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Reflective binary grating with a metal layer for polarization-independent beam splitter

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We describe a reflective beam splitter based on the binary grating with a metal layer, which consists of the phase grating etched in fused silica, the Ag layer evaporated on the substrate. With the optimized grating parameters, especially for the grating duty cycle, the high efficiency and the 50/50 output can be obtained for TE and TM polarizations. Moreover, good performance can be remained within the given range near the central wavelength and Bragg angle. Such a reflective beam splitter based on the binary grating with a metal layer can have advantages of high efficiency, good uniformity, and polarization-independent property.

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Keywords: Binary grating, Metal layer, Beam splitter

1. Introduction

Many optical elements can be designed based on binary gratings with periods comparable to the incident wavelength [1-5]. By optimizing the grating parameters, such gratings can work as polarizing beam splitters [6-8], two-port beam splitters [9,10] and so on. Among them, two-port beam splitters are key elements in numerous optical information processing systems, which can separate an incident beam into two beams with the 50/50 efficiency ratio. A grating-based beam splitter can have merits of high efficiency and good uniformity over multilayer coatings. A lot of binary gratings have been reported as beam splitters, which include transmission and reflection geometrical structures.

On the one hand, a transmissive polarization - independent two-port beam splitter has been designed at a wavelength of 1310 nm [11]. With optimized grating parameters using rigorous coupled-wave analysis (RCWA) [12], the splitting ratio of 47.31% and 47.42% can be obtained for TE polarization, which is 49.34% and 49.51% for TM polarization. The theoretical results for the designed grating can be demonstrated in experiments. On the other hand, a reflective grating etched in fused silica based on dielectric material has been presented as a beam splitter. Such a reflective beam splitter can show the 50/50 splitting ratio at a wavelength of 1064 nm for TE polarization [13]. It is desirable to obtain a reflective beam splitter for both TE and TM polarizations, which is polarization-independent for practical applications.

In this paper, a reflective binary grating with a metal layer is presented as a two-port beam splitter. The grating parameters, especially the duty cycle, can be optimized using RCWA. High efficiency and good uniformity can be achieved with the optimized grating parameters for both TE and TM polarizations. Such a two-port beam splitter based on the binary grating with a metal layer can have advantages of high efficiency, good uniformity, and polarization-independent property in the reflected orders.

2. Reflective polarization-independent beam splitter

Fig. 1 shows the schematic structure of a reflective binary grating with a metal layer for polarization-independent beam splitter. A plane wave with the wavelength of λ=1550 nm is incident upon the beam splitter grating with period of d from air with the refractive index of n_1 = 1. The incident angle meets the Littrow mounting, which is the Bragg angle of $\theta_i = \sin^{-1}(\lambda/(2n_1d))$. The grating is etched in fused silica with depth of h_g and the refractive index of n_2 = 1.45. For the reflective structure, the phase grating is based on the Ag layer with thickness of h_m and the refractive index of n_3. Most grating-based beam splitters are reported by the phase grating, which consists of only the dielectric material. To our knowledge, a polarization-independent beam splitter has not been presented by the binary grating with a metal layer, which is a mixed metal dielectric grating.

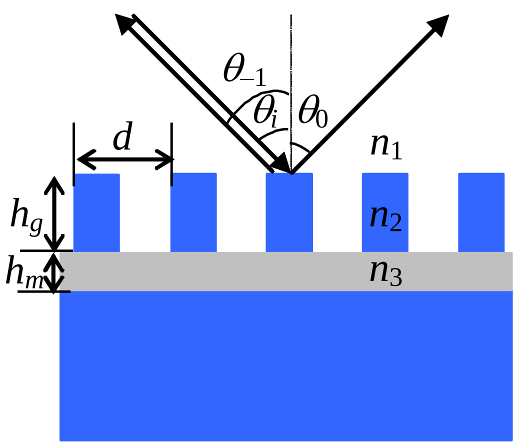
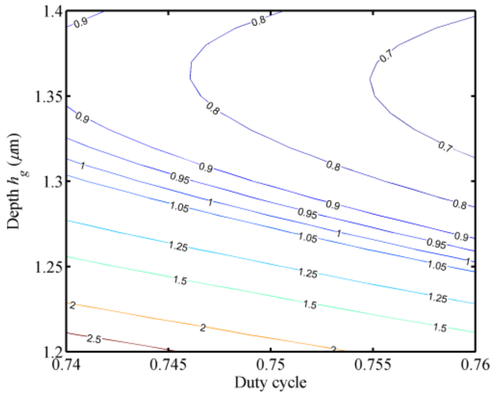
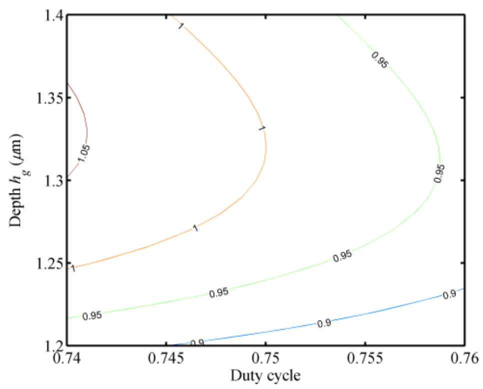


Fig. 1. (Color online) Schematic structure of a reflective binary grating with a metal layer for polarization-independent beam splitter.

For both TE and TM polarizations, the beam splitter can split the incident wave into the reflected -1st and the 0th orders with the 50/50 splitting ratio. The diffraction property of the mixed metal dielectric grating is quite different from that of the pure dielectric grating. However, the RCWA can be successfully applied to not only the phase grating but also the metallic grating. Therefore, the diffraction efficiency can be extensively investigated with the various grating period, depth and duty cycle. Fig. 2 shows the contour of the efficiency ratio between the –1st order and the 0th reflected orders versus grating depth and duty cycle with the period of 1000 nm under Littrow mounting. In Fig. 2, efficiency ratio nearly 1 can be obtained with the grating depth of 1.29 μm and duty cycle of 0.747. Fig. 3 shows the Reflective efficiency versus grating depth for TE and TM polarizations with the grating period of 1000 nm and grating duty cycle of 0.747. In Fig. 3, efficiencies for TE and TM polarizations vary with the grating depth in the reflected orders. With the grating depth of 1.29 μm, efficiencies of 48.93% in the -1st order and 49.30% in the 0th order can be achieved for TE polarization, which are 48.64% and 48.19% for TM polarization with the same optimized grating parameters. It indicates that the good uniformity and high efficiency with the polarization-independent property can be fulfilled by the two-port beam splitter based on the reflective binary grating with a metal layer.



(a)



(b)

Fig. 2. (Color online) Contour of the efficiency ratio between the –1st order and the 0th reflected orders versus grating depth and duty cycle under Littrow mounting: (a) TE polarization, (b) TM polarization.

3. Properties for incident conditions

The beam splitter can be well designed with good performance for the incident wavelength of 1550 nm and the Bragg angle. With the deviations of the incident wavelength and angle from the prescribed conditions, the efficiency and uniformity may be affected to some extent. It is necessary to investigate the diffraction property for the various incident wavelength and angle for practical applications.

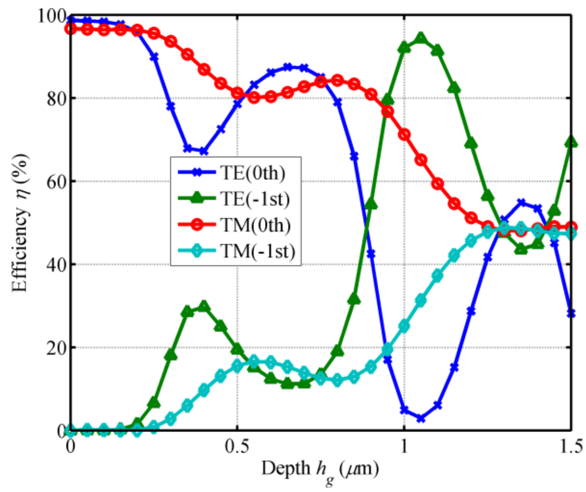
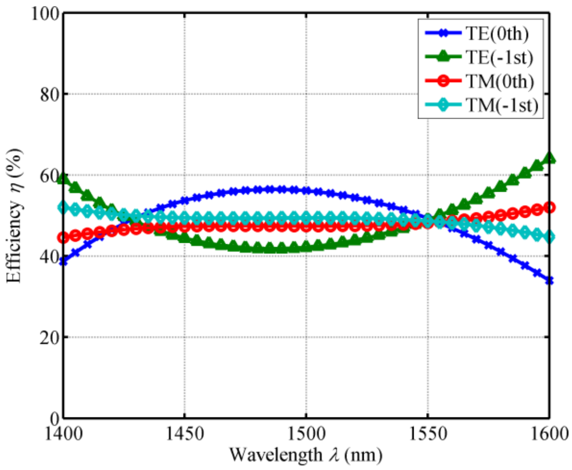
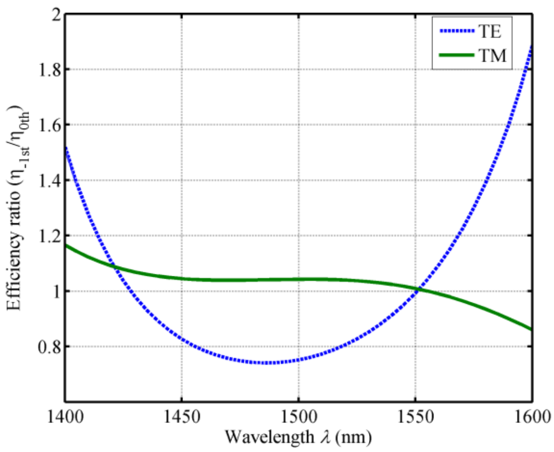


Fig. 3. (Color online) Reflective efficiency versus grating depth for TE and TM polarizations with the grating period of 1000 nm and grating duty cycle of 0.747.

Fig. 4 shows the reflective efficiency and the efficiency ratio versus the incident wavelength with the optimized grating parameters. For the different incident wavelength, the output of TE polarization is affected more than TM polarization. With the deviation of the incident wavelength from the 1550 nm, good uniformity can be remained for TM polarization. In Fig. 4, efficiencies variation of less than 5% within 50±5% can be obtained with the wavelength range of 1529-1567 nm for TE polarization. The efficiency ratio between the -1st and the 0th orders can be calculated, which can be obtained less than 5% within 1±0.05 with the wavelength range of 1545-1556 nm. While for TM polarization, the two ranges above are 1405-1597 nm and 1444-1575 nm, respectively.

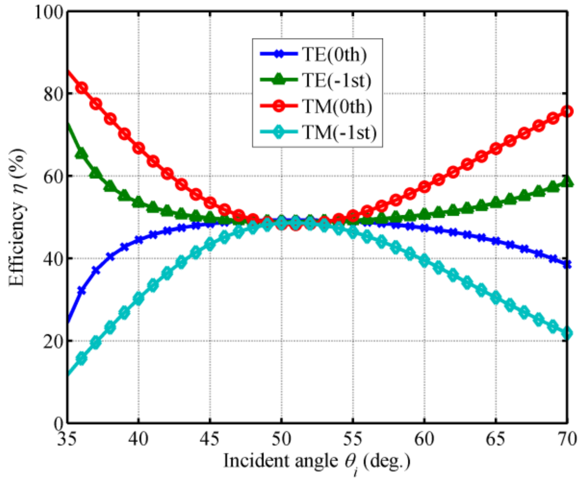


(a)

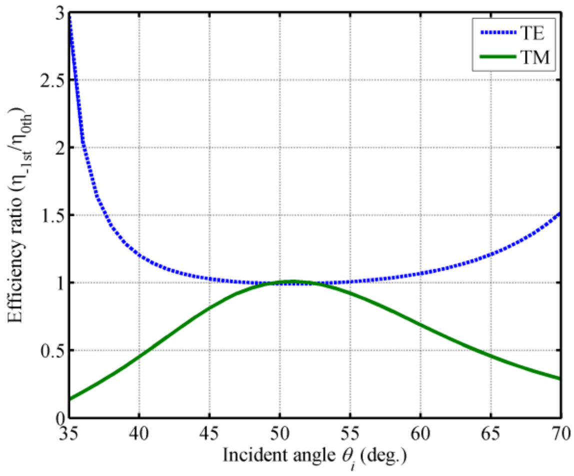


(b)

Fig. 4. (Color online) Reflective efficiency (a) and efficiency ratio (b) versus incident wavelength with the optimized grating parameters.



(a)



(b)

Fig. 5. (Color online) Reflective efficiency (a) and efficiency ratio (b) versus incident angle with the optimized grating parameters.

Fig. 5 shows the reflective efficiency and the efficiency ratio versus the incident angle with the optimized grating parameters. With the deviation of the incident angle from the Bragg angle, the uniformity will be changed from the 50/50 output. In Fig. 5, the performance of TM polarization is affected more than TE polarization, which is different from the property for the different incident wavelength. In Fig. 5 (a), efficiencies of 50±5% can be obtained within the incident angle range of 40.38-64.02° for TE polarization and 45.90-56.29° for TM polarization. In Fig. 5 (b), the efficiency ratio within 1±0.05 can be shown within the incident angle range of 43.78-58.95° and 47.69.-54.22° for TE and TM polarization, respectively.

4. Conclusions

In conclusion, a novel two-port beam splitter is presented based on a reflective binary grating with a metal layer. Using RCWA, the grating parameters are optimized especially for the special grating duty cycle. Such a grating can work as a beam splitter for not only TE polarization but also TM polarization. Efficiencies of 48.93% in the -1st order and 49.30% in the 0th order can be achieved for TE polarization, which are 48.64% and 48.19% for TM polarization. When the incident conditions of the wavelength and the angle are changed from the central wavelength and the Bragg angle, the efficiency and the uniformity are affected to some extent. However, good performance can still be achieved within the given range for the incident wavelength and angle. It indicates the presented reflective beam splitter based on the binary grating with a metal layer can have good merits of high efficiency, good uniformity and the polarization-independent property.

Acknowledgements

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