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50-Wavelength Channel-by-Channel Tunable Optical Dispersion Compensator Using Combination of Arrayed-Waveguide and Bulk Gratings

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Abstract: We propose a novel optical configuration for a channelized tunable optical dispersion compensator (TODC) with channel-by-channel operation across entire the L-band. The TODC consists of a cyclic frequency arrayed-waveguide grating (AWG) whose free spectral range (FSR) coincides with the channel spacing, a bulk grating and a liquid crystal on silicon. We achieved channel-by-channel compensation over 50 channels with a maximum chromatic dispersion of 800 ps/nm.

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 or higher. In such networks, the transmission length and chromatic dispersion (CD) for each wavelength channel varies according to the ROADM setting. Therefore, one approach to dispersion compensation in ROADM 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 with 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) device such as a liquid crystal on silicon (LCOS). Previous studies employed one or two bulk gratings [5, 6], or AWGs [7, 8]. One of the problems of the former configuration is that it is difficult to obtain a large CD because the angular dispersion of the bulk grating is small [5, 6]. To obtain a large CD with a spectrometer-based TODC, it is advantageous to use a highly dispersive grating, such as an AWG. Although the use of an AWG and an LCOS makes the CD tuning range large, the channel count is limited to six owing to the pixel number limitation in an LCOS [7]. A TODC with a double pass configuration of AWGs has been reported that realizes 40-wavelength channel-by-channel operation [8], however, this configuration requires the highly accurate alignment of the optical components.

In this report, we propose a novel configuration for a multi-channel TODC that comprises a cyclic frequency AWG with a free spectral range (FSR) of 100 GHz, a bulk grating and an LCOS. The AWG supplies a large dispersion setting, while the bulk grating provides operation over a wide wavelength range. In other words, the configuration simultaneously provides excellent TODC characteristics, large channel number operation and optics alignment with a relatively large tolerance. Our proposed TODC compensated CDs of up to ± 800 ps/nm for 50 channels ranging over the entire L band.

2. Principle and design

Figure 1 shows a schematic diagram of our TODC. To increase the channel count, we have added a transmission bulk grating between the AWG and the focusing lens to the setup of our previously reported TODC [7]. The LCOS can be efficiently used through this combination of an AWG and a bulk grating.

Before describing our TODC, we explain the principle of the previously reported spectrometer-based TODC, which consists of an AWG and an LCOS operating on a 1-dimensional axis [7]. An input optical signal is spatially dispersed by the AWG, focused on the LCOS with a focusing lens, and then reflected back to the input port. Here,

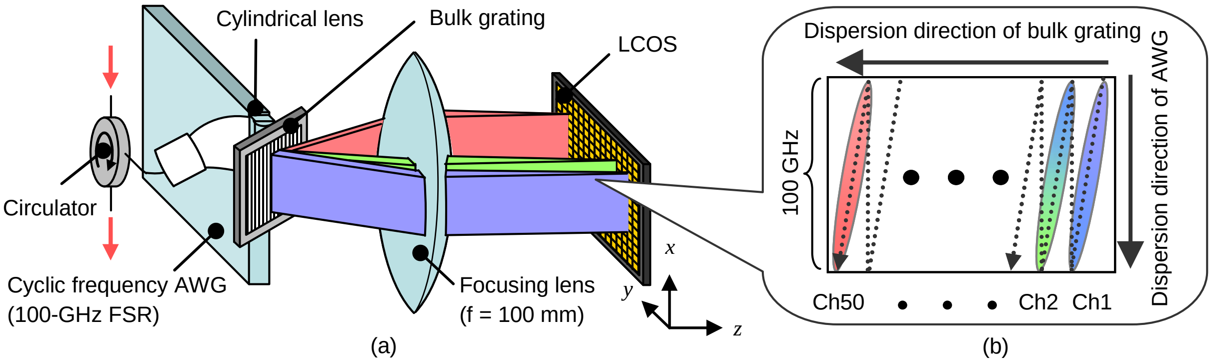

Fig. 1. (a) Schematic diagram of TODC consisting of an AWG with a 100-GHz FSR and an LCOS, (b) wavelength distribution on the LCOS.

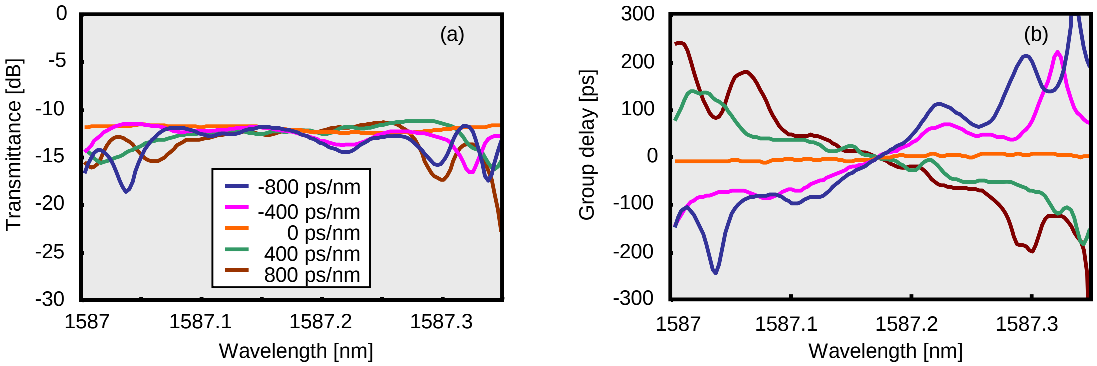

Fig. 2. (a) Measured transmission characteristics and (b) group delay characteristics of TODC.

signals with different diffraction orders are focused at the same position on the LCOS if the FSR of the AWG is the same as the channel spacing. Therefore, when the LCOS provides an input signal with quadratic optical phase shifts along the linear dispersion axis on the LCOS, we obtain the same CD for each wavelength channel. To provide each wavelength channel with a different CD, we need a mechanism that demultiplexes the spatially overlapped signals. Therefore, we added a bulk grating to realize the above mechanism.

Figure 1(a) shows the schematic configuration of our TODC, which consists of an AWG, a transmission bulk grating and an LCOS. Our setup is different from that of our previously reported TODC in that we installed a bulk grating to realize wide wavelength range operation after the AWG, and thus obtain a large dispersion setting. The signal, which is outputted through the collimating lens at the edge of the AWG, is fed into the 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 by the focusing lens. Figure 1(b) shows the distribution of each wavelength signal on the LCOS. The 2-dimensional dispersion on the LCOS is shown by a dashed line, which is a blend of the dispersion axes of the AWG (x direction) and the bulk grating (y direction). We designed two orthogonal dispersion axes in this setup. Therefore, each signal is divided along the y direction on the LCOS surface. Here, the CD in this setup is proportional to the square of ($dx/d\lambda$), which represents the linear dispersion of the AWG in the x direction [7]. Therefore, to obtain a large CD, it is necessary to design an AWG with a large linear dispersion. Our TODC provides a large CD because we can obtain a large linear dispersion by expanding the narrow band (100 GHz) in the x direction. In addition, our TODC can increase the channel count because we can employ a short distance between each signal.

We designed and fabricated an AWG with an FSR of 100 GHz by using a 1.5-% index contrast silica-based planar lightwave circuit (PLC). The focal length was set at 100 mm, so the LCOS and the AWG were placed at the back and front focal points of the focusing lens, respectively. The bulk grating was positioned 10 mm from the edge of the AWG. In other words, the bulk grating was placed 90 mm from the focusing lens. In this setup, the linear dispersion of the AWG was set so that more than 500 pixels of the LCOS covered an optical frequency range of 100 GHz, and the corresponding value for the bulk grating was about 10 pixels.

3. Experimental result

Figure 2(a) shows the measured transmittance and (b) shows the group delay characteristics of the TODC for a single channel. As seen in Fig. 2, we successfully obtained both positive and negative dispersions of ± 800 ps/nm.

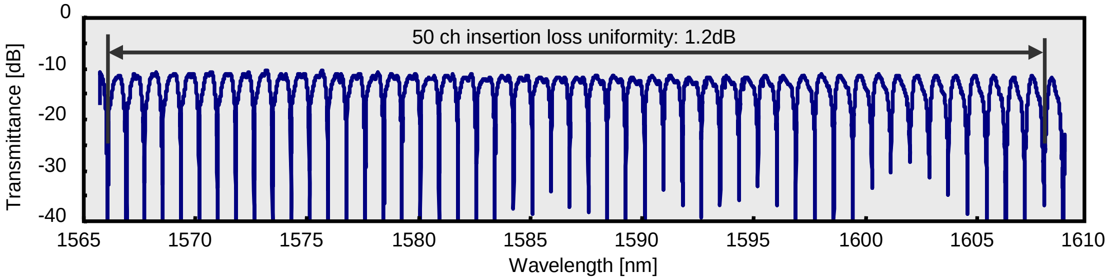

Fig. 3. Transmission spectrum when the CD settings are zero.

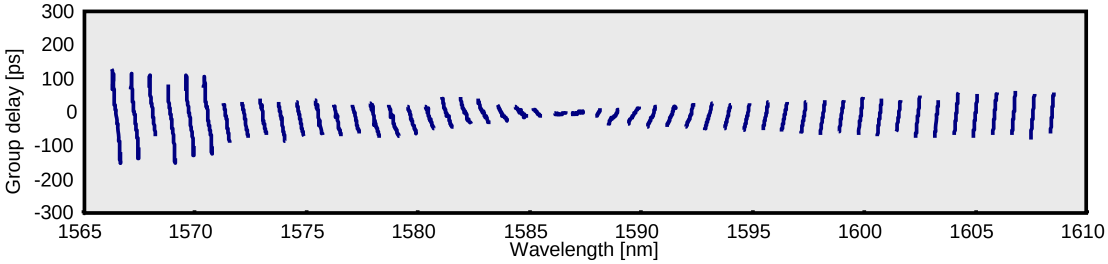

Fig. 4. Channel independently operation over 50 channels.

The 3-dB bandwidth was 27 GHz when the CD setting was 800 ps/nm, although we designed the TODC to obtain a 3-dB bandwidth of 40 GHz. In Fig. 2, we observe ripples in both the intensity and group delay. These ripples cause a narrowing of the 3-dB bandwidth. We assume that the linearity of the optical phase control for the LCOS was not precisely adjusted, so these ripples can be improved up to 40 GHz by improving the phase setting precision.

The insertion loss of the TODC was 10.7 dB. This loss was composed of the 2.1 dB coupling loss between the optical fiber and the AWG, the 1.6 dB loss of the circulator, the 2.3 dB loss of the bulk grating, and the 4.7 dB loss of the AWG diffraction and free space optics including the phase mismatch caused by the aberration of the focusing lens.

Figure 3 shows the transmission spectrum over a wide range when the CD setting was 0 ps/nm. The insertion loss uniformity for 50 channels was only 1.2 dB. This is 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 set to have a continuously changing CD from -800 to +800 ps/nm. All the CD values were simultaneously and independently given to the 50 successive channels with a 100-GHz spacing. Our TODC has the potential to achieve channel-by-channel operation across the C and L-bands if we increase the number of LCOS pixels in the y direction.

4. Conclusion

We proposed a novel configuration for a multi-channel TODC consisting of a cyclic frequency AWG with a 100-GHz FSR, a bulk grating and an LCOS. We demonstrated channel-by-channel compensation for 50 wavelengths. We obtained a CD of 800 ps/nm with a 3-dB bandwidth of 27 GHz and an insertion loss of 10.7 dB. The TODC is a promising candidate for use in future networks.

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