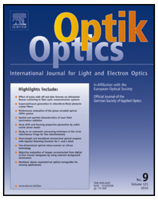
Optik 127 (2016) 955–958

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo



Polarization-independent narrow-band optical filters with suspended subwavelength silica grating in the infrared region

Xu Lin-Hua, Zheng Gai-Ge*, Zhao De-Lin, Chen Yun-Yun, Cao Kun

School of Physics and Optoelectronic Engineering, Nanjing University of Information Science & Technology, Nanjing 210044, Jiangsu, China

ARTICLE INFO

Article history:
Received 31 January 2015
Accepted 27 October 2015

Keywords:
Suspended subwavelength grating
Guided mode resonance
Optical filters
Rigorous coupled wave analysis

ABSTRACT

We numerically demonstrate that a properly designed guided mode resonance filter (GMRF) with suspended silica (SiO_2) subwavelength grating (SSG) can exhibit non-polarizing resonant filtering effect under normal incidence. By choosing appropriate parameters, including the incident wavelength, the grating period, the grating thickness, and the fill factor, the same resonance wavelengths for both transverse electric (TE) and transverse magnetic (TM) polarizations can be achieved. Results show that high reflection (more than 99.9%) can be obtained at the resonance wavelength (1.55 μm), and the full-width at half maximums (FWHMs) of TE- and TM-polarized light are only 1.0×10^{-2} μm and 1.4×10^{-3} μm, respectively. The reflectance peak splits into two branches when the incident light deviates from normal incidence. It is expected that the designed SSG should have applications in optical telecommunication systems or wavelength division multiplexing systems with an arbitrary state of polarization.

1. Introduction

Optical grating is a research topic with long history, which has been extensively studied over the years due to its wide applications in holography, spectroscopy, lasers, and many other optoelectronic devices [1–4]. A grating with a period smaller than the wavelength is usually called a subwavelength grating (SG) [5,6], exhibiting many surprising behaviors, thus many grating properties need to be re-examined. Through periodic modulations of the refractive index, resonant diffraction anomalies are realized, leading to sharp resonant reflection peaks and transmission dips in diffraction spectra, which is known as guided mode resonance (GMR) effect and has many applications in grating waveguides [7–9], optical mirrors [5,10,11], polarizers [12,13], and filtering elements [14–17]. Among these, optical filters with a narrow linewidth and low side bands are highly desired due to applications in wavelength division multiplexing, spectral filtering, and so on.

Various structures have been designed and fabricated to obtain perfect filters with a minimal broadband reflection or transmission, nearly 100% narrowband resonant spectral reflection or transmission, and a broad angular acceptance [18–22]. In previous literatures, the narrow linewidth property is usually realized by a multilayer stack of grating structures and metallic grating structures. However, the fabrication of a multilayer stack is usually difficult owing to the mechanical deflection stress at the interface. For conventional multilayer grating filters, the grating layer is often adherent to a substrate, thus the resonant wavelength cannot be changed for a conventional fixed grating. Metallic grating will not only increase the absorption of the incident light, but also arouses the influence of heat transfer. Therefore, to find a narrow linewidth grating system with less layers and tunable functions simultaneously appears to be an important work [23]. In addition, the independence of the filter characteristics with respect to the polarization of the incident beam is another crucial property that is often requested in some applications such as dense wavelength division multiplexing, polarization-insensitive filters are required to be adaptive to light with an arbitrary state of polarization.

In this paper, we present a design of one SSG which consists of a single grating layer and possesses non-polarizing resonant filtering function. The reflectance properties of the SiO_2 SSG for different polarizations are investigated by the rigorous coupled wave analysis (RCWA) in detail. Through optimizing grating parameters, we reveal that the proposed SiO_2 SSG can hold the same resonant wavelength (1.55 μm) for TE and TM polarizations under normal incidence. The line-width of reflectance spectra for TM-polarized light is much narrower than the one for TE-polarized light. For oblique incidence, the resonant peak will split into two branches.

2. Design principle and structure

The structure considered in this work consists of single layered suspended silica grating that is illustrated in Fig. 1. The incident and

---

* Corresponding author. Tel.: +862558731154; fax.: +862558731154
E-mail address: jsnanophotonics@yahoo.com (Z. Gai-Ge).

http://dx.doi.org/10.1016/j.ijleo.2015.10.186

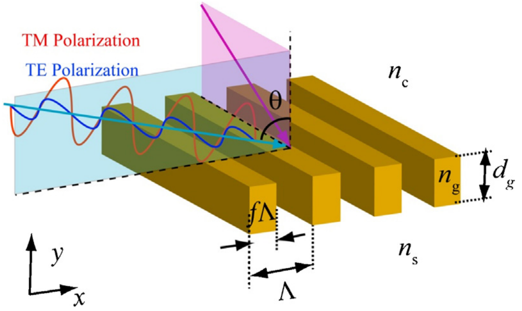


Fig. 1. A geometry of a two-dimensional suspended subwavelength SiO_2 grating.

substrate medium are assumed to be air ($n_c = n_s = 1$), the material of the grating ridge is chosen as SiO_2 crystal [24], whose dispersive characteristic is taken into account in our calculations. For a subwavelength grating, only the zeroth order diffracted wave propagates in the ambient medium and substrate, while all higher order ones are cut off. The physical parameters are the refractive indices n, grating thicknesses d, grating fill factor f, and grating period Λ. The subscripts are c for cover layer, g for grating layer, and s for substrate.

According to the slab waveguide theory [25], the corresponding eigen-value equation is:

$$\tan(\alpha d_g) = \frac{2\alpha\gamma}{\alpha^2 - \gamma^2} \tag{1}$$

where, $\alpha = \sqrt{k^2 n_{eq}^2 - \beta_{eff}^2}$, $\gamma = \sqrt{\beta_{eff}^2 - k^2 n_B^2}$, $k = 2\pi/\lambda$ denotes the wave number in free space. n_{eq} represents the equivalent refractive index of grating region as if it is regarded as a homogeneous region. For TE polarization, the equivalent refractive index of the grating region is approximately given by [26].

$$n_{eq} = \sqrt{f n_g^2 + (1-f) n_s^2} \tag{2}$$

For TM polarization its equivalent refractive index is approximated to be [26].

$$n_{eq} = 1/\sqrt{f/n_g^2 + (1-f)/n_s^2} \tag{3}$$

$\beta_{eff} = k n_{eff} = mK$ denotes the effective propagation constant of the mth diffraction order.

From Eqs. (1) and (2), for the same waveguide structure, the resonance wavelengths for TM and TE polarized lights are different, and the resonance wavelength will change with the variation of the grating parameters. By choosing appropriate waveguide parameters, one wavelength can be realized, which can cause GMR phenomena for both TE and TM polarized lights.

3. Numerical method and calculation results

Rigorous coupled wave analysis (RCWA) is usually used to analyze light propagation through a structure with a periodically varying refractive index [3,4]. The general idea of RCWA lies in expanding all the electromagnetic quantities into the Fourier series. This method is often used to investigate planar gratings because it allows to analyze the spectrum of different structures in a short amount of time and with a good accuracy. Furthermore, the coupled-wave approach gives superior physical insights into the diffraction phenomena and frequently yields simple analytical results. In this method, Maxwell's equations are solved exactly for light diffraction by grating structures. Reflectance and transmittance are found by solving the boundary conditions of the specific problem. RCWA will be used to examine the effects of different sets of grating parameters on the diffraction reflection efficiency of the designed SSG. In the calculations, the dispersive characteristic of SiO_2 is taken into account.

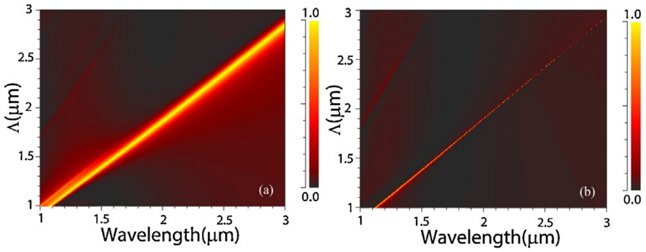


Fig. 2. The reflectance of the SSG versus grating period and the incident.

Firstly, the reflectance dependence of the SiO_2 SSG on the grating period for different polarizations is investigated, as shown in Fig. 2. The investigative range of the grating period is assumed to be from 1 to 3 μm. The grating thickness is preset to 0.6 μm, and the grating filling factor (f) is fixed to 0.5. The light is normally incident from the top side. It is clearly seen in Fig. 2 that there exists a narrow band of high reflectance in the near-infrared wavelength region. When the grating period is increased, the resonant wavelength is increased almost linearly. The linewidth is steadily decreased for TM polarized light, and increased for TE polarized light. Making comparisons between Fig. 2(a) and Fig. 2(b), one can find the line-width for TM-polarized light is much narrower than the one for TE-polarized light. To obtain reflectance resonance around the telecommunication wavelength, the grating period can be chosen as 1.5 μm.

It also demonstrates that the subwavelength structure conduces to the reflectance resonance, because the reflectance resonance exists only when the grating period is less than the incident wavelength. In the top left corner of Fig. 2, an imperfect reflectance resonance has been observed, which can be interpreted as follows. Since the grating period is larger than the incident wavelength, the reflected power concentrates into a number of diffraction orders and thus the zeroth order reflectance is not very high.

Another important parameter of the SSG is its filling factor (f). We furthermore research the reflectance of the SiO_2 SSG versus the grating filling ratio and the incident wavelength, as demonstrated in Fig. 3. The period and thickness of the grating are set to be 1.5 and 0.6 μm, respectively. The scope of the grating filling ratio is chosen from 0.1 to 0.9. In Fig. 3, with the increase of f, the resonant wavelength is increased. For TM polarized light, if f is too small, the equivalent refractive index of the grating region is very small which leads to a result that the grating region can't support guided modes which can be seen in Fig. 3(b).

In the following, with the changing of the grating thickness (d_g), we envisage the reflectance property of the SSG, as drawn in Fig. 4. The grating period is set to 1.5 μm, the grating filling factor is preset to 0.45. The varying grating thickness range is chosen from 0.1 to 1 μm. The light is normally incident from the top side. With the increase of the grating thickness, the reflectance bandwidth is increased, and the resonant wavelength is enlarged

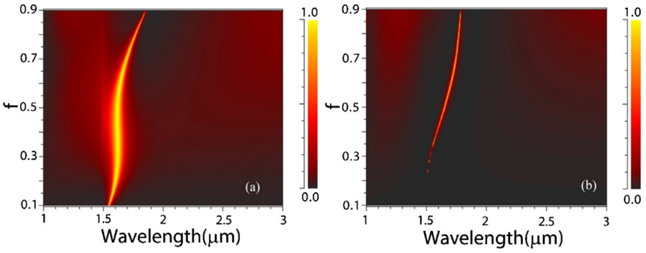


Fig. 3. The reflectance of the SSG versus fill factor and the incident.