Demonstration of mode conversion using anti-symmetric waveguide Bragg gratings

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Abstract: We experimentally demonstrate a novel grating which only produces reflection with mode conversion in a two-mode waveguide. That characteristic can improve the performance of optical devices that currently use tilted Bragg gratings to provide the mode conversion. Tilted Bragg gratings produce also reflections without mode conversion which increases noise and crosstalk of the optical device.

OCIS codes: (130.3120) Integrated optics devices; (060.2330) Fiber optics communications

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References and Links

1. A. S. Kewitsch, G. A. Rakuljic, P. A Willems, and A. Yariv, “All-fiber zero-insertion-loss add-drop filter for wavelength-division multiplexing,” Opt. Lett. **23**, 106 (1998).
2. C. K. Madsen, T. A. Strasser, M. A. Milbrodt, C. H. Henry, A. J. Bruce, and J. Demarco, “Planar waveguide add/drop filter employing a mode converting grating in an adiabatic coupler,” in *Integrated Photonics Research*, Vol. 4 of Tech. Dig. Series (Optical Society of America, Washington, D.C.,1998), pp. 102-104.
3. D.F Geraghty, D. Provenzano, M. M. Morrell, S. Honkanen, A. Yariv, N. Peyghambariam, “Ion-exchanged Waveguide Add/Drop Filter,” Electron Lett. **37**, 829-831, (2001)
4. D F. Geraghty, J. M Castro, B West, Seppo Honkanen,”All-Optical Packet Header Recognition Integrated Optic Chip,” in *Proceedings of IEEE* LEOS (Institute of Electrical and Electronics Engineers, Arizona, 2003), pp 752-753.
5. C. Riziotis and M. N. Zervas, “Design considerations in optical add/drop multiplexers based on grating-assisted null couplers,” IEEE J. Lightwave Technol. **19**, 92-104 (2001).
6. J. M. Castro , D. F. Geraghty, B West, Seppo Honkanen, “Fabrication and Comprehensive Modeling of Ion-Exchanged Bragg Optical Add/Drop Multiplexers,” Appl. Opt. **43**, 6166-6173 (2004).
7. M. Aslund, J. Canning, L. Poladian, C. Martijn de Sterke, and A. Judge, "Antisymmetric grating coupler: Experimental results," Appl. Opt. **42**, pp.6578-6583 (2003)
8. S. Tomljenovic-Hanic, and J. D. Love, “Planar waveguide add/drop wavelength filters based on segmented gratings,” Microw. Opt. Techn. Lett. **37,** 163-165 (2003)
9. S.Tomljenovic-Hanic, “Symmetry-selecting gratings and their applications”, in *Proceedings of 5 th International Conference on Transparent Optical networks*, M. Marciniak, ed. (IEEE , Warsaw, Poland, 2003) pp. 196-199.
10. J. M. Castro, A. Sato, D. F. Geraghty, “Waveguide mode conversion using anti-symmetric gratings,” OFC Conference, California, March 6-11, 2005.
11. T. Erdogan and J.E Sipe, ”Tilted fiber phase gratings,” J. Opt. Soc. Am. **A 13**, pp. 296-313, February (1996).
12. R. Kashyap, *Fiber Bragg Gratings*, (Academic Press, San Diego, CA, 1999).
13. C. Greiner, T. W. Mossberg and D. Iazikov, ”Bandpass engineering of lithographically scribed channel-waveguide Bragg gratings,” Opt. Lett. **29**, 806 (2004)
14. LigthSmyth Technologies,”Channel Waveguide Gratings,” http://www.lightsmyth.com
15. William K. Burns and Fenner Milton, “An Analytic Solution for Mode Coupling in Optical Waveguide branches,” IEEE J. Quantum Electron. **16,** 446 (1980)

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16. R. Adar, C. H. Henry, R. H. Kistler, and R. F. Kazarinov, "Polarization independent narrow band Bragg reflection gratings made with silica-on-silicon waveguides," Appl. Phys. Lett. **60,** 1779 (1992).

1. Introduction

Several devices for wave division multiplexing (WDM) systems which utilize mode conversion in waveguides have been proposed and demonstrated [1-4]. Tilted Bragg gratings (TBGs) have been used to produce the mode conversion in these devices. TBGs can produce nearly complete reflections; they are relatively compact and readily integratable in most device configurations, and they are fabricated using well established techniques. However, TBGs produce multiple reflections, only one of which provides the desired mode conversion [5,6]. The other reflections produce backward traveling signals that will only contribute to the noise, crosstalk and back-reflection of the device. A previous experimental attempt to minimize these spurious reflections required difficult alignment and still produced unwanted reflections of almost -10 dB [7].

Here we present the operating principle and experimental demonstration results of the anti-symmetric waveguide Bragg grating previously proposed [8,9]. Modeling for this structure has shown only the desired, mode-converting reflection [8-10]. The experimental results presented here verify our theoretical analysis. Our design can be utilized in communication and optical signal processing applications such as optical add-drop multiplexers (OADMs), optical header recognition chips, code division multiplexing access (CDMA) encoders and decoders and for optical encryption.

2. Proposed design

Coupled mode theory applied to reflective gratings [11-12] shows that the coupling between two modes, "a" and "b" , is governed by the overlap integral given by

$$\eta_{\mathrm{ab}} = \frac{\iint e_a^*(x,y)\zeta(x,y)e_b(x,y)dxdy}{\sqrt{\iint e_a^*(x,y)e_a(x,y)dxdy \int\int e_b^*(x,y)e_b(x,y)dxdy}} \tag{1}$$

where $\zeta(x,y)$ is the index perturbation in the transversal plane, and $e_a(x,y)$ and $e_b(x,y)$ are the field amplitude profiles of modes "a" and "b", respectively, propagating in the propagation direction. For a Bragg grating, with $\zeta(x,y)$ constant, coupling between orthogonal modes is forbidden. TBGs introduce a linear phase shift in $\zeta(x,y)$, which allows coupling between orthogonal modes but does not forbid coupling between identical mode profiles.

It is possible, however, to obtain coupling exclusively between orthogonal modes "a" and "b" [8-10]. In a two-mode waveguide, which has only one even (fundamental) and one odd mode, the coupling between the even mode profile and the odd mode profile is optimized when using an anti-symmetric structure as shown in Fig. 1(a). Here the index perturbation, $\zeta(x,y)$, has a π-phase shift with respect to the lateral axis of symmetry for the waveguide modes. In this structure, coupling from a forward propagating even mode to a backward propagating odd mode (or visa-versa) will occur at

$$\lambda_{oe} = \Lambda(n_e + n_o) \tag{2}$$

where λ_{oe} is the wavelength on Bragg condition for the reflection with mode conversion, n_e and n_o are the effective indices of the even and odd modes at λ_{oe}, respectively.

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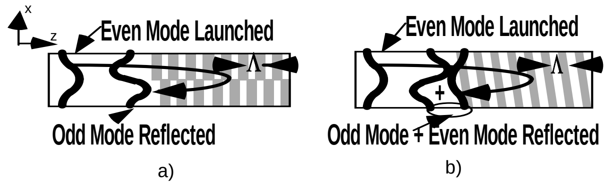

Fig. 1. Schematics of the anti-symmetric waveguide grating (a) and a waveguide with a tilted Bragg grating (b).

A comparison between the predicted performance from our modeling of a TBG [6] and of the anti-symmetric grating [10] is presented in Fig. 2. Gratings of identical length and strength of index modulation are modeled. The spectrum of a TBG (dashed line) exhibits at least two strong reflections peaks. One of them is the desired reflection with mode conversion, i.e. odd-even or even-odd. Other reflection peaks correspond to the reflections without mode conversion, i.e. either odd-odd or even-even reflection. In comparison, the anti-symmetric grating has only the desired reflection with mode conversion, as shown with the solid line in the same figure. This characteristic will relax the tolerances of other elements in the device and will increase the flexibility of the design.

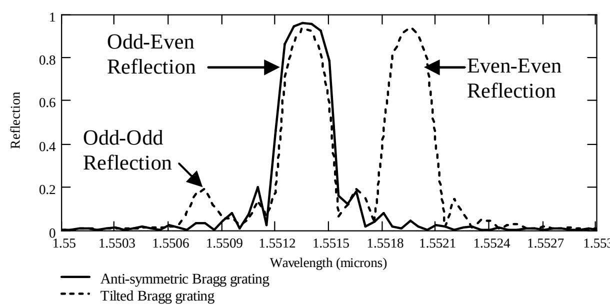

Fig. 2. Comparison of a TBG (dashed line) to the anti-symmetric Bragg Grating (solid line).

3. Experimental results

To experimentally verify our design, a structure, shown in Fig. 3, was fabricated with silica on silicon waveguide technology described previously [13-14]. The refractive index was 1.460 for the core and ~1.448 for the upper and lower claddings. The structure consists of an asymmetric y-branch with two single mode waveguides of different widths that are brought together to form a two-mode waveguide (waist). The function of the asymmetric y-branch is to excite exclusively either the even or the odd mode in the waist [15].The anti-symmetric grating consists of trenches (depth ~400 nm) etched into the waist and filled with cladding material and operates in first grating order corresponding to a grating period of about 500 nm. The length of the grating is 5 mm which from our modeling correspond to 90% of reflection. The widths of the narrow and wide branch are 5.6 μm and 8.4 μm respectively. The waist width is 14 μm. The height of the waist is 2.0 μm where no trenches are written. This allows only the fundamental even mode in the vertical direction. Outside the grating region the height of waist and branches is ~1.6 μm.

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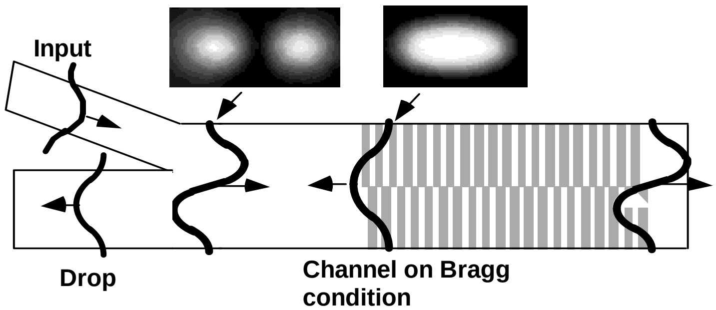

Fig. 3. Schematics of the fabricated device using the anti-symmetric grating. Measured mode profiles of the two-mode waveguide are also shown.

Figure 4 shows the set up for device characterization. Reflection spectra of the device were measured using an erbium doped fiber amplifier (EDFA) as an amplified spontaneous emission (ASE) source and an optical spectrum analyzer (OSA) with a resolution of 0.06 nm. A polarization controller allowed characterization of both the TE and TM performance. A fiber array was used to couple light into and out of the device. After measurements the spectra were normalized using the EDFAs ASE profile.

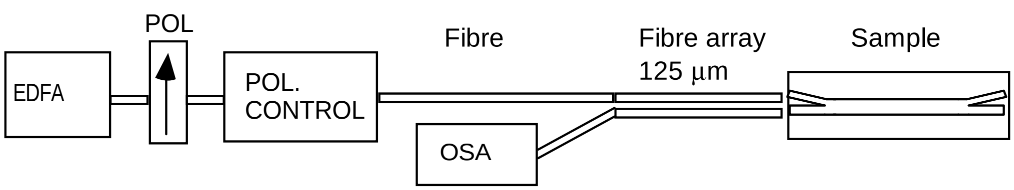

Fig. 4. Set up for sample characterization.

When TE-polarized light was launched to the narrow branch (input port), primarily the odd mode of the waist was excited (>99%) as shown in Fig. 3. It was reflected as an even mode at 1.55135 µm and coupled to the wider branch (drop port). The relevant reflection spectrum measured is shown in Fig. 5. The designation of the ports is arbitrary: power launched to the wider branch excites the even mode which is reflected with mode conversion at the same wavelength and is then coupled to the narrow branch. When the input and output ports were reversed, the measured reflection spectrum was identical. As shown in Fig. 5 (solid line) the reflection spectrum has only one peak due to the desired coupling between the even and odd modes. The measured reflection spectrum is in good agreement with our modeling, shown in the same figure (dashed lines). No spectral peaks are present at the predicted wavelength for even-even and odd-odd reflections, 1.55195µm and 1.55075 µm respectively.

When TM polarized light was launched in both narrow and wider branch only one reflection peak was found at 1.5516 µm as shown in Fig. 6. The polarization dependence of 0.25 nm is likely due to the asymmetry of the waveguide and to strain-induced waveguide birefringence. The second, a well known problem of the silica on silicon platform can be overcome by various fabrication methods yielding essentially polarization-independent gratings [15]. Reflected light coupled back to the launch port should have the same spectral shape as the reflection out the drop port, but reduced by the amount equal to the mode coupling in the asymmetric y-branch (~20 dB).

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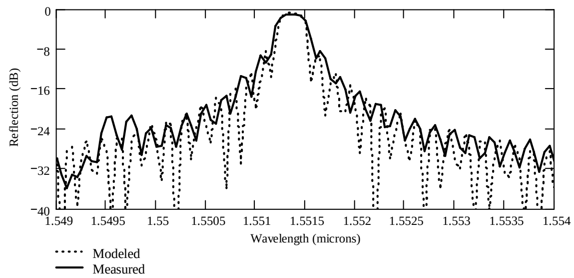

Fig. 5. Calculated and measured TE reflection spectrum of the anti-symmetric waveguide Bragg grating.

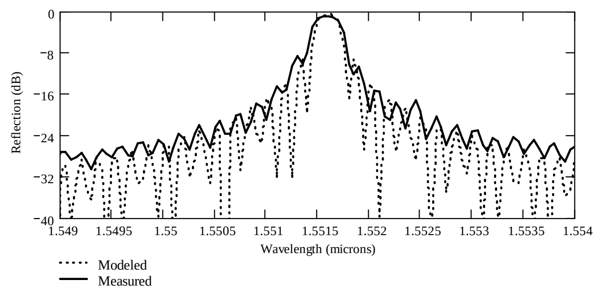

Fig. 6. Calculated and measured TM reflection spectrum of the anti-symmetric waveguide Bragg grating.

4. Summary

We have presented experimental verification for the mode conversion capabilities of the proposed anti-symmetric waveguide grating. The results have excellent agreement with our modeling based on coupled mode theory and beam propagation method. Our modeling predicts that reflection of ~99.9% can be obtained with ~ 1.1 cm length. The proposed grating can improve the performance of several devices, such as OADMs, dispersion compensators and resonators, which currently use TBGs. The key advantage is the elimination of unwanted reflections, since our device produces only one reflection peak corresponding to the odd-even mode conversion. This type of a grating can provide versatility and compactness in integrated optics devices allowing the use of several optical processing functions in small chip area.

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