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Diffractive polarizing beam splitter of two-layer grating for operation in reflection

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ABSTRACT

A diffractive polarizing beam splitter (PBS) of two-layer grating is described for operation in reflection. The novel PBS grating includes two dielectric layers and a metal slab on the substrate. The reflective efficiency is widely simulated and optimized by using rigorous coupled-wave analysis. With the optimized grating parameters, efficiency of 96.46% for TE polarization of the two-layer reflective PBS grating is much more than 88.52% of the single layer PBS grating and 93.07% of the sandwiched PBS grating. The analysis shows that efficiencies more than 90% can be achieved for 394 nm spectral bandwidths within the incident wavelength range of 1480–1874 nm, which are much broader than the bandwidths of 67 nm spectral bandwidths of the reported single layer grating. The novel PBS for operation in reflection can have merits of high efficiency, broad bandwidth for incident wavelength range and high extinction ratio in the −1st order with wide angular range.

1. Introduction

Polarizing beam splitters (PBSs) are basic optical elements for separating different polarized beams [1–3], which play important roles in magneto-optical data storage, liquid crystal displays, and optical communication. The different polarized states obtained by the PBS can increase the information bandwidth or reduce the crosstalk between different channels. Some applications also include polarization-based image systems, quantum computation and so on. The characteristics to evaluate the performance of a PBS include the incident wavelength and angular bandwidths, the extinction ratios, and the efficiency in transmission or reflection. The natural birefringent crystal or the multilayer coating can be utilized for conventional PBSs, which cannot meet requirements of compact size, broad incident bandwidths, and high extinction ratios. Gratings with periods approaching the incident wavelength have distinctive features, especially the polarization-dependent property [4–6]. Furthermore, high-efficiency gratings or resonant gratings can achieve almost 99% of efficiency [7–9]. Many PBS gratings are reported based on high-spatial-frequency structures optimized by using rigorous coupled-wave analysis (RCWA) [10], such as the surface-relief grating [11–15] and the sandwiched grating [16].

A surface-relief PBS grating with the single layer has been presented for operation in transmission [11]. With the optimized grating parameters, the PBS grating can diffract TE polarization into the −1st order with the efficiency of 88.52% and TM polarization into the 0th order with the efficiency of 98.62%. For different incident wavelengths, efficiencies more than 90% can be achieved for 67 nm spectral bandwidths for the optimized single layer PBS grating. Although the validity of the PBS grating is demonstrated by experiments, the efficiency and the bandwidth need to be further improved. To enhance the efficiency, a sandwiched PBS grating has been introduced with a covering layer on the surface-relief grating [16]. Efficiencies of 93.07% for TE polarization and 99.26% for TM polarization can be achieved in the −1st and the 0th orders, respectively. For the broadband property, it is indicated that the two-layer grating can diffract TE and TM polarizations with the broad incident wavelength range in transmission [17].

In this paper, a diffractive PBS of a two-layer grating is presented for operation in reflection. The PBS grating includes two dielectric layers and a metal slab on the substrate. The grating parameters are optimized by using RCWA, which shows that the incident wavelength range is improved greatly by the reflective two-layer grating compared with the single layer grating. The novel reflective PBS grating can have high efficiencies, high extinction ratios, and broad incident wavelength ranges.

2. PBS of two-layer grating for operation in reflection

The diffractive PBS of two-layer grating with period of d is shown in Fig. 1, which is operated in reflection. A metal slab of Ag with depth of h_m and the refractive index n_m is evaporated on the substrate of fused silica. There are two dielectric grating layers on the Ag slab. The first layer is Ta_2O_5 with depth of h_1 and the refractive index $n_1=2$ and the second layer is etched in fused silica with depth of h_2 and the refractive index $n_2=1.45$. The plane wave

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is incident upon the PBS grating from air under Littrow mounting at the Bragg angle of $\theta_i = \sin^{-1}(\lambda/(2d))$. For operation in reflection, TE and TM polarizations are reflected in the –1st and the 0th orders, respectively.

The two-layer grating can achieve high efficiency with the broadband property. The characteristics to be considered for the PBS grating are efficiency, extinction ratio, and the incident wavelength and angular bandwidths. The reflective efficiency can be widely simulated by using RCWA for different grating depths with various grating duty cycles and periods. Fig. 2 shows efficiency in reflection of a two-layer grating versus grating depths of the two-layer with the duty cycle of 0.25 and period of 1000 nm. In Fig. 2, efficiencies of 96.46% for TE polarization in the –1st order and 96.26% for TM polarization in the 0th order can be achieved with $h_1 = 0.27$ μm and $h_2 = 0.62$ μm. One can see that the two-layer grating can separate TE and TM polarizations for operation in reflection. Furthermore, efficiency of 96.46% for TE polarization of the two-layer reflective PBS grating is much more than 88.52% of the single layer PBS grating [11] and 93.07% of the sandwiched PBS grating [16].

The high performance can be achieved by the two-layer grating for operation in reflection. The physical explanation may be described by the modal method of the mixed metal dielectric grating [18]. The even

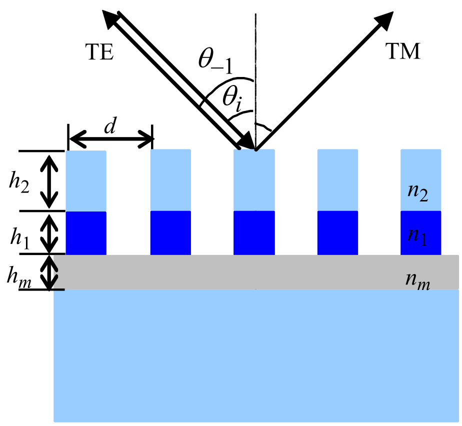

Fig. 1. Schematic of a diffractive polarizing beam splitter of two-layer grating for operation in reflection (refractive indices n_1: Ta_2O_5, n_2: fused silica, n_m: Ag; d: period; h_1 and h_2: grating depths of the first and the second layers, respectively, h_m: thickness of metal slab; θ_i: incident angle, θ_0 and θ_{-1}: diffraction angles of the 0th and the –1st orders, respectively).

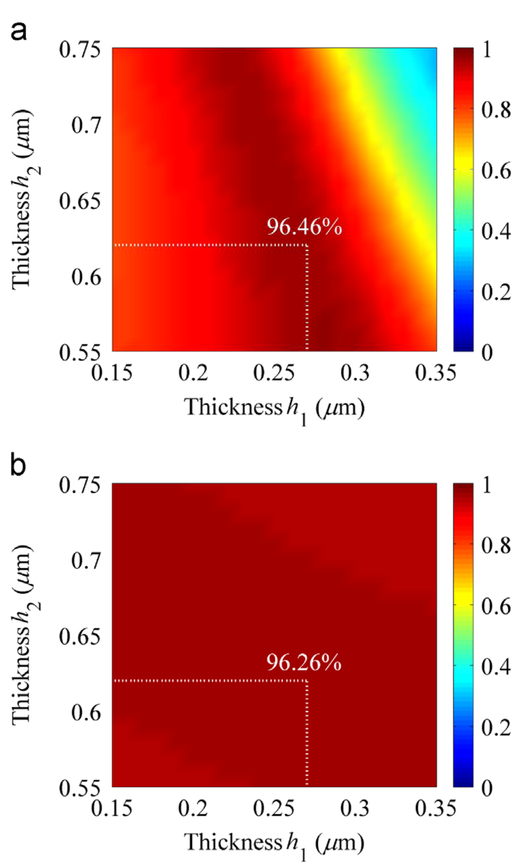

Fig. 2. Efficiency in reflection of a two-layer grating versus grating depths of the two-layer with the duty cycle of 0.25 and period of 1000 nm: (a) TE polarization and (b) TM polarization.

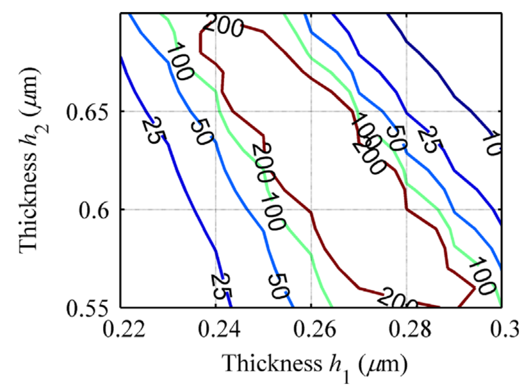

Fig. 3. Extinction ratio contour in reflection of the two-layer PBS grating versus grating depths with the duty cycle of 0.25 and period of 1000 nm.

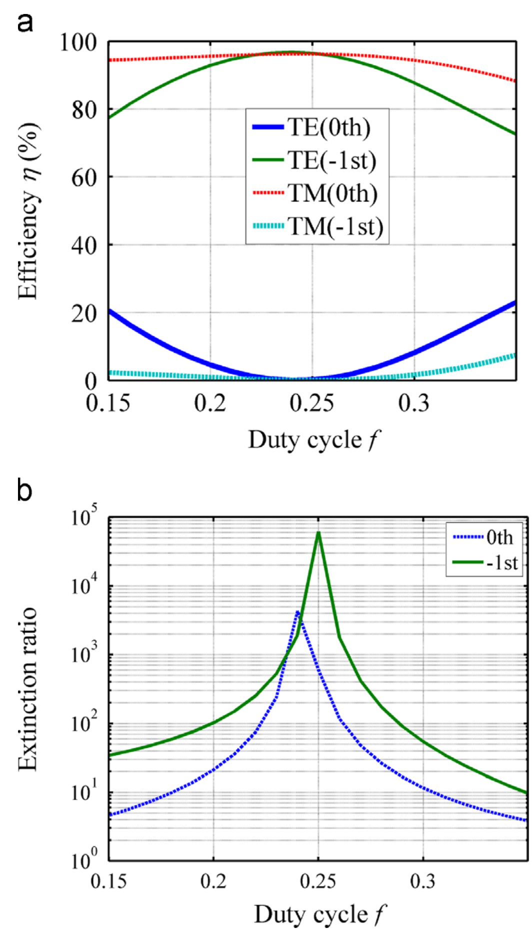

Fig. 4. Reflection efficiency (a) and extinction ratio (b) versus duty cycle under Littrow mounting for the optimized two-layer PBS grating.