

Infrared two-output beam splitter based on reflective two-layer grating

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An infrared two-output beam splitter is proposed based on the reflective two-layer phase grating. The mixed metal dielectric grating can be operated in the reflection region, which is different from the transmission beam splitter grating. Furthermore, the usual duty cycle of 0.5 should facilitate the fabrication compared with the special duty cycle. With the optimized grating parameters, efficiencies of 49.07% together with 49.02% and 48.20% together with 48.22% can be separated into the –1st and the 0th orders for TE and TM polarizations, respectively. Most importantly, wide incident angular bandwidth is exhibited for TM polarization.

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1. Introduction

Gratings with the subwavelength period can have many distinctive diffraction properties, which have been extensively investigated theoretically and experimentally [1-5]. The grating depth can modulate efficiencies of the –1st and the 0th orders. With the proper grating depth, such a subwavelength grating can diffract the incident beam into two orders with the good uniformity [6,7]. However, the subwavelength grating can show different properties for TE and TM polarizations [8,9]. In order to obtain a beam splitter with the polarization-independent property [10,11], the grating parameters can be optimized by using rigorous coupled-wave analysis (RCWA) [12]. Most conventional beam splitters are based on multilayer dielectric coatings, which suffer from the energy loss due to the multiple reflection and refraction. Furthermore, it is not easy to obtain the good uniformity by multilayer coatings. By comparison, the beam splitter grating can have high efficiency and good uniformity with the optimized grating parameters, which is suitable for integration with the compact size [13].

Many works have reported grating-based beam splitters by the transmission structure. A polarization-independent beam splitter can be obtained with the optimized grating period and depth of the binary rectangular grating, which can separate both TE and TM polarizations into the –1st and the 0th orders with good uniformity for the special duty cycle of 0.643 [14]. Moreover, the theoretical analysis and experimental results show that the novel microstructure grating can have the novel diffractive property [15-17]. A two-port beam splitter has been reported based on the two-layer transmission grating. Good splitting ratio can be obtained within the broad angular bandwidth by optimizing the grating for the special duty cycle of 0.6 [15]. For easy fabrication of the grating pattern, it is desirable that the

grating parameters are optimized with the usual duty cycle of 0.5.

In this paper, a reflective infrared two-output beam splitter is proposed based on the two-layer phase grating. The beam splitter grating has the usual duty cycle of 0.5 instead of the reported special duty cycle. Grating parameters of the reflective two-layer phase grating are optimized by using RCWA. Both TE and TM polarizations can be separated into the –1st and the 0th orders with good splitting ratio. Especially, wide angular bandwidth can be exhibited for TM polarization, which should be significant for the practical use in numerous optical systems.

2. Optimization of the infrared two-output beam splitter

The incident beam can be separated into several orders by the diffraction of gratings. However, the uniformity between different ports is determined by the grating parameters. Moreover, the polarization-independent property of the beam splitting can only be obtained by optimizing the grating. Fig. 1 shows schematic of infrared two-output beam splitter based on reflective two-layer phase grating. From bottom to top, the reflective beam splitter grating is composed of the fused-silica substrate, the Ag metal slab with depth of h_m and the refractive index n_m , the Ta₂O₅ layer with depth of h_1 and the refractive index $n_1 = 2$, the fused-silica layer with depth of h_2 and the refractive index $n_2 = 1.45$. The incident beam with wavelength of $\lambda = 1550$ nm illuminates the grating with period of d at the Bragg angle of $\theta_i = \sin^{-1}(\lambda/(2d))$, which is called Littrow mounting. The reflective beam splitter can separate the incident beam into the –1st and the 0th orders with good uniformity and polarization-independent property.

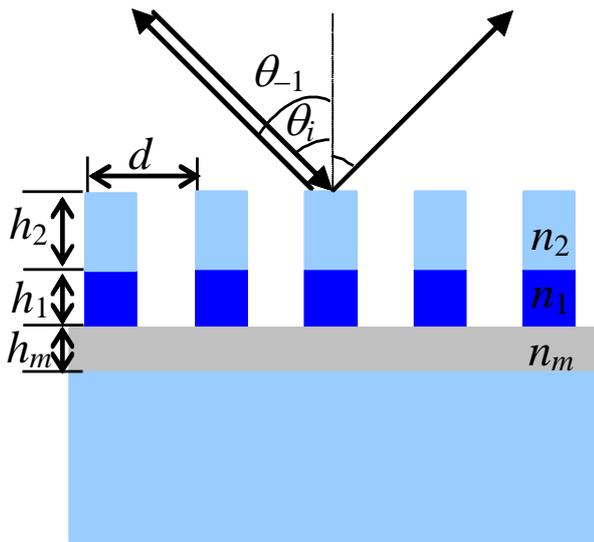
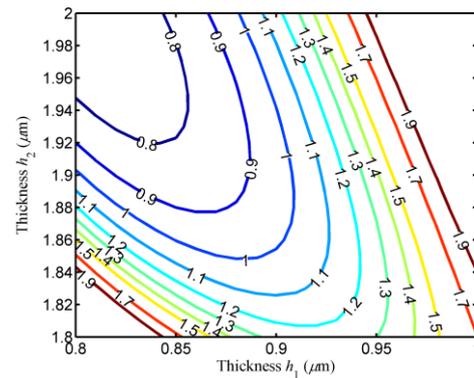


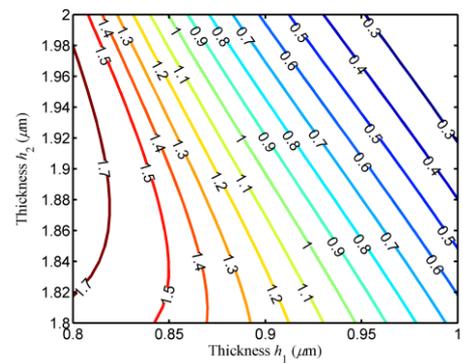
Fig. 1. (Color online) Schematic of infrared two-output beam splitter based on reflective two-layer phase grating.

There are so many grating parameters which should be taken into account during the optimization process such as the grating duty cycle, the period, and the depths of grating layers. The grating duty cycle is set to 0.5, which is the usual value suitable for fabrication. The diffraction of such a mixed metal dielectric grating can be simulated by using RCWA. The efficiency can be calculated for each diffracted order with various grating parameters and different polarizations. Fig. 2 shows contour of efficiency ratio between the -1 st order and the 0 th order versus grating depths with the grating period of 1000 nm for the incident wavelength of 1550 nm under Littrow mounting. In Fig. 2, the efficiency ratio can be nearly 1 for both TE and TM polarizations with the optimized grating depths of $h_1=0.909\text{ }\mu\text{m}$ and $h_2=1.879\text{ }\mu\text{m}$. Meanwhile, efficiencies of 49.07% and 49.02% can be separated into the -1 st and the 0 th orders for TE polarization, respectively. For TM polarization, the splitting results are 48.20% and 48.22% with the same grating parameters.

For the manufacture, the etched depths may deviate from the optimized results of the two dielectric layers. Therefore, the fabrication tolerance should be investigated for the practical production. Efficiencies more than 45% can be tolerated in two orders for both polarizations within the grating depths of $0.899\text{ }\mu\text{m} < h_1 < 0.915\text{ }\mu\text{m}$ and $1.859\text{ }\mu\text{m} < h_2 < 1.899\text{ }\mu\text{m}$. Therefore, the good uniformity and the polarization-independent property for different polarizations can be fulfilled by the reflective two-layer phase grating.



(a)



(b)

Fig. 2. (Color online) Contour of efficiency ratio between the -1 st order and the 0 th order versus grating depths for the incident wavelength of 1550 nm under Littrow mounting: (a) TE polarization, (b) TM polarization.

3. Properties of the reflective infrared beam splitter

Fig. 3 shows reflective efficiency of the two-layer phase grating versus grating period with optimized grating depths and the usual duty cycle of 0.5. The efficiencies in two orders are affected by the period for both two polarizations. Various splitting ratios can be exhibited for the TE and TM polarizations with the different grating period. The splitting ratio can both be nearly 1 for the optimized grating period with the given grating duty cycle and depths.

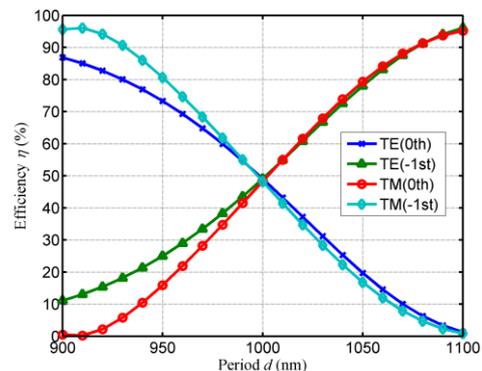


Fig. 3. (Color online) Reflective efficiency of the two-layer phase grating versus grating period with optimized grating depths and the usual duty cycle of 0.5.

The efficiency of the conventional beam splitter varies with the incident angle and wavelength due to multilayer coatings. Although the grating-based beam splitter can have advantages of high efficiency, good uniformity and compact size, it is necessary to study the diffraction property with different incident angles and wavelengths for practical applications. Fig. 4 shows reflective efficiency and efficiency ratio versus incident wavelength for the optimized infrared two-output beam splitter. In Fig. 4 (a), efficiency more than 45% can be achieved within the incident wavelength range of 1546-1555 nm. The splitting ratio is calculated in Fig. 4 (b), where the efficiency ratio can be nearly 1 for the central incident wavelength of 1550 nm.

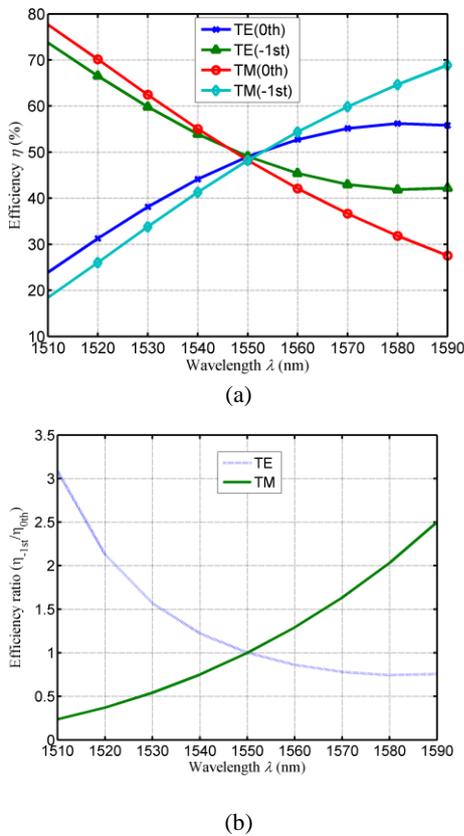


Fig. 4. (Color online) Reflective efficiency (a) and efficiency ratio (b) versus incident wavelength for the optimized infrared two-output beam splitter.

The beam splitter based on multilayer coatings can work only in a narrow angular bandwidth. For such a reflective beam splitter grating, the incident angular range can be improved to some extent. Fig. 5 shows reflective efficiency and efficiency ratio versus incident angle with the incident wavelength of 1550 nm for the optimized infrared two-output beam splitter. One can see from Fig. 5 (a) that efficiencies more than 45% can be obtained within the incident angle range of 48.4-53.4°. In Fig. 5 (b), the efficiency ratio of 0.95-1.05 can be achieved within the incident angle range of 49.5-52.2°. Especially, the uniformity of TM polarization is affected much less than

the TE polarization by the incident angle.

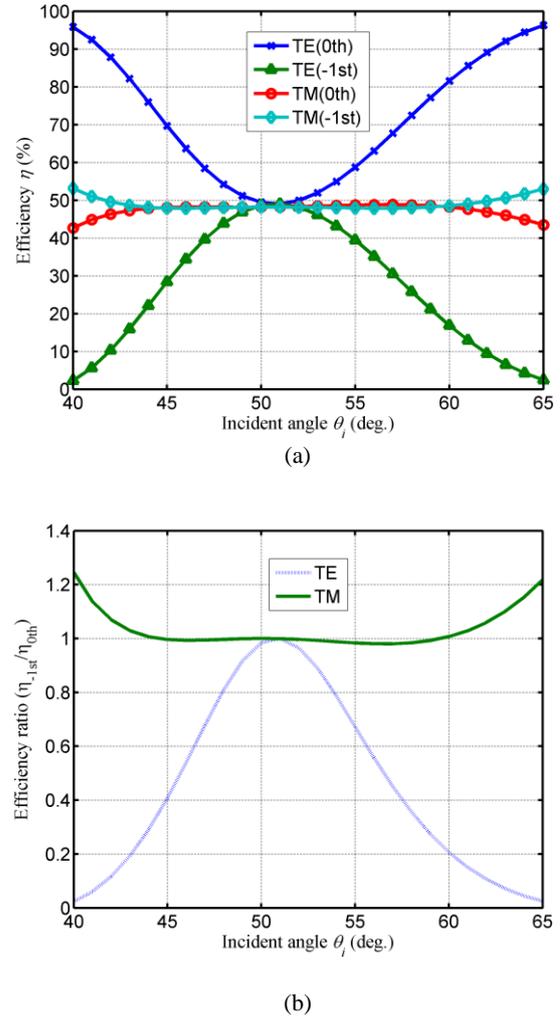


Fig. 5. (Color online) Reflective efficiency (a) and efficiency ratio (b) versus incident angle with the incident wavelength of 1550 nm for the optimized infrared two-output beam splitter.

4. Conclusion

In conclusion, the infrared two-output beam splitter is proposed based on reflective two-layer phase grating. The reflective beam splitter grating has the mixed metal dielectric structure, which is different from the transmission beam splitter grating. The usual duty cycle of 0.5 is introduced, which is suitable for easy fabrication. With the grating parameters optimized, efficiencies of 49.07% together with 49.02% and 48.20% together with 48.22% can be exhibited for TE and TM polarizations, respectively. For different incident wavelengths, efficiency more than 45% can be achieved within the incident wavelength range of 1546-1555 nm. The moderate fabrication tolerance and usual duty cycle should be significant for practical manufacture. The two-output beam splitter based on the reflective two-layer phase grating has advantages of high efficiency, good uniformity,

and improved angular bandwidth for TM polarization compared with the conventional beam splitter based on multilayer coatings.

Acknowledgments

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