Polarization-independent grating with a connecting layer for three-port output of incident laser beam

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A three-port polarization-independent beam splitter is described by the grating with a connecting layer between the grating region and the substrate. Such a novel diffractive three-port beam splitter is optimized to achieve high diffraction efficiency with good uniformity. With the optimized grating parameters, efficiencies of 32.03%/32.06% and 32.14%/32.15% can be separated into the ±1st and the 0th orders for TE and TM polarizations, respectively. Besides, the usual duty cycle of 0.5 and the aspect ratio of the grating depth to the ridge width of 1.83 facilitate the fabrication compared with reported gratings.

1. Introduction

Gratings [1-3] have advantages compared with conventional optical devices including high-efficiency, good uniformity, low cost and simple structure. The beam splitter [4-6] is an important fundamental device in optical communication processing, optical computing, and optical interferometry systems. For subwavelength gratings [7], only part of diffraction orders can be remained when grating periods can be comparable to the incident wavelength. In recent years, there are many beam splitters based on subwavelength structure gratings reported, which can separate an incident wave into several beams, including polarization-independent beam splitter and polarization-selective beam splitter [8-10].

There are some typical research works related to the grating-based three-port beam splitter by the subwavelength structure, where the experimental results are in good agreement with the theoretical values. A polarization-independent diffractive three-port beam splitter has been firstly designed with the optimized grating period and grating depth based on the fused-silica grating by using the rigorous coupled-wave analysis, which can separate both TE and TM polarizations into the ±1st and the 0th orders. For the reported three-port beam splitter grating, the aspect ratio of the grating depth to the ridge width is 4.852 [11]. Moreover, a high-efficiency reflection three-port beam splitter has been reported based on a metal layer reflection grating, which is designed with good splitter ratio for both TE and TM polarizations by optimizing the grating parameters [12]. As far as we know, no one has reported the transmission three-port beam splitter by a new structure of connecting layer grating. It is desirable that a shallow-etched grating with a connecting layer can work as a high-efficiency transmission three-port beam splitter.

In this paper, a three-port beam splitter based on a connecting layer grating is proposed for transmission with good splitting ratio. To obtain polarization-independent property and good uniformity, such a new structure grating parameters are optimized by using rigorous coupled-wave analysis (RCWA) [13]. Both TE and TM polarizations can be separated into the ±1st and the 0th orders. Compared with the reported transmission three-port grating, the aspect ratio of the grating depth to the ridge width is improved greatly based on a connecting layer structure. The novel structure presents a helpful access of grating element in practice effectively.

2. The grating structure optimization

The transmission grating with a connecting layer is shown in Fig. 1. During operating, a plane wave with the wavelength of λ=800 nm illuminates the three-port beam splitter grating with period of d under normal incidence from air with the refractive index n_1=1. After propagating through the grating region depth of h_2 and the refractive index n_2=1.45, the wave will be transmitted into the connecting-layer with depth of h_1 and refractive index of n_2, and the substrate of Ti_2O_5 layer with the refractive index of n_3=2. The incident beam can be separated into the 0th and the ±1st diffracted orders with good uniformity and polarization-independent by the diffraction of grating.
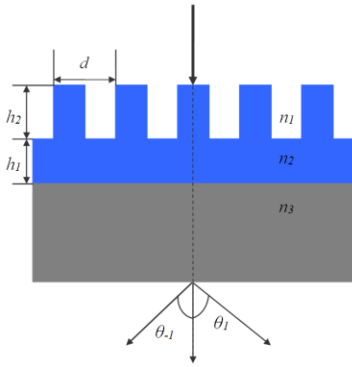
Fig. 1. (Color online) Schematic structure of a new transmission three-port beam splitter grating with a connecting layer

In this paper, the transmission efficiencies of the 1st and the -1st order are always the same because of normal incidence. So, only the 1st and the 0th transmission efficiencies need to be considered. There are many parameters which need to be optimized, which include duty cycle, period, grating depth, and the thickness of connecting layer. The grating duty cycle is defined as the ratio of the grating ridge width to the period. For easy fabrication, a usual duty cycle of 0.5 is chosen in this design. Besides, the aspect ratio the grating depth to the ridge width also should be considered for practical manufacture. The diffractive efficiency can be rigorously optimized by using RCWA.
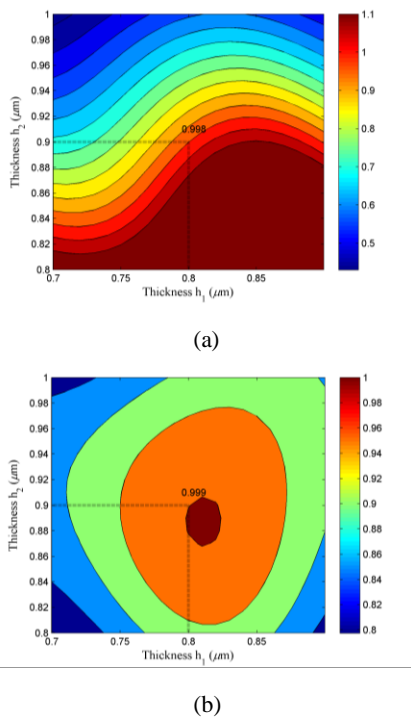

(a)

(b)

Fig. 2. (Color online) Contour of efficiency's ratio between the 1st and 0th orders of the grating versus grating depth and thickness of connecting layer with the duty cycle of 0.5 and the incident wavelength of 800 nm under normal incidence: (a) TE polarization; (b) TM Polarization

For a three-port beam splitter, the performance of the uniformity between the three diffractive orders should be considered in the design. Fig. 2 shows the contour of the efficiency's ratio between the 1st and 0th orders of the grating versus the thickness of connecting layer of h_1 and grating depth of h_2 with the grating period of 982 nm for TE-polarized and TM-polarized waves, respectively. The value of efficiency's ratio can reach 0.998 for TE polarization and 0.999 for TM polarization with the optimized thickness of h_1=0.80 µm and grating depth of h_2=0.90 µm. Meanwhile, efficiencies of 32.03% and 32.06% can be separated into the 1st and the 0th orders for TE polarization, respectively. For TM polarization, the splitting efficiencies are 32.14% and 32.15% with the same grating parameters.

3. Performance of the incident bandwidth

One can see that good uniformity and high efficiency can be achieved by the grating splitter with the optimized special grating period of 982 nm. The grating can function as a perfect 1×3 beam splitter for both TE and TM polarizations with grating depth of 0.9 µm. It is necessary to improve the bandwidth not only for the grating period but also for the duty cycle for practical fabrications. Figure 3 shows diffraction efficiency versus grating period for the optimized grating with a connecting layer. For TE polarization, transmission efficiencies more than 31.5% in the three orders can be achieved within the grating period range of 976-985 nm. For TM polarization, the three orders of transmission efficiencies more than 31.5% within the grating period range of 973-987 nm. It can be seen that grating period of beam splitter can be applied in practical applications with the moderate fabrication tolerance.
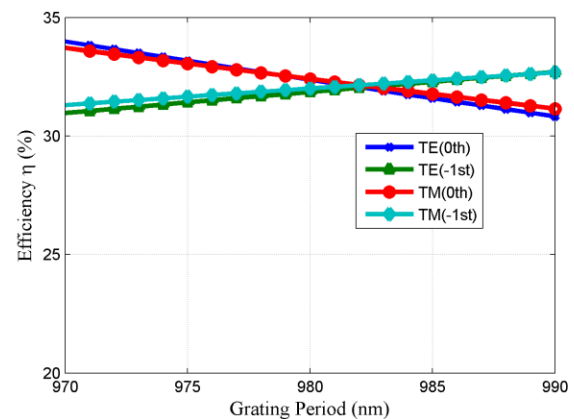

Fig. 3. (Color online) Diffraction efficiency of a connecting-layer-based transmission three-port beam splitter grating versus grating period under normal incidence with the duty cycle of 0.5 and incident wavelength of 800 nm

Fig. 4 shows diffraction efficiency versus incident wavelength for the optimized grating period with the h_1=0.80 μm and h_2=0.90 μm. In Fig. 4, the efficiencies of three orders are affected by the wavelength for TE and TM polarizations. Different splitting ratios can be exhibited with different incident wavelengths. The splitting ratio can be nearly 1 with the given incident wavelength λ=800 nm for both TE and TM polarizations. Besides, efficiencies of three orders are more than 31.5% for both TE and TM polarizations within the wavelength of 798-804 nm.
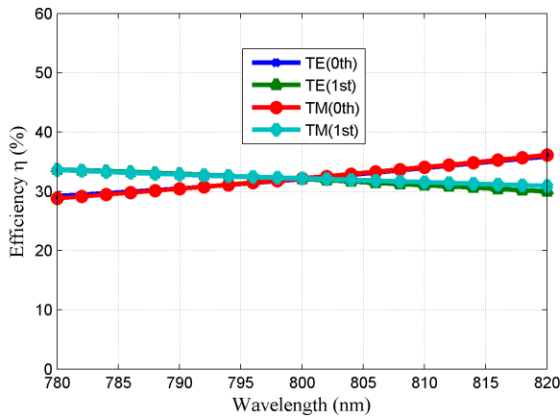

Fig. 4. (Color online) Diffraction efficiency versus incident wavelength under normal incidence with h_1=0.80 μm and h_2=0.90 μm

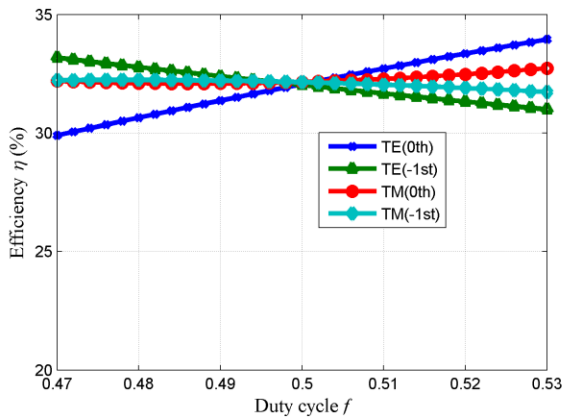*Fig. 5. (Color online) Diffraction efficiency versus duty cycle under normal incidence at the incident wavelength of 800 nm with h_1=0.80 μm and h_2=0.90 μm for both TE and TM polarizations*

High-efficiency and good uniformity can be achieved with the given duty cycle of 0.5. It should be noted that the duty cycle can deviate from the given value during fabrication. The fabrication tolerance should be taken into account for practical manufacture. Fig. 5 shows diffraction efficiency versus duty cycle under normal incidence at the incident wavelength of 800 nm with h_1=0.80 μm and h_2=0.90 μm for both TE and TM polarizations. Efficiencies more than 31.5% in three orders can be obtained within the duty cycle range of 0.492-0.514. It is an advantage of the grating splitter for practical applications.

4. Conclusion

In conclusion, the grating with a connection layer is designed in this paper, which can work as a transmission three-port beam splitter. Diffraction efficiencies of 32.03% /32.06% for TE polarization and 32.14% /32.15% for TM polarization are divided into the ±1st and the 0th orders with grating period of 982 nm, duty cycle of 0.5, h_1= 0.80 μm and h_2=0.90 μm under normal incidence. For different grating period and duty cycle, efficiencies of more than 31.5% for TE and TM polarizations in the 1st and 0th orders can be obtained within the period range of 976-985 nm or duty cycle range of 0.492-0.514. Compared with deep-etched three-port beam splitter gratings, the aspect ratio of the grating depth to the ridge width is only 1.83. The proposed three-port beam splitter grating can have advantages of shallow-etched and good uniformity. It would be very useful for practical applications.

References

[1] A. Shakoor, M. Grande, J. Grant, D. R. S. Cumming, IEEE Photon. J. **9**(1), 6800711 (2017).
[2] M. S. Nisar, X. Zhao, A. Pan, S. Yuan, J. Xia, IEEE Photon. J. **9**(1), 6600208 (2017).
[3] B. Wang, IEEE Photon. J. **8**(1), 7801706 (2016).
[4] W. Su, G. Zheng, L. Jiang, X. Li, Optik **125**(15), 4161 (2014).
[5] Z. Sun, C. Zhou, H. Cao, J. Wu, J. Opt. Soc. Am. A **32**(11), 1952 (2015).
[6] J. Wang, L. Pei, S. Weng, L. Wu, L. Huang, T. Ning, J. Li, IEEE Photon. J. **9**(1), 2200410 (2017).
[7] J. Yang, Z. Zhou, W. Zhou, X. Zhang, H. Jia, IEEE Photon. Technol. Lett. **23**(13), 896 (2011).
[8] X. Zhang, Y. Qiu, H. Chen, W. Liang, Opt. Commun. **333**, 75 (2014).
[9] X. Guan, P. Chen, S. Chen, P. Xu, Y. Shi, D. Dai, Opt. Lett. **39**(15), 4514 (2014).
[10] L. Chen, X. Jing, Y. Tian, S. Jin, K. Yang, L. Wang, J. Laser Appl. **27**(2), 022001 (2015).
[11] J. Feng, C. Zhou, B. Wang, J. Zheng, W. Jia, H. Cao, P. Lv, Appl. Opt. **47**(35), 6638 (2008).
[12] W. Shu, B. Wang, H. Li, L. Lei, L. Chen, J. Zhou, Superlattices Microstruct. **85**, 248 (2015).
[13] M. G. Moharam, D. A. Pommet, E. B. Grann, J. Opt. Soc. Am. A **12**(5), 1077 (1995).

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