Circulator-free Thin-film Lithium Niobate Dispersion Compensator Using Chirped Bragg Grating

Fujin Huang*, Mengyue Xu*, Jingyi Wang, Xinlun Cai
State Key Laboratory of Optoelectronic Materials and Technologies and School of Electronics and Information Technology, Sun Yat-sen University, Guangzhou 510000, China
Author e-mail address: xumy26@mail2.sysu.edu.cn, caixlun5@mail.sysu.edu.cn
These authors contributed equally to this work

Abstract: We demonstrate an on-chip lithium niobate dispersion compensator based on chirped Bragg grating and multimode interferometer structure, featuring a dispersion value of 390 ps/nm/m in a length of 0.54 mm, covering a 45 nm bandwidth.

1. Introduction

Chirped Bragg grating (CBG) is an essential device for on-chip dispersion compensation, which is widely used in optical communication. Specifically, in long-haul transmission links and time lens systems, dispersion compensation can be used for compressing optical signals [1,2]. To date, most of the CBG-based dispersion compensation schemes are based on fiber Bragg grating, with the assistance of circulators. On-chip dispersion compensation is more attractive for a wide range of applications. Recently, an on-chip dispersion-engineered waveguide for on-chip dispersion management has been demonstrated in a Thin-film lithium niobate (TFLN) [3,4] platform, featuring a dispersion of -2.15 ps/nm/m at the wavelength of 1557 nm, a factor of 120 higher than that of SMF-28 fibers [1]. The required TFLN waveguide length for dispersion compensation is about 10 cm, which is too long for dense integration. In [1], a TFLN chirped Bragg grating (CBG) with a dispersion value of 610 ps/nm/m was also demonstrated. However, the configuration proposed in [1] introduces at least an intrinsic 6-dB loss.

Here, we report a circulator-free reflection-type dispersion compensator based on the cascading 2×2 multimode interferometer (MMI) [5] and two identical CBGs, without intrinsic extra 6-dB loss [6]. Our MMI-CBG structure realizes a dispersion value of 390 ps/nm/m without a circulator in a compact footprint (~ 0.8 mm).

2. Design and simulation

The linear chirp of the CBG can introduce a quadratic phase in the reflection spectrum hence a linear group delay (GD), which offers a fixed dispersion value based on differentiating the GD against the angular frequency. The dispersion can be expressed as $D = -2n_g L/\mathrm{BC}$, where D is the dispersion, n_g is the group velocity, a function of wavelength, B is the bandwidth of the grating and C is the vacuum speed of light. Here, we use the transfer-matrix method (TMM) to simulate the dispersion and spectrum of the CBG.

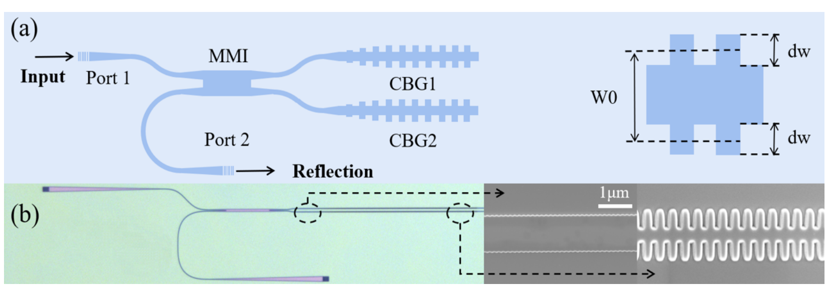

Fig. 1 (a) Schematic diagram of the MMI-CBG structure. (b) Optical image of the structure and SEM image of the grating.

The schematic of MMI-CBG is shown in Fig. 1. The structure consists of one 2×2 MMI and two identical CBGs (CBG1 and CBG2). The beam is first coupled to the input port of the MMI (port 1) and is split into two, which are then coupled to two CBGs. The distance between the two CBGs and the MMI is set equal to ensure that the reflected beams at the output port of the MMI (port 2) constructively interfere. We carefully design the MMI and its access waveguides to minimize the imbalance of the phase and amplitude of two reflections. Fig. 1(b) shows the optical microscope image and SEM image of the fabricated device. We fabricated the device on an X-cut thin film LN with a device layer of 360 nm and an etch depth of 180 nm. We set an average waveguide top width (*W0*) as 1 μm and the grating period starts at 429 nm and then increases along the length to 445 nm linearly. We chose the hyperbolic tangent function [7] for the apodization profile, which provides better GD linearity, less GD ripple, and large optical bandwidth.

Then, we studied the variation of the periodic width perturbations (*dw*) of the CBG, which is designed with a length of 1 mm and an operating band in the C-band. Fig. 2(a) shows that the larger *dw*, the wider the operation bandwidth. As *dw* increases, the linear region of GD expands toward longer wavelengths, and the dispersion slope increases, while the ripple also increases. To balance the trade-off among large dispersion, large bandwidth, and small ripples, we set the *dw* to 0.65 µm.

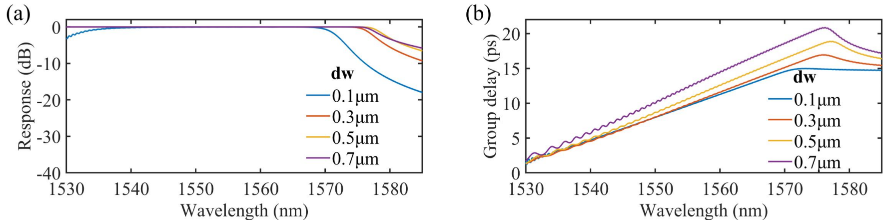

Fig. 2 Simulation results of the CBGs with different *dw*, *W0*=1 µm, *L*=1 mm: (a) reflection spectrum and (b) GD curves.

3. Experiment result

We perform the group delay measurement based on the experimental setup shown in Fig. 3(a). An optical signal from a C-band tunable laser is sent to a commercial lithium niobate modulator. Here, we use a 2-port vector network analyzer (VNA) to generate sinusoidal signals for driving the modulator and receive the modulated signal through a photodetector. Thus, we can extract the group delay of the whole optical link from the EO S_{21} phase response. We can obtain the accurate group delay of the fabricated device by de-embedding and calibrating the group delay of the external optical link and on-chip coupler. Fig. 3 shows the simulation and experiment results of the fabricated device with 0.54-mm-long CBG. As shown in Fig. 3 (b), the simulated GD reaches 0.2219 ps/nm in the wavelength range from 1530 nm to 1575 nm. The measured GD is 0.2111 ps/nm, which is well consistent with the simulated result (Fig. 3 (c)). We observe a 10-nm blue shift in the reflection spectra, which is caused by the fabrication deviation of the duty cycle of the CBG and can be further compensated by fabrication. Our fabricated device provides a low-loss and circulator-free dispersion compensation of 390 ps/nm/m in the whole C band. Compared to the demonstration in ref. [1], our device features a zero intrinsic loss and the measured on-chip insertion loss is less than 1dB.

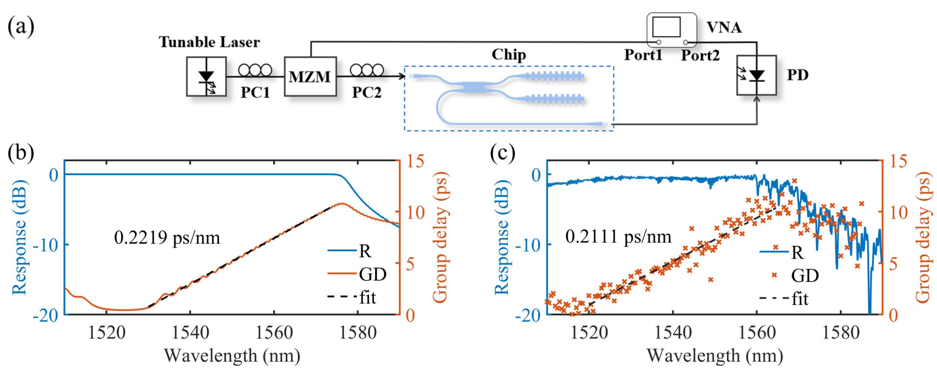

Fig. 3 (a) Set-up for GD measurement. (b) Simulation and (c) measured reflection spectra and corresponding group delay of the MMI/CBG with *L*=0.54 mm, *W0*=1 µm, *dw*= 0.65 µm.

4. Conclusion

We demonstrated a compact, wideband, low-loss, and circulator-free dispersion compensator using chirp grating couplers on the TFLN platform, offering a dispersion value of 390 ps/nm/m. This on-chip compensator can integrate with high-performance coherent modulators [3] or frequency combs [8] on the TFLN platform, performing as a building block in next-generation transmission systems and quantum networks.

5. References

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