Dielectric grating with a metal slab for high efficiency in optical communication

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We propose a dielectric grating with a metal slab with high efficiency for dense wavelength division multiplexing in optical communication. The grating is a mixed structure of the fused-silica grating and the Ag slab. For the special duty cycle of 0.65 and optimized grating depth and period, the grating can show the efficiency of 97.57% for TE polarization and 97.10% for TM polarization. Furthermore, it indicates that the wideband incident wavelength can be obtained from the analysis of performance. Most importantly, the good fabrication tolerance for efficiency higher than 95% can facilitate the fabrication and application of such a grating.

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Keywords: Dielectric grating, Metal slab, High efficiency

1. Introduction

The different optical signals can be carried by different wavelengths with very close spacing for dense wavelength division multiplexing (DWDM) in optical communication [1,2]. The DWDM technology can enhance the number of channels in optical communication to improve the bandwidth. In order to realize such a DWDM technology, thin-film filters, arrayed waveguide gratings, and fiber Bragg gratings can be employed [3-5]. However, those devices have disadvantages such as the low efficiency, polarization-dependent loss and so on. With the development of the theoretical analysis and the experimental technique, free-space diffraction gratings are designed and fabricated for the application of DWDM [6]. For subwavelength gratings, only the –1st and the 0th orders can be remained, which can lead to high efficiency with the reduction of diffraction orders for high-density gratings [7,8]. If the grating parameters are further optimized, the incident energy can be concentrated on the –1st order for both TE and TM polarizations. Therefore, diffraction gratings can have high efficiency and low polarization-dependent loss, which is very suitable for DWDM.

For the transmission grating, a deep-etched high-density grating has been designed and fabricated [9]. The grating is optimized for the incident wavelength of 1550 nm using rigorous coupled-wave analysis (RCWA) [10]. With the optimized grating depth and period range, the grating can reach the efficiency more than 95% for TE polarization and above 80% for TM polarization. It indicates that the efficiency may be improved, especially for TM polarization. For the reflection grating, high efficiency can be obtained if the new grating structure is designed [11,12]. A total internal reflection grating is designed in the C+L bands as the (de)multiplexer in DWDM [13]. With the optimized grating parameters, efficiency more than 97% can be obtained for both TE and TM polarizations. And the grating can show efficiency higher than 96% over a 2° window.

In this paper, a dielectric grating with a metal slab is presented with high efficiency for the application of DWDM in optical communication. With the special duty cycle of 0.65 proposed in this paper, the grating depth and period are optimized using RCWA. The optimized grating can show high efficiency for both TE and TM polarizations with the wide bandwidth. The fabrication tolerance given would make it easy to fabricate the dielectric grating with a metal slab effectively.

2. Grating design

Fig. 1 shows the geometrical structure of a dielectric grating with a metal slab which is covered by air with the refractive index of $n_1 = 1$, where h_g is the etched depth of fused silica and h_m is the thickness of Ag layer. The thickness of Ag slab is 100 nm, which is enough to reflect the incident wave. The mixed metal dielectric grating with period of d is illuminated by a plane wave with wavelength of λ at an incident Bragg angle of $\theta_i = \sin^{-1}(\lambda/(2n_1d)$, which can be called Littrow mounting. The plane wave propagates through the grating depth etched in fused silica with the refractive index $n_2 = 1.45$ and is reflected by the Ag layer with the refractive index n_3. Therefore, after propagating with grating depth again, high efficiency can be obtained in the reflected order. In order to achieve high efficiency for both TE and TM polarizations in the –1st order, the grating parameters should be optimized, including grating duty cycle, period, and depth.

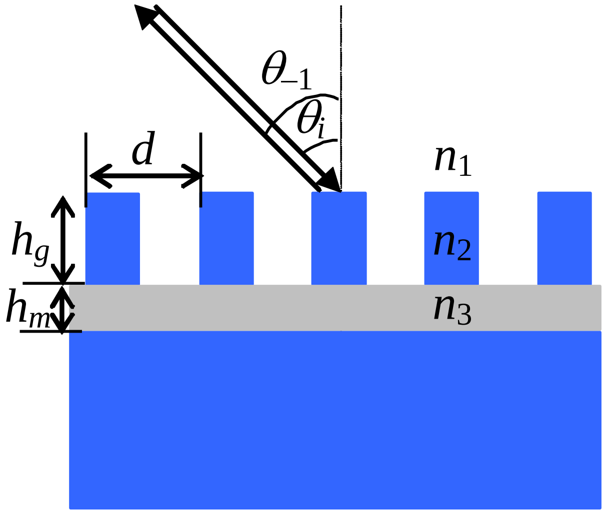

Fig. 1. (Color online) Schematic structure of a dielectric grating with a metal slab for high efficiency.

The efficiency can be evaluated by the developed program base on the formulation of RCWA [10] for such a mixed metal dielectric grating. A lot of numerical simulations can be done for the various grating duty cycle, period, and depth. And the grating parameters ban be optimized based on the numerical calculation. In this design, the special grating duty cycle of 0.65 is optimized and chosen based on systematic simulation of reflective efficiency by RCWA. Fig. 2 shows the efficiency in the reflected –1st order of a dielectric grating with a metal slab versus grating depth and period under Littrow mounting. With the optimized grating depth of 1.72 μm and period of 1471 nm, the efficiency can reach 97.57% for TE polarization and 97.10% for TM polarization in the reflected –1st order, which is much higher than the optimized efficiency above 95% for TE polarization or the efficiency approaching 80% for TM polarization of reported transmission grating [9]. The measured efficiency can reach 87.1% in experiments of reference [9], which can be improved by the dielectric grating with a metal slab. Moreover, the efficiency can remain very high for TM polarization within a wide parameters range. In Fig. 2 (b), for the grating depth range of 1.56-1.90 μm and period range of 1400-1550 nm, the efficiency can be higher than 95% for TM polarization. It is desirable to achieve high efficiency for both TE and TM polarizations. For the practical manufacture, the fabrication tolerance should be given with the polarization-independent property. Within the fabrication range of 1.69 μm<h_g<1.75 μm and 1415 nm<d<1545 nm, the mixed metal dielectric grating can show efficiency higher than 95% for both TE and TM polarizations. For the special grating duty cycle of 0.65, it indicates that the dielectric grating with a metal slab can have efficiency higher than 95% within a wide fabrication tolerance, which will make it easy to be realized during fabrication.

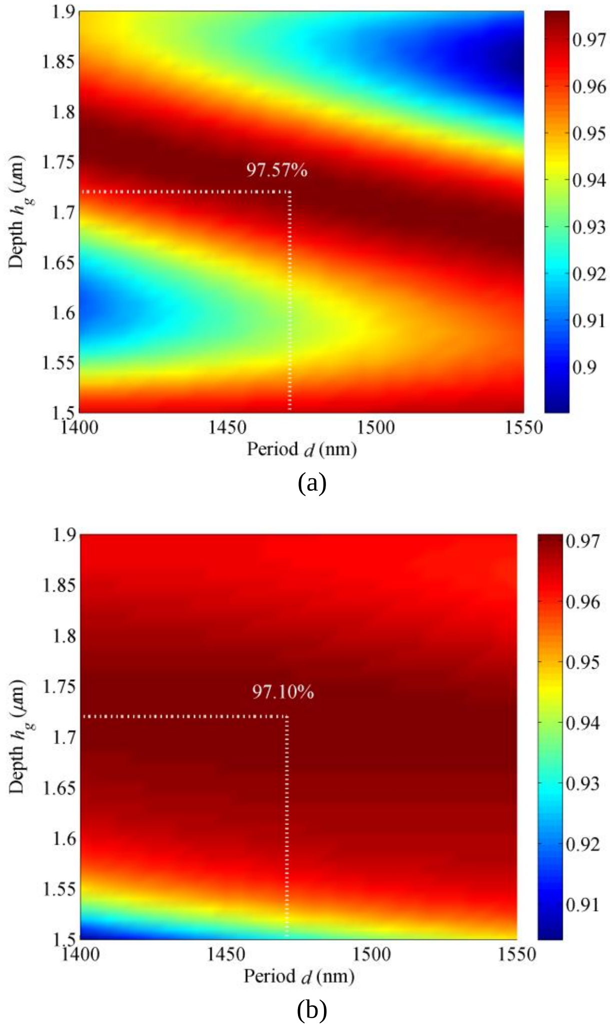

Fig. 2. (Color online) Efficiency in the reflected –1st order of a dielectric grating with a metal slab versus grating depth and period with the duty cycle of 0.65 under Littrow mounting: (a) TE polarization, (b) TM polarization.

3. Performance analysis

Fig. 3 shows the efficiency in the reflected –1st order versus grating depth with the grating period of 1471 nm and grating duty cycle of 0.65. The efficiency varies with the grating etched depth for both TE and TM polarizations. The depth affects the efficiency of TE polarization more than that of TM polarization. Efficiency higher than 95% can be obtained within etched depth of 1.65-2.01 μm for TE polarization and 1.53-2.03 μm for TM polarization.

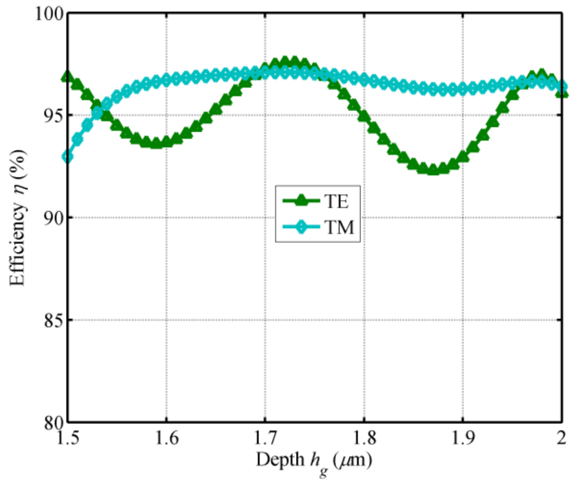

Fig. 3. (Color online) Efficiency in the reflected –1st order versus grating depth with the grating period of 1471 nm and grating duty cycle of 0.65.

For DWDM, the wideband property of high efficiency is necessary in practical applications. Fig. 4 shows efficiency in the reflected –1st order versus incident wavelength with the optimized grating parameters. In Fig. 4, the deviation from the central wavelength of 1550 nm will introduce the effect on the efficiency. However, efficiency higher than 95% can still be obtained within the incident wavelength range of 1507-1591 nm. Fig. 5 shows efficiency in the reflected –1st order versus incident angle with the optimized grating parameters. For Littrow mounting, the Bragg angle is 31.79°, and high efficiency can be obtained near the Bragg angle. When the incident angle varies from 31.79°, the efficiency and the polarization-independent property can be affected. Efficiency higher than 95% can be obtained within the incident angle range of 29.30-34.36°.

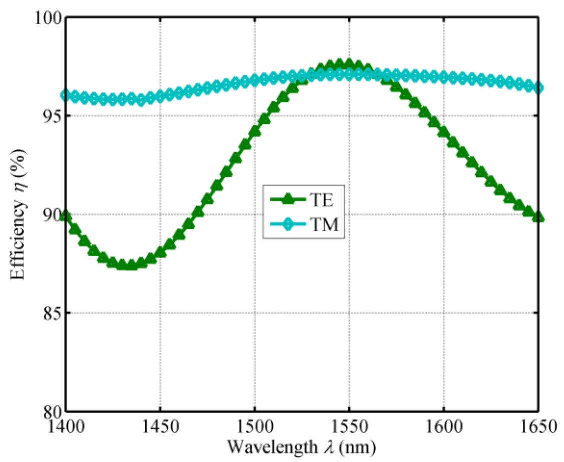

Fig. 4. (Color online) Efficiency in the reflected –1st order versus incident wavelength with the optimized grating parameters.

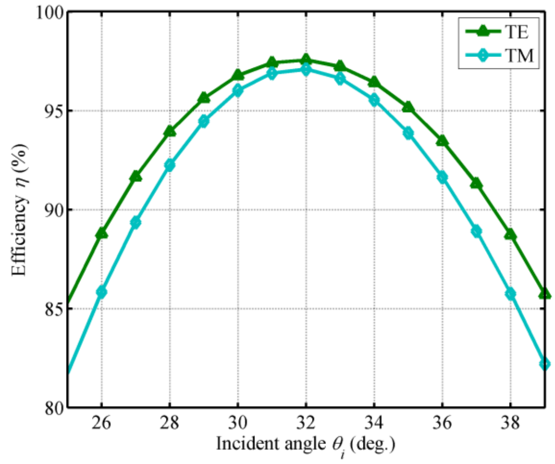

Fig. 5. (Color online) Efficiency in the reflected –1st order versus incident angle with the optimized grating parameters.

4. Conclusions

In conclusion, a dielectric grating with a metal slab is firstly proposed with high efficiency for DWDM in optical communication to our knowledge. The mixed metal dielectric grating includes the phase grating etched in fused silica and the Ag slab, which is quite different from the conventional transmission dielectric grating [9]. For the special duty cycle of 0.65, efficiencies reaching 97.57% for TE polarization and 97.10% for TM polarization can be achieved with the optimized grating parameters, which are much higher than the optimized and measured efficiencies of the reported transmission grating [9]. For easy manufacture, the fabrication tolerance of 1.69 μm$<h_g<$1.75 μm and 1415 nm$<d<$1545 nm is given with efficiencies higher than 95% for both TE and TM polarizations. In the design of special duty cycle of 0.65 and optimized grating depth and period, the dielectric grating can have good merits of high efficiency and wide incident wavelength for DWDM, whose moderate fabrication tolerance for efficiency higher than 95% would make it feasible to be fabricated effectively.

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