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Theoretical reflective performance of a sandwiched two-layer grating polarizer

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HIGHLIGHTS

- Usual grating duty cycle of 0.5 for easy fabrication.
- TE and TM polarizations diffracted in different diffraction orders.
- Extinction ratios of 45.5 dB and 41.9 dB in two diffraction orders.

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ABSTRACT

The reflective polarizer is described by a sandwiched two-layer grating with a metal slab. Such a new polarizer is aimed to improve the performance of a reflective grating-based polarizer. The grating is optimized with the usual duty cycle of 0.5, where TE and TM polarizations are reflected in the −1st and the 0th diffraction orders, respectively. With optimized grating parameters, the extinction ratio can reach 45.5 dB and 41.9 dB in two diffraction orders, which are greatly improved compared with the conventional reported surface grating polarizer with the simple structure. Attractive merits of the new design are high efficiency, high extinction ratio, wide incident wavelength bandwidth for TE polarization, and wide angular range for TM polarization. Numerical results are expected to open new opportunities for the design of a grating-based polarizer with the enhanced performance by the complicated grating configuration.

1. Introduction

Optical polarizers are elements which can control the polarization state of the incident beam [1–3]. Conventional polarizers utilize the natural crystal birefringence or polarization selectivity of multilayer structures. The progress in microfabrication technologies has led to the miniaturization of optical elements [4,5]. Grating structures are found to have polarization properties when their periods are comparable to the wavelength of the incident light [6,7]. Compared with conventional polarizers, grating-based polarizers have advantages, such as compact size, low cost, and high extinction ratio [8].

A reflective polarizing beam splitter (PBS) has been proposed by using the metal-covered relief grating, which can be operated at a single wavelength for the He–Ne laser [9]. The validity can be demonstrated in experiments with efficiencies of 59% for TE polarization and 0.5% for TM polarization in one diffraction order and 85% for TM polarization and 3% for TE polarization in the other diffraction order. The extinction ratio can be calculated by the efficiencies, which are 20.7 dB and 14.5 dB for the two diffraction orders, respectively. Such a PBS grating is based on the single-layer surface-relief structure. From reported results above, the performance should be improved, especially for the efficiency and the extinction ratio. Furthermore, it is reported that the PBS must be etched in materials that are not so expensive as InP [9]. A metal-multilayer dielectric grating structure is proposed at a central wavelength of 1053 nm, where extinction ratios can reach 48.8 dB and 62.2 dB in two diffraction orders [10]. For the double-layer structure, a Si–ZnS grating is described at the incident wavelength of 1550 nm with reflection and transmission rates of 99.35% for TE polarization and 98.17% for TM polarization, respectively [11]. In other experiments, a wire-grid polarizer with antireflection grating has been manufactured with the extinction ratio over 20 dB at the 11 μm wavelength [12].

In this paper, it is aimed to improve the performance and propose different grating materials by a new grating structure. The reflective polarizer is presented based on a sandwiched two-layer

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grating with a metal slab. The performance can be enhanced greatly, including the efficiency, the extinction ratio, and the bandwidth. The novel polarizer can be etched in Ta_2O_5 and fused silica. Especially, fused silica is an excellent optical material with low cost compared with InP of the reported reflective PBS grating.

2. Optimized design and fabrication tolerance

The graphical representation of the presented polarizer is shown in Fig. 1. For such a sandwiched structure, it is easy to clean and protect the grating surface compared with the conventional surface-relief grating. And high efficiency can be achieved effectively based on a sandwiched grating by the covering layer. To be operated in reflection, a metal slab of Ag with the depth of 100 nm is coated on the fused-silica substrate. Grating layers with period of d are etched in Ta_2O_5 with the depth of h_1 and the refractive index $n_1 = 2$ and fused silica with the depth of h_2 and the refractive index $n_2 = 1.45$. An unpolarized wave with the wavelength of λ is incident upon the mixed metal dielectric grating under Littrow mounting at the Bragg angle of $\theta_i = \sin^{-1}(\lambda/(2n_2d))$. TE polarization returns in the direction of the incident wave. And TM polarization is reflected symmetrically.

To achieve high efficiency for TE polarization in the −1st diffraction order and TM polarization in the 0th diffraction order, optimized grating parameters can be determined by searching the grating duty cycle, period, and depths by using the rigorous coupled-wave analysis (RCWA) [13]. Furthermore, numerical results of the diffraction are simulated by the developed MATLAB software codes in this paper according to RCWA. Fig. 2 shows the reflective efficiency of a sandwiched two-layer grating polarizer versus grating depths at the incident wavelength of 1550 nm under Littrow mounting for both TE and TM polarization, where the duty cycle is the usual value of 0.5 and the period is numerically designed as 1110 nm. It can be seen that efficiencies of 97.04% for TE polarization and 96.56% for TM polarization can be diffracted into the different reflective diffraction orders with depths of $h_1 = 0.96$ μm and $h_2 = 1.82$ μm. Such efficiencies are much more than 59% for TE polarization and 85% for TM polarization of the reported conventional reflective polarizer [9]. Based on optimized results, the extinction can be calculated, which are 45.5 dB and 41.9 dB in the −1st and the 0th diffraction orders, respectively. Extinction ratios are enhanced greatly compared with 20.7 dB and 14.5 dB of the reported reflective polarizer with the simple structure [9]. The new grating-based polarizer has two layers with many parameters, such as the grating duty, period, and depths of two layers. By optimizing parameters, efficiencies are 0.0027% and 0.0062% for TM polarization in the −1st diffraction order and TE polarization in the 0th diffraction order, respectively, where very low efficiencies lead to high extinction ratios.

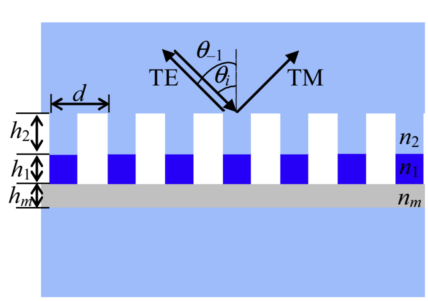

Fig. 1. Graphical representation of a reflective sandwiched two-layer grating polarizer (refractive indices n_1: Ta_2O_5, n_2: fused silica, n_m: Ag; grating groove: air; d: period; h_1 and h_2: grating depths of the first and the second layers, respectively, h_m: thickness of metal slab; θ_i: incident angle, θ_{-1}: diffraction angle of the −1st order).

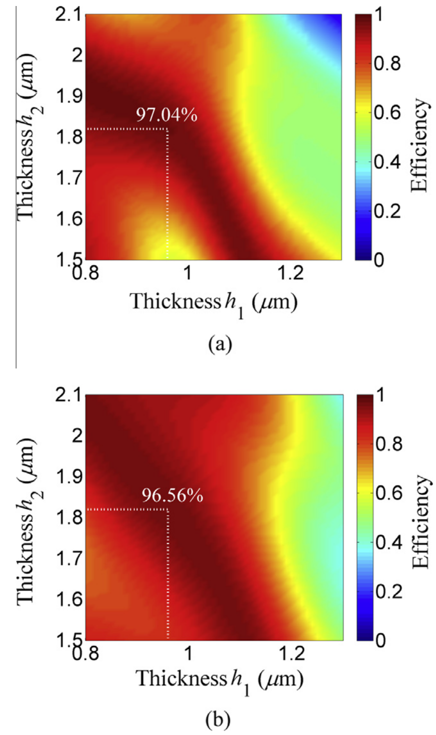

Fig. 2. Reflective efficiency of a sandwiched two-layer grating polarizer versus grating depths at the incident wavelength of 1550 nm under Littrow mounting: (a) TE polarization in the −1st diffraction order and (b) TM polarization in the 0th diffraction order.

For the practical fabrication, grating parameters may deviate from optimized results due to the less control of etching conditions. It is necessary to investigate the fabrication tolerance. Fig. 3 shows the extinction ratio (unit: dB) of the reflective sandwiched two-layer grating polarizer versus depths of two layers at an incident wavelength of 1550 nm. In Fig. 3, extinction ratios more than 20 dB can be obtained within etched depths of 0.95 μm < h_1 < 0.97 μm and 1.80 μm < h_2 < 1.85 μm. Furthermore, the duty cycle may vary during the chemical etching in experiments. Such a parameter can be sensitive to the efficiency for both TE and TM polarizations, where the tolerance for duty cycle should be taken into account. Fig. 4 shows the reflective efficiency and extinction ratio versus the duty cycle for the optimized grating polarizer at an incident wavelength of 1550 nm. On the one hand, efficiencies more than 90% for TE polarization in the −1st

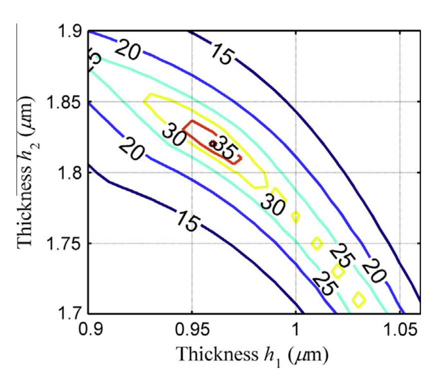

Fig. 3. Extinction ratio (unit: dB) of the reflective sandwiched two-layer grating polarizer versus depths of two layers with the usual duty cycle of 0.5 and period of 1110 nm at an incident wavelength of 1550 nm.