Splitting of three-port output by two-layer grating with high efficiency

HONGTAO LI, BO WANG*, HAO PEI, SUFANG YIN, LI CHEN, LIANG LEI, JINYUN ZHOU
School of Physics and Optoelectronic Engineering, Guangdong University of Technology, Guangzhou 510006, China

A two-layer three-port output grating with high-efficiency beam splitting is presented in this paper. The grating can split the incident wave into the 0th order and the ±1st orders for both TE and TM polarizations at the wavelength of 800 nm. According to the property of the incident angular bandwidth, the efficiency of every diffracted order exceeds 30% within the incident angular bandwidth range of -1.04-3.14°. Compared with the conventional reported single-layer three-port grating, the two-layer three-port grating has merits of not only the higher efficiency but also the broader angular bandwidth.

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1. Introduction

According to the reported diffraction gratings, there are some grating-based optical elements, including coupler [1], sensor [2], modulator [3], display [4], absorber [5], and signal processing [6]. Two-layer diffraction gratings are proposed in a lot of reported papers [7,8]. They can be used in numerous important optical devices, for example, amorphous silicon thin film solar cell. Therefore, the two-layer grating should have attached importance for its valuable performances. By analyzing the metallic grating, it can diffract the normal incident wave into the 0th and the ±1st orders for both TE and TM polarizations, respectively [9,10]. Efficiencies of the three diffraction orders would be obtained by using rigorous coupled-wave analysis (RCWA) [11] with the optimized grating parameters.

A single-layer three-port beam splitter grating has been proposed, which is operated in transmission [12]. With the optimized grating parameters, the grating can diffract the TE and TM polarizations with efficiencies of 96.31% and 96.96% under the normal incidence, respectively. In purpose of acquiring the property of the broadband which is useful in practice [13-19], the two-layer grating can be designed. As can be seen from the values of numerical simulation, the highly-efficient beam splitting and the broad bandwidth with the novel two-layer three-port output grating are interesting for operation in practice. The designed of the grating would be helpful for mass production.

The novel two-layer three-port output grating is proposed in this paper, the grating has merits of high efficiencies for both TE and TM polarizations and the broad angular bandwidth with the designed two-layer structure under the normal incidence. The efficiency of each port can reach nearly 33% for both TE and TM polarizations with higher efficiency and better uniformity compared with the single-layer three-port output grating.

2. Numerical simulation and optimization

The profile of two-layer three-port output grating with period d is shown in Fig. 1. The substrate of the grating is fused silica. The groove depth of the three-port output grating can be separated into two different layers, where the first layer is etched in Ta_2O_5 with the depth of h_1 and the refractive index $n_1 = 2.0$ and the second layer is etched in fused silica with the depth of h_2 and the refractive index $n_2 = 1.45$. When the light from the air with the refractive index of the air $n_3 = 1.0$ vertically incidents the two-layer grating, it can be mainly diffracted into the 0th and the ±1st orders for TE/TM polarization. Due to the symmetry of the diffracted orders, the energy of the 1st order can be same with the -1st order's.

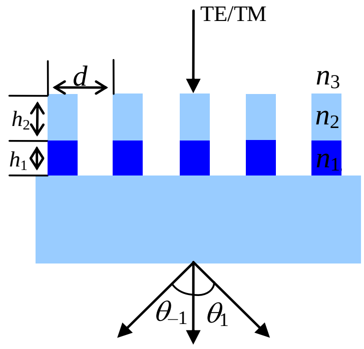

Fig. 1. (Color online) Schematic of a two-layer three-port with high-efficiency beam splitting grating

When optimizing the initial grating parameters, there are some parameters should be considered, for instance, grating period, duty cycle, and grating depths, which can influence the diffraction efficiencies for both TE and TM polarizations. To begin with, the grating period can be set to 1 μm. Most importantly, it is necessary to optimize the other grating parameters. With the optimized grating depths, the high efficiency of TE/TM polarization can be obtained during beam splitting. Fig. 2 shows the transmission efficiencies of the 0th order and the 1st order of the two-layer three-port output grating versus the first layer thickness of h_1 and the second layer thickness of h_2 with the special duty cycle of 0.65. In Fig. 2, efficiencies of 98.15% and 99.91% can be diffracted into the 0th order and the ±1st orders for TE and TM polarizations, respectively. With optimized the first layer thickness of h_1 = 1.0 μm and the second layer thickness of h_2 = 1.28 μm, efficiencies of 32.97%/32.59% can be diffracted into the 0th order and the 1st order for TE polarization and 33.03%/33.44% can also be diffracted into the 0th order and the 1st order for TM polarization, respectively. The values of efficiency's ratios of the 1st order to the 0th order are 0.988 for TE polarization and 1.012 for TM polarization, respectively. The efficiency ratios mentioned above are both near to 1.

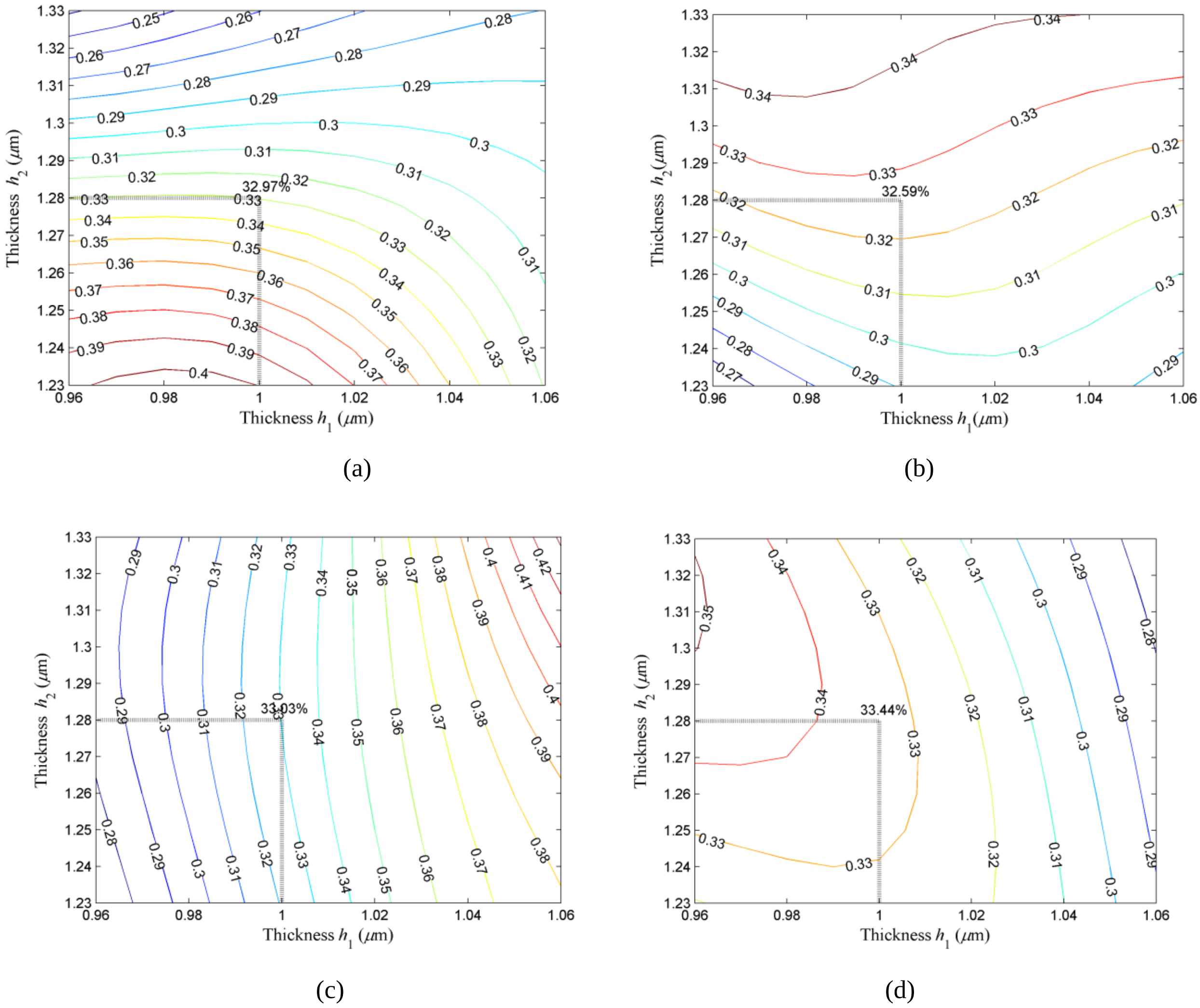

Fig. 2. (Color online) Transmission efficiency versus grating depths of the first layer and second layer for the incident wavelength of 800 nm: (a) TE polarization in the 0th order, (b) TE polarization in the 1st order, (c) TM polarization in the 0th order, (d) TM polarization in the 1st order

During the less controlled dry etching process, the duty cycle would be varied. Therefore, the fabrication tolerance must be considered for the two-layer three-port output grating. Fig. 3 exhibits diffraction efficiency of the two-layer three-port output grating versus the duty cycle under the normal incidence at a wavelength of 800 nm. As is shown in Fig. 3, with the optimized grating depths, the high efficiency for TE/TM polarization and the good uniformity of all diffraction orders' efficiencies can be shown at the special duty cycle of 0.65. However, efficiencies of the 0th order and the 1st order for both TE and TM polarizations are higher than 30% within the duty cycle range of 0.646-0.657.

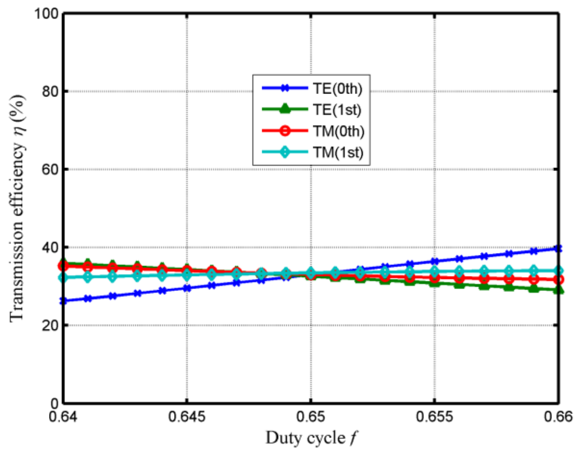

Fig. 3. (Color online) Transmission efficiency versus duty cycle for the optimized grating depths of h_1 = 1.0 μm and h_2 = 1.28 μm under the normal incidence

3. The characteristics of the bandwidth

With the exact numerical simulation, the transmission efficiencies of the three orders for both TE and TM polarizations are improved. Fig. 4 presents the diffraction efficiency versus incident wavelength under the normal incidence with the optimized grating depths of h_1 = 1.0 μm and h_2 = 1.28 μm. In Fig. 4, the efficiencies of the diffraction orders can meet the optimized results for the incident wavelength of 800 nm. When it deviates from a central wavelength of 800 nm, the efficiencies of the three orders are greater than 30% within the incident wavelength range of 795-805 nm.

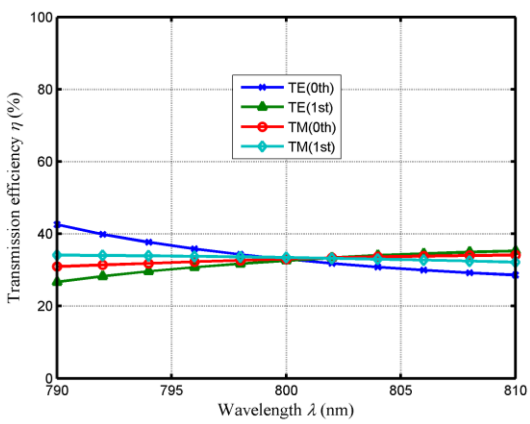

Fig. 4. (Color online) Transmission efficiency versus incident wavelength with the optimized grating depths of h_1 and h_2 under the normal incidence

Fig. 5 shows the efficiency versus incident angle for the incident wavelength of 800 nm with the optimized grating depths of h_1 = 1.0 μm and h_2 = 1.28 μm. As can be seen from Fig. 5, the diffraction efficiencies of the three orders are greater than 30% within the angular bandwidth range of -1.04-3.14°, which can demonstrate the excellent performance of the broad angular bandwidth for this two-layer three-port output grating. It illustrates that the good uniformity and the high efficiency of TE/TM polarization can be achieved under the normal incidence by the two-layer three-port output grating and the broad angular tolerance can be helpful and be used easily.

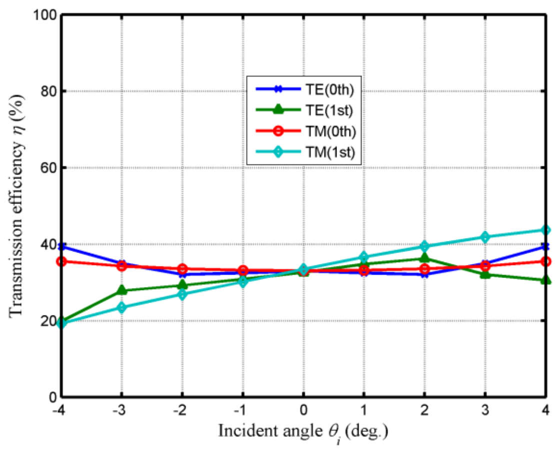

Fig. 5. (Color online) Transmission efficiency versus incident angle for the incident wavelength of 800 nm with the optimized grating profile parameters

4. Conclusions

In conclusion, a two-layer three-port output grating with high-efficiency beam splitting is proposed in this paper. From the optimum results, the different layer depths of the two-layer grating can be obtained versus h_1 =1.0 μm and h_2 = 1.28 μm for the incident wavelength of 800 nm and the special duty cycle of 0.65 by using RCWA. With the optimized grating depths, the high efficiency of TE/TM polarization can be realized. The grating can diffract TE polarization with efficiency of 98.15% and TM polarization with efficiency of 99.91%, where the efficiency of TM polarization can be close to 100%. Furthermore, the values of the efficiency's ratio can reach 0.988 for TE polarization and 1.012 for TM polarization, respectively. In addition, the property of the angular wideband can be obtained by the numerical simulation with the optimized grating depths, where the efficiencies of the three diffraction orders can surpass 30% within the angular bandwidth range of -1.04-3.14°. So the presented two-layer three-port output grating with high-efficiency beam splitting and good uniformity would be a useful optical element in the future.

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References

[1] M. S. Nisar, X. Zhao, A. Pan, S. Yuan, J. Xia, IEEE Photon. J. **9**(1), 6600208 (2017).
[2] A. Shakoor, M. Grande, J. Grant, D. R. S. Cumming, IEEE Photon. J. **9**(1), 6800711 (2017).
[3] K. Y. Lee, J. W. Yoon, S. H. Song, R. Magnusson, Sci. Rep. **7**, 46508 (2017).
[4] J. Jia, J. Chen, J. Yao, D. Chu, Sci. Rep. **7**, 44656 (2017).
[5] Y. Zhang, Y. Cui, T. Ji, Y. Hao, F. Zhu, IEEE Photon. J. **9**(1), 8400207 (2017).
[6] I. Gasulla, D. Barrera, J. Hervas, S. Sales, Sci. Rep. **7**, 41727 (2017).
[7] L. Guo, J. Ma, Optik **125**(1), 232 (2014).
[8] X. Yan, M. Qian, L. Gao, X. Yang, Y. Dai, X. Yan, G. Ma, Opt. Express **21**(26), 31852 (2013).
[9] J. Wu, C. Zhou, H. Cao, A. Hu, Opt. Commun. **309**, 57 (2013).
[10] M. Britzger, D. Friedrich, S. Kroker, F. Bruckner, O. Burmeister, E. B. Kley, A. Tunnermann, K. Danzmann, R. Schnabel, Appl. Opt. **50**(22), 4340 (2011).
[11] M. G. Moharam, D. A. Pommet, E. B. Grann, J. Opt. Soc. Am. A **12**(5), 1077 (1995).
[12] J. Feng, C. Zhou, B. Wang, J. Zheng, W. Jia, H. Cao, P. Lv, Appl. Opt. **47**(35), 6638 (2008).
[13] X. Ke, H. Zhu, J. Li, L. Chen, X. Li, Sci. Rep. **7**, 574 (2017).
[14] Z. Liu, H. Liu, X. Wang, H. Yang, J. Gao, Sci. Rep. **7**, 42750 (2017).
[15] L. Wang, T. Zhao, D. Wang, D. Wu, L. Zhou, J. Wu, X. Liu, Y. Wang, A. Wang, IEEE Photon. J. **9**(2), 7201412 (2017).
[16] Z. Liu, L. Liu, H. Lu, P. Zhan, W. Du, M. Wan, Z. Wang, Sci. Rep. **7**, 43803 (2017).
[17] M. Aghaeipour, M.-E. Pistol, H. Pettersson, IEEE Photon. J. **9**(3), 4501310 (2017).
[18] Q. Meng, Z. Zhong, B. Zhang, Sci. Rep. **7**, 45708 (2017).
[19] X. Zang, Y. Zhu, X. Ji, L. Chen, Q. Hu, S. Zhuang, Sci. Rep. **7**, 40941 (2017).

*Corresponding author: wangb_wsx@yeah.net