. 5 BER curve of the format conversion

induced by the pattern converter is about 2 dB. Considering the sensitivity difference between RZ and NRZ signals of BER test system, the power penalty is very small.

3 Conclusions

We have successfully demonstrated a high performance RZ to NRZ data format conversion at 40 Gbps using a SOA. An average power penalty of less than 2 dB could be achieved. The experimental results presented that RZ to NRZ at 40 Gbps using SOA have high performance for application to future optical networks.

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