Dispersion Compensation of 30GBaud/s NRZ and PAM4 data using integrated Silicon Nitride Gratings

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Abstract: Dispersion compensation is demonstrated using on-chip Silicon Nitride Bragg Gratings. Impaired 30GBaud/s NRZ and PAM4 eye diagrams are restored and a power penalty improvement of 1.3dB at a Bit Error Rate of 10^{-12} is achieved.

1. Introduction

Transceiver companies serving data centers, core/metro markets are opting for higher order Pulse Amplitude Modulation (PAM) to scale up data rates. PAM utilizes Intensity Modulation and Direct Detection (IMDD) scheme, offering cost, power and latency advantages compared to coherent detection. The lowest order PAM is PAM-2 (2 levels), commonly known as Non-Return-Zero (NRZ). Higher order PAM refers to PAM4 (4 levels) and above. PAM signals are susceptible to degradation from optical fiber dispersion, with the extent of degradation worsening with longer fiber reaches. Without proper dispersion compensation, transmitted data will experience high Bit Error Rates (BER) at the receiver [1]. In this manuscript, we demonstrate a low loss, on-chip CMOS-compatible device providing dispersion compensation for 2km of single mode fiber, based on integrated Silicon Nitride transmission Bragg Gratings. This is suitable for transceiver products within the PSM4 (Parallel Single Mode 4 Channel) and CWDM4 (Coarse Wavelength Division Multiplexing 4 Channels) Multi Source Agreements where the fiber reach is 2km or less [2,3]. The device has very low insertion losses of 1±0.5 dB, providing a total dispersion of 31 ps/nm without the need for a circulator. High-speed data measurements showcase restoration of the eye diagram for 30 Gb/s NRZ and 60 Gb/s PAM4 data as well as a 1.3dB improvement in the power penalty induced by dispersion in a 2km fiber.

2. Device Design, Fabrication and Experimentation

Fig. 1(a) shows the schematic of the CMOS-compatible Silicon Nitride (SiN) grating with sinusoidally modulated sidewalls. The grating width is 1.5µm and the length is 4mm. The sidewall modulation amplitude on each side of the waveguide is 150 nm. The Bragg condition, $\lambda=2.n_{eff}.\Lambda$, governs the operating wavelength, λ, where n_{eff} is the effective index of the waveguide, Λ is the grating pitch. Cosine^2 apodization is implemented to minimize ripple in the transmission spectrum. Importantly, the mode of operation of the grating is in transmission and no circulator is required. The operating wavelength is very close to the grating stopband where the transmission is high and group index increases rapidly [4,5]. On the red- (blue-) side of the grating stopband, dispersion is large and normal (anomalous). Chirped gratings operating in reflection generate dispersion by distributing the Bragg wavelengths spatially along the grating length. In contrast, the mechanism generating dispersion in our device emerges from the interaction between the forward and propagating optical fields as a result of the artificial bandgap of the grating [6]. Standard single mode fibers possess a dispersion of 16ps/nm/km at 1550nm [7]. Consequently, normal dispersion of -32 ps/nm is needed to compensate for a fiber length of 2km.

The SiN Bragg grating is fabricated on 800 nm thick silicon nitride, deposited using low pressure chemical vapor deposition a thermal SiO_2 on a silicon substrate, followed by photolithography and etching. 2µm of SiO_2 is deposited as an upper cladding. The transmission spectra of the fabricated devices are measured using an amplified spontaneous emission source and optical spectrum analyzer as shown in Fig. 1(b). Gratings with Λ = 420 nm, 427 nm, 434 nm result in Bragg wavelength of 1532nm, 1554 nm and 1576 nm. The devices are terminated with inverse tapers, and transverse electric light is coupled in using lensed fibers. The insertion loss of the gratings is characterized to be 1 ± 0.5 dB. The group delay properties of the devices are measured using a dispersion analyzer and plotted in Fig. 1(c). On the red- (blue-) side of the grating stopband, it is observed that the group delay decreases (increases) rapidly as the wavelength increases, indicating normal (anomalous) dispersion. The re-side of the grating stopband is therefore the region to be used for dispersion compensation of single mode at the C- and L-bands. The extracted dispersion from the group delay vs. wavelength profile as shown in Fig. 1 (c) is -31 ps/nm, which is close to the required dispersion of 2 km of SMF dispersion (32 ps/nm).

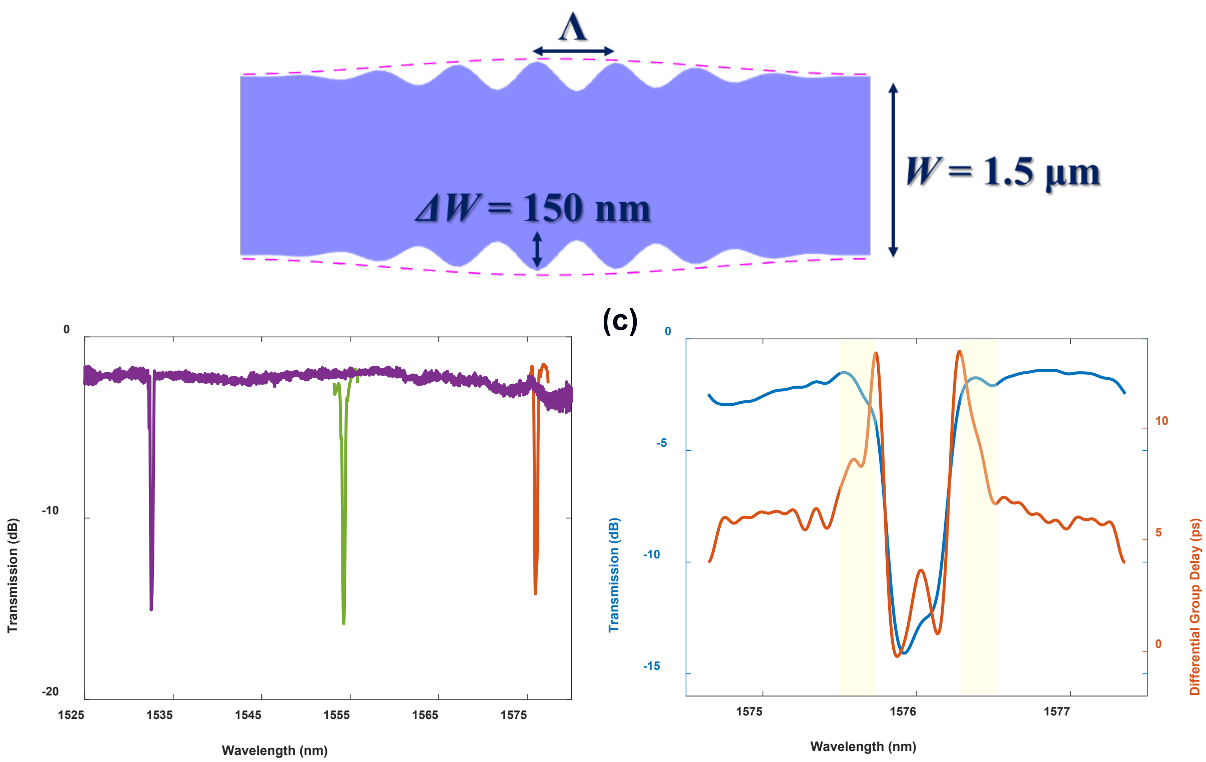

Figure 1 (a) Schematic of the silicon nitride grating device. Red dashed line denotes a raised cosine envelope profile. (b) Measured transmission spectrum of gratings with Λ = 420 nm (purple), 427 nm (green), 434 nm (yellow). (c) Measured transmission and Group Delay spectrum for a grating with a center wavelength of 1576 nm (Λ = 434 nm). The regions of high dispersion are highlighted in yellow.

3. Eye diagram and Bit Error Rate Characterization

High-speed measurements using 30GBaud/s NRZ and PAM4 data were done to study the device's performance in dispersion compensation. A Mach Zehnder Optical Transmitter modulates a Continuous Wave (CW) Laser operating at 1576.2nm using a PRBS31 patterns generated by a Pattern Generator from the Bit Error Rate Tester (BERT). The modulated output is then launched into a 2 km single mode fiber. The light is then adjusted for TE polarization before coupling into the SiN grating device for dispersion compensation. The device output is then fed into a photoreceiver for Optical-To-Electrical conversion. A digital sampling oscilloscope is used to characterize the eye diagram, as shown in Fig. 2 (a). After propagating in 2 km single mode fiber, eye closure is observed for both 30 Gb/s NRZ and 30 Gbaud/s PAM4 data. Upon undergoing dispersion compensation using the on-chip grating, the eye diagram is restored close to its original state before propagation in the 2km fiber.

Next, we characterize the BER. The output of the Photoreceiver is fed into the Receiver port of the BERT. The BER as a function of Received power without the 2km and without dispersion compensation is first measured to serve as a control experiment (black dots in Fig. 2 (b)). Next, we put insert the 2km fiber into the optical path, but without any dispersion compensation, and measure its BER (blue dots in Fig. 2 (b)). Finally, the dispersion compensation SiN gratings are added to the optical path using lensed fibers and the resulting BER is shown as the red dots in Fig. 2 (b). It is important to note that the total insertion loss from the output of the Optical Transmitter to the input of the Photoreceiver must be the same for all 3 measurements.

From Fig. 2 (b), we observe that the addition of the 2km fiber results in a power penalty of 1.2dB (A to B) and 1.8dB (D to E) at the forward error correction threshold (BER = 10^{-4}) and error-free operation (BER = 10^{-12}) respectively. When the SiN gratings are used in the optical path for dispersion compensation, the BER plot experiences a leftward shift, indicating that the power penalty from the fiber dispersion has been reduced. The measured power penalty improvement is 0.6dB and 1.3dB for at the Forward Error Correction (FEC) level (B to C) and error-free level (E to F) respectively. This means that the SiN dispersion compensation can ameliorate impairments at the error-free regime, potentially bypassing any need for FEC correction.

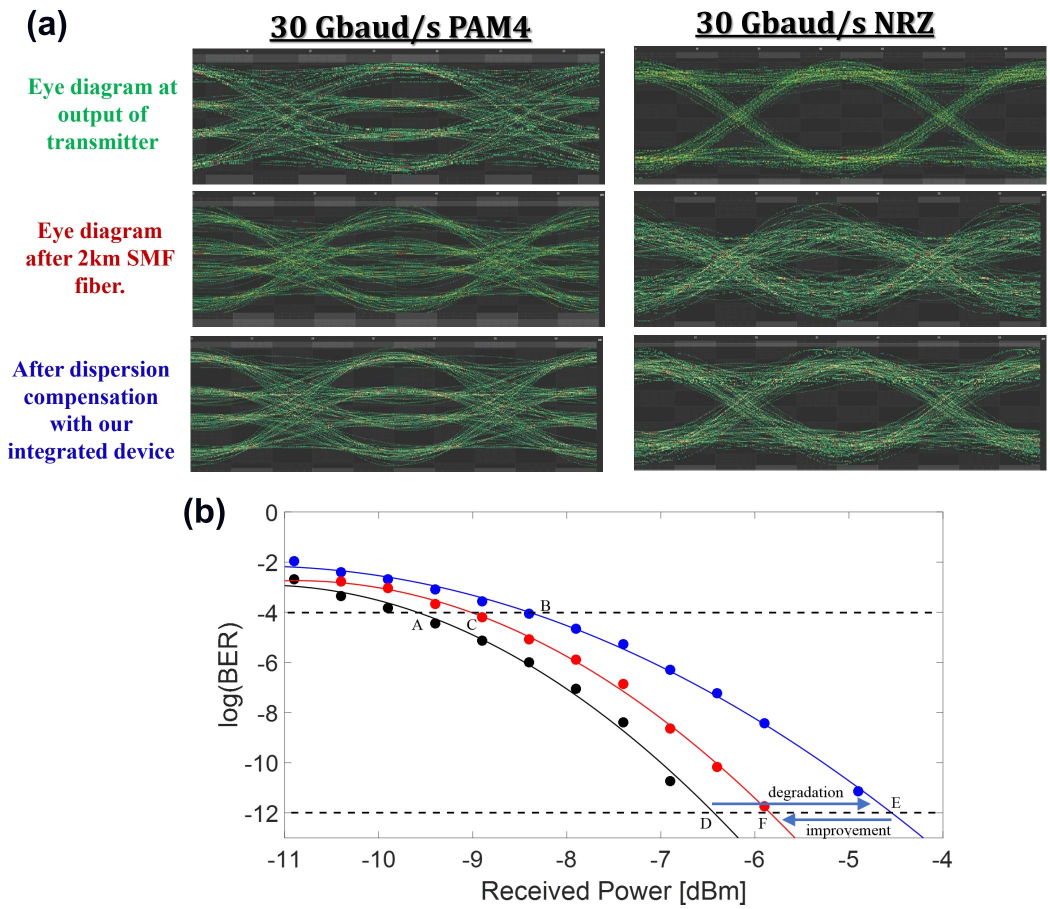

Figure 2 (a) Eye diagrams measured using a digital sampling oscilloscope at (i) the transmitter output, (ii) after transmission through 2km of single mode fiber and (iii) after dispersion compensation with our integrated devices, for both 30 Gbaud/s PAM4 and 30 Gb/s NRZ data. (b) BER characterization when (i) fiber and SiN are absent (black), (ii) fiber is present, SiN absent (blue) and (iii) fiber and SiN are present (red).

4. Conclusion

We have experimentally demonstrated a low loss, CMOS-compatible silicon nitride grating, notably operating in transmission (circulator-free), for dispersion compensation of 2 km of fiber. High-speed characterization using 30 Gb/s NRZ and 30 Gbaud/s PAM4 data showed a restoration of the eye diagram that deteriorated after propagating through 2km of optical fiber. BER characterization showed a 1.3dB improvement in power penalty out of a 1.8dB degradation at the error-free (BER = 10^{-12}) level.

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References

[1] M. Traverso et. al., “Integrated Silicon Photonics Transceiver Module for 100Gbit/s 20km Transmission,” 2021 Optical Fiber Communication Conference and Exhibition (OFC), 2021, paper M3A.3.

[2] 100G PSM4 multi-source agreement, Retrieved from http://psm4.org/

[3] CWDM4 multi – source agreement, Retrieved from http://www.cwdm4-msa.org/files/CWDM4_MSA_4-29-14_FINAL.pdf

[4] E. Sahin, A. Blanco-Redondo, P. Xing, Doris K. T. Ng, Ching E. Png, Dawn T. H. Tan, and Benjamin J. Eggleton, “Bragg soliton compression and fission on CMOS-compatible ultra-silicon-rich nitride” Laser & Photon. Rev. 1900114 (2019).

[5] Y. Cao, E. Sahin, J. W. Choi, P. Xing, G. F. R. Chen, D. K. T. Ng, B. J. Eggleton, and D. T. H. Tan, "Thermo-optically tunable spectral broadening in a nonlinear ultra-silicon-rich nitride Bragg grating," Photon. Res. 9, 596-604 (2021).

[6] B. J. Eggleton, C. Martijn de Sterke, and R. E. Slusher, "Nonlinear pulse propagation in Bragg gratings," J. Opt. Soc. Am. B 14, 2980-2993 (1997)

[7] G. P. Agrawal, Fiber-Optic Communication Systems, 3rd ed. (Wiley, New York, 2002).