

Mixed metal dielectric grating for reflective polarization-selective diffraction

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The phase gratings can be optimized to obtain high efficiency in one order or achieve two-port output beam splitting. It is desirable that two functions can be fulfilled by one grating for different incident polarized waves. A polarization-selective element is presented based on the mixed metal dielectric grating. For TE polarization, high efficiency is diffracted into the reflected -1 st order. And for TM polarization, two-port output with good splitting ratio uniformity is shown in the -1 st and the 0th orders. The reflective polarization-selective grating can show different functions for TE and TM polarizations with wide incident wavelength and angular bandwidths.

(Received December 30, 2012; accepted September 18, 2013)

Keywords: Mixed grating, Reflective efficiency, Polarization-selective diffraction

1. Introduction

Phase gratings are extensively investigated with high spatial frequency theoretically and experimentally. For gratings with period comparable to the incident wavelength, the diffraction property can be interesting [1], such as high efficiency [2], polarization-dependent [3], and so on. The high-spatial-frequency grating can be optimized using rigorous coupled-wave analysis (RCWA) [4]. The validity has been demonstrated in experiments by dry etching method. A series of grating-based elements [5-7] have been reported due to the compact size and the good performance, which can be widely used in various optical information processing systems. On the one hand, high efficiency can be shown only in one diffracted order with optimized grating parameters [8] and the high-efficiency grating can work as a miniature pulse compressor. A transmissive grating has been optimized with high efficiency at an incident femtosecond laser wavelength of 800 nm for TE polarization. Such a grating pattern is recorded by holographic interference and etched in fused silica with inductively coupled plasma method. In experiments, the input 73.9 fs pulses can be compressed into the nearly Fourier transform-limited 43.2 fs pulses [9]. On the other hand, a beam splitter [10] can be acquired by optimizing the grating parameters, which can be a useful element in optical computing, holography, and metrology. The unified design of two-port beam splitter has been presented for not only TE polarization but also TM polarization [11], which is a good guideline for designing a beam splitter from ultraviolet to near infrared. Moreover, conventional beam splitters based on multilayer coatings suffer from energy loss due to the reflection and the refraction. And it is not easy to obtain the good splitting ratio uniformity between different channels. However, grating-based beam splitters can have high efficiency and good splitting ratio uniformity.

It can be seen that both high efficiency in one order

and two-port beam splitter can be useful elements. Many gratings are presented for either high efficiency or beam splitting and it is desirable to obtain two functions above with one grating [12]. A mixed metal dielectric grating has been reported for high efficiency in the -1 st order at a femtosecond wavelength of 800 nm under Littrow mounting, which can show efficiency higher than 90% with the wideband and the polarization-independent properties [13]. In this paper, a reflective polarization-selective element is proposed based on a mixed metal dielectric grating at an incident wavelength of 1550 nm. For TE polarization, high efficiency can be obtained in the reflected -1 st order. For TM polarization, two-port output can be achieved in the reflected -1 st and the 0th orders with nearly 50/50 splitting ratio. A reflective polarization-selective diffraction of high efficiency for TE polarization and beam splitting for TM polarization can be acquired by one mixed metal dielectric grating.

2. Grating design

The mixed metal dielectric grating structure with period of d on fused-silica substrate is shown in Fig. 1 illuminated by a plane wave with wavelength of λ from air with the refractive index of $n_1 = 1$. The incident condition meets Littrow mounting of the Bragg angle of $\theta_i = \sin^{-1}(\lambda/(2n_1d))$. After propagating through the grating region of fused silica with depth of h_g and the refractive index $n_2 = 1.45$, the incident wave is reflected by the metal layer of Ag with thickness of h_m and the refractive index of n_3 . The diffraction can be obtained in the reflected region after propagating the phase grating again. As a reflective polarization-selective element, high efficiency can be shown in the -1 st order for TE polarization and two-port output with nearly 50/50 splitting ratio in the -1 st and the 0th orders can be obtained for TM polarization.

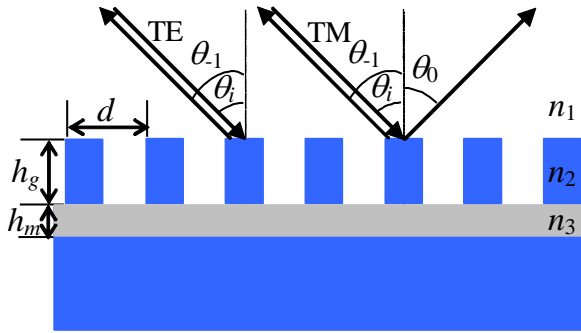


Fig. 1. (Color online) Schematic illustration of the reflective polarization-selective diffraction based on a mixed metal dielectric grating.

The mixed metal dielectric grating has high spatial frequency, whose polarization property is unlike to the low density grating. Furthermore, the diffraction property with a metal layer is different from that of the pure dielectric grating. The grating parameters will modulate the reflective efficiency, such as the duty cycle, period, and depth. To simulate the diffraction efficiency, the RCWA can solve the problem not only for the dielectric grating but also for the metal grating. Fig. 2 shows the efficiency in the reflected $-1st$ order for TE polarization and efficiency's ratio between the $-1st$ and the $0th$ orders for TM polarization versus grating depth and period with the usual duty cycle of 0.5 under Littrow mounting. The optimum grating parameters with period of 1286 nm and depth of 0.98 μm can be obtained based on the simulation of reflective efficiency for both polarizations. For TE polarization, high efficiency of 97.26% can be obtained in the reflective $-1st$ order with the optimized grating parameters. And for TM polarization, two-port output of 48.21% and 48.18% can be achieved in the $-1st$ and the $0th$ order, respectively, which is nearly 50/50 splitting ratio with good uniformity.

Fig. 3 shows reflective efficiency in the $-1st$ order versus grating depth with the period of 1286 nm and the usual duty cycle of 0.5. One can see that the grating depth affect the reflective efficiency of TM polarization more than that of TE polarization. Although efficiencies in two orders change with the depth, each order can have some incident energies for TM polarization. However, efficiencies vary just a few for TE polarization in the two orders. Especially, the efficiency in the $-1st$ order is always much higher than that in the $0th$ order. By calculation, efficiency higher than 97% can be obtained within the etched grating depth range of 0.98-1.45 μm . Therefore, a quite moderate etched depth tolerance can be indicated to obtain high efficiency for TE polarization, which should be useful for the practical fabrication and application.

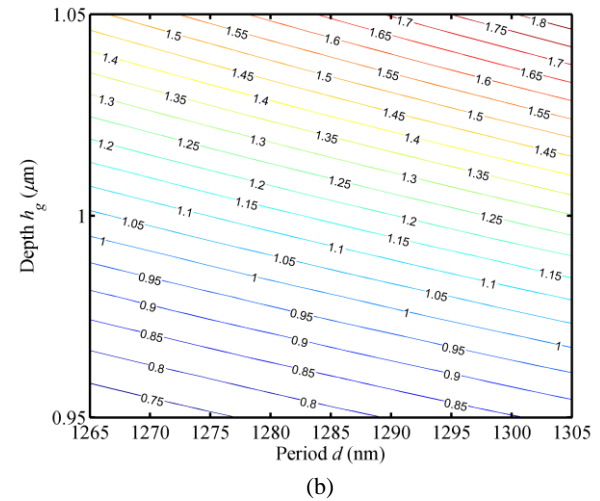
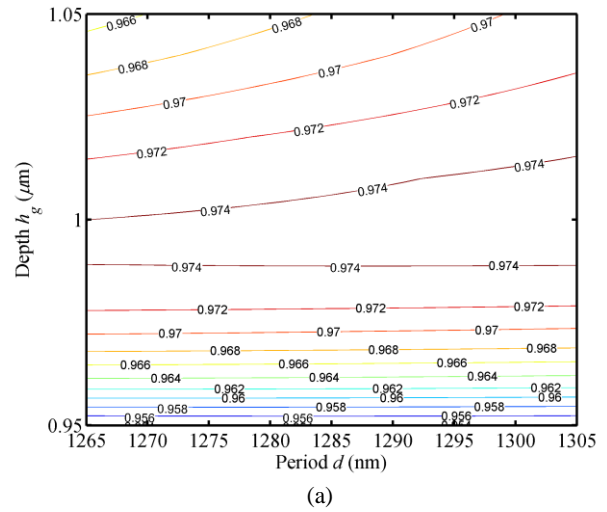


Fig. 2. (Color online) Efficiency in the reflected $-1st$ order for TE polarization (a) and efficiency's ratio between the $-1st$ and the $0th$ orders for TM polarization (b) versus grating depth and period with the usual duty cycle of 0.5 under Littrow mounting.

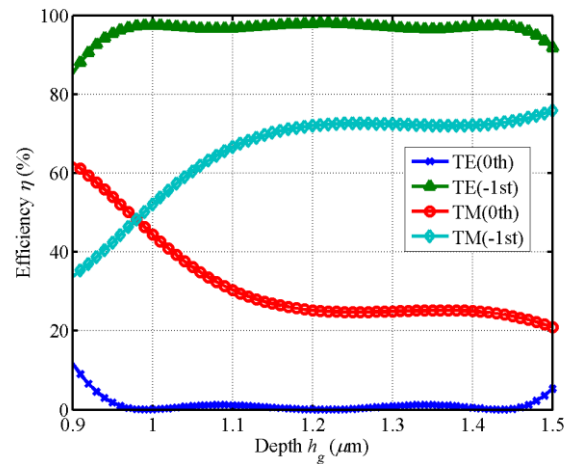


Fig. 3. (Color online) Reflective efficiency in the $-1st$ order versus grating depth with the period of 1286 nm and the usual duty cycle of 0.5.

3. Performance analysis

It is necessary to investigate the performance for different incident wavelengths and angles. Although the polarization-selective grating is designed under Littrow mounting, it is desirable that the element can still show good performance with the deviation from Littrow mounting. Fig. 4 shows the reflective efficiency in the -1 st order versus incident wavelength with the optimized grating parameters. In Fig. 4, the efficiency for TE polarization and splitting ratio uniformity can be affected by the deviation of the incident wavelength from the central wavelength of 1550 nm to some extent. However, efficiencies higher than 90% for TE polarization and efficiencies higher than $(45\% \times 2) = 90\%$ for TM polarization can be obtained within the incident wavelength range of 1537–1563 nm. Fig. 5 shows the reflective efficiency in the -1 st order versus incident angle with the optimized grating parameters. Perfect performances can be obtained at the incident Bragg angle. Within the incident angle range of $32.02\text{--}42.46^\circ$, efficiencies can be obtained higher than 90% for TE polarization in the -1 st order and $(45\% \times 2) = 90\%$ for TM polarization in the -1 st and 0th orders, respectively.

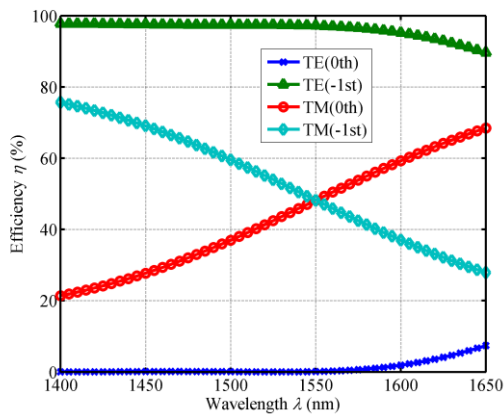


Fig. 4. (Color online) Reflective efficiency in the -1 st order versus incident wavelength with the optimized grating parameters.

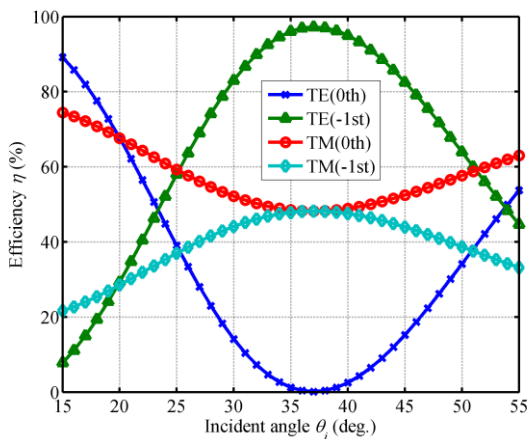


Fig. 5. (Color online) Reflective efficiency in the -1 st order versus incident angle with the optimized grating parameters.

4. Conclusions

In conclusion, a reflective polarization-selective grating is presented based on the mixed metal dielectric structure. With the optimized grating period of 1286 nm and depth of $0.98\ \mu\text{m}$, high efficiency of 97.26% can be obtained for TE polarization in the reflective -1 st order and nearly 50/50 splitting ratio is shown for TM polarization in the -1 st and 0th order. When the incident conditions deviate from the Littrow mounting, higher than 90% for TE polarization and efficiencies higher than $(45\% \times 2) = 90\%$ for TM polarization can be obtained within the wide incident wavelength and angular range. The polarization-selective element can fulfill two functions for different incident polarizations by one grating. The advantages of reflective high efficiency and good splitting ratio uniformity should be useful for practical applications.

Acknowledgements

This work is supported by the National Natural Science Foundation of China (11304044, 61107029).

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