Optimization design of polarizing beam splitter based on metal-multilayer high-contrast reflecting grating

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Abstract—**A reflecting polarizing beam splitter (RPBS) with structure of metal-multilayer high-contrast grating (MMHG) is designed using a genetic algorithm and the Fourier mode method. The proposed RPBS grating can work at a central wavelength of 1053 nm, and reflect the transverse electric (TE) wave in the -1st order and the transverse magnetic (TM) wave in the 0th order. The optimized RPBS grating has high extinction ratios over 20dB from 1030nm to 1076nm and at angle range from 48.6° to 55.1°. The highest efficiency over 98% and polarization extinction ratios of the 0th order and -1st order with 62.2 dB and 48.8 dB at 1053 nm is obtained, respectively. In addition, the optimized MMHG structure shows acceptable tolerances for grating fabrication. This kind of MMHG may be a potential candidate for the RPBS used in different optical systems.**

I. Introduction

The polarizing beam splitter (PBS) [1-3] that can split a light beam into two orthogonally polarized beams is an important optical device for various applications. Usually, a conventional PBS is a birefringent prism or consisted of multilayer dielectric coatings. The birefringent prism has high extinction ratio and wide bandwidth, but they are with high prices, large sizes, scarce natural birefringent crystals, and complex techniques of fabrication. Multilayer dielectric PBSs are based on the light interference effects and the optical losses can be very low. Unfortunately, they are narrow bandwidth and sensitive to the angle of incidence. Thus, conventional PBS cannot fulfill the requirements of modern optical systems and there exists a demand for more efficient PBS. Compared with conventional PBS, PBS grating has attracted increasing attention with its miniaturization feature, good performance and simple fabrication. Reflecting polarizing beam splitter (RPBS) grating reflects the TE wave at the −1st order and the TM wave at the 0th order, respectively. In this paper, a metal-multilayer dielectric grating (MMDG) RPBS working at 1053 nm is theoretically investigated; it reflects the TE wave at the −1st order and the TM wave at the 0th order, respectively. A genetic algorithm[18] is employed for the optimization of the proposed RPBS design. The diffraction efficiency of RPBS is calculated by the Fourier mode method (FMM) [19]. Reflection extinction ratios larger than 20dB in the 0th and -1st orders over a certain angle and wavelength range in the RPBS are obtained.

II. Model

To review the properties of the MMDG, the structure comprising a metal layer, a trilayer dielectric, and a corrugated last layer at the air side is considered (Fig. 1).

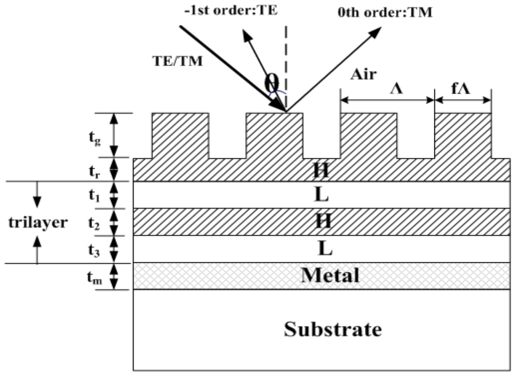

Fig. 1. Schematic of an MMDG with one metal HR mirror, a trilayer dielectric, and the surface-relief grating etched in the high-index material layer

In the above schematic of an MMDG, Ag is considered as the metal layer (n = 0.2309 + 7.1452i at 1053 nm) for its low absorption. The Ag layer is quite important in this kind of structure because it typically provides high reflectance and broad reflection bandwidth. The trilayer structure on the metal layer in this MMDG is deposited in order of L, H, and L. The respective thicknesses are t1, t2, and t3. H and L are supposed to be HfO2 (n = 1.96) and SiO2 (n = 1.45), respectively. Multiparameter optimization is chosen for our design. The optimization design of an RPBS is obtained by a genetic algorithm in the current paper. The merit function (MF) is considered as an rms error function:

$$MF=\{\frac{1}{N}\sum_{\theta_i}[(100\%-R_0^{TM}(\theta_i))^2+(R_0^{TE}(\theta_i))^2+(100\%-R_{-1}^{TE}(\theta_i))^2+(R_{-1}^{TM}(\theta_i))^2]\}^{1/2}$$

To obtain high reflection extinction ratios at a central wavelength of 1053nm, the desired R_0^{TM} and R_{-1}^{TE} of each angle is set as 100%, R_0^{TE} and R_{-1}^{TM} of each angle is set as 0. N is the number of angle points. FMM is used to calculate the diffraction efficiency of the RPBS grating. All included parameters in the proposed design are arrayed as {f, tg, tr, t1, t2, t3, Λ}. The minimum and maximum values of each parameter are set as {0.2, 200, 0, 10, 10, 10, 400} and {0.5, 800, 150, 300, 300, 300, 900}, respectively.

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III. Results

The corresponding values of (f, tg, tr, t1, t2, t3, Λ) are 0.2, 417nm, 0nm, 52nm, 95nm, 171nm, and 680.6nm.

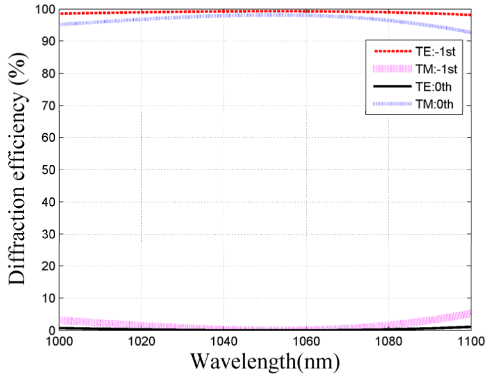

Fig. 2. Diffraction efficiency versus the incident wavelength at 50.7° for the RPBS grating working at 50.7° with f = 0.2, tg = 417 nm, tr = 0nm, t1 =52nm, t2=95nm, t3=171nm and Λ= 680.6nm

Fig.2 shows the relationship between reflection diffraction efficiency and incident wavelength of the optimized RPBS working at 50.7°. is higher than 96.9%, and keeps higher than 99% over the wide wavelength range from 1030 to 1076nm. At the same time, and is smaller than 1.2% over the wavelength range from 1030 to 1076nm.

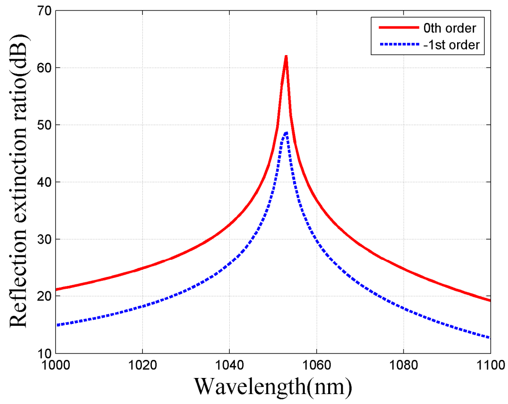

Fig. 3. Extinction ratios of the 0th and -1st orders versus the wavelength for the RPBS grating working at 50.7° with f = 0.2, tg = 417 nm, tr = 0 nm, t1 =52 nm, t2=95 nm, t3=171 nm and Λ= 680.6 nm

The extinction ratio C0 is over 24dB in a large wavelength range from 1020 to 1080 nm (Fig. 6). C-1 is over 20 dB in a smaller wavelength range from 1030 to 1076 nm. Thus, the designed RPBS can work well in the -1st and 0th orders over a large wavelength width of 46 nm. Meanwhile, the maximum value of C0 and C-1 are obtained as 62.2 and 48.8 dB at 1053nm, respectively. A large angle of 14.5o and a wavelength bandwidth of 46 nm with extinction ratio over 20 dB are obtained. This result provides a potential application in the beam splitting optics

In this MMHG structure, groove depth tg, duty cycle f, and grating profile may be the most important factors that affect on the bandwidth with high reflection diffraction efficiency. This section will give a detailed analysis of tg, f, and grating profile error on the performance of the RPBS, according to the model in Fig.1.

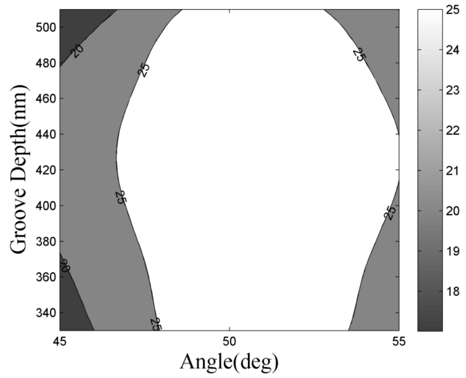

Fig. 4. Extinction ratios of 0th order versus the groove depth and angle at 1053nm for the RPBS grating

When the incidence angle changes from 45° to 55°, C0 is higher than 20 dB in a remarkably wide groove depth range from 374 to 476 nm. To have high extinction ratios in the 0th and -1st orders at the same time, the groove depth can change from 374 to 476 nm, which is very conducive to the manufacture of RPBS grating..

IV. Conclusions

In this paper, an RPBS based on the MMDG is theoretically investigated by a genetic algorithm and FMM. Numerical results show that the RPBS working at 1053nm can exhibit high diffraction efficiency and extinction ratio within a wide angular tolerance and board wavelength band. With the parameters in the proposed design, there is a good tolerance for grating fabrication. Such RPBS gratings will be useful in practical optical applications, such as optical information processing, optical fiber communication and other laser systems..

Acknowledgment

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