Journal of the Optical Society of Korea
Vol. 12, No. 4, December 2008, pp. 244-248

DOI: 10.3807/JOSK.2008.12.4.244

Performance Evaluation of A Tunable Dispersion Compensator based on Strain-Chirped Fiber Bragg Grating in a 40 Gb/s Transmission Link

Chul Han Kim*

School of Electrical and Computer Engineering, University of Seoul 13 Siripdae-gil, Dongdaemun-gu, Seoul 130-743, Korea

Junkey Bae, Kwanil Lee, and Sang Bae Lee

Photonics Research Center, Korea Institute of Science and Technology (KIST) 39-1 Hawolgok-dong, Seongbuk-gu, Seoul 136-791, Korea

(Received September 9, 2008 : revised October 22, 2008 : accepted October 22, 2008)

We have evaluated the performance of strain-chirped fiber Bragg grating (FBG) based tunable dispersion compensator in a 40 Gb/s transmission link. In our proposed compensator, the value of dispersion could be changed from -353 ps/nm to -962 ps/nm by adjusting the rotation angle of the metal beam on which the FBG was mounted. In order to evaluate the effect of ripples in reflectivity and variations in passband of the FBG based dispersion compensator, transmission performance has been measured with our tunable dispersion compensator. Error-free transmission of a 40 Gb/s non-return-to-zero (NRZ) signal over conventional single-mode fiber (SMF) was achieved.

Keywords : Dispersion compensation, Fiber Bragg grating

OCIS codes : (060.2330) Fiber optics communications; (060.3735) Fiber Bragg gratings; (060.2340) Fiber optics components

I. INTRODUCTION

Chromatic dispersion-induced pulse distortion is one of the main limiting factors on the performance of high-speed transmission systems operating at 40 Gb/s and beyond [1]. To resolve this problem, various types of tunable optical dispersion compensators using different technologies, such as a chirped fiber Bragg grating (FBG), an all-pass multicavity etalon, arrayed-waveguide grating, a Mach-Zehnder interferometer and a planar lightwave circuit lattice-form filter, have been proposed and demonstrated [1-5]. Among them, the chirped FBG based tunable dispersion compensator is an attractive solution for the dispersion management in high-speed optical transport networks, since it can provide high dispersion, wide passband for high bit-rate applications and wide tunability [1, 6-8]. However, it has been reported that the ripples in amplitude and phase response of a chirped FBG could affect the transmission system's performance [9-10]. Therefore, the system's performance should be evaluated for the feasibility demonstration of FBG based tunable dispersion compensators. Previously, we have proposed and demonstrated a novel tunable dispersion compensator based on a strain-chirped FBG [8]. The value of dispersion in our compensator could be changed by simply adjusting the rotation angle of the metal beam on which the FBG was mounted. In this paper, we evaluate the performance of our tunable dispersion compensator in a 40 Gb/s non-return-to-zero (NRZ) signal transmission link, in order to demonstrate the feasibility of our compensator which has some ripples in amplitude and phase response of the chirped FBG. Error-free transmission with a proper extraction of clock signal is readily achieved with our tunable dispersion compensator for a 40 Gb/s NRZ signal.

*Corresponding author: chkim@uos.ac.kr

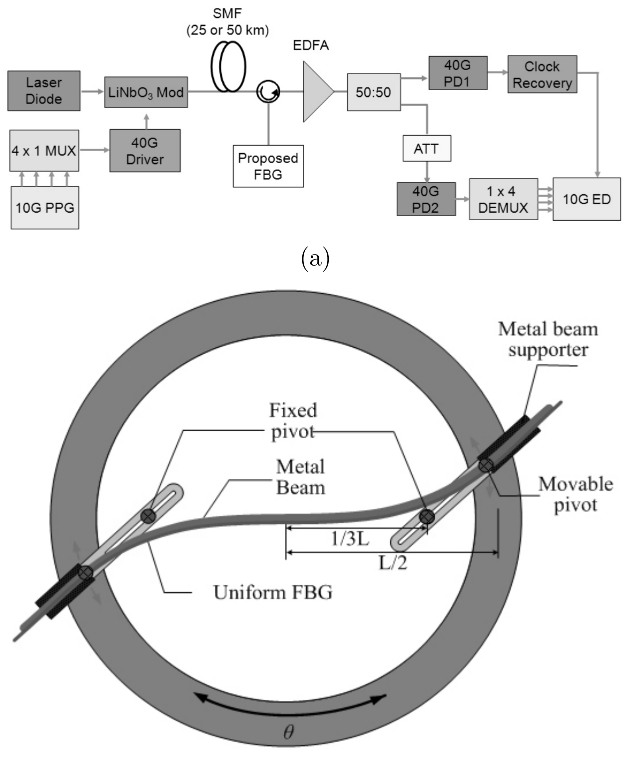

FIG. 1. Experimental setup for performance evaluation in a 40 Gb/s transmission link (b) schematic diagram of the proposed FBG-based tunable dispersion compensator.

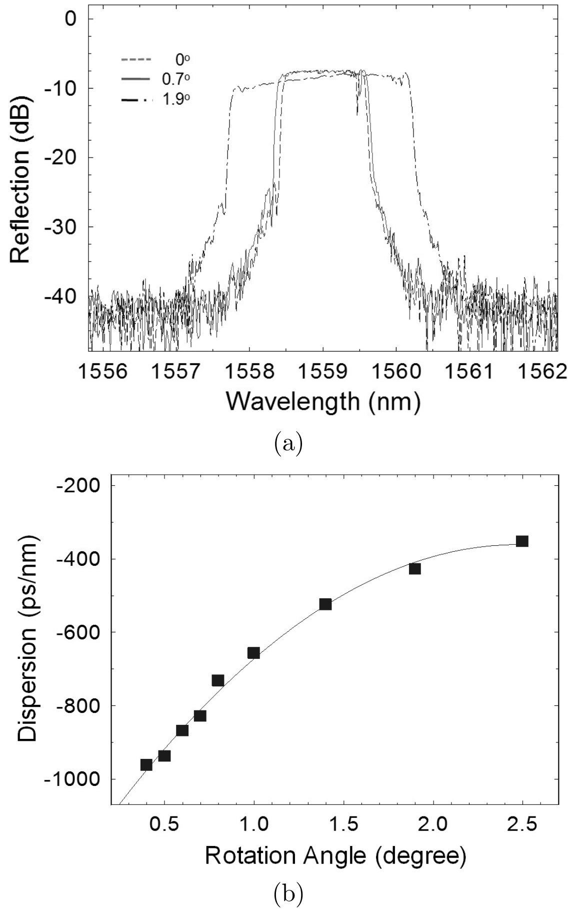

FIG. 2. Characteristics of our strain-chirped fiber Bragg grating based tunable dispersion compensator (a) reflection spectra and (b) dispersion measured as a function of rotation angle.

II. RESULTS AND DISCUSSION

Fig. 1(a) shows the experimental setup for performance evaluation of our tunable dispersion compensator. A 40 Gb/s electrical signal was generated by using a 4:1 multiplexer (MUX) which had four input ports for 10 Gb/s electrical signals and one output port for a 40 Gb/s signal. A pulse pattern generator (PPG) was used to generate four 10 Gb/s electrical signals with pseudo random bit sequence length of 2^{23}-1. After passing through a 40 Gb/s driver, this multiplexed 40 Gb/s electrical signal was launched into a $LiNbO_3$ external modulator for the generation of a 40 Gb/s NRZ optical signal. An external cavity laser operating at 1559 nm was used as an optical signal source. After transmission over 25 or 50 km of conventional single-mode fiber (SMF), a 40 Gb/s optical signal was launched into our tunable dispersion compensator based on a strain-chirped FBG. The proposed tunable dispersion compensator was implemented with a rotation stage, a metal beam plate, two metal beam supporters and four pivots as shown in Fig. 1(b). An FBG was mounted on a metal beam which was clamped on two metal supports. By adjusting two movable pivots with the rotation stage, the metal beam could be bent into an S-shape. Therefore, in our tunable dispersion compensator, S-bending induced chirp could change the dispersion value of FBG. It has been well known that the amount of strain induced by S-bending on FBG is proportional to the rotation angle of a metal beam. Thus, the dispersion value of our FBG based compensator could be calculated by using an Eq. (4) in [8]. The dispersion compensated optical signal was amplified by using an erbium-doped fiber amplifier (EDFA), as it can be seen in Fig. 1(a). Then, the amplified signal was split into two 40 Gb/s optical signals. One of two signals was used for the extraction of the clock signal and the other for data recovery.

At first, the characteristics of our FBG based compensator were measured as a function of rotation angle. Fig. 2(a) shows the reflection spectra of our tunable dispersion compensator measured at two different rotation angles. For comparison, the reflection spectrum of the FBG without rotation was also represented in Fig. 2 (a). As the rotation angle was increased, the 3-dB passband and insertion loss of the FBG were also increased. At the rotation angle of 0.7°, the center wavelength and the

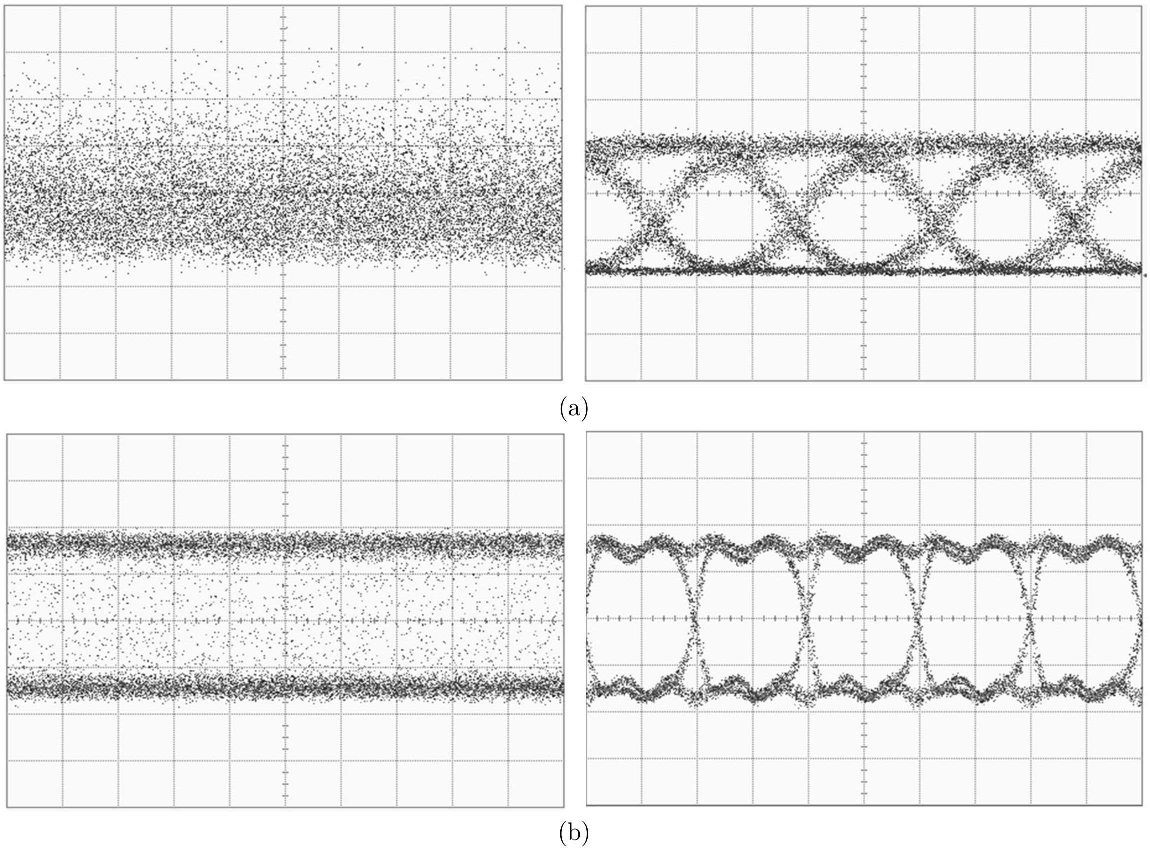

FIG. 3. Measured eye diagrams without (left-side) and with (right-side) using a proposed dispersion compensator after 25 km SMF transmission (a) 40 Gb/s optical eyes and (b) demultiplexed 10 Gb/s electrical eyes.

3-dB passband of the FBG were measured to be 1559 nm and 1.2 nm, respectively. By adjusting the rotation angle to be 1.9°, the 3-dB passband was increased to be 2.5 nm. However, the center wavelength of the FBG remained constant. Thus, in both cases, passbands of the FBG were wide enough for a 40 Gb/s NRZ signal transmission. Previously, it has been reported that the ripple in reflectivity spectra of the FBG based dispersion compensator should be less than 1.67 dB for <1-dB penalty in a 10 Gb/s NRZ transmission link [9]. As it can be seen in Fig. 2(a), the peak-to-peak amplitude deviation in reflectivity of our FBG was measured to be less than 1 dB in the wavelength range of 1558.5 nm to 1559.5 nm. The effect of this amplitude ripple in our FBG based compensator will be evaluated in BER measurements with a 40 Gb/s signal. Fig. 2(b) shows the dispersion values of our compensator measured as a function of rotation angle. The fitting curve of measured data was also plotted in Fig. 2(b). The dispersion value of our compensator can be changed from -353 ps/nm to -962 ps/nm by adjusting the rotation angle from 0.4° to 2.5°. This amount of negative dispersion can be used to compensate the dispersion of conventional SMF (~17 ps/nm/km) in the range of 21 to 56 km. In addition, it has been well known that the additional polarization-mode dispersion (PMD) and polarization-dependent loss (PDL) could be induced by S-bending of FBG [7]. Therefore, the polarization related effects need to be investigated for the application of our tunable dispersion compensator in high-speed transmission systems. As it can be seen in Fig. 2(b), the maximum rotation angle of our chirped FBG based dispersion compensator was to be less than 2.5°. With this small rotation angle, the PDL of our tunable dispersion compensator was measured to be less than 0.5 dB.

Fig. 3(a) shows the optical eye diagrams of 40 Gb/s NRZ signals measured after transmission of 25 km SMF without and with our compensator. In these measurements, the recovered clock signal from a clock recovery circuit was used for the trigger signal of digital communication analyzer. For 25 km SMF transmission case, the rotation angle was adjusted to be 1.9°, as shown in Fig. 2(b). Without using our compensator, we could not recover the clock signal at all. Therefore, it could not be possible to measure the eye diagram as shown in the left-side of Fig. 3(a). However, using a tunable dispersion compensator enabled us to obtain a clearly-opened eye of 40 Gb/s NRZ signal as shown in right-side of Fig. 3(a). Fig. 3(b) shows the electrical eye diagrams of one of four 10 Gb/s electrical signals measured after

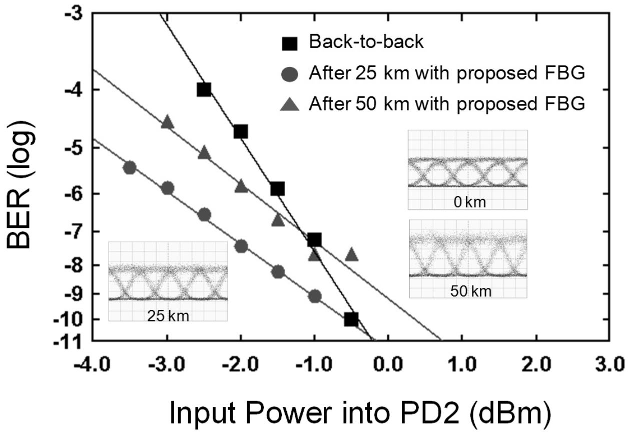

FIG. 4. Measured BER curves with a 40 Gb/s NRZ signal after 25 and 50 km SMF transmission. Insets represent the measured eye diagrams.

1:4 demultiplexer (DEMUX). From these measurements, we confirmed that our compensator could mitigate the effect of dispersion-induced pulse distortion. Thus, by using the proposed dispersion compensator, a clock signal could be extracted properly from a 40 Gb/s NRZ signal.

In order to confirm the feasibility of a 40 Gb/s NRZ signal transmission and data recovery with our tunable dispersion compensator, the bit-error-rate (BER) curves were also measured after transmission of 25 and 50 km SMF as shown in Fig. 4. The rotation angles of our compensator in 25 and 50 km transmission links were set to be 1.9° and 0.7°, respectively. Insets represent the optical eye diagrams of 40 Gb/s NRZ signal at each transmission link configurations. For comparison, a back-to-back transmission performance without SMF and our tunable dispersion compensator was also represented in Fig. 4. After 25 km SMF transmission, error-free transmission was obtained with a clearly-opened eye. Even though the slope of BER curve was slightly degraded, there was some improvement in BER performance as compared to back-to-back transmission. This was mainly because of a negative chirp of our LiNbO3 modulator [10]. For the case of 50 km SMF transmission, an error floor at BER of $\sim 10^{-8}$ was observed. We believe that both ripple in reflectivity spectrum and narrow passband of our FBG based compensator at 0.7° might contribute this BER floor at 50 km SMF transmission [10-11]. However, the proper data recovery could be achieved by using a forward-error correction (FEC) scheme even with this level of BER floor. From these results, we confirmed that our tunable dispersion compensator could be used for the dispersion management in 40 Gb/s transmission systems, such as span dispersion compensation of non-zero dispersion shifted fiber (NZ-DSF) link and dispersion trimming for demultiplexed high bit-rate signals. However, careful attention must be paid to ripples in reflectivity spectra and passband of FBG if excessive penalty is to be avoided in high bit-rate signal transmission systems with our proposed tunable dispersion compensator.

III. SUMMARY

We have evaluated the performance of a novel tunable dispersion compensator based on S-bending induced chirp in a 40 Gb/s transmission system. The dispersion level of our proposed tunable dispersion compensator could be changed from -353 ps/nm to -962 ps/nm by adjusting the rotation angle from 0.4° to 2.5°. In our transmission experiment, we confirmed that the clock signal could be extracted properly from the dispersion compensated data signal with our tunable dispersion compensator. Error-free transmission of a 40 Gb/s NRZ signal over SMF was also achieved even with the ripples in reflectivity spectra of our FBG-based tunable dispersion compensator. We believe that our compensator would be suited for use in dispersion management for high-speed transport networks.

ACKNOWLEDGMENT

This work was supported by High-Tech Instrument Grant which was funded by the University of Seoul in 2007.

REFERENCES

[1] G.-Y. Kim, S.-J. Park, and K.-T. Jeong, “Comparison with dispersion compensation scheme using 10 Gbit/s × 40 Channels wavelength division multiplexing transmission over 323 km of field installed non-zero dispersion shift fiber,” *J. Opt. Soc. Korea*, vol. 10, no. 3, pp. 112-117, Sep. 2006.

[2] D. J. Moss, M. Lamont, S. McLaughlin, G. Randall, P. Colbourne, S. Kiran, and C. A. Hulse, “Tunable dispersion and dispersion slope compensators for 10 Gb/s using all-pass multicavity etalons,” *IEEE Photon. Technol. Lett*, vol. 15, no. 5, pp. 730-732, May 2003.

[3] T. Suzuki, K. Masuda, H. Tsuda, R. Inohara, H. Takahashi, H. Ishikawa, Y. Abe, S. Kashimura, and H. Uetsuka, “Dispersion compensation experiments of 40 Gbit/s NRZ signal using arrayed-waveguide grating based dispersion compensator,” in Proc. European Conference on Optical Communication (ECOC2005), Paper Th.1.5.1, Galsgow UK, Sep. 2005.

[4] C. R. Doerr, S. Chandrasekhar, and L. L. Buhl, “Tunable optical compensator with increased bandwidth via connection of a Mach-Zehnder interferometer to an arrayed-waveguide grating,” *IEEE Photon. Technol. Lett*, vol. 20, no. 8, pp.560-562, Apr. 2008.

[5] J. Takiguchi, H. Takahashi, and T. Shibata, “Tunable

chromatic dispersion slope compensator using a planar lightwave circuit lattice form filter," *Opt. Lett.*, vol. 33, no. 11, pp. 1243-1245, Jun. 2008.

[6] C. S. Goh, S. Y. Set, and K. Kikuchi, "Design and fabrication of a tunable dispersion-slope compensating module based on strain-chirped fiber Bragg gratings," *IEEE Photon. Technol. Lett*, vol.16, no. 2, pp.524-526, Feb. 2004.

[7] J. Kwon and B. Lee, "Dispersion tuning of a chirped fiber Bragg grating using a multisectional bending structure," *IEEE Photon. Technol. Lett*, vol. 17, no. 2, pp. 408-410, Feb. 2005.

[8] Y. J. Lee, J. Bae, K. Lee, J.-M. Jeong, and S. B. Lee, "Tunable dispersion and dispersion slope compensator using strain-chirped fiber Bragg grating," *IEEE Photon. Technol. Lett*, vol. 19, no. 10, pp. 762-764, May 2007.

[9] K. Ennser, M. Ibsen, M. Durkin, M. N. Zervas, and R. I. Laing, "Influence of nonideal chirped fiber Bragg grating characteristics on dispersion cancellation," *IEEE Photon. Technol. Lett*, vol. 10, no. 10, pp. 1476-1478, Oct. 1998.

[10] N. Cheng and C. Cartledge, "Power penalty due to the amplitude and phase response ripple of a dispersion compensating fiber Bragg grating for chirped optical signals," *J. Lightwave Tech.*, vol. 24, no. 9, pp. 3363-3369, Sep. 2006.

[11] A. E. Willner, "SNR analysis of crosstalk and filtering effects in an amplified multichannel direct-detection dense-WDM system," *IEEE Photon. Technol. Lett*, vol. 4, no. 2, pp. 186-189, Feb. 1992.