Nonpolarizing guide-mode resonance filter with ultra-narrow linewidth

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Ultra-narrow linewidth, nonpolarizing guide-mode resonance (GMR) filters with single and double common resonance wavelengths are designed. The guide-mode resonance filters consist of a single grating layer with asymmetric profiles. By choosing appropriate parameters, 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%) is obtained at every resonance wavelength, and the full-width at half-maximums (FWHMs) of TE- and TM-polarized light are only 0.008 and 0.215 nm, respectively.

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Guide-mode resonance (GMR) is excited when an incident wave is phase-matched to a leaky waveguide mode[1−3]. A GMR effect usually occurs within narrow parameters such as wavelength, incident angle, and polarization states when evanescent diffractive-order waves diffracted by the grating layer are coupled into the waveguide layer. GMR excitation at normal incident will especially result in two leaky modes counterpropagating along the grating layer and an efficient energy exchange between the reflection wave and transmission wave[4,5]. Based on this characteristic, various kinds of GMR filters were designed in many fields, such as laser devices, authentication labels, and optical communication[6−8]. Although GMR filters have been extensively studied and designed[9−14], the reflection of a one-dimensional (1D) grating structure depends essentially on the polarization state of the incidence light. The resonance wavelengths of transverse magnetic (TM)- and transverse electric (TE)-polarized light will locate at different wavelengths with the same GME structure parameters[15]. This characteristic limits the usage of this kind of GMR filter in the nonpolarizing field. Recently, Fu *et al.* reported a nonpolarizing GMR filter with a general multilayer GMR structure consisting of four film layers and one layer of symmetric grating at the top[16]. In this letter, a nonpolarizing GMR filter with ultra-narrow linewidth is designed with a single grating layer having one-dimensional periodicity and asymmetric profile on a low-index 1D substrate. Profile asymmetry can break the resonant leaky mode degeneracy at normal incident[5,17], thereby permitting the controllable numbers and separation of GMRs. In this letter, a single layer GMR structure with asymmetric profile is demonstrated as an alternative to the multilayer GMR structure[16]. Ultra-narrow linewidth, nonpolarizing GMR filters with single and double same resonance wavelengths for both TE- and TM-polarized light can also be realized.

Figure 1 illustrates the single layer GMR structure with asymmetric profile in three cases. They are 1D grating GMR filters, so the index refractive is invariant and homogeneous in the other two dimensions. The grating structure is also multi-period (has three periods) in a fundamental period. For clarity and convenience of comparison with the multilayer GMR structure in Ref. [16] the same n_c, n_s, n_L, and n_H are chosen as 1.0 (air), 1.52 (BK7 glass), 1.38 (MgF_2), and 2.0 (HfO_2), respectively. Asymmetric grating profiles in a fundamental period in three cases are formed by periodically arranging two or three kinds of dielectric materials (air, MgF_2, and HfO_2), and a single period (Λ) is divided into four parts with different fill factors (f_1, f_2, f_3) as shown in Fig. 1, with d_g as the thickness of the single grating layer. The light is normally incident at the GMR structure. The refractive index of the cover and substrate layers are 1.0 and 1.52, respectively.

The rigorous Eigen-mode theory of binary gratings[18], which is an exact electromagnetic grating diffraction model providing purely numerical solutions, is used to calculate the GMR filter's spectra for both TE- and TM-polarized light. Figure 2 illustrates the spectra of the nonpolarizing GMR filter for both TE- and TM-polarized light. The profile parameters in three cases are presented in Table 1. The number and spacing of the resonance wavelengths in the spectrum for both

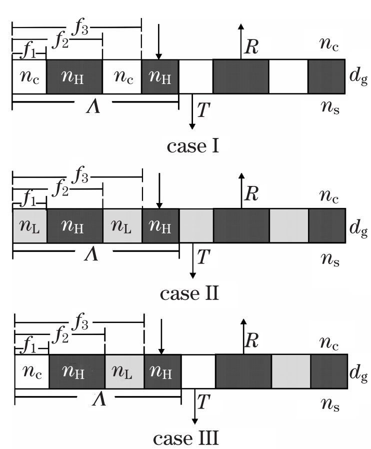

Fig. 1. Single layer GMR structure with asymmetric profile in three cases.

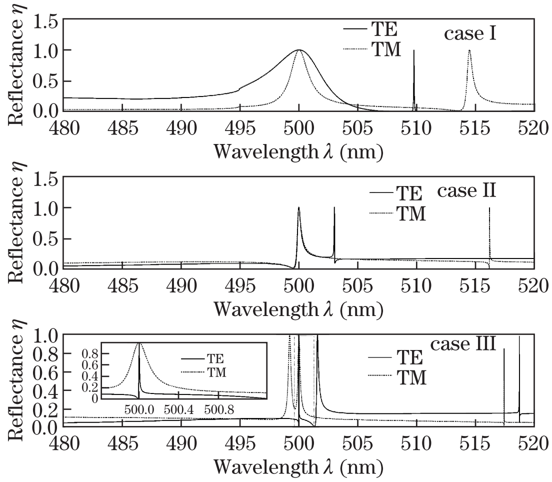

Fig. 2. Spectra of the nonpolarizing GMR filters for both TE- and TM-polarized light in three cases.

Table 1. Grating Profiles (Fill Factors, Period, and Thickness of Grating Layer) for Three Cases

Case	f_1	f_2	f_3	d_g (nm)	Λ (nm)
I	0.1599	0.6645	0.8720	761.0709	325.6022
II	0.1121	0.6238	0.7591	756.4153	315.0570
III	0.1233	0.5680	07164	771.6224	310.7340

TE- and TM-polarized light are different, while the common resonance wavelength for both TE- and TM-polarized light is 500 nm in three cases. At each resonance wavelength, the GMR filter has high reflection (more than 99.9%) for both TE- and TM-polarized light. The full-width at half-maximums (FWHMs) of the resonance wavelengths are shown in Table 2 for three cases. Case II is shown to have a narrower linewidth than case I at the common resonance wavelength of 500 nm, and case III has the narrowest linewidth for both TE- and TM-polarized light. The former can be explained by the decrease of modulation strength in the modulated region, which is $\Delta\varepsilon = n_H^2 - n_c^2$ in case I and $\Delta\varepsilon = n_H^2 - n_L^2$ in case II. Meanwhile, the latter is derived from the asymmetric grating profiles formed by more than two dielectric materials with different fill factors. The distribution of the materials within a single period by choosing the various fill factors, affords control of Fourier harmonic content and, thus, the pertinent leaky-mode resonance linewidth[17]. As shown in Table 2, FWHMs at the common resonance wavelengths for TE-polarized light are narrower than that for TM-polarized in all cases. In addition, the narrowest linewidth for both TE- and TM-polarized light are obtained in case III, which are 0.008 and 0.238 nm, respectively.

Figure 3 gives an example for designing a multi-resonance-wavelength nonpolarizing GMR filter with narrow linewidth. Two different common resonance wavelengths (485 and 505 nm) are obtained for both TE- and TM-polarized light by adopting the asymmetric grating profiles of the third case, in which f_1, f_2, f_3, d_g, and Λ are chosen as 0.1223, 0.5915, 0.7134, 769.1779, and 313.663 nm, respectively. By choosing the appropriate parameters, three GMRs in the spectrum are obtained for both TE- and TM-polarized light, and two of them are common by adjusting their separation. This verifies that the asymmetric profiles can break the resonant leaky mode degeneracy at normal incident, and the separation of double GMRs is controllable through the modulation profile by inducing asymmetry and, thus, modal nondegeneracy. Compared with the multilayer symmetric GMR structure[16], inducing asymmetry in our design can increase the number of available resonances and realize the multi-common-GMR for both TE- and TM-polarized light. Table 3 gives the FWHMs at the two common resonance wavelengths (485 and 505 nm). The narrowest linewidth is 0.039 nm at 485 nm for TE-polarized light.

In conclusion, ultra-narrow linewidth, nonpolarizing GMR filters with single and double common resonance wavelengths are designed. The GMR filters consist of a single grating layer with asymmetric profiles; it has high reflection (more than 99.9%) at each resonance wavelength, and the FWHMs of the TE- and TM-polarized light are 0.008 and 0.215 nm, respectively.

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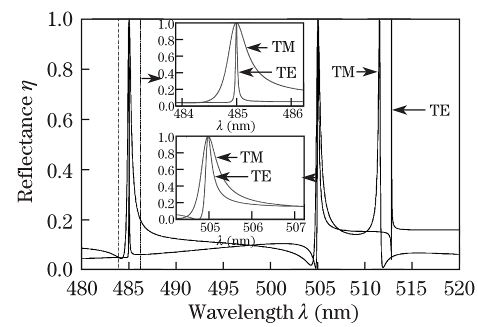

Fig. 3. Multi-resonance-wavelength nonpolarizing GMR filter.

Table 2. FWHM of Resonance Wavelength (500 nm) for TE- and TM-Polarized Light

Polarization Status	FWHM of Case I (nm)	FWHM of Case II (nm)	FWHM of Case III (nm)
TE	5.885	0.396	0.008
TM	1.92	0.457	0.238

Table 3. FWHM of Two Different Resonance Wavelengths for TE- and TM-Polarized Light

Polarization Status	FWHM of 485 (nm)	FWHM of 505 (nm)
TE	0.039	0.486
TM	0.215	0.524

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