Phase grating with a connecting layer for reflective splitter with high efficiency

BO WANG*, WENHAO SHU, LI CHEN, LIANG LEI, JINYUN ZHOU
School of Physics and Optoelectronic Engineering, Guangdong University of Technology, Guangzhou 510006, China

A phase grating with a connecting layer is proposed for reflective splitter with high efficiency. A fused-silica layer and a metal slab are between the grating region and the substrate, which are different from the conventional grating directly etched in material. The grating parameters are optimized by numerical simulation, including the grating depth and connecting layer thickness. The reflective beam splitter can have merits of high efficiency and wideband property to some extent, especially for TE polarization.

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1. Introduction

The phase grating is widely used in various optical information processing systems [1-5] for the high efficiency. Moreover, many distinctive properties can be exhibited with diffractive sizes approaching the incident wavelength [6,7]. By using the rigorous coupled-wave analysis (RCWA) [8], the diffractive performance can be investigated with numerical simulation. Therefore, many micro-optical elements are designed based on phase gratings [9-11], including beam splitters, polarizers, and so on. Such grating-based elements are suitable for integration with small sizes. Among them, beam splitters are key devices in laser interferometers. Two-port with good uniformity can be achieved by the optimized phase grating.

A reflective diffractive beam splitter has been reported at an incident wavelength of 1064 nm for TE polarization [12]. With the optimized grating parameters, good uniformity can be contributed by both orders at the operating angles of 27° and 63°. Such a beam splitter can be used for gravitational wave detectors without thermal lensing effects. The conventional phase grating is directly etched in dielectric material by the wet or dry etching. It is reported that the good performance can be exhibited with other layers embedded between the grating region and the substrate [12]. Since the mixed metal dielectric grating has been presented for high efficiency in the –1st order [13], it can also be optimized as the reflective beam splitter.

In this paper, the phase grating with a connecting layer is proposed for the reflective beam splitter. Such a novel grating is different from the conventional grating with the grating layer on the substrate. A dielectric layer and a metal slab are embedded between the grating region and the substrate. The two-port beam splitter can be optimized for either TE polarization or TM polarization. High efficiencies are diffracted for both orders with good uniformity.

2. Reflective splitter by phase connecting-layer grating

Fig. 1 shows schematic of phase grating with a connecting layer for reflective splitter. The phase grating with period of d is etched in fused silica with grating depth of h_g and refractive index of n_2=1.45. There are a connecting dielectric layer with thickness of h_c and a metal slab of Ag with h_m and refractive index of n_3. The beam splitter can be illuminated by a plane wave with wavelength of λ under Littrow mounting at the Bragg angle of $\theta_i=\sin^{-1}(\lambda/(2n_1d)$ from air with the refractive index of n_1=1. For TE or TM polarization, the incident wave can be divided into the reflective orders with good uniformity.

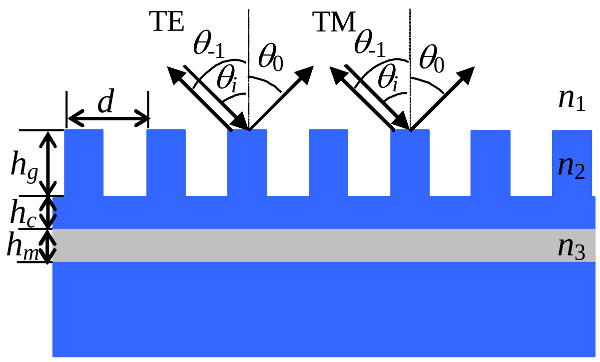


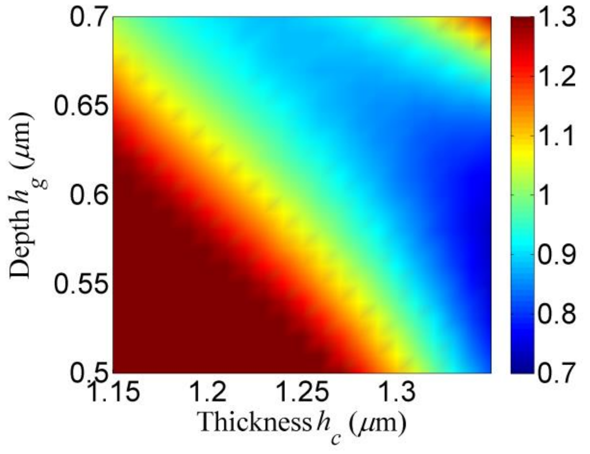
Fig. 1. Schematic of phase grating with a connecting layer for reflective splitter.

The RCWA [8] can be used to study the reflective efficiency for various grating parameters. The enhanced transmittance matrix approach is developed by the RCWA [8]. The grating layer, the connecting layer, and the metal slab can be divided into a large number of sufficiently thin slabs. The electromagnetic fields are determined by the coupled-wave approach in each slab. And the boundary conditions can be applied in sequence at the interfaces among the slabs. The reflected and the transmitted diffracted field amplitudes and the diffracted efficiencies can be achieved. The main efficiency equation used is Eq. (18) of RCWA [8]. Numerical diffraction efficiencies are calculated by the developed MATLAB software codes in this paper according to the RCWA.

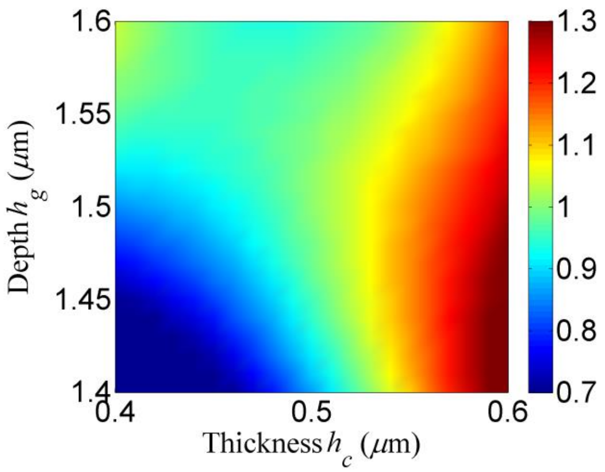
The connecting layer and metal slab are embedded between the grating region and the substrate for the novel grating. The metal slab thickness is 100 nm to reflect the incident wave while the connecting layer needs to be optimized. The grating duty cycle is 0.5 and period can be 1100 nm. Fig. 2.shows reflective efficiency's ratio between the –1st and the 0th orders versus connecting layer thickness and grating depth at the infrared wavelength of 1550 nm for TE or TM polarization. With grating depth of h_g=0.60 μm and covering layer thickness of h_c=1.25 μm for TE polarization, the reflective efficiencies of 49.19% and 49.09% can be diffracted into the –1st and the 0th orders, respectively.

Furthermore, for TM polarization, efficiencies separated into two orders are both 48.64% with good uniformity for optimized depth of h_g=1.50 μm and thickness of h_c=0.50 μm. As can be seen from the results, high efficiency can be achieved, especially for TE polarization.

For practical manufacture, it is necessary to give the fabrication tolerance for the grating depth. Fig. 3 shows reflective efficiency versus grating depth for the optimized grating connecting layer thickness with TE or TM polarization. One can see that efficiencies more than 45% can be obtained in the –1st and the 0th orders within the depth variation 0.55 μm<h_g<0.77 μm for TE polarization in Fig. 3 (a). For TM polarization, the beam splitter can divide the incident wave into two orders with efficiencies more than 45% within the depth range of 1.40 μm<h_g<1.66 μm in Fig. 3 (b). Therefore, the good fabrication tolerance can be exhibited for both TE and TM polarizations, which be useful for the practical manufacture of the novel reflective beam splitter grating.

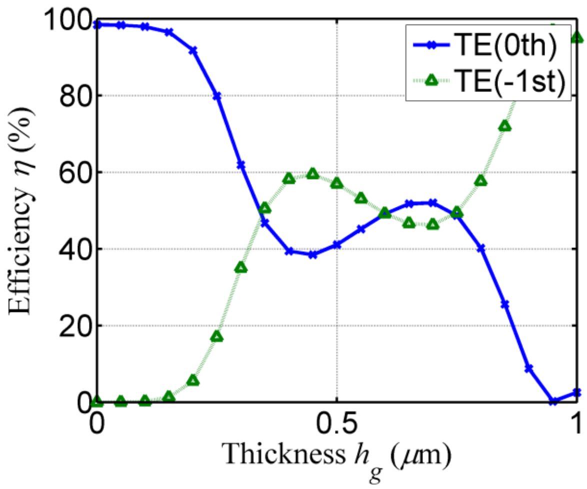


(a)

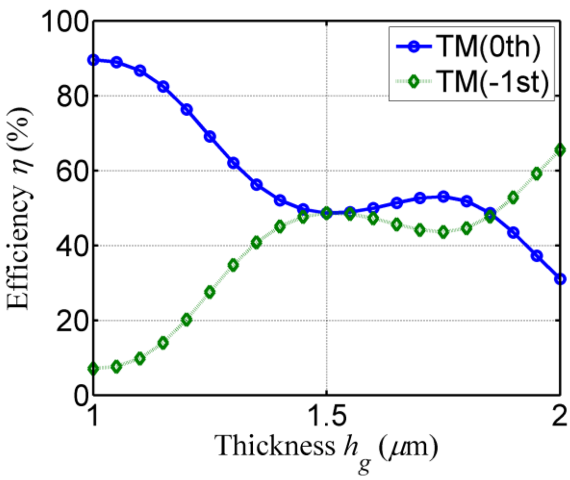


(b)

Fig. 2. (Color online) Reflective efficiency's ratio between the –1st and the 0th orders versus connecting layer thickness and grating depth at the infrared wavelength of 1550 nm: (a) TE polarization, (b) TM polarization.



(a)

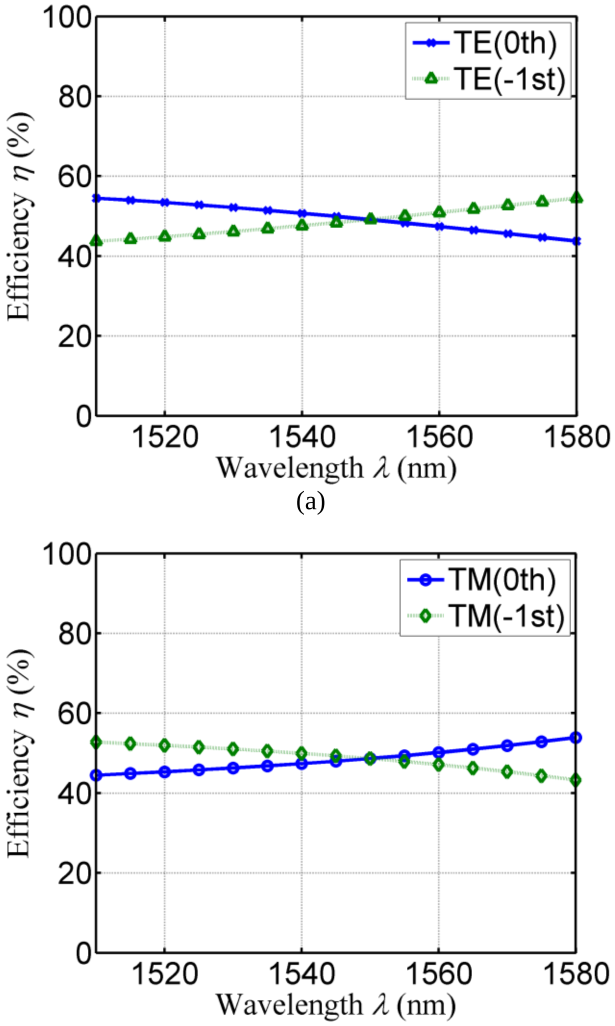


(b)

Fig. 3. (Color online) Reflective efficiency versus grating depth for the optimized grating connecting layer thickness: (a) TE polarization with h_c=1.25 μm, (b) TM polarization with h_c=0.50 μm.

3. Operating wavelength and angle

For most beam splitters based on multilayer coatings, the performance depends on the incident wavelength and angle. With deviations of the incident wavelength and angle, the performance can be affected, such as efficiency and uniformity. It is desirable to present a beam splitter with relatively wide bandwidth for the incident wavelength and angle. Fig. 4 shows reflective efficiency versus incident wavelength for TE polarization with h_g=0.60 μm and h_c=1.25 μm and TM polarization with h_g=1.50 μm and h_c=0.50 μm. For TE polarization in Fig. 4 (a), efficiencies more than 45% can be separated into the –1st and the 0th orders within the incident wavelength range of 1522-1573 nm. For TM polarization in Fig. 4 (b), the reflective beam splitter can diffract the incident wave with efficiencies more than 45% into two orders within the incident wavelength range of 1517-1571 nm.

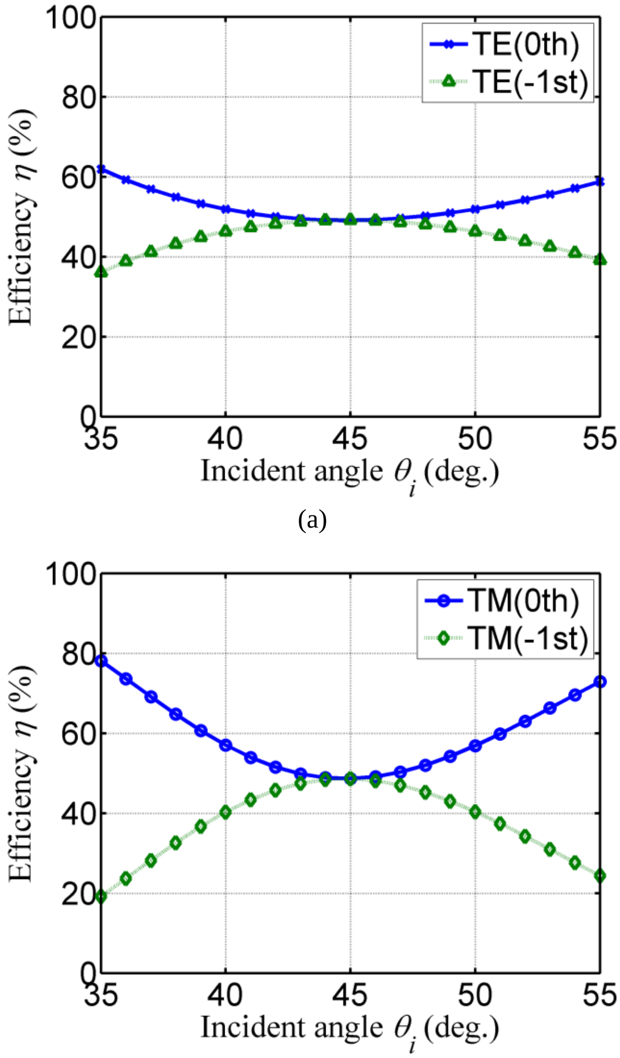


(a)

(b)

Fig. 4. (Color online) Reflective efficiency versus incident wavelength for the optimized grating parameters: (a) TE polarization with h_g=0.60 μm and h_c=1.25 μm, (b) TM polarization with h_g=1.50 μm and h_c=0.50 μm.

In the design, the incident wave illuminates the beam splitter at the Bragg angle. For most conventional beam splitters, the uniformity can be affected with the variation of the incident angle. Fig. 5 shows reflective efficiency versus incident angle for TE polarization with h_g=0.60 μm and h_c=1.25 μm and TM polarization with h_g=1.50 μm and h_c=0.50 μm. For the period of 1100 nm and incident wavelength of 1550 nm, the Bragg angle is 44.8°. When the incident angle changes around the Bragg angle for TE polarization, reflective efficiencies more than 45% can be exhibited in the –1st and the 0th orders within the incident angular bandwidth of 39.1–51.1° in Fig. 5 (a). The efficiency difference between two orders can be calculated based on the reflective efficiency, which is less than 8.01% within the given range. For TM polarization, the beam splitter can separate the incident wave into two orders with efficiencies more than 45% within the incident angle range of 41.7-48.1° in Fig. 5 (b). Moreover, efficiency difference less than 7.16% can be shown within the given range for TM polarization.



(a)

(b)

Fig. 5. (Color online) Reflective efficiency versus incident angle for the optimized grating parameters: (a) TE polarization with h_g=0.60 μm and h_c=1.25 μm, (b) TM polarization with h_g=1.50 μm and h_c=0.50 μm

4. Conclusions

In conclusion, a phase grating with a connecting layer is presented for reflective splitter with high efficiency. The grating parameters including the grating depth and connecting layer thickness are optimized by numerical simulation. With the optimized results, the reflective efficiencies of 49.19% and 49.09% can be diffracted into the –1st and the 0th orders. While for TM polarization, efficiencies in two orders can be both 48.64%. The fabrication tolerance for grating depth is given with the grating duty cycle of 0.5 and period of 1100 nm for the optimized connecting layer thickness, which is 0.55 μm< h_g <0.77 μm for TE polarization and 1.40 μm< h_g <1.66 μm for TM polarization. For the different operating wavelength and angle, efficiencies more than 45% can be diffracted for the given wavelength or angle range, which can exhibit the wideband property to some extent.

Acknowledgements

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References

[1] P. R. Gill, Opt. Lett. **38**, 2074 (2013).
[2] M. T. Flores-Arias, A. Castelo, C. Gomez-Reino, G. F. de la Fuente, Opt. Commun. **282**, 1175 (2009).
[3] C.-F. Kao, H.-L. Huang, S.-H. Lu, Opt. Commun. **283**, 1950 (2010).
[4] L. Xia, P. Shum, Opt. Commun. **281**, 4317 (2008).
[5] S. Kumar, D. V. Udupa, A. Debnath, N. Prasad, R. B. Tokas, N. K. Sahoo, Opt. Laser Technol. **47**, 305 (2013).
[6] B. Wang, L. Chen, L. Lei, J. Zhou, IEEE Photon. Technol. Lett. **25**, 863 (2013).
[7] J. Wu, C. Zhou, J. Yu, H. Cao, S. Li, W. Jia, Opt. Commun. **329**, 38 (2014).
[8] M. G. Moharam, D. A. Pommet, E. B. Grann, J. Opt. Soc. Am. A **12**, 1077 (1995).
[9] B. Wang, L. Chen, L. Lei, J. Zhou, Optoelectron. Adv. Mat. **7**, 797 (2013).
[10] J. Wu, C. Zhou, H. Cao, A. Hu, Opt. Commun. **309**, 57 (2013).
[11] W. Sun, P. Lv, C. Zhou, H. Cao, J. Wu, Appl. Opt. **52**, 2800 (2013).
[12] S. Fahr, T. Clausnitzer, E.-B. Kley, A. Tünnermann, Appl. Opt. **46**, 6092 (2007).
[13] A. Hu, C. Zhou, H. Cao, J. Wu, J. Yu, W. Jia, Appl. Opt. **51**, 4902 (2012).

*Corresponding author: wangb_wsx@yeah.net