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RESEARCH ARTICLE

Binary blazed grating-based polarization-independent filter on silicon on insulator

Danhua WU, Xin SUI, Junbo YANG, Zhiping ZHOU (✉)

The State Key Laboratory of Advanced Optical Communication Systems and Networks, Peking University, Beijing 100871, China

Abstract In this paper, a binary blazed grating-based polarization independent filter on silicon on insulator (SOI) under full conical incidence is presented. The properties of the grating filter are investigated by rigorous coupled-wave analysis. It's shown that the filter demonstrates high reflectivity ($R > 99\%$) at its resonant wavelength, which stays the same under three different polarization states. It indicates that this grating filter is polarization-independent. The final data shows its polarization-dependent loss (PDL) is only 0.04 dB and the full width at half maximums (FWHMs) of the transverse electric (TE-) and transverse magnetic (TM-) polarized light are 0.24 and 0.46 nm, respectively.

Keywords narrow filter, binary blazed grating, full conical incidence, polarization-independent

1 Introduction

Guided-mode resonance grating filters (GMRGFs) have attracted more attentions due to their unique advantages over classical multilayer structures and fiber Bragg grating filters in a system of dense wavelength demultiplexing (DWDM) [1]. A GMRGF normally consists of a waveguide layer and a grating layer, where the incident light can be coupled into a guided mode. Compared with the other aforementioned filters, GMRGFs offer the possibility to achieve a narrow band reflection filter with a relatively simpler fabrication process [2]. A GMRGF can be designed under classical incidence or conical incidence according to the direction of the incidence plane. Much research work has been done to realize a polarization-independent grating filter under classical incidence. Hu et al. have presented a method to design a polarization-independent GMRGF under classical incidence [3]. Wu et al. have designed a broadband polarization-independent reflector based on binary blazed grating under classical incidence as well [4]. For full conical incidence, the incident wave vector is parallel to the grooves of the grating. A pair of waveguide modes, which have mirror symmetry with respect to the incidence plane, can be excited. Thus it is possible to realize a polarization-independent grating filter [5]. This characteristic enables this device to be applied in the field where the polarization state is unknown or unstable [6]. Based on the principle, Lacour et al. have designed a polarization-independent grating filter under both classical and full conical incidence based on uniform grating structure [7]. Niederer et al. have designed a polarization-independent tunable filter under full conical incidence using uniform grating structure as well [6]. In this paper, we propose a polarization-independent grating filter under full conical incidence based on binary blazed grating with a characteristic of narrow width and very high reflectivity at the resonant wavelength.

2 Theoretical model

Figure 1 shows the coordinate system for a grating in a conical mounting. A linearly polarized electromagnetic plane wave is obliquely incident on a binary blazed grating. θ is the angle of incidence, and α is called conical angle, when $\alpha = 90°$, which means that the incident wave vector is in the (xOz) plane, it's so-called full conical incidence. φ is the angular deviation of the principle electric field direction away from transverse electric (TE) towards transverse magnetic (TM), $\varphi = 0°$ for pure TE, and $\varphi = 90°$ for pure TM.

Under full conical incidence, the incident wave vector has a non-zero component along the grooves direction. The effective indices of the guided-modes depend only on the optical indices of each layers, and the depths of the grating

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E-mail: zjzhou@pku.edu.cn

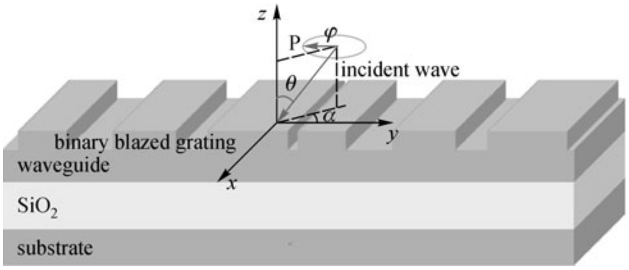


Fig. 1 Coordinate system for binary blazed grating in conical mounting

and the waveguide, but not on the incident wave. When a guide mode is excited, its wave vector has two components: the *x* direction of the mode is linked to the *y* component of the incident wave vector and the *y* direction of the mode to the periodicity of the grating. The direction of the incident wave and the guide-modes are never in the same plane. Actually, as shown in Fig. 2, the *x* component of the guided-wave vector is identical to the same component of the incident wave vector, and its *y* component is related to the periodicity of the grating [8].

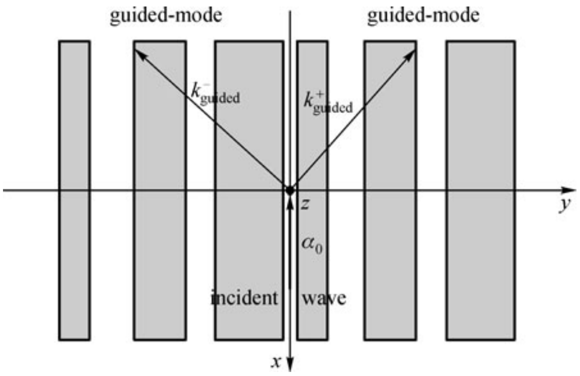


Fig. 2 Full conical incidence for resonant excitation of two identical guided-modes

Let us denote by $k^{\pm}_{\text{guided}}$, two guided-modes propagating vectors. k^{+}_{guided} and k^{-}_{guided} are such that,

$$k^{\pm}_{\text{guided}} = \begin{cases} \alpha_0, \\ \pm n\dfrac{\lambda}{T}, \\ 0, \end{cases} \tag{1}$$

where $\alpha_0 = -\sin\theta\cos\varphi$, n is taken equal to ± 1 to have only the specular order, and T is the grating period. Since k^{+}_{guided} and k^{-}_{guided} have the same modulus, the two modes are necessary identical. Hence they correspond to the same TE or TM mode. Two TE modes are to be excited, and then we have to satisfy [9],

$$\alpha_0^2 + \left(n\frac{\lambda}{T}\right)^2 = \beta_{\text{TE}}^2. \tag{2}$$

And if we want to excite two TM modes, we have the same relation replacing β_{TE} by β_{TM}. In order to excite the guide-modes, the incident electric field should at least have one of these components. The only case, where this condition is not fulfilled, is the angle of incidence θ. So in practical cases, the two guided modes are excited simultaneously. Nevertheless, the incident electric filed can be orthogonal to the electric field of one of the guided-modes. Then this guided-mode is not excited, and the resonance effect proceeds from the excitation of the other mode.

3 Structural design

Proposed structure has a multilayer configuration, and a thin grating layer is etched on the top silicon waveguide of a silicon on insulator (SOI) wafer [10]. Figure 3 shows the scheme of a SOI-based polarization-independent filter using binary blazed grating. The binary blazed grating consists of subwavelength grooves with uniform heights, which can be fabricated by only one etching step. It can be seen from Fig. 3, this gating has three subperiods in the period T of this grating, and f_1, f_2, f_3 are the corresponding fill factors of each subperiod, which is defined as the ratio of groove width to grating subperiod. t_{g} and t_{w} are the depth of the grating layer and waveguide layer, respectively. Rigorous coupled-wave analysis (RCWA) [11–13] is adopted to calculate the reflectivity of this grating filter. All the optimized parameters of this grating are given in Table 1.

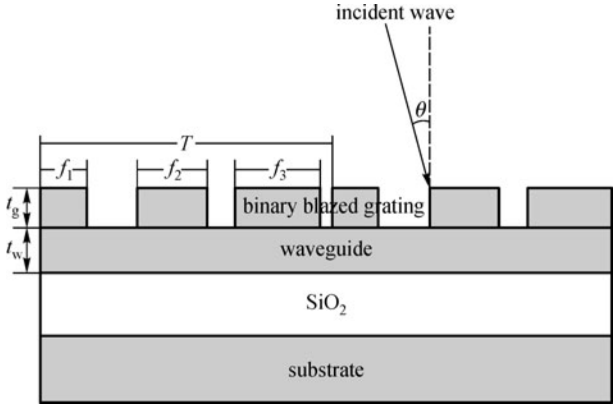


Fig. 3 Scheme of SOI-based polarization-independent filter using binary blazed grating

During the process of optimizing this grating filter, the fill factors of this binary blazed grating are used to displace the position of the two guided-mode resonances, which means we have to choose proper fill factors and have a

Table 1 Optimized parameters of grating filter

f_1	f_2	f_3	θ/(°)	α/(°)	T/nm	t_g/nm	t_w/nm
0.432	0.735	0.874	45	90	700	70	250

precise control on them to make the two resonant wavelengths place at the same position. The bandwidth of the filter can be adjusted by proper choice of the grating depth. Because of the characteristics of the binary blazed grating and the large refractive index difference among materials, we can obtain high reflectivity at the resonant wavelength.

We have optimized the grating filter by adjusting those important parameters in order to get a polarization-independent narrow filter. Table 1 shows the optimized parameters of this grating filter.

In many optical systems, insertion loss (IL) and polarization-dependent loss (PDL) are used to quantify the performance of devices. To follow this, we define the IL as

$$\mathrm{IL}_{\mathrm{TX}} = -10\log R_{\mathrm{TX}}(\mathrm{dB}), \tag{3}$$

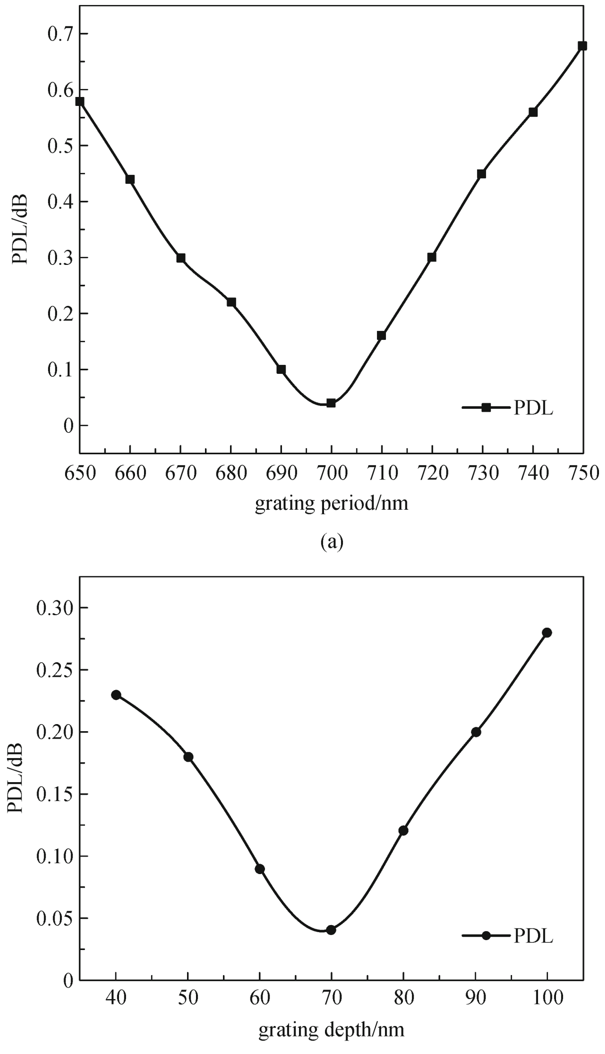
where R_{TX} is the reflectivity of either TE or TM polarization.

PDL is the maximum difference of IL between orthogonal polarization states, which is determined by [14]

$$\mathrm{PDL} = |\mathrm{IL}_{\mathrm{TM}} - \mathrm{IL}_{\mathrm{TE}}|(\mathrm{dB}). \tag{4}$$

We have investigated the PDL curves under different grating periods and grating depths. As shown in Fig. 4, PDL is the lowest (0.04 dB) when grating period T = 700 nm and grating depth t_g = 70 nm, where this filter has the maximal polarization independence. So we can design a polarization-independent grating filter using those optimized parameters in Table 1 and get the corresponding spectral reflectivity as well.

Figure 5 shows the spectral reflectivity of the grating filter when the angle of incidence θ = 45° and the conical angle α = 90°. In order to demonstrate its polarization independence, the spectral reflectivity of the filter is obtained by adjusting three different polarization angles φ (0°, 45° and 90°). It can be seen from Fig. 5 that all the three reflection curves are very symmetric and have very narrow bandwidths and high reflectivity ($R > 99\%$) at the resonant wavelength, indicating that an excellent filter is realized, and more importantly, they all have the same resonant wavelength (1549.5 nm) under three different polarization states, from which we can deduce this grating filter is polarization-independent in this case.



(a)

(b)

Fig. 4 PDL curves under different grating periods and depths. (a) As a function of grating period. All other parameters are the same as those in Table 1; (b) as a function of grating depth. All other parameters are the same as those in Table 1

4 Conclusions

We have designed a binary blazed grating-based polarization-independent narrow grating filter on SOI under full conical incidence and given a theoretical model of designing this kind of device. We have also considered about the impact of grating period and depth on PDL in order to make sure of the optimized parameters. Spectral reflectivity of this grating filter has been investigated under three different polarization states and this optimized filter shows polarization-independence with high reflectivity ($R > 99\%$) at the resonant wavelength and comparatively narrow bandwidths. These characteristics make the filter very attractive to be applied in fiber-based long-haul communication and computer communication systems.

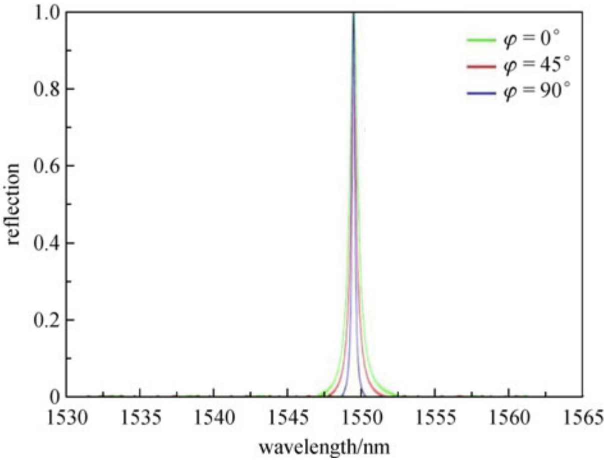


Fig. 5 Spectral reflectivity of the filter based on binary blazed grating

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References

1. Lemarchand F, Sentenac A, Cambril E, Giovannini H. Study of the resonant behavior of waveguide gratings: increasing the angular tolerance of guided-mode filters. Journal of Optics A: Pure and Applied Optics, 1999, 1(4): 545–551
2. Liu W X, Lai Z Q, Guo H, Liu Y. Guided-mode resonance filters with shallow grating. Optics Letters, 2010, 35(6): 856–867
3. Hu X H, Gong K, Sun T Y, Wu D M. Polarization-independent guided-mode resonance filters under oblique incidence. Chinese Physics Letters, 2010, 27(7): 074211
4. Wu H M, Hou J, Gao D S, Zhou Z P. A multilayered configuration broadband polarization insensitive reflector utilizing a multi-subpart profile grating structure. Chinese Physics Letters, 2010, 27(7): 74216–74218
5. Lacour D, Granet G, Plumey J P, Mure-Ravaud A. Polarization independence of a one-dimensional grating in conical mounting. Journal of the Optical Society of America A, Optics, Image Science, and Vision, 2003, 20(8): 1546–1552
6. Niederer G, Nakagawa W, Herzig H, Thiele H. Design and characterization of a tunable polarization-independent resonant grating filter. Optics Express, 2005, 13(6): 2196–2200
7. Lacour D, Plumey J P, Granet G, Ravaud A M. Resonant waveguide grating: analysis of polarization independent filter. Optics and Quantum Electronics, 2001, 33(4–5): 451–470
8. Sara N H, Victor R R. Dispersion relation of guided-mode resonances and Bragg peaks in dielectric diffraction gratings. Physical Review E: Statistical, Nonlinear, and Soft Matter Physics, 2001, 64(3): 036614
9. Fehrembach A L, Sentenac A. Study of waveguide grating eigenmodes for unpolarized filtering applications. Journal of the Optical Society of America A, Optics, Image Science, and Vision, 2003, 20(3): 481–488
10. Feng J B, Zhou Z P. Polarization beam splitter using a binary blazed grating coupler. Optics Letters, 2007, 32(12): 1662–1664
11. Moharam M G, Gaylord T K. Rigorous coupled-wave analysis of planar-grating diffraction. Journal of the Optical Society of America, 1981, 71(7): 811–818
12. Chateau N, Hugonin J P. Algorithm for the rigorous coupled-wave analysis of grating diffraction. Journal of the Optical Society of America A, Optics, Image Science, and Vision, 1994, 11(4): 1321–1331
13. Moharam M G, Pommet D AGrann E B, Gaylord T K. Stable implementation of the rigorous coupled-wave analysis for surface-relief gratings: enhanced transmittance matrix approach. Journal of the Optical Society of America A, Optics, Image Science, and Vision, 1995, 12(5): 1077–1086
14. Marciante J R, Hirsh J I, Raguin D H, Prince E T. Polarization-insensitive high-dispersion total internal reflection diffraction gratings. Journal of the Optical Society of America A, Optics, Image Science, and Vision, 2005, 22(2): 299–305