OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 12, No. 5-6, May-June 2018, p. 279 - 282

Beam splitting based on connecting-layer grating with improved efficiency

SUFANG YIN, BO WANG*, CHENGYUE SU, WENHUA ZHU, LI CHEN, LIANG LEI, JINYUN ZHOU
Guangdong University of Technology, Guangzhou 510006, China

The beam-splitting element is described based on the connecting-layer grating to improve the performance. A connecting layer is introduced between the grating region and the substrate. Efficiencies are improved especially for TE polarization. For TE polarization with the grating depth of 0.65 μm and connecting layer thickness of 0.45 μm, efficiencies of 49.50% and 49.53% can be diffracted into the –1st and the 0th orders, respectively. For TM polarization with the grating depth of 1.00 μm and connecting layer thickness of 0.72 μm, splitting efficiencies of 49.32% and 49.62% can be divided into the two orders.

(Received August 31, 2017; accepted June 7, 2018)

Keywords: Beam splitting, Transmission efficiency, Micro-optical element

---

1. Introduction

Beam-splitting elements are useful in many applications [1-3], such as optical information processing, laser pulse compression, and optical computing. For the beam splitter design, efficiency and uniformity should be taken into account. Conventional beam splitters are based on multilayer coatings, which have disadvantages of energy power loss and low damage threshold. High-density gratings are found that efficiencies of diffracted orders can be modulated by grating parameters. It is interesting that a high-density grating is optimized as a beam splitter [4-6], which can have merits of high efficiency and simple structure. Furthermore, such grating-based beam splitters can be possibly fabricated with techniques in microphotolithography, holographic recording, and inductively coupled plasma etching [7]. A polarization-independent two-port beam splitter has been firstly presented by a simple dielectric grating [8]. Such a beam splitter grating can diffract TE polarization into the 0th order with the efficiency of 47.31% and the -1st order with the efficiency of 47.42%, respectively. It can be seen that efficiencies should be further improved by the novel grating structure [9,10].

In this paper, to improve the efficiency, a beam-splitting element is proposed based on the connecting-layer grating. Such a novel grating is different from the conventional simple grating. A connecting layer is introduced between the grating region and the substrate. The grating duty cycle is the usual value of 0.5. To obtain a beam splitter with high efficiency and good uniformity, grating parameters and the connecting layer thickness are optimized by using the rigorous coupled-wave analysis (RCWA) [11]. The attractive advantage of the novel grating is that the efficiency can be effectively improved.

2. Beam splitting by connecting-layer grating

The schematic diagram of beam-splitting element is shown in Fig. 1, which is based on the connecting-layer grating. The novel grating is composed of the substrate with refractive index of n_3=2, the connecting layer of fused silica with thickness of h_c and refractive index of n_2=1.45, and the grating region with depth of h_g. The grating period d can be comparable to the incident wavelength. A plane wave with wavelength of λ is incident upon the grating 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. The incident energy can be separated into the –1st and 0th orders with good uniformity.

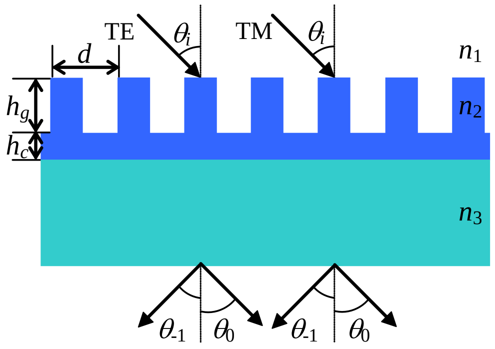
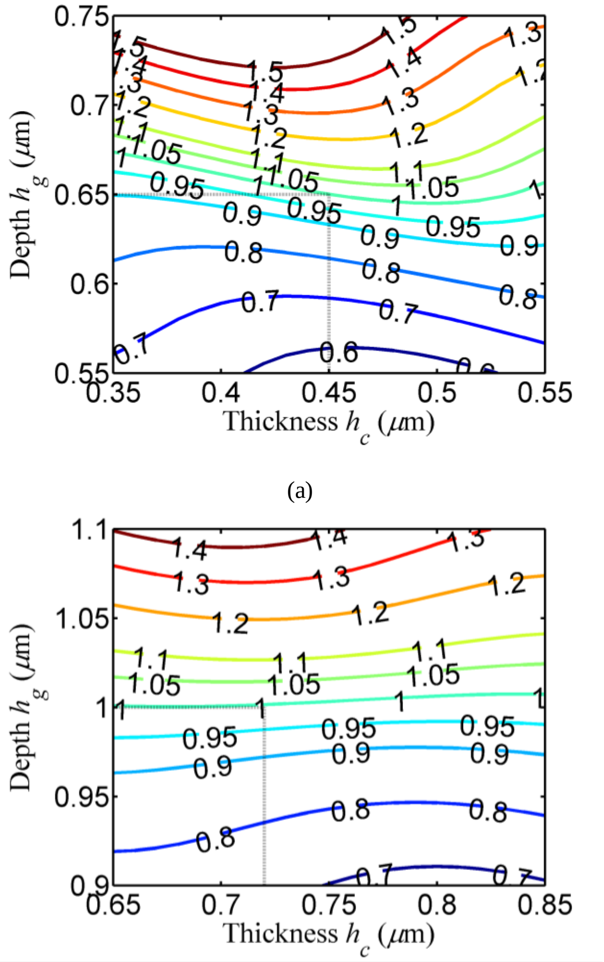


Fig. 1. (Color online) Schematic of beam splitting based on connecting-layer grating

For the high-density grating, efficiencies can be modulated by the grating parameters. In order to obtain a beam-splitting element, the novel grating should be optimized. Fig. 2 shows contour of the efficiency's ratio between the –1st and the 0th orders versus grating depth and connecting layer thickness with the usual duty cycle of 0.5 and period of 700 nm for both TE and TM polarizations. In Fig. 2 (a), the splitting ratio of nearly 1 can be obtained with the optimized grating depth of h_g=0.65 μm and connecting layer thickness of h_c=0.45 μm for TE polarization. By calculation, efficiencies of 49.50% and 49.53% can be diffracted into the –1st and the 0th orders, respectively. Such optimized efficiencies by connecting-layer grating are much higher than 47.42% and 47.31% reported by simple grating structure [8]. In Fig. 2 (b), good uniformity can be achieved with h_g=1.00 μm and h_c=0.72 μm for TM polarization. Efficiencies of 49.32% and 49.62% can be divided into the two orders with the optimized grating parameters, respectively.

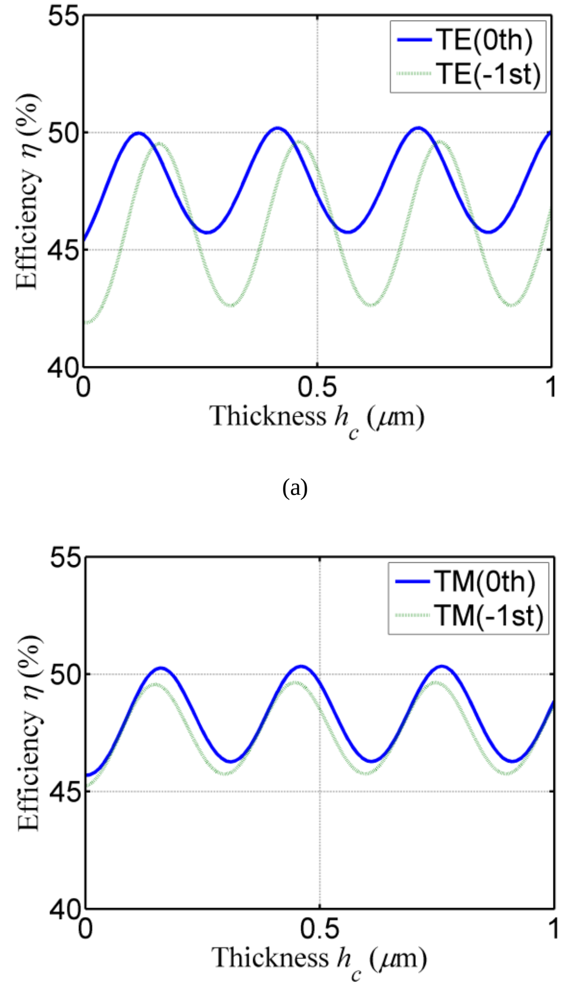


(a)

(b)

Fig. 2. (Color online) Contour of the efficiency's ratio between the –1st and the 0th orders versus grating depth and connecting layer thickness with the usual duty cycle of 0.5: (a) TE polarization, (b) TM polarization

Fig. 3 shows efficiency versus connecting layer thickness with the optimized grating depth for TE and TM polarizations. One can see that the difference between two orders for TM polarization is much lower than TE polarization. It indicates that the performance of uniformity can be kept quite good for TM polarization to some extent when the connecting-layer thickness changes around the optimized result.



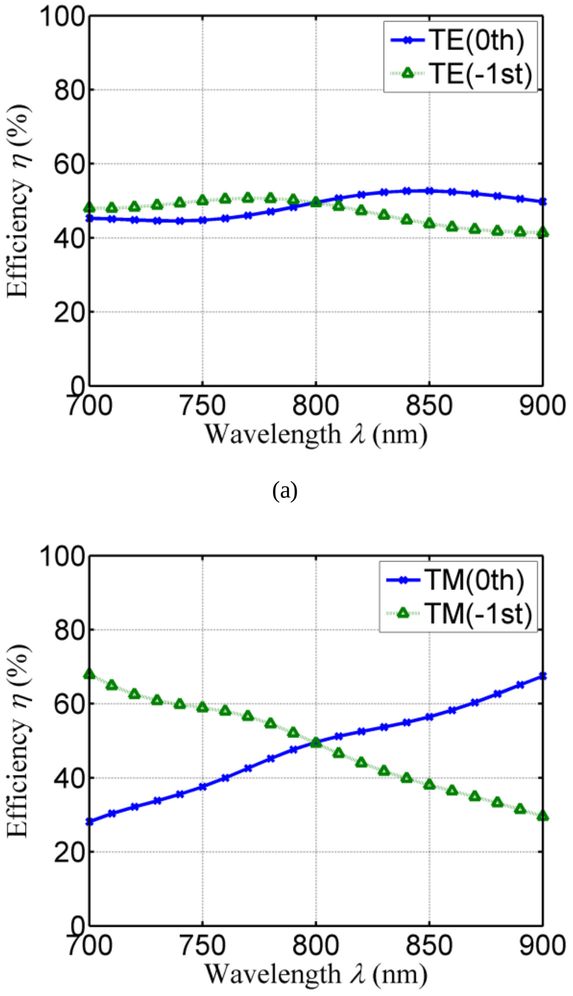
(a)

(b)

Fig. 3. (Color online) Efficiency versus connecting layer thickness with the optimized grating depth: (a) TE polarization with h_g=0.65 μm, (b) TM polarization with h_g=1.00 μm

3. Performance with different incident conditions

For conventional beam splitters based on multilayer coatings, the uniformity can usually be good for the certain incident wavelength and angle. With deviations of incident conditions from the central wavelength and the Bragg angle, the performance may be affected. It is desirable to design a beam-splitting element with the wideband property. Fig. 4 shows efficiency versus incident wavelength with the optimized grating parameters. In Fig. 4, the efficiencies in two orders are not same with the variation of the wavelength. For TE polarization, efficiencies more than 45% can be obtained within the incident wavelength range of 756-838 nm. For TM polarization, the novel beam splitter can exhibit efficiencies more than 45% within the wavelength range of 780-815 nm. It can be seen that wide bandwidth can be obtained for TE polarization.

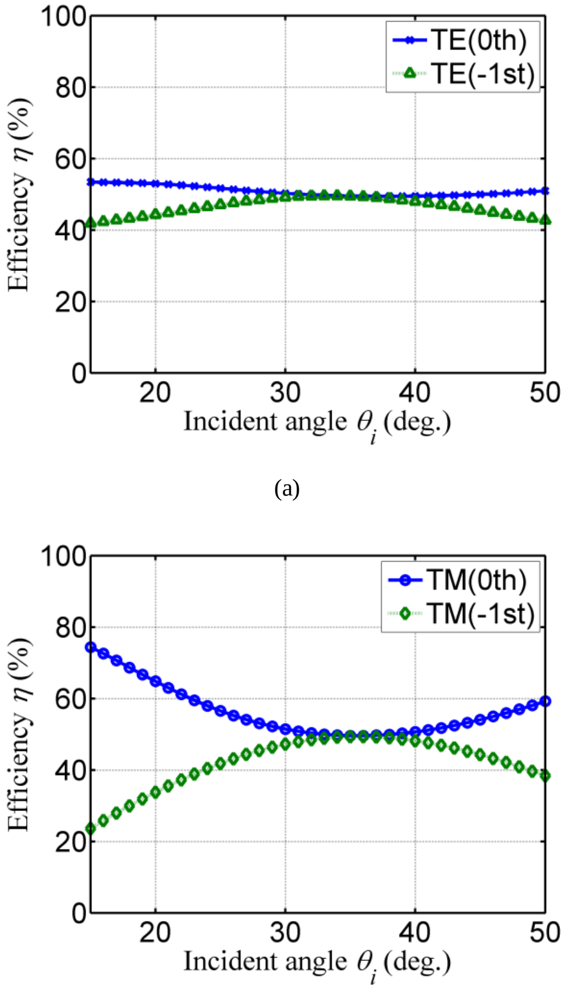


(a)

(b)

Fig. 4. (Color online) Efficiency versus incident wavelength with the optimized grating parameters: (a) TE polarization with h_g*=0.65 μm and* h_c*=0.45 μm, (b) TM polarization with* h_g*=1.00 μm and* h_c*=0.72 μm*

Although many beam splitters have been reported, most of them are operated only at the given incident angle. Figure 5 shows efficiency versus incident angle with the optimized grating parameters. For TE polarization, efficiencies more than 45% can be obtained within the incident angle range of 21.3-45.9°. For TM polarization, the novel grating-based beam splitter can diffract efficiencies more than 45% into two orders within incident angle range of 27.6-44.2°. One can see that the angular performance for TM polarization is more sensitive than TE polarization. Most importantly, wide incident angular bandwidth can be exhibited by such a beam-splitting element based on connecting-layer grating. Compared with other beam splitters used only at certain incident angle, the merit of wide incident angle range in the connecting-layer grating design is significant for practical operation.



(a)

(b)

Fig. 5. (Color online) Efficiency versus incident angle with the optimized grating parameters: (a) TE polarization with h_g*=0.65 μm and* h_c*=0.45 μm, (b) TM polarization with* h_g*=1.00 μm and* h_c*=0.72 μm*

4. Conclusion

Connecting-layer-based gratings can be optimized as useful optical elements, such as polarizer [9], high-efficiency diffraction with polarization-independent property [10], and beam splitting of two-port in this paper. References [9], [10] and the grating in this paper report three types of grating-based elements with different functions. In reference [9], the optical element can work as a polarizer to obtain TE polarization in the -1st order or

TM polarization in the 0th order. Two polarizations are in different diffracted directions. In reference [10], the grating diffract TE and TM polarization in the -1st order with high efficiency, which can be used in dense wavelength division multiplexing systems with low polarization-dependent loss. In this paper, the connecting-layer-based grating can split TE or TM polarization with good uniformity in two orders. Such optimized efficiencies by connecting-layer grating are much higher than that of reported simple grating structure [8]. Moreover, The two-port beam splitter has been optimized by using RCWA, which can be demonstrated by holographic recording technology and inductively coupled plasma etching [8]. Therefore, the presented connecting-layer-based grating can be potentially fabricated to split beams with good uniformity.

In conclusion, a beam-splitting element can be optimized based on connecting-layer grating. With the optimized grating parameters for TE polarization, efficiencies of 49.50% and 49.53% can be separated into two orders, respectively. With the optimized design for TM polarization, efficiencies of 49.32% and 49.62% can be diffracted, respectively. The efficiencies are improved compared with the simple grating-based beam splitter. Furthermore, the performance is studied with different incident conditions. Efficiencies more than 45% can be exhibited within the incident wavelength range of 756-838 nm for TE polarization and 780-815 nm for TM polarization. With the incident angle deviating from Littrow mounting, the novel beam splitter can exhibited efficiencies more than 45% within the range of 21.3-45.9° for TE polarization and 27.6-44.2° for TM polarization, respectively. The novel connecting-layer grating provides good design to improve the performance of beam-splitting element.

Acknowledgements

This work is supported by the Pearl River Nova Program of Guangzhou (201506010008), the Science and Technology Research Project of Guangdong Province (2016B090918124), and the National Natural Science Foundation of China (61475037, 61675050).

References

[1] S. Huang, C.-W. Zou, F. Lin, C. Lu, IEEE Photon. J. **10**(1), 6500507 (2018).
[2] Z. Zhen, L. Zhuo, W. Zhu, L. Chen, J. Yu, H. Guan, H. Lu, J. Dong, W. Qiu, Z. Chen, IEEE Photon. J. **10**(2), 4500307 (2018).
[3] J.-S. Choe, H. Ko, B.-S. Choi, K.-J. Kim, C. J. Youn, IEEE Photon. J. **10**(1), 7600108 (2018).
[4] Y. Liu, H.-J. Fuchs, Z. Liu, H. Chen, S. He, S. Fu, E.-B. Kley, A. Tünnermann, Appl. Opt. **49**(23), 4450 (2010).
[5] F. Jacky Wen, P. S. Chung, Appl. Opt. **50**(19), 3187 (2011).
[6] B. Wang, L. Chen, L. Lei, J. Zhou, IEEE Photon. Technol. Lett. **25**(9), 863 (2013).
[7] S. Wang, C. Zhou, Y. Zhang, H. Ru, Appl. Opt. **45**(12), 2567 (2006).
[8] J. Feng, C. Zhou, J. Zheng, H. Cao, P. Lv, Appl. Opt. **48**(29), 5636 (2009).
[9] B. Wang, L. Lei, L. Chen, J. Zhou, Opt. Laser Technol. **44**(7), 2145 (2012).
[10] B. Wang, L. Lei, L. Chen, J. Zhou, Opt. Laser Technol. **45**, 424 (2013).
[11] M. G. Moharam, D. A. Pommet, E. B. Grann, J. Opt. Soc. Am. A **12**(5), 1077 (1995).

---

*Corresponding author: wangb_wsx@yeah.net