ABSTRACT

We proposed and experimentally demonstrated that wideband tunable wavelength conversion can be performed by using only 1.9 meter of bismuth-based highly-nonlinear fiber in optical loop mirror configuration (Bi-NOLM). Both inverted and non-inverted wavelength conversion of NRZ-formatted signal at 10 Gb/s were carried out. The range of wavelength conversion is 56 nm. No stimulated Brillouin scattering (SBS) suppression scheme was required to reduce the reflection problem in the loop due to the high SBS threshold of the fiber. The bit error rate of the wavelength converter is also measured.

Keywords: Bismuth based fiber, wavelength conversion, optical signal processing, nonlinear optical loop mirror (NOLM)

1. INTRODUCTION

Wavelength conversion is one of the basic elements required in high speed wavelength division multiplexing (WDM) transmission and network systems. All-optical wavelength conversion techniques are attractive because they do not require optical-electrical-optical (o-e-o) conversion. All-optical wavelength conversion based on cross gain modulation (XGM) in semiconductor optical amplifier (SOA) [1], four-wave mixing (FWM) in highly nonlinear fiber [2], cross-absorption modulation in electro-absorption modulator (EAM) [3], and cross phase modulation (XPM) in Mach-Zehnder interferometer (MZI) [4] and nonlinear optical loop mirror (NOLM) [5] have been proposed and demonstrated. Semiconductor-based [6] NOLMs are compact but their processing speed is slow compared with fiber-based NOLMs. Fiber-based NOLMs on the other hand are bulky because of the long length of fiber typically required. The use of bismuth-based fiber which has a nonlinear coefficient $\gamma = 1000 \text{ W}^{-1}\text{km}^{-1}$ can significantly reduce the length of the NOLMs. The walk-off due to dispersion is negligible because of the short length of fiber used. Recently, a number of optical signal processing experiments using bismuth-based fiber has been demonstrated [7]-[11]. In this paper, we proposed and demonstrated wavelength conversion by using bismuth fiber based NOLM.

2. OPERATING PRINCIPLE

Figure 1 shows the schematic of the Bi-NOLM. If the control signal at wavelength $\lambda_c$ is not input to the loop, the continuous-wave (CW) probe signal at wavelength $\lambda_s$ will be reflected back to the input port. If the control signal is present, XPM will occur between the control signal and the co-propagating probe signal. If the power of control signal is sufficiently strong enough, an additional $\pi$ phase shift will be induced in the co-propagating probe signals. The probe signal will therefore exit through the output port upon recombination at the input coupler. The power requirement of the control signal is given in [12] as:

$$P_c = \frac{1}{2} P_s [1 - \cos(2\gamma P_s L)]$$

where $P_c$ is the output power in wavelength $\lambda_c$, $P_s$ is the probe signal power, $P_c$ is the control signal power and $L$ is the loop length. For a 1.9 meter long bismuth-based fiber with $\gamma = 1000 \text{ W}^{-1}\text{km}^{-1}$, the minimum power required to achieve maximum output power is 0.826 W if there are no propagation loss in the fiber and splicing loss. For the bismuth-based fiber we have used, the propagation loss is 2.0 dB/m and the total splicing loss is 3 dB. The high splicing loss is due to the mismatch of the core diameter between the bismuth-based fiber and the ultra-high numerical aperture (UHNA) fiber, which is used as an intermediate fiber between bismuth-based fiber and single mode fiber. The dispersion coefficient $D$ of the bismuth-based fiber is $-280 \text{ ps/nm/km}$. No significant walk off effect and dispersion effect is resulted in using only 1.9 meter long bismuth-based fiber.
3. EXPERIMENTAL SETUP

In Fig. 1, the 10 Gb/s input non-return-to-zero (NRZ) bits pseudorandom control signal is prepared by externally modulating a tunable laser diode (TL_1) output with a LiNbO₃ modulator driven by a 10 Gb/s NRZ pulse pattern generator at wavelength 1550 nm. The NRZ signal is then amplified by a 27-dBm high power erbium-doped fiber amplifier (EDFA) and launched into the Bi-NOLM through a 3-dB coupler. The average and the peak power of the amplified control signal are 27 dBm and 2.3 W, respectively. Another tunable laser diode (TL_2) is used to generate the CW light. The range of wavelength used in this tunable laser is from 1510 to 1580 nm. This CW probe signal is amplified by a 13-dBm EDFA to enhance the extinction ratio at the output port. The CW is then launched into the NOLM through a 3-dB coupler. Polarization controllers are used to control the state of polarizations of both the control signal and the probe signal before entering into the loop mirror. The loop consisted of a 1.9 meter long bismuth-based fiber and a polarization controller. The bismuth-based fiber served as the nonlinear medium. The polarization controller inside the loop is used to control which output port through which the light exit the NOLM in the absence of the control signal [13]. Non-inverted and inverted probe signal can be obtained by adjusting the polarization controller inside the NOLM. The output is filtered using a tunable bandpass filter with a 3-dB bandwidth of 1.5 nm.

4. RESULTS AND DISCUSSION

The temporal diagrams in the input and output port are as shown in Fig. 2. The upper trace is the original control signal at 1549.72 nm, the middle trace and the bottom trace are the non-inverted and inverted converted probe signal at 1544.73 nm respectively. The non-inverted and inverted signal was obtained by adjusting the polarization controller in the loop. All of the three temporal diagrams used the same vertical and horizontal scale. The signal-to-noise ratio (SNR) penalty is due to the EDFA. The wavelength spectrum of the converted signal after the bandpass filter with 0.01 nm resolution is shown in Fig. 3. The bandpass filter with bandwidth of 1.5 nm suppressed the control signal over 50 dB. Figure 4 shows the bit error rate measurement (BER). The power penalty between the converted signal at 1544.73 nm and the back-to-back measurement at 1549.72 nm at BER=10⁻⁹ is measured to be 0.5 dB. Figure 5 plots the extinction ratio of the wavelength converted signal with wavelength while the control wavelength is fixed at 1549.72 nm and the wavelength of the probe signal varies from 1517 nm to 1580 nm. The 3-dB bandwidth of the wavelength converter is reach 56 nm. Figure 6 shows the dependence of the extinction ratio of the converted signal as a function of the pump power of the EDFA. We observed that the extinction ratio of the converted signal increases with the increases in the pump power of the EDF which agrees with Eq. (1). Because of the coupling loss, insertion loss and propagation loss, the maximum pump power used in the experiment has not
yet reached the optimal point for a \( \pi \) phase shift. The extinction ratio can be further enhanced if higher power of control signal is used for wavelength conversion.

5. CONCLUSION

We proposed and demonstrated that a 56 nm wideband tunable wavelength conversion by using only 1.9 meter long bismuth-based fiber in a nonlinear optical loop mirror (Bi-NOLM). Wavelength conversion of both inverted and non-inverted NRZ signal at 10 Gb/s can be performed. No SBS suppression scheme was required to reduce the reflection problem in the loop due to the high SBS threshold of the bismuth-based fiber. The performance of the Bi-NOLM can be improved by increasing the control signal power.

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7. REFERENCES


