Optics & Laser Technology 72 (2015) 42–47

Contents lists available at ScienceDirect

Optics & Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Performance of a double-layer guided mode resonance filter with non-subwavelength grating period at oblique incidence

Linyong Qian, Dawei Zhang *, Yuanshen Huang, Chunxian Tao, Ruijin Hong, Songlin Zhuang

Engineering Research Center of Optical Instrument and System, Ministry of Education and Shanghai Key Lab of Modern Optical System, University of Shanghai for Science and Technology, No. 516 JunGong Road, Shanghai 200093, China

ARTICLE INFO

Article history:
Received 25 November 2014
Received in revised form
6 February 2015
Accepted 9 February 2015
Available online 8 April 2015

Keyword:
Diffraction gratings
Guided mode resonant
Filters
Oblique incidence

ABSTRACT

A double-layer guided-mode resonance (GMR) filter with a non-subwavelength grating period is proposed for light reflection at oblique incidence. A zinc oxide coated photo-resist grating GMR filter was fabricated, which exhibits good filter properties. For a transverse magnetic-polarized wave, the grating period is larger than the resonance wavelength, which will reduce the difficulties associated with pattern production. The grating structure with a 750 nm period was fabricated utilizing a low cost two-beam interference system, with resonance obtained at 659.76 nm. In addition, the fabrication tolerance concerning the fill factor and the grating thickness were discussed. The device was designed utilizing numerical methods based on a rigorous coupled-wave analysis. Our design may promote the practical application of GMR filters.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Guided-mode resonance (GMR) is a remarkable diffraction phenomenon of waveguide gratings for certain parameters and incident conditions. Resonant grating structures utilize a periodic modulation of the refractive index to couple the incident light into a leaky guided mode supported by the structure [1]. Previous studies suggested or demonstrated that gratings exhibiting narrow-band GMR phenomena are promising candidates for a future application in filters [2], modulators, lithography [3] and label-free biosensors [4,5], and theoretical analyses and some valuable experimental results concerning GMR filters have been published [6–10]. The performance of GMR filters highly depends on their geometric dimensions, and some investigations have focused on reducing the difficulties associated with the fabrication and application process. In 2004, Mateus et al. reported on a high refractive index contrast grating structure with a low-index cladding layer added between the grating layer and the high refractive index substrate [11]. Liu et al. have fabricated and studied GMR filters with a high refractive index substrate for the visible wavelength region [12], and GMR filters with shallow grating were presented [13]. Xu et al. reported on a real-time angular sensitivity compensation of GMR filter for deviating incident angle [14].

Classic single- or double-layer GMR filter structures are often referred to as "subwavelength surfaces" or as "nanostructured surfaces" [15]. Until now, to our knowledge, to easily exploit GMR effects, most research has focused on subwavelength devices, i.e., devices with grating periods much smaller than the resonance wavelength [16]. Small-period structures are more susceptible to parameter deviations during the fabrication progress [17]. However, the precise control of the fill factor and the structure period present a bigger challenge. In addition, expensive pattern recording equipment is often required. Thus, it is highly desirable to find novel methods to fabricate GMR filters with a larger period to compensate for this disadvantage. Much less attention has been drawn to the devices with a larger period, especially for the device with a non-subwavelength period.

In this paper, we aimed to realize a GMR filter with the period larger than the resonance wavelength. The filters were fabricated using laser interferometric lithography for patterning. A high resonance reflectivity with a symmetrical spectrum and a low sideband was obtained. The diffraction characteristics and the influence of the physical parameters were investigated. The results in this paper were calculated by the software GSolver which is based on the rigorous coupled wave analysis (RCWA). Our theoretical and experimental investigations demonstrate that it is possible to decrease the difficulty of GMR device fabrication by reducing the grating line density.

2. Theory and design method

The most basic structure is a planar, unslanted grating with a asymmetric waveguide geometry as shown in Fig. 1. The first layer is the grating structure with high and low refractive indices of n_h

* Corresponding author. Fax: +86 02155276078.
E-mail address: dwzhang@usst.edu.cn (D. Zhang).

http://dx.doi.org/10.1016/j.optlastec.2015.02.017
0030-3992/© 2015 Elsevier Ltd. All rights reserved.

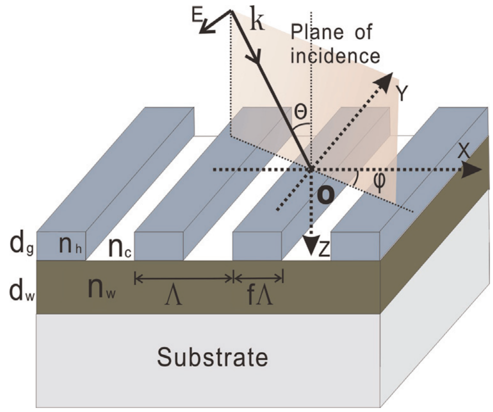

Fig. 1. Structure of the double-layer GMR filter.

and n_c (cover layer); n_w and n_s are the refractive indices of the waveguide layer and substrate; d_g and d_w are the thicknesses of grating layer and waveguide layer; Λ is the grating period and f is the fill factor. For a typical GMR filter, a guided wave can be excited if the effective waveguide refractive index $N=\beta/k$ is in the range [10]

$$max\{n_c, n_s\} \le |N| < n_{eff} \tag{1}$$

where n_{eff} is the effective refractive index of the grating layer; β is the propagation constant; $k=2\pi/\lambda$, λ is the free space wavelength. The effective refractive index of the grating layer for TM-polarization can be obtained by utilizing the effective medium theory (EMT),

$$n_{eff} = \left\{n_h{}^2 n_c{}^2/[f n_c{}^2 + (1-f) n_h{}^2]\right\}^{1/2} \tag{2}$$

If the grating layer modulation amplitude remains close to zero, the effective propagation constant of the waveguide grating can be calculated as follows:

$$\beta \to \beta_i = k\left(n_{eff}\sin\theta - i\lambda/\Lambda\right) \tag{3}$$

A combination of in-Eq. (1) and Eq. (3) leads to:

$$\frac{\lambda^2}{n_{eff}\cos^2\theta} < \Lambda^2 \le \frac{\lambda^2}{n_s - n_{eff}\sin^2\theta} \tag{4}$$

These equations can be used to roughly estimate the resonance position with respect to the wavelength, grating thickness, homogeneous layer thickness, and other parameters. The exact resonance location of the waveguide grating can be accurately obtained by using rigorous diffraction algorithms. These equivalent relations are valid for both TE- polarization (electric-field vector perpendicular to the k**O**z plane) and TM-polarization (electric-field vector parallel to the k**O**z plane). According to in-Eq. (3), if the incident angle θ is increased, which means an oblique incidence wave is employed, the upper limit of period Λ_1 will be increased for a specific resonant wavelength. In other words, it is possible to obtain a resonant wavelength with larger period grating structure for oblique incidence.

Eqs.(1), (2) and (3) were used to produce a plot which roughly describes the selected structure parameters at different diffraction orders for TM-polarization incident light. In this case, the EMT does not provide the rigorous n_{eff} in the non-subwavelength region where the grating period is not much smaller than the wavelength. However, the dispersion equation of the slab waveguide can provide a reliable approximation for estimating the resonance locations. The parameters are $n_h=1.59$ (photo-resist), $n_w=1.95$ (zinc oxide), $n_c=1$, $f=0.57$, and $n_s=1.52$ (BK7 glass). In Fig. 2, the shaded regions indicate the parameter values for which

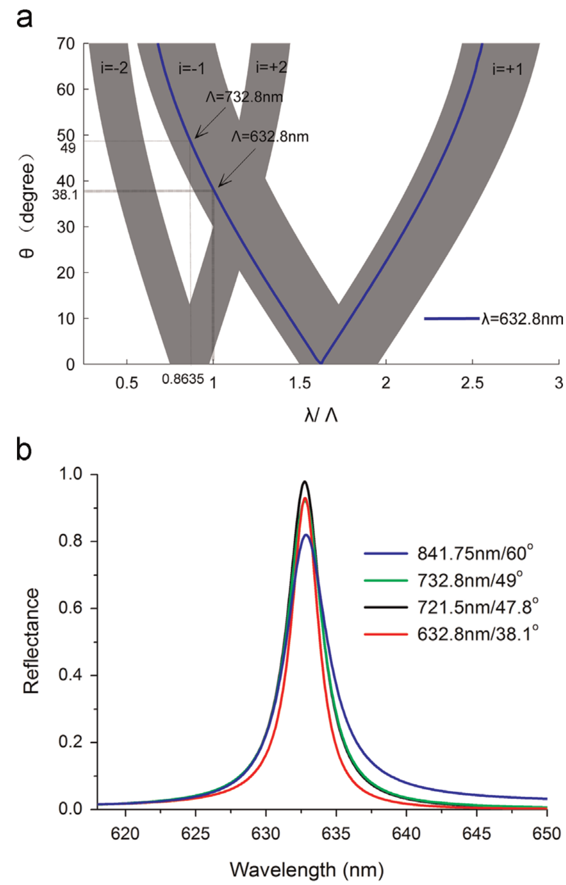

Fig. 2. (a) Resonance regimes of waveguide gratings. The blue solid curve indicates the locations for the resonance of $\lambda=632.8$ nm.

a resonance can occur. The blue solid curve was obtained for $d_g=110$ nm, $d_w=170$ nm, and a resonant wavelength $\lambda=632.8$ nm. For normal incidence, at the intersection of the two solid curves, only the 0th forward and back-ward diffracted waves propagate with all higher order waves cut off. Note the 100% energy exchange and the smooth lines obtainable. In this case, when $\Lambda=389.75$ nm GMR effect can be exploited at 632.8 nm under normal incidence. However, GMR effects also occur at non-normal incident angles, because the GMR effect results from the coupling of the ±1th evanescent diffraction order to leaky waveguide modes. Consequently, in contrast to the classical picture of a TM-polarized wave at a dielectric interface, the reflected 0th order is re-radiated efficiently in specular direction even though the polarization vector of the incident wave in the film is oriented parallel to the direction of reflection. As the incident angle increases, the supporting grating period also increases due to the GMR effect based on the coupling of the -1th diffraction order to a leaky waveguide mode, opposite tendency appears for $+1$th diffraction order. At the right side of $\lambda/\Lambda=1$, i.e. the resonant wavelength is larger than grating period which means the subwavelength condition. On the other hand, at the left side of $\lambda/\Lambda=1$, i.e. the incident angle beyond 38.1 °, non-subwavelength structures can be used to exploit the GMR effect.

However, in order to obtain high efficiency filters, subwavelength grating (grating period $<\lambda$) pattern is always selected to prevent the propagation of higher-order diffractions. For devices with a non-subwavelength pattern, it is difficult to obtain a resonant efficiency of 100% because GMR occurs due to the coupling of the -1th evanescent diffraction order to a leaky waveguide, and not all higher-order diffractions can be prevented. The diffraction efficiency represents the intensities of various diffracted waves. A

Download English Version:

https://daneshyari.com/en/article/733403

Download Persian Version:

https://daneshyari.com/article/733403

Daneshyari.com