InP-Based Polarization-Insensitive Planar Waveguide Concave Grating Demultiplexer with Flattened Spectral Response

Oh Kee Kwon, Chul Wook Lee, Dong Hun Lee, Eun Deok Sim, Jong Hoi Kim, and Yong Soon Baek

ABSTRACT—InP-based planar waveguide 48-channel concave grating demultiplexers with a channel spacing of 0.8 nm (100 GHz) are described and demonstrated. Polarization insensitivity and flattened spectral response are successfully achieved by the introduction of a polarization compensator and a two-focus grating, respectively. The fabricated device shows a polarization-dependent wavelength shift of less than 20 pm and a -3 dB spectral width of about 0.55 nm (68.75 GHz) over all channels.

Keywords—Planar waveguides, demultiplexer, concave grating, polarization, wavelength division multiplexing.

Planar waveguide grating devices have been widely used for wavelength (de)multiplexing, switching, and optical add-drop applications in dense wavelength-division multiplexing optical communication systems. Among the various types of devices to implement a demultiplexer (demux) [1]-[4], the InP-based planar waveguide concave grating (CG) has shown great potential due to its compactness [2] and monolithic integration with laser diodes (LDs), photodetectors (PDs) [3], and semiconductor optical amplifiers [4]. However, compared to silica- or polymer-based CGs, it is difficult to achieve desirable performance in such areas as high channel-spacing accuracy, low polarization dependence, and flat-top spectral response over all channels due to its high refractive index dispersion, high birefringence, and spectral inhomogeneity, respectively. To overcome these problems, it is necessary to introduce the appropriate optical structures that can modify the birefringence of the waveguide and change the spectral shape of the grating as well as control the material and structural parameters of the device accurately. In this letter, we show that all of these problems in developing InP-based CG demuxes for monolithic integration can be solved. In particular, the polarization-insensitive CG demux with extremely wide and flat spectral response is demonstrated.

Figure 1(a) shows a chip image of a 3×48-channel CG demux with a channel spacing of 0.8 nm (100 GHz). The device consists of input/output waveguides (WGs), a slab WG, a polarization compensator (PC), and a CG with two-focal points. Based on a 7.8 mm radius Rowland circle (RC) construction, it was implemented in a Littman configuration with an *echelle* grating working in the 16th order. The grating period is about 5.4 μm along the grating circle, and there are 600 facets in total. The incidence angle of the beam from the center input waveguide at the grating pole is 47°. The input and output WGs have a deep ridge WG structure (2.5 μm width), separated by gaps of about 10 μm and 6 μm on the RC, corresponding to spectral separations of 1.25 nm and 0.8 nm, respectively. The epitaxial layers were grown by low-pressure metal-organic chemical vapor deposition. As shown in Fig. 1(b), the layer structure consists of a 1.0 μm InP upper cladding layer, a 0.5 μm InGaAsP core (band-gap wavelength λ_{bg}=1.05 μm), and a 1.0 μm InP buffer layer on an InP substrate, with a 0.01 μm InGaAsP etch-stop layer (λ_{bg}=1.24 μm). The grating was patterned using stepper lithography and dry-etched to about 1 μm below the core by an inductively coupled plasma

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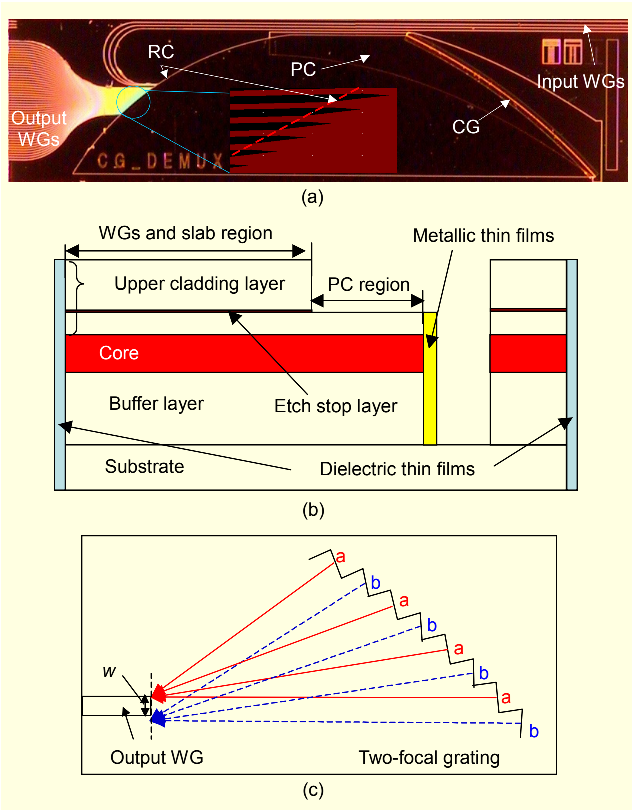

Fig. 1. (a) Chip image of a CG demux. The chip size is 2.5×8.8 mm^2. The inset image shows output WGs near an RC. The red dashed line indicates an RC. (b) Cross-sectional view of the device. (c) Geometric configuration for the two-focus grating (types *a* and *b*), where *w* denotes the separation between the focal points.

process. Its facets were then coated with metallic thin films. To implement a polarization-insensitive demux that can eliminate TE-TM shift in channel output wavelengths, we used an integrated polarization compensator [5] consisting of a region with a different birefringence which was formed by etching the upper cladding layer to the etch-stop layer. To obtain a minimum difference of TE-TM shift over all channel wavelengths, PCs with various upper cladding thicknesses were tested.

Figure 2 shows the effective refractive index of the TE mode n_{effTE} and the birefringence Δn for the PC region with a 0.3 μm-thick upper cladding layer and the slab waveguide. It is clearly shown that the birefringence of the slab region slightly decreases with the wavelength, while that of the PC region increases. This results in a minimum difference of TE-TM shift because the PC boundary is designed at 1,550 nm. Based on these parameters, we designed the interface boundary to focus TE and TM polarized light at the same output positions on the RC. The design method is similar to that of the dispersive pattern in our previous work [4]. In the CG demux with Gaussian-type spectral response, a -3 dB spectral width $\Delta\nu_{3\,\mathrm{dB}}$ of about 0.2 nm is typically obtained. To flatten the spectral

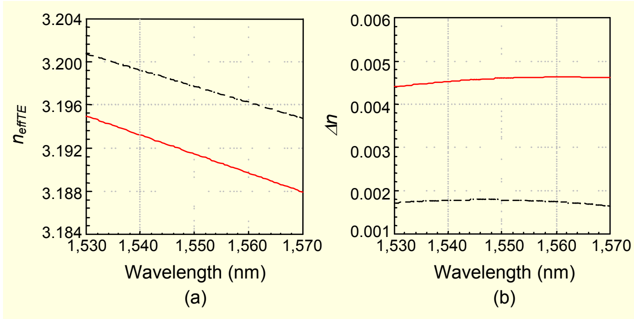

Fig. 2. (a) Effective refractive index of TE mode n_{effTE} and (b) birefringence Δn ($=n_{effTE}-n_{effTM}$) as a function of wavelength for the PC region (solid lines) and slab waveguide (dashed lines).

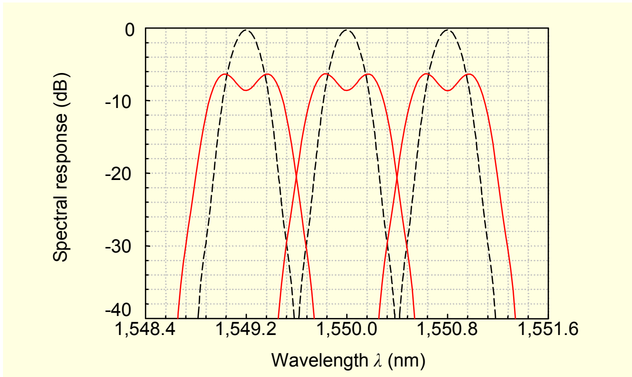

Fig. 3. Calculated spectral responses for the two-focal (w=2.5 μm, solid lines) and Gaussian-type (dashed lines) gratings.

response without a change of mode distribution in the input waveguide [6], we introduced a two-focus grating [7] that provides a double-peaked field distribution at the output plane while keeping the input and output waveguides in single mode as shown in Fig. 1(c). The demultiplexing of the designed structure was analyzed with a scalar diffraction method based on the Kirchhoff-Huygens formula.

Figure 3 shows the calculated spectral responses for the two-focus and the Gaussian-type gratings. The designed grating provides a free spectral range (FSR) of about 48 nm to cover a full C-band from 1,530 nm to 1,570 nm in a DWDM system. A $\Delta\nu_{3\,\mathrm{dB}}$ of 0.2 nm and a $\Delta\nu_{20\,\mathrm{dB}}$ of 0.52 nm were obtained for the Gaussian-type grating. For the two-focus grating, $\Delta\nu_{3\,\mathrm{dB}}$ of 0.56 nm, $\Delta\nu_{20\,\mathrm{dB}}$ of 0.9 nm, excess loss due to a spectral broadening of about 6.2 dB, and a ripple of about 2.2 dB were obtained.

Figure 4 shows the measured spectral responses of the TE mode for both gratings. The curve near -40 dB is the transmission of the TE mode for an 8.8 mm-long straight waveguide. In comparison with this curve, the envelopes of the channel peaks have a similar shape, where the WG grating loss is about 5.5 dB, and the excess loss due to spectral broadening is 6.5 dB. A channel spacing deviation of less than ±0.02 nm

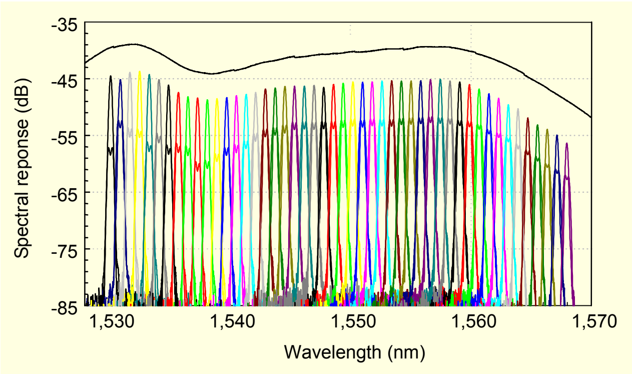

Fig. 4. Measured spectral responses of TE mode for two-focus and Gaussian-type gratings. The bold line represents the transmission of TE mode for an 8.8 mm-long straight waveguide when an EDFA is used as an input source.

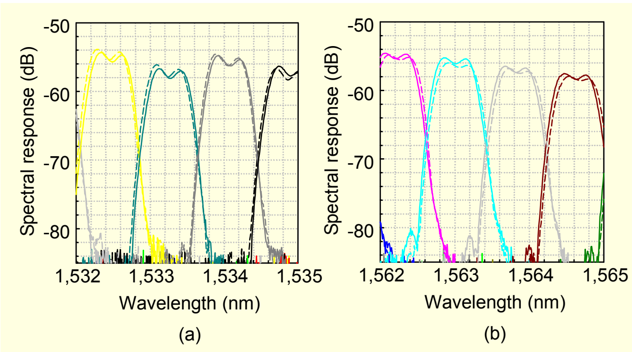

Fig. 5. Measured spectral responses of TE mode (solid lines) and TM mode (dashed lines) near (a) 1,530 nm and (b) 1,560 nm.

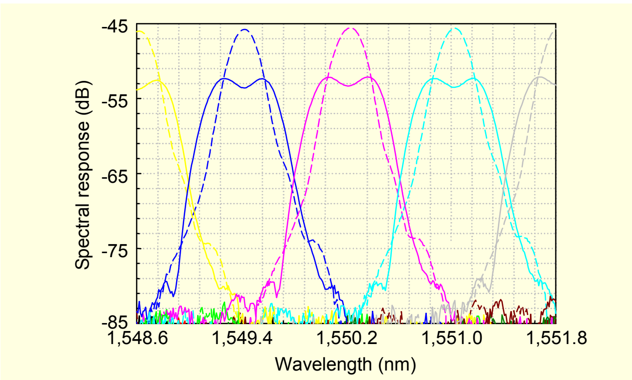

Fig. 6. Measured spectral responses (TE mode) for the two-focus (solid lines) and Gaussian-type (dashed lines) gratings.

was obtained over all channels. As shown in Fig. 5, the polarization-dependent wavelength shift is less than 20 pm, and the polarization-dependent loss is less than 1 dB, with an adjacent channel crosstalk of -30 dB or better.

Figure 6 shows the measured spectral responses for the two-focus grating and the Gaussian-type grating near a wavelength of 1,550 nm. Compared to the calculated data in Fig. 3, the $\Delta\nu_{3\,\mathrm{dB}}$ of the Gaussian-type grating was broadened from 0.2 nm to 0.23 nm, while the $\Delta\nu_{3\,\mathrm{dB}}$ of the two-focus grating was slightly reduced from 0.56 nm to 0.55 nm. This is the reason for ripple reduction (2.5 dB to 1 dB) of the two-focus grating; therefore, the design for the spectral flattening is thought to be slightly over-estimated. From the measured data, it is expected to obtain a nearly zero-ripple near w=2.2 μm ($\Delta\nu_{3\,\mathrm{dB}}$ of about 0.45 nm and an excess loss of about 5.8 dB). On the other hand, we also experimentally confirmed in this layer structure that the three-focus grating of [9] has spectral responses with a ripple of < 0.1 dB at w=2.6 μm. Due to the reduction of the FSR, it was impossible to apply to a full C-band. Although this problem can be solved by using a grating with a low diffraction order ($m\leq 11$ for FSR ≥ 45 nm), it was still difficult to design the flattened spectral response within the 0.8 nm channel spacing because of the spectral broadening of the Gaussian-type grating. Therefore, we think that the two-focus design will be one of the best spectral-flattening methods in InP-based CG demuxes for monolithic integration.

In conclusion, we have demonstrated an InP-based 48-channel CG demux with 100 GHz channel spacing, polarization insensitivity, and flattened spectral response. Based on the precise control of the effective refractive index and the birefringence in design and fabrication, a channel spacing deviation of less than ±20 pm, a TE-TM shift of less than 20 pm, and a -3 dB spectral bandwidth of about 0.55 nm were achieved over all channels.

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