A Multi-Channel Chromatic Dispersion Compensation for 15-km Front-Haul Transmission

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Abstract: We report an integrated Bragg grating based multi-wavelength dispersion compensation. We achieve +20 ps/nm and -28 ps/nm at 1270 and 1335nm, with a on-chip loss of 4dB, showing a broadband dispersion compensation capability.

1. Background

The revolutions of today's autonomous driving, VR/AR industries, and IoTs largely depend on the rapid development of 5G networks that offer high-speed wireless broadband networks [1,2]. To match the demand of data traffic, the Intensity-modulation-Direct Detection (IM-DD) bandwidth of front-haul, which connects the remote radio unit (RRU) and the baseband unit (BBU), has been scaled from 25 Gbps (NRZ) to 50Gbps (PAM4) for a 5G Advanced network and 100Gbps (PAM4) for a 6G network. Moreover, radio access networks are ongoing the transition from distributed radio access networks (D-RAN) to centralized radio access networks (C-RAN). As a consequence, the transmission distance of the front-haul link drastically extends from 300m to as much as 15km. Beyond challenges in baud rate and transmission distance, WDM technology has been widely adopted in the C-RAN, such as O-band CWDM6 in China and C-band DWDM in Japan and South Korea [3], the chromatic dispersion discretization in each wavelength channel in single-mode fibers severely distorts the transmission quality, results in power fading on the received signal spectrum. Despite the fact that digital signal processing (DSP) can compensate for most of the nonlinearity owing to its comprehensive software-defined functionalities [4], the power-hungry nature and single-channel correspondence make it not the optimum solution for multiple channels - long distance IM-DD front-haul transmission.

Here, we propose and demonstrate in the experiment, for the first time to the best of our knowledge, an integrated multi-channel dispersion compensation module based on the asymmetric Bragg grating waveguides (ABG). Two sets of corrugation with different periods and opposite chirps were applied on one waveguide segment, providing a 20ps/nm dispersion at 1270nm and -28ps/nm at 1330nm. We measured a maximum 4dB on-chip

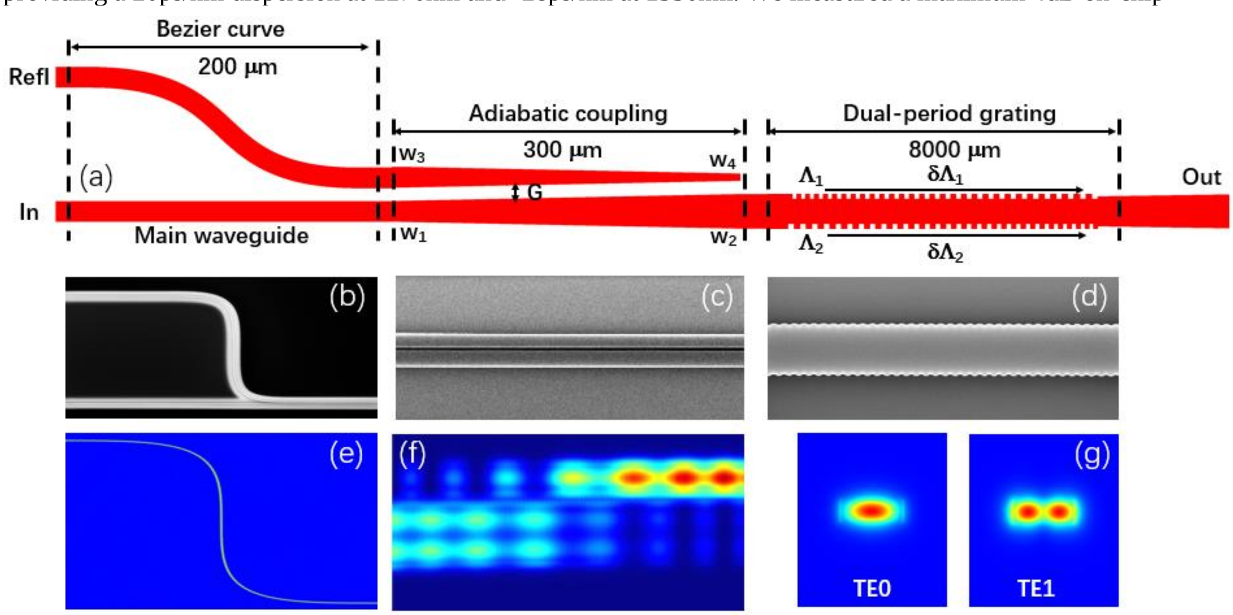

Figure 1. (a) The schematic diagram of the multi-channel dispersion compensation. (b)-(d) show the SEM images of the as-fabricated ABG compensation module. (e)-(g) show the simulation results of each section of the ABG compensation module.

insertion loss with an 8.5mm total device length. We show that the power fading in the above-mentioned wavelengths at 100G up to 15km could be compensated simultaneously by our novel dispersion compensation module.

2. Designs and fabrication

Fig. 1(a) shows a schematic diagram of a multi-channel ABG compensation waveguide consisting of two sets of independently chirped corrugations with different periods. We designed the main waveguide to support only TE0 mode to reduce the mode crosstalk from the reflection in the ABG section. The main waveguide is followed by an adiabatic mode coupler, designed to couple the TE1 mode in the main waveguide to the TE0 mode in the tapered waveguide. The main waveguide in the adiabatic coupler section has a width of W1 = 500nm and W2 = 800nm with a length of 300 μm. For the tapered waveguide, we have W3 = 600nm and W4 = 300nm, with a 100nm gap to guarantee the coupling efficiency. The optical wave at TE0 mode passes the adiabatic coupler and enters the multi-channel ABG section. We realize two distinct corrugation profiles on two side walls of the ABG waveguide. Such a single-side-wall corrugation on each side-wall also forms asymmetrical perturbations in the waveguide geometry, enabling a non-zero overlap integral between TE0 to TE1 mode. We first determine the center reflection wavelength by the phase matching condition:

$$\Lambda_B = \frac{\lambda_r}{n_{TE0} + n_{TE1}} \quad (1)$$

Where Λ_B is the corrugation period, λ_r is the reflection wavelength, n_{TE0} and n_{TE1} represent the effective refractive indices of the ABG waveguide for TE0 and TE1 mode. The corresponding mode profiles are shown in Fig. 1(g). To support both modes, the width of the Bragg grating waveguide is set to 800nm. We note that corrugation amplitude needs to be small to keep the weak perturbation, thus minimizing the reflection of adjacent channels. In the operation of the dispersion compensation, the ABG corrugations need to be chirped to provide wavelength-discriminated group delay difference. The optical wave reflected by the ABG waveguide in TE1 mode will be coupled back to TE0 mode through the adiabatic coupler and finally be dropped at the reflection port through the low-loss Bezier curve waveguide. We fabricated our dispersion compensation structures on a 220nm SOI platform, with a 2μm thick SiO2 buried oxide layer and a 2 μm thick cladding layer. Fig. 1(b)-(g) shows the microscope images of the structure details and simulation results. The total length of our device is 8500 μm.

Fig.2(a) shows the dispersion curve at the fixed corrugation period. For our ABG waveguide, we set the first corrugation period Λ_{B1} = 234nm, corresponding to a center wavelength of around 1270nm. On the other side of the waveguide, we set the second corrugation period Λ_{B2} = 250nm, corresponding to a center wavelength of around 1335nm. To compensate for the negative dispersion in fiber at 1270nm and the positive dispersion at 1335nm, we chirp the first period Λ_{B1} by $\delta\Lambda_{B1}$ = 2nm and $\delta\Lambda_{B2}$ = -1nm for Λ_{B2}. Fig. 2(b) shows the spectral response of the dispersion compensation in blue lines. Both sets of corrugations have 30000 periods, and the grating waveguide is assumed to have 3dB/cm propagation loss. The 234nm-period corrugations with +2nm chirp shows a reflection starting at the wavelength of 1273nm, with a chirp bandwidth of 10nm. While the 250nm-period corrugation with -1nm chirp has in a reflection starting at 1335nm with a 5nm chirp bandwidth. The maximum insertion loss at both reflection band is less than 3.5dB. We plot the group delay in the reflection port in blue dashed lines in the same figure. Due to multiple chirps applied in the waveguide corrugation, the reflection shows a 20ps/nm dispersion around the wavelength of 1275nm and -28ps/nm at 1335nm. Such a dispersion response can compensate for the discrete dispersion exhibited in fiber, resulting in a zero-dispersion response at the receiver side.

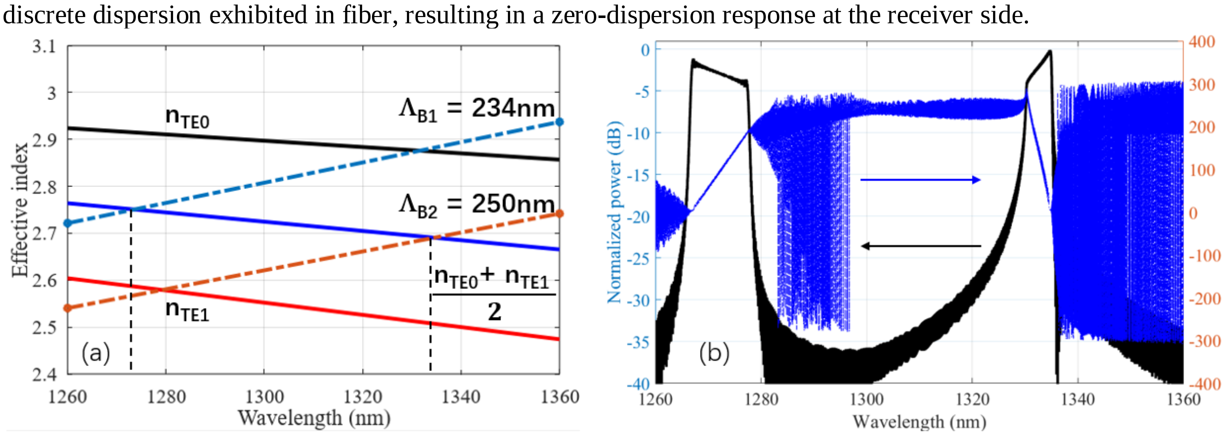

Figure 2. (a) The Bragg grating waveguide dispersion curve at the corrugation periods of 234nm and 250nm. (b) simulated reflection spectrum (in the black curve) and group delay spectrum (in the blue dashed curve).

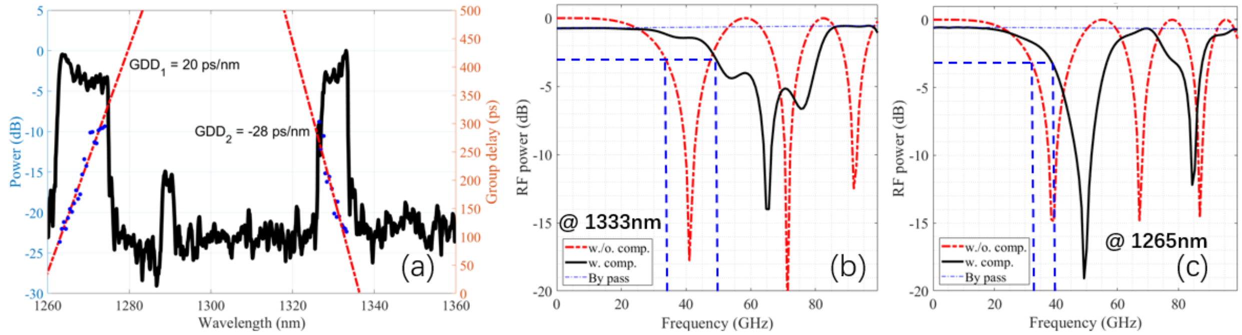

Figure 3. (a) Optical spectrum at the reflection port (in the black curve), with measured group delay sample at discrete wavelength points (in blue dots). The estimated received power at functions of RF frequency for a 15-km transmission distance at a carrier wavelength of 1333nm (b), and 1265nm (c), the uncompensated spectra are red dashed curves, the compensated spectra are represented in black curves, the bypass loss experienced by other wavelength without the compensation is plotted in thin blue dashed lines.

3. Experimental results

We first measured the spectral response at the reflection port, as shown in Fig. 3(a). In particular, the first reflection starts from 1264nm and is red-chirped to 1274nm, while the second reflection starts from 1333nm and is blue-chirped to 1327nm. We determined the insertion loss by normalizing the measured spectral response to the straight waveguide transmission. Results showed a minimum 0.5 dB insertion loss at the starting wavelength and a maximum of 4.5 dB at the ending wavelength, meaning the total intrinsic loss of the adiabatic coupler and the Bezier curve waveguide is about 0.5dB. The 4-dB insertion loss of our ABG waveguide can also be optimized by implementing a rib waveguide that reduces the side wall roughness. We observe ripples in both reflection spectra, which we attribute to the fact that a constant corrugation depth for the finite grating length results in a truncated Fourier transform. Such ripples can be mitigated by applying apodization functions to the corrugations [5]. We applied a 5GHz sinusoidal modulation onto the input optical power to evaluate the dispersion compensation performance and measured the waveform time delay in the high-speed oscilloscope. The measured group delay sampled from discrete wavelength points at the reflection port was plotted in blue dots, as depicted in Fig. 3(a), since both sets of corrugations cumulate 30000 periods, resulting in a 200ps group delay for both reflection bands. As a consequence of the individually chirped corrugations, we obtain 20ps/nm chromatic dispersion centered at 1270nm and -28ps/nm chromatic dispersion centered at 1330nm, showing a capability of ultra-broadband dispersion compensation across the entire O or C-band. We estimated the benefit of our dispersion compensation to received RF power for 15-km transmission at 1265nm in Fig. 3(b) and 1333nm in Fig. 3(c). Both plots show clear power fading at 40GHz without any dispersion compensation. On the other hand, when implementing the dispersion compensation module, the power fading around 40GHz was successfully replaced by a 3-dB maximum insertion loss caused by the ABG waveguide intrinsic scattering. As feasibility demonstration, we noted that the dispersion provided by our ABG is under-compensating at both channels. The critical compensation of multi-channel dispersion can be easily realized by optimizing the number of corrugation periods to match the total dispersion of the fiber at a certain IM-DD transmission distance.

4. Conclusions

In this paper, we proposed and experimentally demonstrated a multi-channel dispersion compensation scheme for multi-channel long-distance IM-DD transmission. The on-chip loss is about 4dB for both channels, providing 20ps/nm and -28ps/nm dispersion compensation in each band. We noted that our scheme could be further expanded to a multi-channel scheme by adding more corrugations along the waveguide length, enabling a highly integrated ultra-broadband dispersion compensation for CWDM BBU front-haul transmission.

5. References

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