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Fused-silica sandwiched three-port grating under second Bragg angle incidence

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The fused-silica sandwiched three-port grating under second Bragg angle incidence is presented with operation in transmission. To obtain a highly-efficient three-port grating for a working wavelength of 800 nm, the grating depth and period should be optimized by using rigorous coupled-wave analysis. With the optimized different three-port grating depths and periods, both TE-polarized and TM-polarized waves can be diffracted into three orders with nearly 33% efficiency for the given duty cycle of 0.6. Based on the grating parameters of numerical optimization, modal method may be employed to explain the physical mechanism of the beam propagation in the grating and analyze the splitting behavior. For the sandwiched three-port grating, it is feasible that the diffraction efficiencies can be enhanced for both TE and TM polarizations.

1. Introduction

Sandwiched gratings can be used as grating coupler [1,2], light absorber [3], which is aimed at improving the diffraction efficiency [4]. Under second Bragg angle incidence [5,6], a three-port grating can separate both TE-polarized wave and TM-polarized waves into the 0th order, the -1st order and the -2nd order. In the reported work, a fused-silica single-layer three-port grating under second Bragg angle incidence was proposed with low diffraction efficiency, where the only one polarization was to be demonstrated [5]. Fused silica is a perfect optical material with high optical quality and stable performance [7], which can stand with high laser power [8–11]. For realizing and obtaining a highly-efficient three-port grating, grating parameters should be optimized by using rigorous coupled-wave analysis (RCWA) [12]. Based on the optimized numerical values, modal method can be employed to analyze the coupling mechanism in the grating for TE and TM polarizations [13]. As for a qualified three-port grating, the diffraction efficiency of each order need to surpass 30% and the efficiency's ratio can be approached to 1 with good uniformity for not only TE polarization but also TM polarization [14]. To our knowledge, no one has proposed a fused-silica three-port sandwiched transmission grating under second Bragg incidence for a working wavelength of 800 nm.

In this paper, a fused-silica three-port sandwiched transmission grating is designed and investigated. With the optimized grating parameters for TE and TM polarizations, performances of high efficiency and good uniformity can be obtained for both TE and TM polarizations. The theoretical analysis of the coupling mechanism and splitting behavior can be well explained by using the modal method. Compared with the reported three-port grating under second Bragg angle incidence, the designed

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grating can have advantages of high efficiency and broad incident bandwidth. Therefore, the proposed grating with the enhanced diffraction efficiency can be put into use for many optical systems.

2. Optimization and modal analysis of the sandwiched three-port grating

Fig. 1 presents the fused-silica sandwiched three-port transmission grating under second Bragg angle incidence for TE polarization and TM polarization. A plane wave illuminates the sandwiched grating with an incident angle $\theta_{TE} = \sin^{-1}(\lambda/n_2 d_{TE})$ or $\theta_{TM} = \sin^{-1}(\lambda/n_2 d_{TM})$, where λ is the incident wavelength, n_2 is the refractive index of covering layer, d_{TE} and d_{TM} are the grating period for TE polarization and TM polarization, respectively. Such an embedded grating is etched in the fused silica with the refractive index $n_2 = 1.45$, where the depth of grating ridge can be expressed as h_{TE} for TE polarization and h_{TM} for TM polarization. Moreover, the duty cycle of f is defined as the ridge width to the period for both TE and TM polarizations. The TE- and TM-polarized wave can be coupled into different propagating direction and output to the diffraction orders, where the propagating direction can be determined by the grating equation as follow:

$$n_1 \sin\theta_m = n_2 \sin\theta + m\frac{\lambda}{d}, \tag{1}$$

where n_1 is the refractive index of air, θ_m depicts the angle of mth diffraction order. The coupled diffraction orders can be only set to the -2nd order, the -1st order and the 0th order within the grating period range of λ–2λ based on calculating the equation (1).

Fig. 2 demonstrates efficiencies of the 0th order, the -1st order and the -2nd order versus grating period and depth for both TE and TM polarizations for an incident wavelength of 800 nm and duty cycle of 0.6. As can be seen from Fig. 2, with the grating depth $h_{TE} = 0.89$ μm and period $d_{TE} = 1075$ nm, efficiencies of 32.9%, 33.0% and 33.3% can be diffracted into the 0th order, the -1st order and the -2nd order, respectively for TE polarization. For TM polarization, with the optimized depth $h_{TM} = 1.24$ μm and period $d_{TM} = 1134$ nm, efficiencies in the 0th order, the -1st order and the -2nd order can be arrived at 32.0%, 31.8% and 31.6%, respectively.

For different polarized-waves, the different exact grating parameters can be obtained for the sandwiched three-port grating by using RCWA. It is necessary to give a clearly physical explanation about splitting behavior from the incident wave to the diffraction orders for both TE and TM polarizations. Modal method can give a whole propagating pattern on account of some numerical results of the energy exchanging. The incident wave can be coupled into some diverse modes, the grating modes propagate in the grating ridge by their propagating constants. Thus, the effective index should be taken into consideration. For TE-polarized wave, the grating modes and effective indices can be determined by following [15]:

$$F\left(n_{eff}^2\right) = \cos k_1(1-f)d_{TE}\cdot\cos k_2 f d_{TE} - \frac{k_1^2 + k_2^2}{2k_1k_2}\cdot\sin k_1(1-f)d_{TE}\cdot\sin k_2 f d_{TE} = \cos\alpha d_{TE} \tag{2}$$

For TM-polarized wave, the equation can meet:

$$F\left(n_{eff}^2\right) = \cos k_1(1-f)d_{TM}\cdot\cos k_2 f d_{TM} - \frac{n_2^4k_1^2 + k_2^2}{2n_2^2k_1k_2}\sin k_1(1-f)d_{TM}\cdot\sin k_2 f d_{TM} = \cos\beta d_{TM} \tag{3}$$

where

$$k_j = k_0\sqrt{n_j^2 - n_{eff}^2}, \alpha = k_0\sin\theta_{TE}, \beta = k_0\sin\theta_{TM}, k_0 = \frac{2\pi}{\lambda}. \tag{4}$$

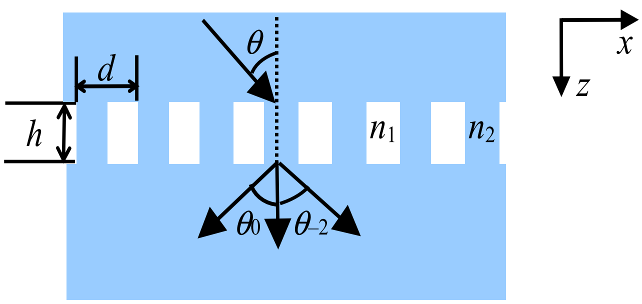

Fig. 1. Schematic of fused-silica sandwiched three-port transmission grating under second Bragg angle incidence.