Wide-Passband 88-Wavelength Channel-by-Channel Tunable Optical Dispersion Compensator with 50-GHz Spacing

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Abstract: We realized a wide-passband multi-channel tunable optical dispersion compensator for 88 WDM signals with 50-GHz spacing by combination of an arrayed-waveguide and bulk gratings. It utilizes a novel optics arrangement for high wavelength resolution.

OCIS codes: (130.2035) Dispersion compensation devices; (230.7390) Waveguides, planar; (050.2770) Gratings; (070.6120) Spatial light modulators

1. Introduction

A tunable optical dispersion compensator (TODC) is an indispensable device for reconfigurable optical add/drop multiplexed (ROADM) networks operating at a bit rate of 40 Gbps. In such networks, the transmission length and chromatic dispersion (CD) for each wavelength channel vary according to the ROADM setting. Therefore, one approach to dispersion compensation in an ROADM network involves compensating for the CD of each channel by using single-channel TODCs. A number of technologies have already been employed to realize such TODCs including lattice filters [1], fiber Bragg gratings [2], virtually imaged phased arrays (VIPAs) [3] and arrayed-waveguide gratings (AWGs) [4]. By contrast, a multi-channel TODC providing channel-by-channel operation is particularly attractive, because it reduces both the device count and the power consumption of the network. Channel-by-channel TODCs have been achieved with a spectrometer-based configuration consisting of various grating devices and a spatial light modulator (SLM) such as a liquid crystal on silicon (LCOS) [5-10].

We have already developed an advanced TODC that consists of a cyclic frequency AWG and a bulk grating [9]. This configuration enabled us to increase the channel number of TODCs by taking advantage of the two dimensional feature of LCOS devices. The TODC achieved a CD of up to 800 ps/nm for 50-channel 100 GHz spacing signals, and its 3-dB bandwidth was 27 GHz [9]. However, the 3-dB bandwidth of the TODC becomes relatively narrow when applied to 40 Gbps signals. In addition, as we detail in the following, a CD crosstalk between channels arises when we increase the channel count up to 88 with 50-GHz channel spacing.

In this report, we discuss how to optimize the optical design of the TODC in order to overcome the above issues. Then we demonstrate experimentally that our new configuration using double gratings and an anamorphic beam expander realizes a wider 3-dB bandwidth of 30 GHz for a CD of 1200 ps/nm with no CD crosstalk between channels even with narrow channel spacing of 50 GHz.

2. Principle and design

Figure 1 is a schematic diagram of our TODC, which comprises a cyclic frequency AWG with a free spectral range (FSR) of 50 GHz, a bulk grating and an LCOS. An optical signal, which is output through the collimating lens at the edge of the AWG, is fed into a transmission bulk grating whose dispersion axis is orthogonal to that of the AWG. Each signal that passes through the two dispersive gratings is focused on the LCOS with a focusing lens. A WDM signal is divided into channels along the dispersion direction of the bulk grating on the LCOS surface and each channel signal is dispersed along the AWG axis (Fig. 1(b)). To provide each wavelength channel with a different CD, we impart a different phase shift to each input signal via the LCOS.

First, we discuss how to expand the bandwidth of the TODC. As shown in previous reports, the factor which narrows the bandwidth includes the design of an AWG and transmittance ripples. Since the predominant factor is the AWG design, we analyze the relationship between the bandwidth (BW) and design parameters.

A relationship between the 3-dB bandwidth, *BW*, and the chromatic dispersion value, *CD*, can be expressed by using equations (3), (4) and (5) in Ref. [7],

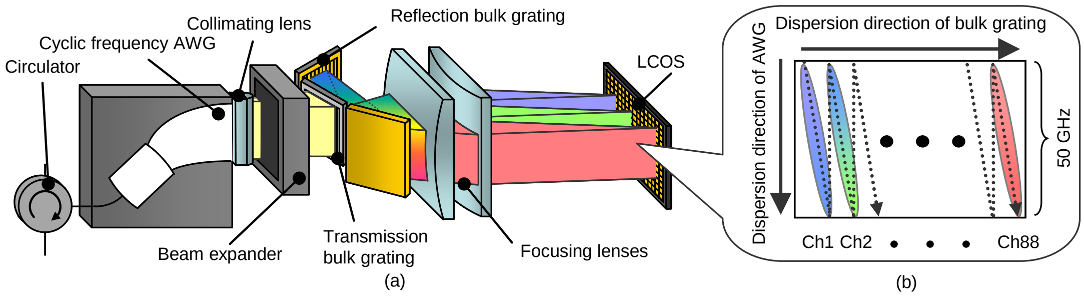

Fig. 1. (a) Schematic diagram of TODC consisting of an AWG, bulk gratings and an LCOS, (b) channel map on the LCOS.

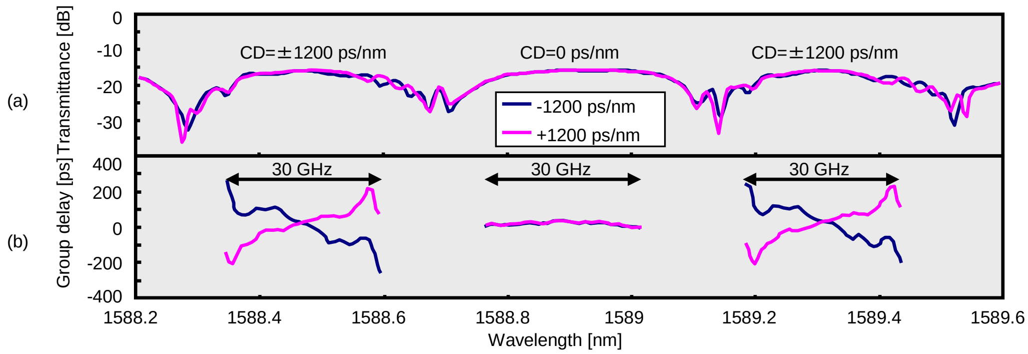

Fig. 2. (a) Measured transmission characteristics and (b) group delay characteristics of TODC.

$$BW = \frac{2n_g}{\lambda_0 n_c}\sqrt{\frac{3}{10\log e}\frac{Nm}{CD}}, \qquad (1)$$

where n_g is the group index, n_c is the effective index of the array waveguide, λ_0 is the center wavelength, N is the number of arrayed waveguides and m is the diffraction order of the AWG. This equation is generally applied to the AWG-based TODC. As seen from the equation, there are two ways to obtain a large BW with a constant CD; one is to use a high diffraction order m, and the other is to employ a large number of waveguides N. The m value of an AWG with an FSR of 50 GHz is double compared with that at 100 GHz, and so we can obtain twice the BW by using an AWG with an FSR of 50 GHz.

Next, we discuss how to avoid the CD crosstalk between channels when the channel spacing is 50 GHz. If we utilize an AWG with an FSR of 50 GHz, the channel separation degrades, because the beam spots of the adjacent channel on the LCOS become closer and overlap. The separation is halved compared with the case of 100 GHz spacing. As a result, the phase setting of a channel affects the adjacent signal. Here, we employ two countermeasures. One is to increase the angular dispersion of the bulk grating and the other is to make the beam spot size on LCOS small.

An optical system satisfies the following relation

$$\left(W_{grating}G\right) \geq \frac{3\lambda_0 \cos\beta}{\pi}\frac{1}{\Lambda}, \qquad (2)$$

where $W_{grating}$ is the beam spot size on the bulk grating, G is the grating constant, β is the diffraction angle and Λ is the channel spacing. As shown in Eq. (2), ($W_{grating}G$), which represents the number of lines on the bulk grating, should be in inverse proportion to Λ and should be enlarged. When we design a λ_0 of 1587 nm, a β of 46.5 deg and a Λ of 0.42 nm, the right part is calculated with 2483, and the tolerance is twice tight compared with previous report in Ref. [9]. Therefore, to set a large ($W_{grating}G$), we have employed cascading transmissive and reflective gratings for a large G, and added an anamorphic beam expander between the AWG and the bulk grating for a large $W_{grating}$, as shown in Fig.1.

We designed and fabricated an AWG with an FSR of 50 GHz by using a 1.5-% index contrast silica-based planar lightwave circuit (PLC). The m value and the number of waveguides were 3707 and 18, respectively. We designed an anamorphic optical system that matched the focus point to each of two gratings. The focal lengths of the focusing lenses for the AWG and the bulk grating were set at 100 and 95 mm, respectively. We also set ($W_{grating}G$) at 2494 by using double-grating configuration and an anamorphic beam expander. In this setup, we set the linear dispersion of the AWG so that more than 1000 pixels of the LCOS covered an optical frequency range of 50 GHz, and the corresponding value for the bulk grating was about 7.5 pixels.

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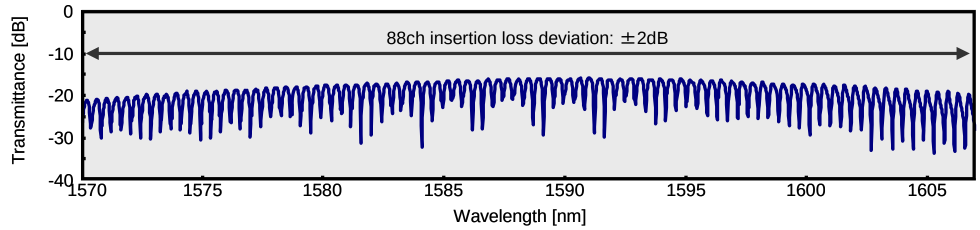

Fig. 3. Transmission spectrum when the CD settings are zero.

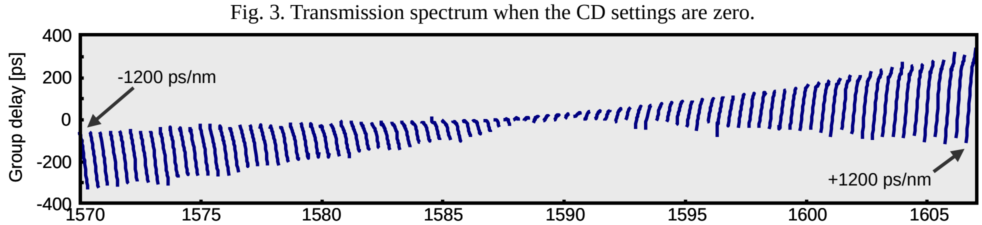

Fig. 4. 88 channels independent operation.

3. Experimental result

Figure 2(a) shows the measured transmittance and (b) shows the group delay characteristics of the TODC for three successive channels. We set the CD of the central channel at zero and those of the two adjacent channels at ±1200 ps/nm.

As seen in Fig. 2, we successfully obtained both positive and negative dispersions of ±1200 ps/nm. The 3-dB bandwidth was 30 GHz when the CD setting was 1200 ps/nm. This characteristic is suitable for 40 Gbps system applications. In addition, both the transmittance and group delay spectra are unchanged although we set the CD of both the adjacent channels. Thus, we confirmed the realization of channel-by-channel operation.

Figure 3 shows the transmission spectrum over a wide range when the CD setting was 0 ps/nm. The insertion loss uniformity for 88 channels was ±2 dB. This results from an optical design problem caused by the aberration of the focusing lens and the position of the bulk grating.

Figure 4 shows typical characteristics for the channel-by-channel operation of the proposed TODC. The phase distribution of the LCOS was designed to have a CD that changed continuously from -1200 to +1200 ps/nm. All the CD values were given simultaneously and independently to the 88 successive channels with a 50-GHz spacing. The group delay spectrum was inclined over a wide wavelength range. Although this is the effect of the above-mentioned defocusing of the bulk grating, it is vanishingly small because this inclination corresponds to a CD of only 7 ps/nm.

4. Conclusion

We demonstrated a 50 GHz-spaced 88-wavelength TODC consisting of a cyclic frequency AWG, bulk gratings and an LCOS. We achieved channel-by-channel operation in a 50 GHz-channel spacing by employing double gratings and an anamorphic beam expander. Our TODC using a high-resolution AWG exhibited a CD of 1200 ps/nm and wide 3-dB bandwidth of 30 GHz.

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