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RESEARCH ARTICLE

Broadband filter using multi-layer sub-wavelength high-contrast grating structure

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Abstract This paper proposed a novel broadband filter using multi-layer sub-wavelength high-contrast grating (HCG) structure. This filter has wide bandwidth and good sideband suppression. We simulated and analyzed the effects of different numbers of layers and different grating indexes on filtering performance of the broadband filter. According to the simulated results, we designed a multi-layer HCG broadband filter, which has bandwidth of 843 nm and center wavelength of 1550 nm.

Keywords filter, sub-wavelength, high-contrast grating (HCG)

1 Introduction

A sub-wavelength high-contrast grating (HCG) has been attracting much attention for various applications, including vertical-cavity surface-emitting lasers, high-*Q* resonator, polarizing beam splitter, couplers, spectroscopy, and photodetectors for optical communications. It is a sub-wavelength grating of alternating sections of high refractive index semiconductor material and a low refractive index material such as air. High index gratings (blue) are surrounded by low index material, typically air. This index contrast is extremely critical for achieving broadband high reflectivity. Sub-wavelength grating has the optical character of guided-mode resonance anomaly, which can be used as spike filter [1–4]. This kind of spike filter has the advantages of high diffraction efficiency, good symmetry and fine sideband suppression [5]. Sub-wavelength grating can be not only used as a spike filter, but also achieves the function of the broadband filter [6,7]. Both broadband and spike filters play important role in the field of optical communications and optical processing [8,9]. There are many studies about spike filters already published, but the broadband filters based on sub-wavelength grating had not been researched much. In this paper, we combined multiple single-layer HCG to make a multi-layer HCG structure. With our design, this multi-layer HCG structure has a very broad reflection spectrum and high reflectivity, and it can be used as broadband filter.

2 Design and analysis of multi-layer HCG structure broadband filter

2.1 Basic principle of multi-layer HCG structure broadband filter

As shown in Fig. 1, the structure of a multi-layer HCG structure broadband filter is the superposition of a number of single-layer HCGs, and these HCGs have the same grating period and duty cycle. Because the period of

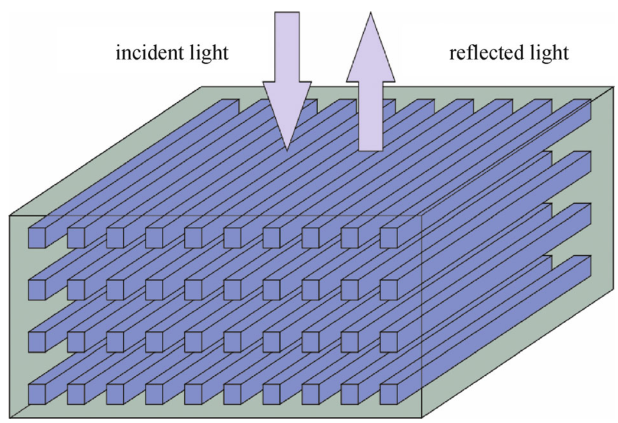

Fig. 1 Schematic of multi-layer HCG broadband filter

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*These authors contributed equally to this work grating is much smaller than the wavelength of incident light, there are only zero-order reflected diffraction wave and zero-order transmitted diffraction wave, and the sub-wavelength grating can be equivalent to a layer of dielectric film. Similarly, each HCG layer in the multi-layer HCG broadband filter can be seen as a periodic dielectric film [10,11], the air layers in the multi-layer HCG broadband filter can be seen as dielectric film with refractive index = 1. The multi-layer HCG broadband filter can be seen as a high-index and low-index dielectric film-stack, and the stack is periodic. The broadband filter is influenced by the interference effect of the multi-layer film structure [12–14], so we can use the interference effect to improve the filtering performance of the broadband filter.

2.2 Structural parameter of HCGs and the space between the HCGs

We can treat HCGs and the space between the HCGs as dielectric thin films, using the effective medium theory [15,16]. For the purpose of making these films have a high reflectivity for incident light. The thickness of the films should be a quarter of the wavelength. The thickness of the space between the HCGs is 388 nm. We used three different grating refractive indexes of HCGs in this study, and the parameters of HCGs are shown in Table 1.

Table 1 HCGs parameters

grating refractive index	grating period/nm	duty cycle	thickness/nm
2.0	400	0.5	245
2.5	400	0.5	204
3.0	400	0.5	173

2.3 Effect of number of HCG layers on filtering performance

Figure 2 shows that the filter reflection spectrum width becomes wider and the shape of the passband more and more like a rectangle as the number of HCG layer increases. At the same time, sideband suppression is getting worse.

2.4 Effect of HCG grating refractive index on filtering performance

Figure 3 shows that HCG grating refractive index has the same effects on the filter reflection spectrum width, the passband and the sideband suppression as that of the number of HCG layers when the HCG grating refractive index increases.

2.5 Multi-layer HCG structure broadband filters combining HCGs with high and low grating refractive indexes

As we presented above, the filter reflection spectrum width becomes wider and the shape of the passband more and more like a rectangle as the number of HCG layer increases as well as the HCG grating refractive index increases, while the sideband suppression is getting worse. To improve the shape of the passband and sideband suppression simultaneously, we proposed a new structure combining HCGs, which has high and low grating refractive indexes. We choosed low refractive indexes of 2.0 and high refractive indexes of 3.0.

Figure 4 is the filter performance of those new structures with HCG which has low grating refractive index, and

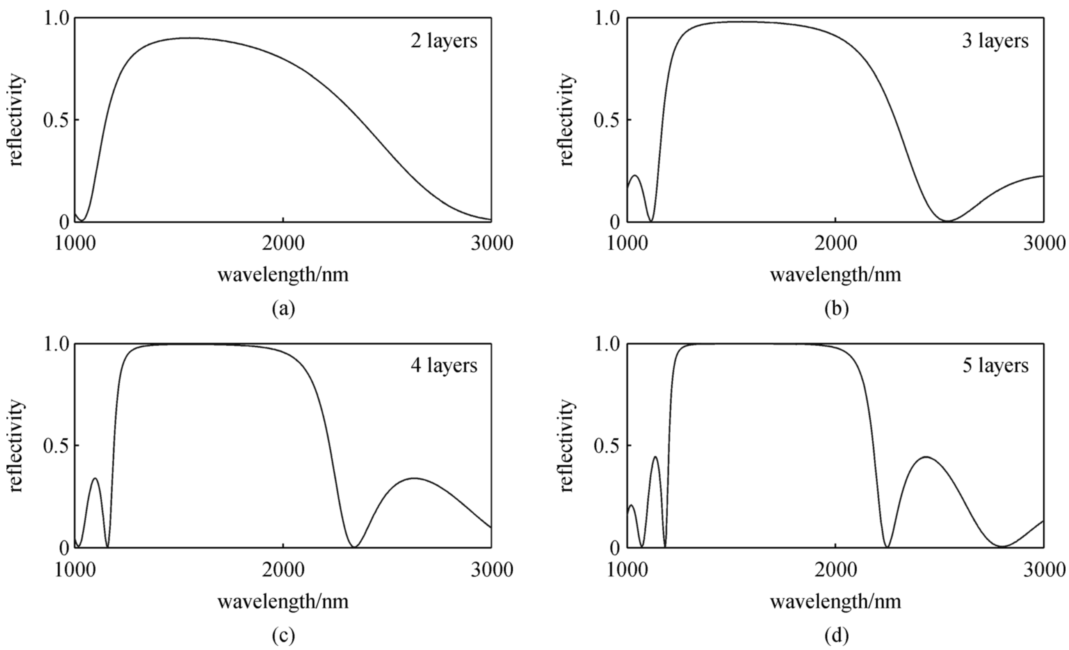

Fig. 2 Reflection spectrum of filter when the number of HCG layer is (a) 2, (b) 3, (c) 4 and (d) 5 respectively

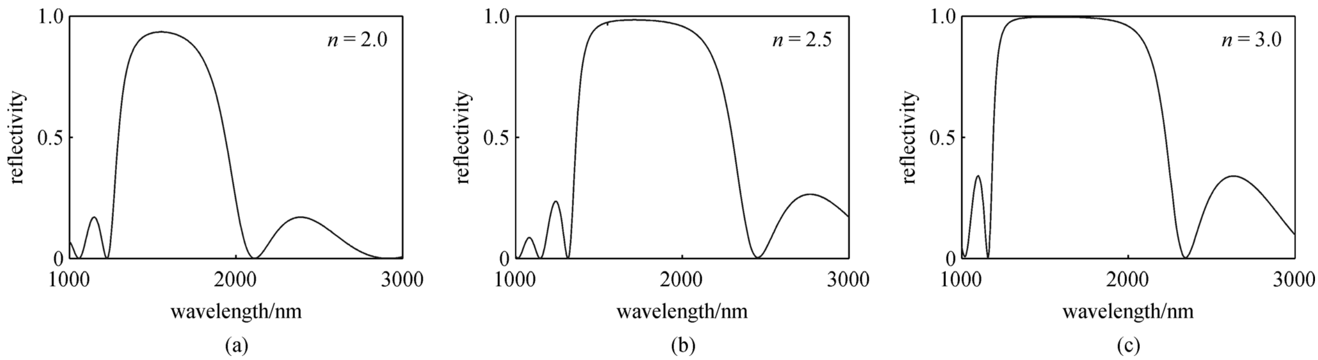

Fig. 3 Reflection spectrum of filter when HCG grating refractive index is (a) 2.0, (b) 2.5 and (c) 3.0 respectively

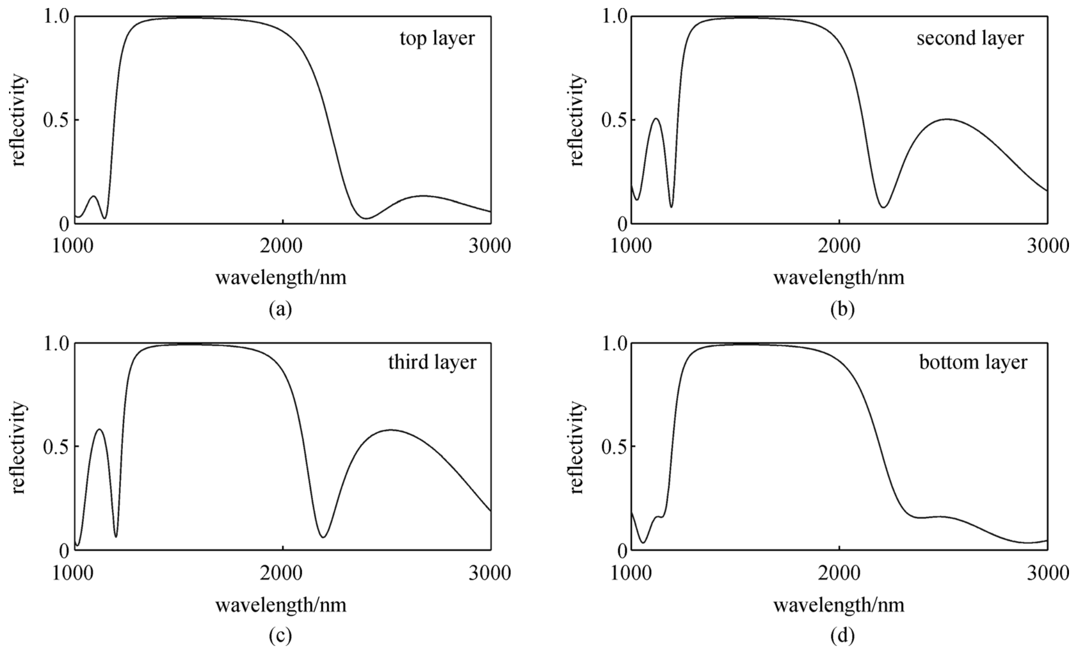

Fig. 4 Reflection spectrum of filter with different HCG structures. (a) Low index at the top layer; (b) low index at the second layer; (c) low index at the third layer; (d) low index at the bottom layer

HCG was placed at different layers. The low index layer is set at the top, second, third and bottom layer correspond to Figs. 4(a)–4(d), respectively. It was found that when the HCG with low grating refractive index is placed at the top or bottom layers, the sideband suppression is better than those at the second and third layers.

To reach the best sideband suppression effect, we combined the structures in Figs. 4(a) and 4(d), the HCG with low grating refractive index is at top and bottom layers at the same time. The structure is shown in Fig. 5. Figure 6 shows the reflection spectrum of the filter. We define that wavelength range where the reflectivity is more than 90% is the line width of the filter reflection spectrum. The line width of the reflection spectrum of the filter that we designed is 843 nm.

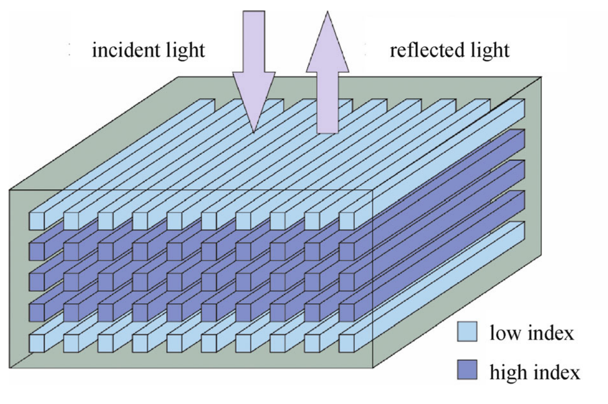

Fig. 5 HCG structure with low grating refractive index at top and bottom layers

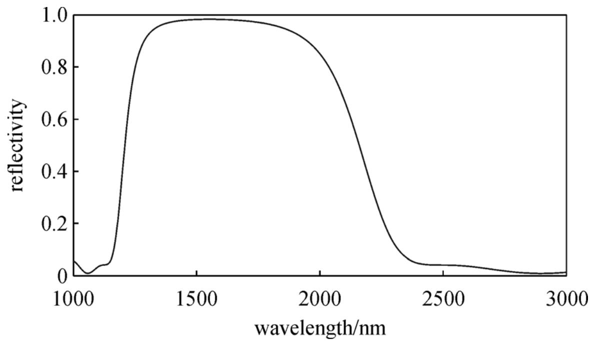

Fig. 6 Reflection spectrum of sideband suppressed multi-layer HCG filter

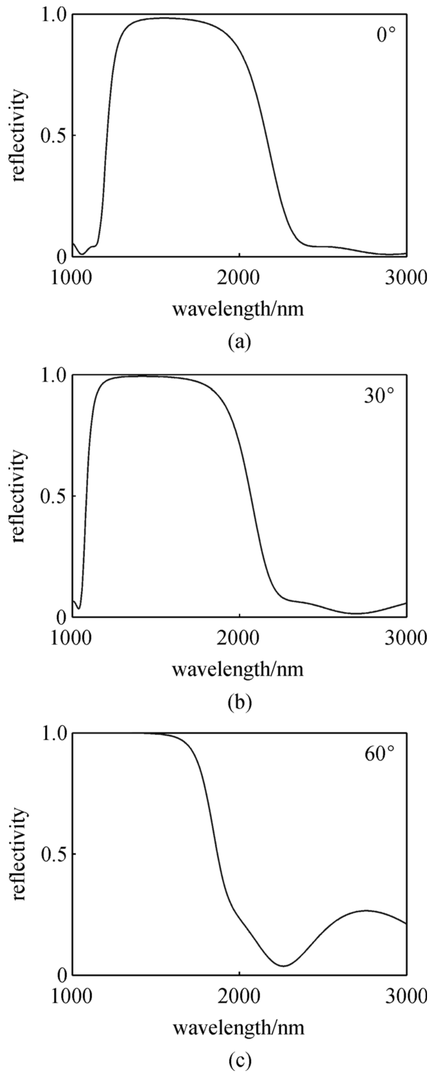

Fig. 7 Reflection spectrum of filter with different incident angles. (a) 0°; (b) 30°; (c) 60°

2.6 Effect of angle of incident light on filtering performance

Then we discussed the influence of the angle of incident light on the filtering performance. According to the results depicted in Fig. 7, we can find that as the incident angle of light increases, the passband will slowly and gradually move to a shorter wavelength while the width and shape of the passband and the sideband suppression remain constant. This result suggests that the filter with multi-layer HCG structure could maintain a good filtering performance in a large range of incident angle. We can change the filter range of the filter easily based on this feature, so this kind of filter with high rate of filter range conversion can be used in the field of optical communication.

3 Conclusions

In this paper, we proposed a new multi-layer HCG structure which can achieve the function of broadband filters. We designed several sets of structural parameter for the HCG and simulated the performance. According to the simulation results, in order to achieve better filtering performance, 5-layer-HCG which has high and low grating refractive index HCG combined should be used, and HCG of low grating refractive index should be put at the top and bottom layers at the same time in this structure. We also tested the effect of the angle of incident light on the filtering performance, and found a passband drift toward shorter wavelength. The results suggest that this structure which has a very broad reflection spectrum and high reflectivity can achieve the function of broadband filters.

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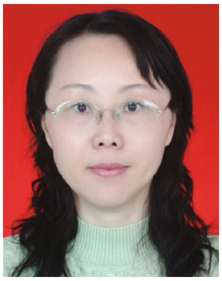

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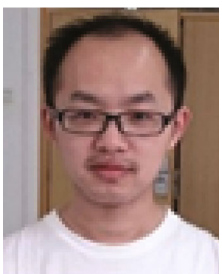

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