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Highly-efficient three-port output by metal-mirror-based grating

HONGTAO LI, BO WANG*, WENHAO SHU, LI CHEN, LIANG LEI, JINYUN ZHOU

School of Physics and Optoelectronic Engineering, Guangdong University of Technology, Guangzhou 510006, China

*Corresponding author: wangb_wsx@yeah.net

A highly-efficient three-port output of metal-mirror-based grating is proposed in this paper. The metal-mirror-based grating can function as a beam splitter which can diffract the normal incident wave into the 0th and the ±1st orders for both TE and TM polarizations with the usual duty cycle of 0.5. The analysis of the grating parameters can be optimized by rigorous coupled-wave analysis. The high efficiency for TE and TM polarizations shall be realized. By means of the numerical simulation, the depth and connecting layer thickness of grating can be accurately calculated. The efficiency of per port is near 33.3%, so the novel three-port output grating with a connecting layer would be an excellent optical element.

Keywords: three-port output, metal-mirror-based grating, rigorous coupled-wave analysis.

1. Introduction

The high-efficiency grating plays an important role in recent years. It is applied to numerous areas including optical coupling, silica-based hybrid photodetector integration and so on [1–3]. And the three-port output operation is reported for slow neutrons-splitting of the incident intensity [4]. In addition, the metal/multilayer grating can fulfill high diffraction efficiency [5]. To optimize the grating for beam splitting [6, 7], the rigorous coupled-wave analysis (RCWA) [8] can be used. Conventional beam splitter gratings, such as the Dammann gratings, have some disadvantages such as low diffraction efficiency.

It is possible to enhance efficiencies of TE and TM polarizations by the metal dielectric grating, which consists of a rectangular-groove transmission dielectric grating on the top layer and a highly reflective mirror composed of a connecting layer and a metal film [9]. HUI CHEN *et al.* designed a high-efficiency metal-multilayer-dielectric grating at the wavelength of 810 nm [10]. ANDUO HU *et al.* reported that an optimized metal-dielectric grating could achieve diffraction efficiency exceeding 95% [11].

In this paper, a highly-efficient three-port output by metal-mirror-based grating is put forward. Diffraction of the 0th and the ±1st orders is capable of high efficiency under the normal incidence. Therefore, the novel three-port output grating can increase efficiencies of TE and TM polarizations in the further practical applications.

2. The design of three-port output by metal-mirror-based grating

Figure 1 shows the highly-efficient three-port output by metal-mirror-based grating with period of d, the incident angle of $\theta_i = 0$, and the grating depth of h_g. In order to obtain highly-efficient property, the connecting layer of h_c is necessary to be designed. Furthermore, the metal slab of Ag with the thickness of h_m can reflect the incident wave. Under the normal incidence, the incident wave with wavelength of λ illuminates the grating from the air with the refractive index of $n_1 = 1$. The material of ridge and connecting layer are both fused silica with the refractive index $n_2 = 1.45$. And the reflective index of metal slab Ag is $n_3 = 0.469 - 9.32i$. For the TE/TM polarization, the normal incident wave can diffract into the 0th and the ±1st orders. On account of the symmetry, the efficiency of diffraction in the –1st order is the same with the 1st order.

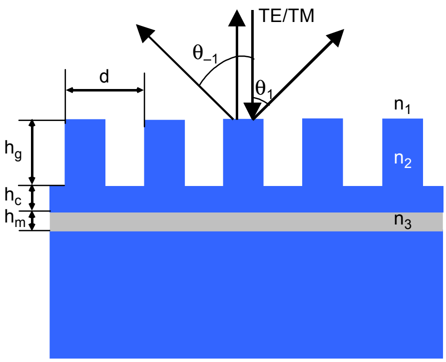

Fig. 1. Schematic of a highly-efficient three-port output by metal-mirror-based grating.

In purpose of obtaining high efficiencies of TE and TM polarizations, the various parameters should be considered by using RCWA. There are five parameters to be considered including the thickness of metal slab, the duty cycle, the period, the grating depth, and the connecting layer thickness. Firstly, the thickness of metal slab is 0.1 μm which can reflect the incident wave. Secondly, the duty cycle of the grating is usual value of 0.5. Thirdly, the period of $d = 1910$ nm is chosen based on numerical calculation by using RCWA. Therefore, there are two parameters to be optimized, which are the grating depth and the connecting layer thickness. Figure 2 shows the three-port output by metal-mirror-based grating *versus* grating depth and connecting layer depth

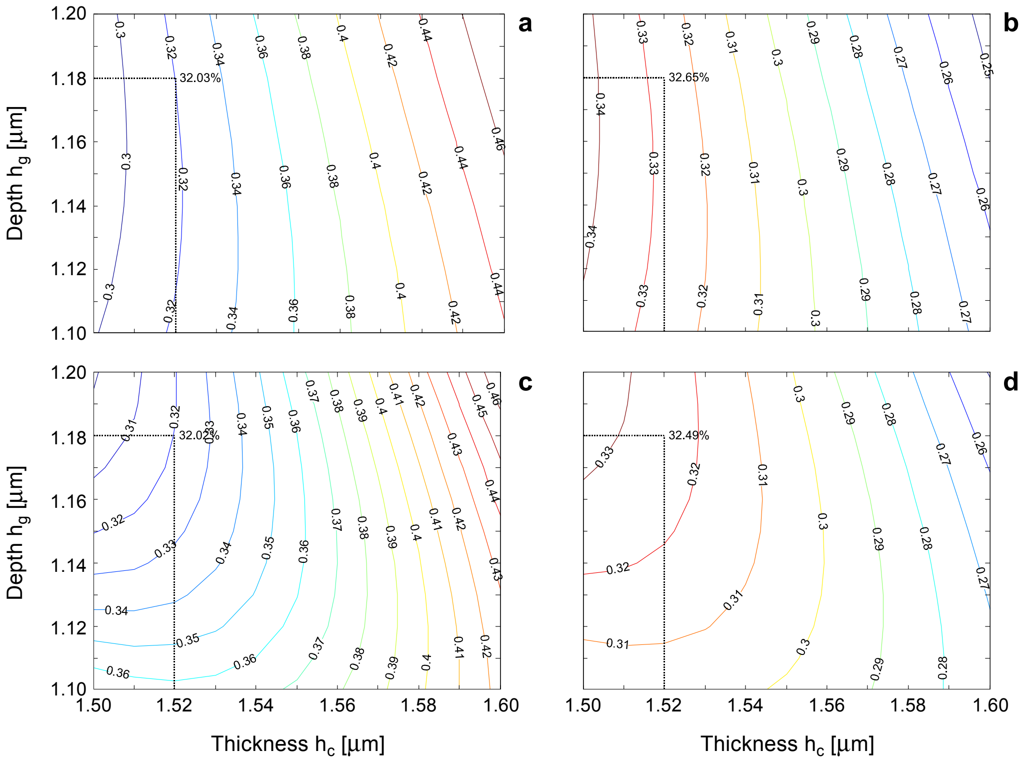

Fig. 2. Diffraction efficiency *versus* grating depth and thickness of the connecting layer with the duty cycle of 0.5 and period of 1910 nm for the wavelength of 1550 nm: TE polarization diffracted into the 0th order (**a**), TE polarization diffracted into the 1st order (**b**), TM polarization diffracted into the 0th order (**c**), and TM polarization diffracted into the 1st order (**d**).

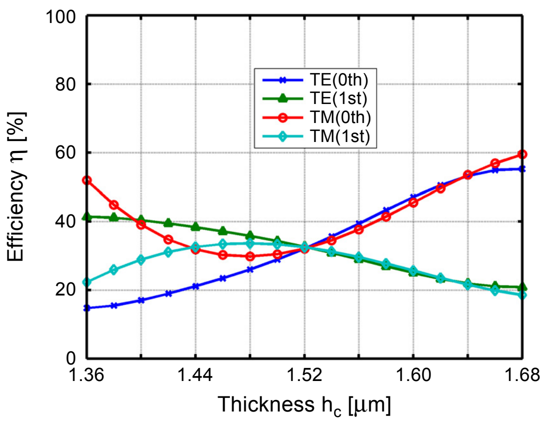

Fig. 3. Diffraction efficiency *versus* thickness of the connecting layer with the duty cycle of 0.5, the period of 1910 nm and the depth of 1.18 µm for the wavelength of 1550 nm.

with $\lambda = 1550$ nm and $d = 1910$ nm. For the three-port output grating, the efficiency in each port ought to be greater than 30%. The highly-efficient property of the grating would be achieved with the connecting layer thickness of $h_c = 1.52$ μm and the depth of $h_g = 1.18$ μm. In Figure 2, grating efficiencies with different depth and connecting layer thickness are calculated by RCWA. For the TE polarization, diffraction efficiencies of the 0th and the 1st diffractive orders are 32.03% and 32.65%. For the TM polarization, diffraction efficiencies of the 0th order and the 1st order correspond to 32.02% and 32.49%. From the result of the accurate numerical calculation, one can see that the efficiency of the TE polarization can realize 97.33% and the efficiency of the TM polarization can realize 97%. Figure 3 shows diffraction efficiency *versus* thickness of the connecting layer with the duty cycle of 0.5, the period of 1910 nm and the depth of 1.18 μm for the wavelength of 1550 nm. In Figure 3, the reflective efficiency can be affected by the connecting layer thickness. With the optimized result of $h_c = 1.52$ μm, three-port beam splitting can be achieved for both TE and TM polarizations with high efficiency.

3. The analysis of diffraction property

The spectral bandwidth for the incident wavelength can be studied by using RCWA. Figure 4 shows diffraction efficiency *versus* incident wavelength with the usual duty cycle of 0.5 for the optimized grating depth of $h_g = 1.18$ μm and connecting layer thickness of $h_c = 1.52$ μm under the normal incidence. Under the tolerance of the wavelength within the range of 1540–1554 nm, the reflection efficiencies of three orders are beyond 30%. One can draw the conclusion that highly-efficient property can be diffracted with the reflection efficiencies over 90% for both TE and TM polarizations. Figure 5 shows the diffraction efficiency with the different incident angle. The incident

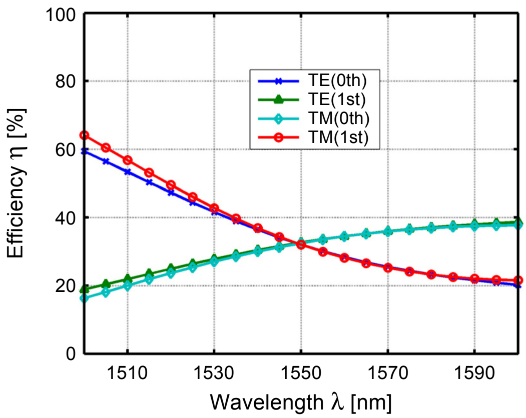

Fig. 4. Diffraction efficiency *versus* incident wavelength with the usual duty cycle of 0.5 for the optimized grating depth and connecting layer thickness $h_g = 1.18$ μm and $h_c = 1.52$ μm under the normal incidence.

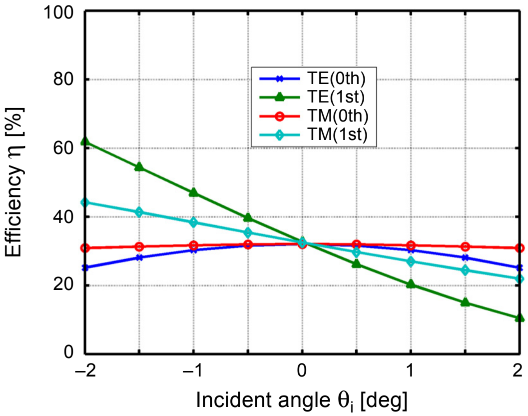

Fig. 5. Diffraction efficiency *versus* angle of incidence for the wavelength of 1550 nm with the optimized grating profile parameters.

angle is restricted from –1.07° to 0.19° in order that the efficiencies in the 0th order and the 1st order can surpass 30%.

4. Conclusions

In conclusion, the three-port output by metal-mirror-based grating is proposed with the merit of high diffraction efficiency. Reflection efficiencies of TE and TM polarizations are 32.03%/32.65% and 32.02%/32.49% in the 0th and the ±1st orders with the optimized grating depth of $h_g = 1.18$ μm and the thickness of $h_c = 1.52$ μm. The diffraction efficiency simulation reveals that the efficiencies in the 0th and the 1st orders are more than 30% within the wavelength range of 1540–1554 nm under normal incidence or the angle range of –1.07° to 0.19° at the incident wavelength of 1550 nm. Therefore, the three-port output by metal-mirror-based grating is a high-efficiency element which can apply to various optical systems.

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