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Embedded grating splitter with reflective design

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The embedded grating splitter is proposed with the reflective design. Unlike the conventional grating, a metal layer is added between the grating region and the substrate to reflect the incident wave in the novel grating. And a covering layer is introduced to improve the efficiency and protect the grating surface during cleaning. Such a novel reflective beam splitter is optimized to achieve high efficiency with good uniformity. Furthermore, the moderate fabrication tolerance for the grating duty cycle is given for practical manufacture. The simulated results show that wide incident wavelength range and angular bandwidth are exhibited by the embedded reflective grating splitter, especially for TM polarization.

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Keywords: Embedded grating, Reflective efficiency, Splitter

1. Introduction

Optical beam splitter [1-3] is a fundamental device commonly used in optical interferometry, optical computing, and optical information processing. Most commercial splitters are made of multilayer coatings, where the efficiency is low due to multiple reflection and refraction and the uniformity is sensitive to the incident wavelength and angle. To avoid these problems, an alternative approach can be based on the diffractive optical grating [4-7]. For the subwavelength grating, the incident energy can be concentrated on the two diffractive orders. By optimizing the grating parameters, the 1-to-2 beam splitter can be designed with high efficiency and wide bandwidth.

As an example of the grating beam splitter, a transmission two-port beam splitter has been proposed by the surface-relief grating at the incident wavelength of 1310 nm [8]. With the optimized grating parameters by using the rigorous coupled-wave analysis (RCWA) [9], efficiencies of 47.31%/47.42% and 49.34%/49.51% can be split into two diffractive orders for TE and TM polarizations, respectively [8]. The validity has been confirmed by holographic recording technology and inductively coupled plasma etching in experiments for the transmission. For the reflection, such a beam splitter can also attract attention, which can be applicable in the high-precision laser interferometer. Furthermore, it was reported that the embedded grating might improve the efficiency and protect the grating surface compared with the surface-relief grating [10,11].

In this paper, the embedded grating is proposed as a beam splitter with reflective design. On the one hand, a metal layer is added between the grating region and the substrate to make the incident energy couple out in the reflective orders. On the other hand, a covering layer is introduced on the grating region to improve the efficiency and protect the grating surface, which can make the cleaning easy compared with the surface-relief grating.

2. Embedded grating for reflective splitter

Fig. 1 shows schematic of embedded grating splitter with reflective design. During operation, the incident wave with wavelength of λ illuminates the beam splitter grating with period of d under Littrow mounting at the Bragg angle of $\theta_i = \sin^{-1}(\lambda/(2d))$ from air with the refractive index n_1=1. From top to bottom, the embedded reflective grating is made of the covering layer with thickness of h_c, the grating region with depth of h_g and refractive index of n_2=1.45, the Ag metal slab with depth of h_m=100 nm and the refractive index n_3, and the substrate of fused silica. The grating duty cycle is defined as the ratio of the grating ridge width to the period.

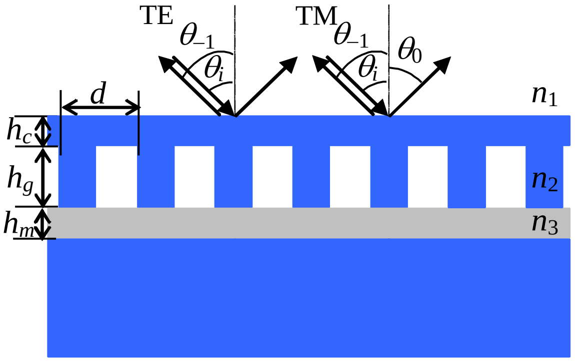
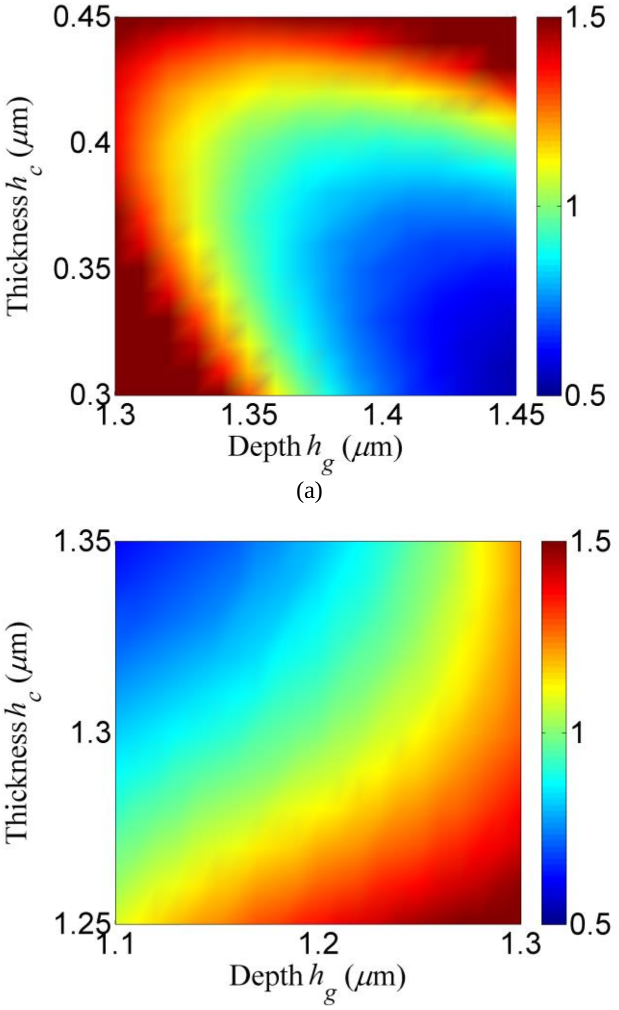


Fig. 1. (Color online) Schematic of embedded grating splitter with reflective design.

The novel grating is aimed to work as a beam splitter by an embedded grating with reflective design. There are many parameters to be optimized, which include duty cycle, period, grating depth, and covering layer thickness. The reflective efficiency can be widely investigated with such various grating parameters by using RCWA. For a beam splitter, the performance to be considered in the design is the uniformity between the two reflective orders. Fig. 2 shows reflective efficiency's ratio between the –1st and the 0th orders versus covering layer thickness and grating depth for the embedded grating for TE and TM polarizations with duty cycle of 0.5 and period of 1190 nm at an incident wavelength of 1550 nm. In Fig. 2 (a), good uniformity can be achieved with optimized h_c=0.41 μm and h_g=1.37 μm for TE polarization. By numerical calculation using RCWA, the reflective efficiencies are 49.21%/49.28% in the –1st and the 0th orders. In Fig. 2 (b), the optimized point is h_c=1.30 μm and h_g=1.20 μm, where efficiencies of 48.70%/48.77% can be split into two orders for TM polarization.

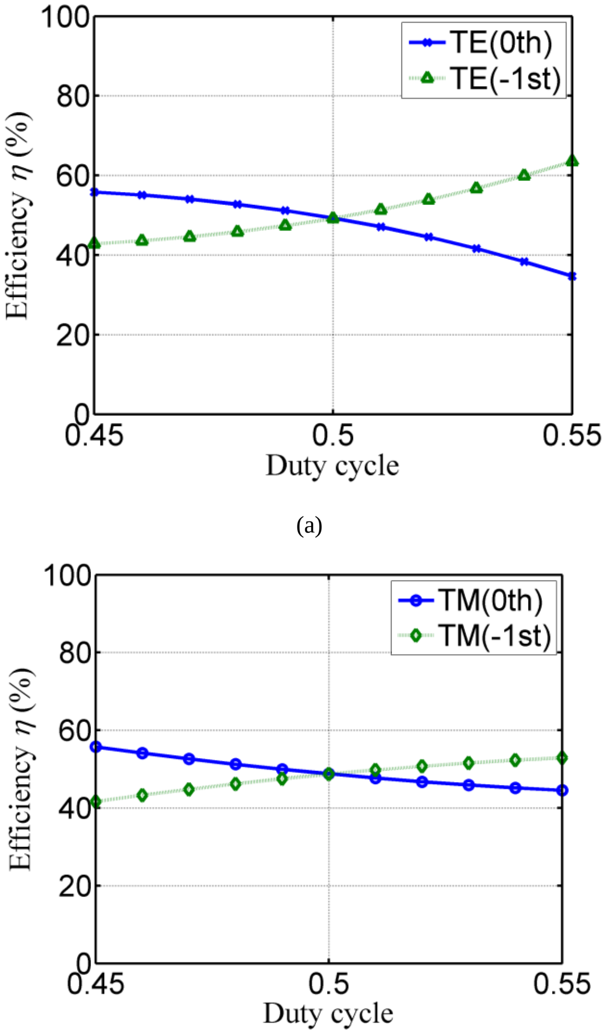


(a)

(b)

Fig. 2. (Color online) Reflective efficiency's ratio between the –1st and the 0th orders versus covering layer thickness and grating depth for the embedded grating: (a) TE polarization, (b) TM polarization.

One can see that good uniformity and high efficiency can be optimized by an embedded grating splitter with the given duty cycle of 0.5. It should be noted that the duty cycle can deviate from the given value during etching. The fabrication tolerance should be taken into account for practical manufacture. Fig. 3 shows reflective efficiency versus grating duty cycle for the optimized embedded grating with TE and TM polarizations. It can be seen that the grating duty cycle can affect the reflective efficiency and the uniformity between two orders. For TE polarization, efficiencies more than 45% in the two orders can be obtained within the etched duty cycle range of 0.48-0.51. For TM polarization, the beam splitter can split the incident wave into two orders with efficiencies more than 45% within the duty cycle range of 0.48-0.54. From the analysis of grating duty cycle, it indicates that the embedded grating splitter can be manufactured with the moderate fabrication tolerance.



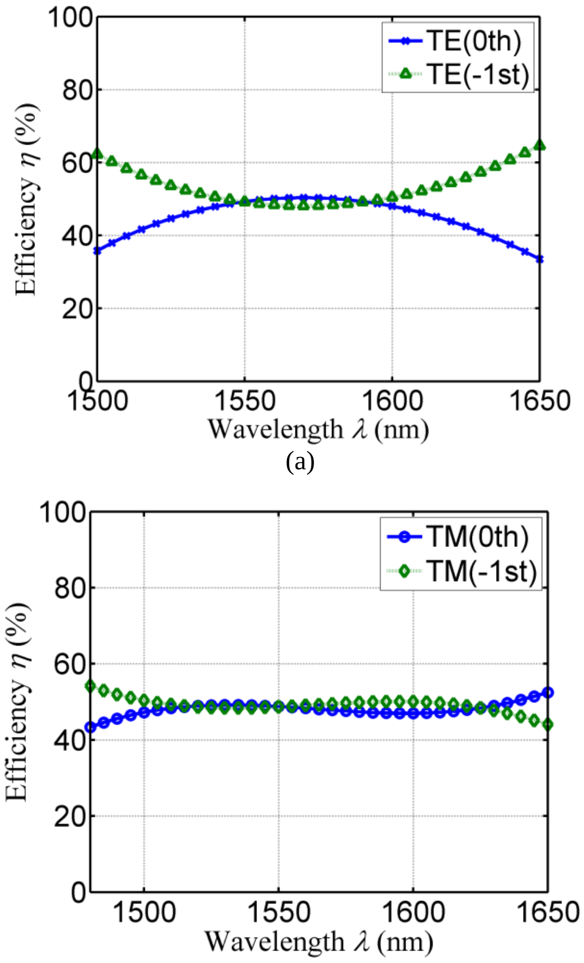
(a)

(b)

Fig. 3. (Color online) Reflective efficiency versus grating duty cycle for the optimized grating parameters: (a) TE polarization with h_c=0.41 μm and h_g=1.37 μm, (b) TM polarization with h_c=1.30 μm and h_g=1.20 μm.

3. Simulated results and discussions

For the embedded grating splitter, good uniformity and high efficiency can be obtained in the –1st and the 0th orders. Since the commercial beam splitters based on multilayer coatings are sensitive to the incident wavelength and angle, it is interesting if wide wavelength range and angular bandwidth are exhibited by the embedded grating splitter with reflective design. Fig. 4 shows reflective efficiency versus incident wavelength for the optimized embedded grating with TE and TM polarizations. In Fig. 4 (a), efficiencies more than 45% can be split into two orders for TE polarization within 88 nm bandwidths from 1527 nm to 1615 nm. In Fig. 4 (b), the embedded grating splitter can divided TM polarization into two orders with efficiencies more than 45% within 158 nm bandwidths from 1487 nm to 1645 nm. By comparison, the incident wavelength range is much wider for TM polarization than TE polarization. Furthermore, the embedded grating splitter can work well for both TE and TM polarizations within certain wavelength range.

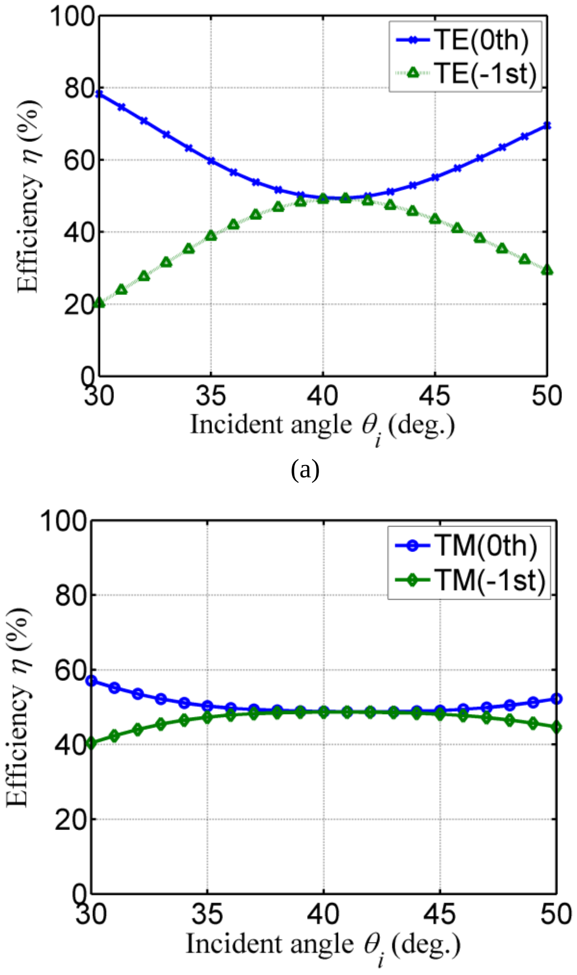


(a)

(b)

Fig. 4. (Color online) Reflective efficiency versus incident wavelength for the optimized embedded grating: (a) TE polarization with h_c=0.41 μm and h_g=1.37 μm, (b) TM polarization with h_c=1.30 μm and h_g=1.20 μm.

The wide incident wavelength range can be applicable for the embedded reflective beam splitter at the Bragg angle. If the incident angle varies from such Littrow mounting, the efficiencies can change for both orders. Fig. 5 shows reflective efficiency versus incident angle for the optimized embedded grating with TE and TM polarizations. For TE polarization, efficiencies more than 45% can be obtained within 7.1° angular bandwidths from 37.2° to 44.3°. For TM polarization, the embedded grating splitter can reflect the incident wave into two orders with efficiencies more than 45% within 16.9° angular bandwidths from 32.7° to 49.6 °. It can be seen that the angular bandwidth is much wider for TM polarization than TE polarization. Moreover, both polarizations can be reflected into two orders with high efficiency within wide angular bandwidth for the embedded grating splitter. While for multilayer coatings beam splitter, the performance is much sensitive to the incident angle.



(a)

(b)

Fig. 5. (Color online) Reflective efficiency versus incident angle for the optimized embedded grating: (a) TE polarization with h_c=0.41 μm and h_g=1.37 μm, (b) TM polarization with h_c=1.30 μm and h_g=1.20 μm.

4. Conclusion

In conclusion, the embedded grating can work as a beam splitter with reflective design. Efficiencies of 49.21%/49.28% and 48.70%/48.77% are divided into the –1st and the 0th orders for TE and TM polarizations, respectively. High efficiency and good uniformity can be exhibited by optimizing the embedded reflective grating. For the different wavelength, efficiencies more than 45% can be separated into two orders within the 88 nm and 158 nm spectral bandwidths for TE and TM polarizations, respectively. When the incident angle varies around the Littrow mounting, 7.1° and 16.9° angular bandwidths are exhibited with efficiencies more than 45% for TE and TM polarizations, respectively. Wide bandwidth can be achieved by the embedded grating splitter with reflective design, especially for TM polarization.

Acknowledgments

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