Polarization-independent grating with the zeroth order suppressed

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In this paper, a polarization-independent grating with the suppression of the zeroth order under normal incidence is introduced. In order to suppress the zeroth order, the rigorous coupled-wave method is used to optimize height of the grating groove and the thickness of the connecting layer, where the total efficiency of the +1st order and the -1st order is greater than 90%. The modal method can explain the physical mechanism of the grating transmission and the 0th order suppression. Then the process tolerance of the grating is studied, which provides a basis for the design of the zeroth order suppressed.

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1. Introduction

A optical splitter [1-7] is a key device widely used in the field of optical waveguides [8-10]. It is mainly used in optical path switches [11-13], photoelectric coupling [14,15], multi-channel polarizer [16-18], etc. According to the number of grating splitting ports, the grating splitter is divided into a two-port beam splitter [19], a three-port beam splitter [20], and a multi-channel beam splitter [21]. A two-port beam splitter splits a beam of light into two beams of equal energy output. The splitting effect of the two ports is also different depending on the incident characteristics. *Feng et al.* designed a two-port single-layer dielectric grating beam splitter with polarization independence at a Bragg angle of incidence [22]. *Wang et al.* designed a total internal reflection two-port grating under the incidence of quadratic Bragg [23]. A single-layer two-port grating was proposed under normal incidence [24]. The efficiency of TE polarization is 46.15%, and the efficiency of TM polarization is 43.6%. In contrast to the Ref. [24], we have designed a two-port grating splitter with high efficiency and good uniformity under two polarizations.

The basic theories of analyzing gratings are rigorous coupled-wave method [25], time domain finite difference method, finite element method and modal method [26]. The theory we use in this design is the modal method and the rigorous coupled-wave method. Rigorous coupled-wave analysis method is used to design a two-port grating splitter to obtain a good beam splitting effect. Then the modal method is used to obtain each mode of the grating region, which can verify the correctness of the rigorous coupled-wave analysis method and analyze the energy distribution of the grating diffraction process.

A polarization-independent two-port grating is designed with the suppression of the zeroth order at normal incidence. The grating structure is a single-layer fused-silica grating with a connecting layer. After multiple optimizations, we set the duty cycle of the grating to 0.28 and the period to 1676 nm. Using rigorous coupled-wave analysis method, the splitting effect of the two ports of the grating is obtained. Due to the periodicity of the grating, the energy of the -1st order is equal to the energy of the +1st order. For TE-polarized light, the efficiency of 0th order is 3.02%, and the efficiency of 1st order is 45.64%. For TM-polarized light, the efficiency of 0th order is 0.42%, and the efficiency of 1st order is 45.62%. And the grating has good incident bandwidth and process tolerance.

2. Modal analysis and numerical design

The polarization-independent two-port grating is shown in Fig. 1 with the zeroth order suppressed. The grating groove medium is air, the refractive index is n_1=1.00, the medium of the grating ridge and the connecting layer is fused silica [27-29] with the refractive index n_2=1.45. The width and height of the grating ridge are b and h_1, and the thickness of the connecting layer is h_2. The material of the grating substrate is Ta_2O_5 with the refractive index n_3= 2.00. The incident wavelength of the grating is 800 nm.

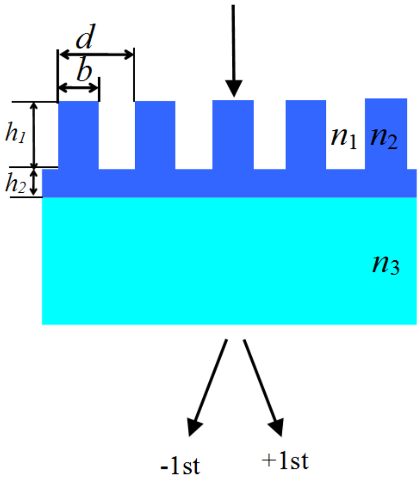
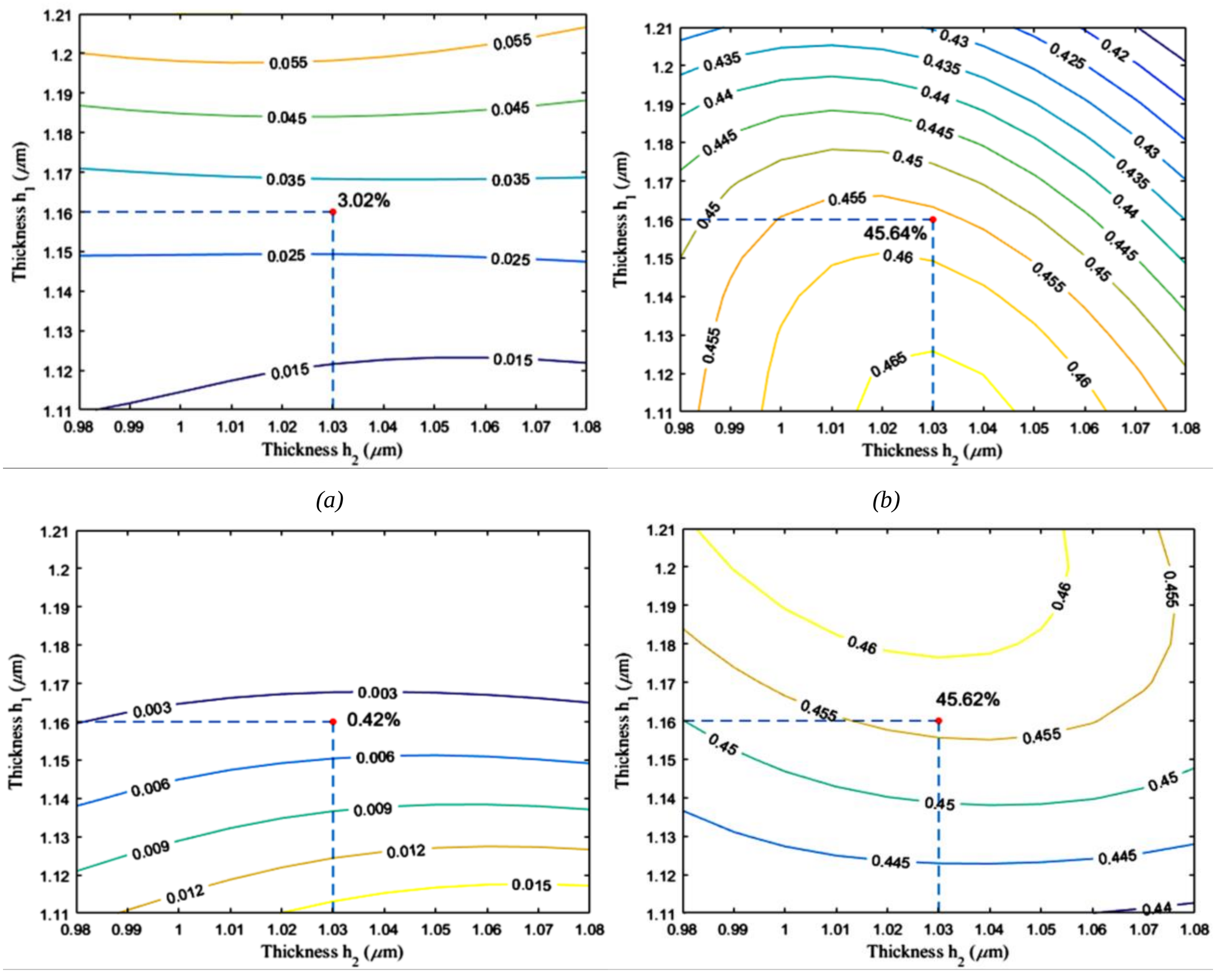


Fig. 1. (Color online) The schematic diagram of the grating with the zeroth order suppressed at wavelength of 800 nm with duty cycle of 0.28 under normal incidence (color online)

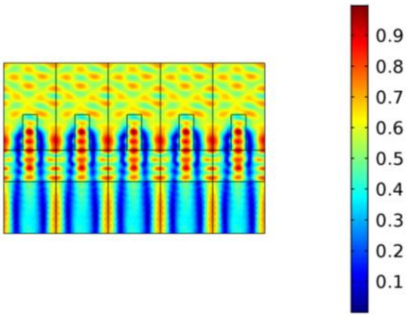
Fig. 2 shows the relationship between the efficiency of grating and the height h_1 of the grating groove and the thickness h_2 of the connecting layer. For the TE-polarized light, when h_1 =1.16 μm and h_2 = 1.03 μm, the efficiency of the 0th order is 3.02% and the efficiency of the 1st order is 45.64%. The total efficiency of the +1st and the -1st orders is 91.28%. For TM-polarized light, the efficiency of 0th order is 0.42%, and the efficiency of 1st order is 45.62%. The total efficiency of the two orders is 91.24%. It can be seen that the grating structure exhibits polarization-independent characteristics.



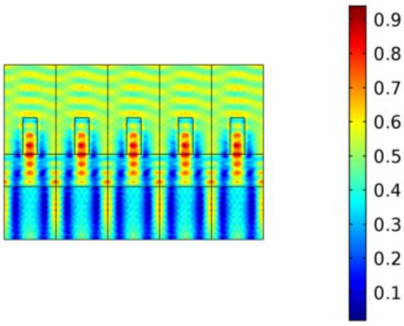
(c) (d)

Fig. 2. Efficiencies in two orders for the grating versus the grating groove depth and the thickness of the connecting layer for both two polarizations at wavelength of 800 nm under normal incidence: (a) the 0th order for TE polarization, (b) the 1st order for TE polarization, (c) the 0th order for TM polarization, (d) the 1st order for TM polarization (color online)

Based on the optimized grating parameters of Fig. 2, we use the modal method to explain the diffraction phenomenon of a single-layer grating with connecting layer under normal incidence. Fig. 3 shows the normalized field distribution of the grating with the zeroth order suppressed. We can see the energy distribution of 800 nm incident light from the upper surface of the grating to the substrate.



(a)



(b)

Fig. 3. (Color online) Normalized field magnitude distribution for the grating with the zeroth order suppressed under normal incidence: (a) TE polarization, (b) TM polarization (color online)

There are two couplings in the energy exchange inside the grating. The incident light passes through the grating region to produce a first coupling. The incident light is excited by four modes, and then the four modes propagate through different effective refractive indices to the exit surface to produce a second coupling. Table 1 shows the effective refractive indices of the four modes under two polarizations. The second coupling is the coupling of the four modes of the grating and the diffraction order. We can see from the overlapping integral of Table 2 that the energy of the four modes is mainly coupled with the first order, and Less energy of the four modes is coupled to the second order.

Table 1. Effective refractive index of grating modes for two polarizations

polarization	TE	TM
Mode 0	1.34084	1.29350
Mode 1	1.03534	0.99528
Mode 2	0.95274	0.96003
Mode 3	0.64041	0.61214

Table 2. Coupling overlap integration between four grating modes and three diffraction orders of an optimized grating parameter at an incident wavelength of 800 nm: (a) TE polarization and (b) TM polarization

Mode → Order	-2nd/+2nd	-1st/+1st	0th
(a) TE			
Mode 0	0.03912	0.22517	0.46498
Mode 1	0.09156	0.38590	0
Mode 2	0.00568	0.23364	0.51955
Mode 3	0.36857	0.10972	0
(b) TM			
Mode 0	0.05687	0.22110	0.41943
Mode 1	0.06883	0.41090	0
Mode 2	0.02157	0.24832	0.44495
Mode 3	0.41967	0.03315	0.00127

3. Results and discussion

The grating achieves a good splitting effect with the zeroth order suppressed at a given period of 1676 nm. But in the process of making the grating, we also need to consider the effect of the variation of the period and duty cycle on polarization- independent grating with the zeroth order suppressed. Figure 4 shows the relationship between the efficiency of the grating under two polarizations and the grating period. The abscissa is the period of the grating and the ordinate is the efficiency of the grating. Under two polarizations, the efficiency of 0th order is less than 5% and the efficiency of 1st order is greater than 40% when the grating period is 1555-1870 nm.

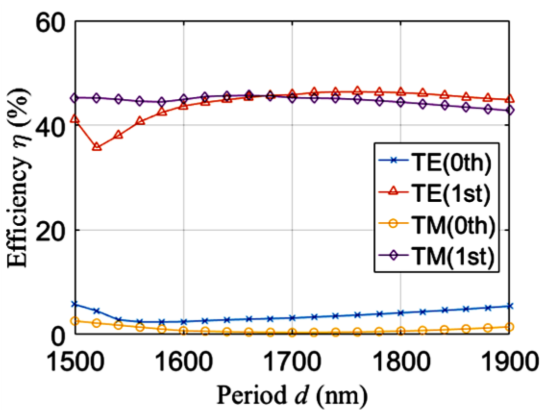


Fig. 4. (Color online) The diffraction efficiency corresponding to the period at wavelength of 800 nm with duty cycle of 0.28 under normal incidence (color online)

Fig. 5 shows the relationship between transmission efficiency and duty cycle of the grating under two polarizations. We found that the grating is in the range of 0.237-0.306, where the efficiency of the 0th stage is less than 5%, the efficiency of the first order is more than 40%.

The device has a good two-port effect with the zeroth order suppressed.

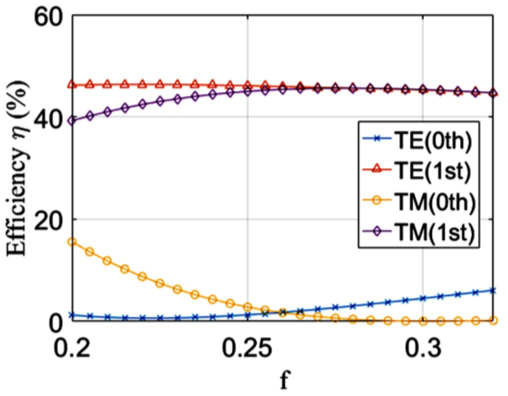


Fig. 5. (Color online) The diffraction efficiency corresponding to the duty cycle at wavelength of 800 nm under normal incidence (color online)

In addition, the influence of the incident wavelength range on the splitting effect with the zeroth order suppressed should also be considered. Figure 6 shows the relationship between the transmission efficiency of the grating with the zeroth order suppressed and the incident wavelength. The abscissa is the incident wavelength and the ordinate is the transmission efficiency. It can be seen that when the efficiency of the 0th order is less than 5% and the efficiency of the 1st order is greater than 40% when the wavelength range of the grating is 780-841 nm, where the incident wavelength bandwidth of the grating is 61 nm. In this range of gratings, the splitting effect grating under TE polarization and TM polarized is substantially equal.

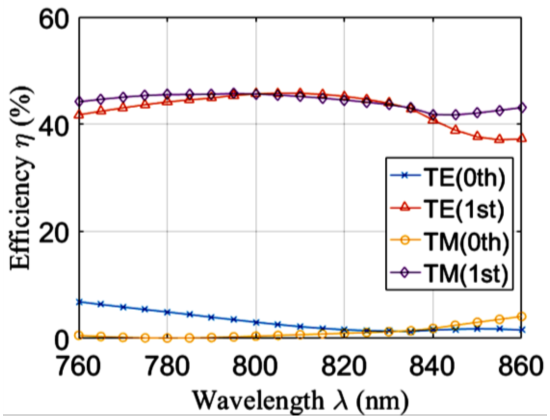


Fig. 6. (Color online) The efficiency corresponding to the incident wavelength with duty cycle of 0.28 under normal incidence (color online)

4. Conclusion

According to the reported single-layer two-port grating, we have designed a single-layer two-port grating splitter with the zeroth order suppressed. The grating splitter has high transmission efficiency and large period process tolerance. The structural parameters of the grating are analyzed and calculated by the rigorous coupled-wave theory. For TE-polarized light, the efficiency of the 1st order is 45.64%, and for the TM-polarized light, the efficiency of the 1st order is 45.62%. This grating has a good suppression effect on the 0th order. In the case of ensuring efficient efficiency, we discuss the influence of the incident characteristics of the grating and process tolerance. The results show that the grating has a good incident bandwidth and period tolerance under two polarizations.

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