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Wavelength-adjustable all-optical wavelength conversion using a tunable fiber laser and an electroabsorption modulator

Chih-Lung Tseng[1], Ya-Wen Lin[1, 2, 3], Po-Jui Ching[1*], Yuang-Tung Cheng[1],
Jau-Ji Jou[1], Cheng-Kuang Liu[1]

[1] Department of Electronic Engineering, National Kaohsiung University of Applied Sciences,
No. 415, Chien-Kung Rd., Sanmin District, Kaohsiung City 807, R.O.C.

[2] Compulsory Education Advisory Group, Education Bureau, Kaohsiung City Government,
No. 1, Tzu-Yu 3st Rd., Zuoying District, Kaohsiung City 813, Taiwan, R.O.C.

[3] Tzukuan Junior High School, Education Bureau, Kaohsiung City Government,
No. 71, Chung-Hsueh Rd., Tzukuan District, Kaohsiung City 826, Taiwan, R.O.C.

[*] Corresponding author: pjchiang@kuas.edu.tw

A wavelength conversion scheme is presented experimentally using a wavelength tunable erbium-doped fiber laser as a probe light source and an electroabsorption modulator with a DC bias only. For the input wavelength of 1557 nm with a 10-Gb/s non-return to zero signal, the Q value is 10.6 and the power penalty is less than 1.5 dB at a bit error rate of 10^{-9} at the probe wavelength of 1560 nm. Given a fixed Q value of 6, probe wavelengths cover a range of 25 nm. Furthermore, the relationship between the range of probe wavelength and the amount of power penalty is also investigated.

Keywords: wavelength conversion, fiber ring lasers, erbium-doped fiber, electroabsorption modulator, wavelength division multiplexing (WDM) network.

1. Introduction

In wavelength division multiplexing (WDM) distribution networks, a large burst of traffic at a routing node and contention among wavelength channels may cause problems [1]. The conflict of signal wavelengths between optical networks may be precluded by the wavelength conversion at the routing nodes. Different techniques have been proposed for the wavelength conversion, such as cross-gain modulation (XGM) [2], cross-phase modulation (XPM) [3], cross-polarization modulation (CPM) [4], and four-wave mixing (FWM) [5] in semiconductor optical amplifiers (SOAs). However, using SOAs for wavelength conversion would generate excess amplified spontaneous emission (ASE) noise. ASE noise is usually larger than other noises such as shot noise and thermal noise, and is the dominant cause of power penalty in wavelength conversion. Another technique for the wavelength conversion is using cross-absorption modulation (XAM) in an electroabsorption modulation (EAM). It has the advantages in high-speed conversion, low-chirp characteristics, and keeping the same polarity [6].

Many researches have focused upon the voltage bias, input optical power, and wavelength range of the EAMs [6–9]. One attractive feature is the effect of probe light source on the wavelength conversion. Most of the probe light sources used in previous studies are semiconductor laser diodes, but its wavelength tuning scheme is rather complicated. Although a commercial tunable semiconductor laser source (TSLS) has a large wavelength tuning range, it is generally expensive for light source applications. Another option is tunable fiber lasers. It is superior to semiconductor laser diodes in the compatibility with fiber-based components, its narrow line-width (as narrow as a 2 kHz [10]), low-intensity noise characteristics, and more affordable than TSLS instruments. A tunable fiber ring laser has narrow longitudinal mode-spacing owing to a long-length cavity. However, it is generally difficult to control the lasing frequency in a fiber laser compared to a semiconductor laser diode, because the lasing frequency fluctuates easily due to laser instability or environmental variation [11]. The instability and laser quality issues are essential to signal transmissions. This difficulty can be overcome using our erbium-doped fiber lasers [12].

Some tunable wavelength conversion applications have been reported [13, 14]. Using FWM in a semiconductor-fiber ring cavity, a 1 Gb/s tunable wavelength conversion is achieved by Lu *et al.* [13]. Using a mode-locked fiber in a periodically poled lithium niobate fiber ring cavity, a 40 Gb/s wavelength conversion can be achieved by Wang *et al.* [14]. The tunable erbium-doped fiber laser (T-EDFL) with an SOA noise suppresser can generate a single-frequency light, and its wavelength can be tuned easily through an optical tunable filter (OTF) [15]. Therefore, this T-EDFL will be suitable to be used as a probe light source in wavelength conversion applications. In this letter, we use the T-EDFL as a probe light, a distribution feedback (DFB) laser as a signal light, and an EAM as a wavelength conversion device to achieve the 10 Gb/s non-return to zero (NRZ) wavelength conversion applications.

2. Experimental setup

Figure 1 shows the experimental setup of all-optical wavelength conversion using the EAM and T-EDFL. The T-EDFL is composed of an erbium-doped fiber (EDF), an OTF, an optical polarization controller (OPC), an SOA, two optical isolators (OIs), a 980 nm pump laser, and an output coupler [12, 15]. In our experiment, the DFB laser was externally modulated by an electrooptical modulator (EOM) with a 10 Gb/s NRZ ($2^{31} - 1$) pseudo-random binary sequence (PRBS) from a pulse pattern generator (PPG). An erbium-doped fiber amplifier (EDFA) was used to amplify the input light which was introduced into a commercial EAM through an optical circulator (OC). The T-EDFL was fed into the opposite side of the EAM modulator as the probe light. In this way, the probe light will experience the same modulated absorption pattern as the input data

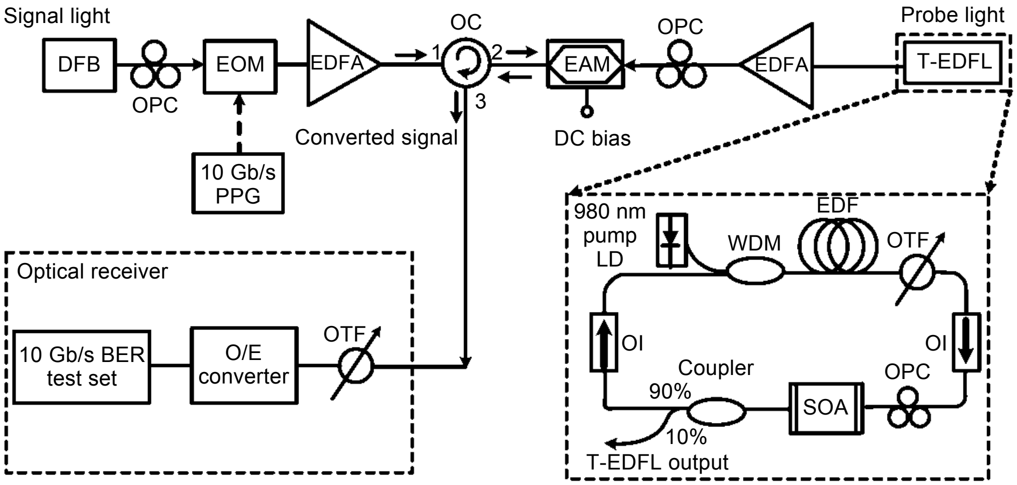

Fig. 1. Experimental setup for all-optical wavelength conversion. DFB – distributed feedback laser, EOM – electrooptical modulator, EDFA – erbium-doped fiber amplifier, OC – optical circulator, EAM – electro-absorption modulator, OPC – optical polarization controller, T-EDFL – tunable erbium-doped fiber laser, PPG – pulse pattern generator, BER – bit-error-rate, OTF – optical tunable filter, WDM – wavelength division multiplexing, EDF – erbium-doped fiber, OI – optical isolation, SOA – semiconductor optical amplifier [12, 15].

signal, and hence, the intensity of the outgoing probe light will be a replica of the input signal (*i.e.*, the logic polarity is kept the same). Owing to the XAM of the input signal light and the probe light inside the EAM, a wavelength converted signal was coming out of the EAM and going into the OC. After noise filtering, signal amplifying, the wavelength converted signal was passing and fed into a digital communication analyzer (DCA) and a bit-error-rate (BER) tester for performance evaluation.

Considering the potential applications of fiber laser in fiber-based systems, we carried out wavelength conversion experiments for the fiber lasers using EDF. It was demonstrated that the wavelength conversion can be accomplished by using fiber lasers. In the setup, the EAM is reverse-biased at –1 V and the power of a pump laser is 55 mW using a 980 nm pump laser for all cases. The measured wavelength of the signal light is 1557 nm and the seven probe lights are 1535 to 1565 nm with a 5 nm spacing. The input average power to the EAM modulator of the signal light and probe light of each channel are 12 and 0 dBm, respectively.

3. Results and discussion

Figure 2 shows the measured Q value (filled square key) and extinction ratio (empty circle key) after wavelength conversion for different probe wavelengths. The insets show typical eye diagrams for both 1557 and 1560 nm wavelengths. Generally, when the Q value is above 6 at a BER of 10^{-9}, the range of converted probe wavelength is 25 nm. The Q value and extinction ratio are 12.4 and 12 dB, respectively, for the back-to-back

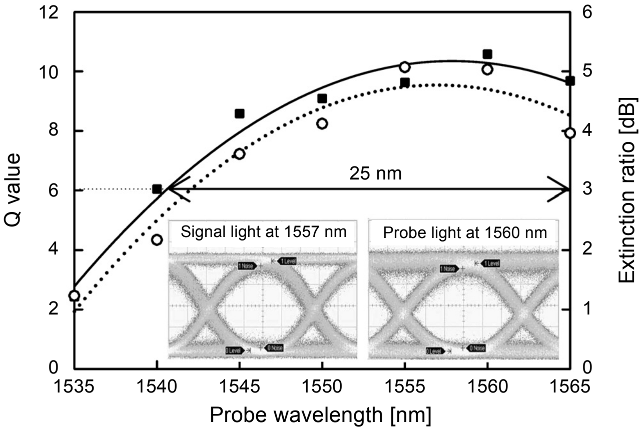

Fig. 2. Q value and extinction ratio as functions of probe wavelengths. Insets indicate typical eye patterns for the input at 1557 nm and the probe wavelength at 1560 nm.

transmission for the input wavelength. For the converted probe wavelength, they are 10.6 and 5.0 dB, respectively. The Q value was improved as the probe wavelength getting closer to the input signal wavelength.

Figure 3 shows BER performance *versus* received optical power for 10 Gb/s NRZ data wavelength conversion, employing a DFB signal laser light at a wavelength of 1557 nm and a T-EDFL probe light at wavelengths of 1545, 1550, 1560, and 1565 nm. The power penalties at a BER of 10^{-9} are 1.5, 3.0, 4.0, and 6.0 dB for the probe wavelengths of 1560, 1550, 1565, and 1545 nm, respectively. Nevertheless, our results indicate that the T-EDFL can be a potential candidate for wavelength conversion light source.

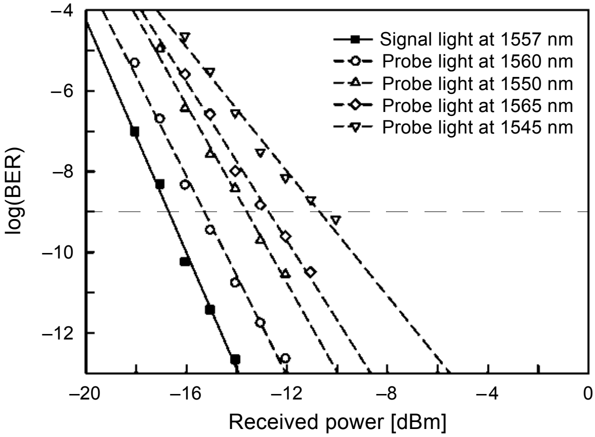

Fig. 3. BERs for 10 Gb/s NRZ signal transmissions at the input wavelength of 1557 nm and several probe wavelengths.

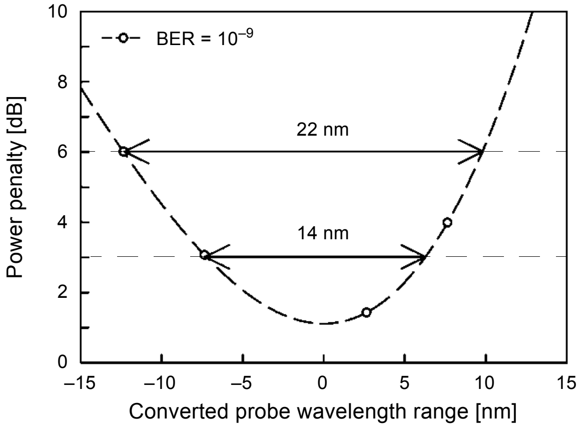

Fig. 4. Relationship between the range of probe wavelength and power penalty at a BER of 10^{-9}.

We have also investigated the relation between the power penalty and the range converted probe wavelength for a signal transmission at 10 Gb/s. Figure 4 shows power penalties at a BER of 10^{-9} *versus* the range of converted probe wavelength. When the power penalties are 3 and 6 dB, the range of converted probe wavelength is 14 and 22 nm, respectively.

4. Conclusions

We have successfully demonstrated a novel 10 Gb/s NRZ all-optical wavelength conversion employing a T-EDFL as a probe light, a DFB semiconductor laser as a signal, and an EAM light to form a hybrid light source wavelength conversion. Difficulties in wavelength conversion due to an instability problem of fiber lasers in all-optical WDM networks are overcome. The T-EDFL has a converted wavelength range of 30 nm in the C-band. For the input wavelength of 1557 nm with a 10-Gb/s NRZ signal, the Q value is 10.6 and the power penalty is less than 1.5 dB at a BER of 10^{-9} at the probe wavelength of 1560 nm. The range of converted probe wavelength is 22 nm and is obtained for the power penalty 6 dB. It may apply to wavelength conversion between subnetworks to subnetworks when the wavelengths are in clashes. Moreover, it is wavelength tunable and can be also applied to dynamic wavelength assignment.

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