

Wide band polarizer with suspended germanium resonant grating

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Received May 15, 2012; accepted May 25, 2012; posted online September 28, 2012

An ultra broad band polarizer that operates in the telecommunication wavelength band is proposed. This device, which consists of a single suspended germanium resonant grating layer, is designed using the inverse mathematical method and the rigorous vector diffraction theory. Calculated results indicate that the ultra broad band polarizer exhibits extremely high reflection ($R > 99\%$) for TE polarization light and high transmission ($T > 99\%$) for TM polarization at the wavelength range greater than 300 nm, and it has an extinction ratio of approximately 1000 at the 1550-nm central wavelength. The results of the rigorous coupled wave analysis indicate that the extremely wide band property of the TE polarization is caused by the excitation of strong modulation guided modes in the design wavelength range.

OCIS codes: 230.0230, 230.5440.

doi: 10.3788/COL201210.112301.

A polarizer that can convert unpolarized light into a specific polarized state is an extremely important optical element in telecommunication and photonic systems. Actual applications mainly use metal grid grating (MGG) and dielectric multilayer stacks (DMSs) as polarizers^[1,2]. MGG is based on polarization absorption and it has been investigated extensively because of its simple structure and compactness. On the other hand, DMS polarizers have been fabricated using thin-film technology to overcome the issue of metal material absorption^[3,4]. However, DMS polarizers require the use of several layers with precise layer thicknesses and refractive indices. Thus, although DMS polarizers can provide wide bandwidth and large extinction ratio, they can only be used in oblique incident angles. Therefore, sub-wavelength grating combined with dielectric thin-films can be used to accommodate the issue of normal incidence^[5,6].

A new type of sub wavelength element based on the guided mode resonance (GMR) effect of dielectric grating exhibits versatile spectra properties. Various optical elements, such as broadband reflectors^[7], polarizers^[8], and narrow band filters^[9], among others, can be produced based on the GMR effect. In 2008, Lee *et al.* fabricated a silicon-based GMR polarizer with an experimental extinction ratio of approximately 97 at a central wavelength of 1510 nm over the wavelength range of approximately 40 nm^[8]. In 2011, the same group reported an improved silicon-based GMR polarizer with bandwidth of approximately 200 nm around the optical communication wavelength band^[10].

Based on the physical mechanism of the GMR effect, this letter introduces an excellent wide band suspended germanium polarizer (SGP) that operates in the telecommunication spectrum band by using the global optimization technique and rigorous coupled wave analysis (RCWA) method^[11]. Germanium material is the most commonly used optical IR material in terms of modern nano-device processing technology. Germanium exhibits high refractive index contrast and low optical absorbance properties, making it very easy to integrate into other

optical devices. Suspended grating (SG) is widely used in micro-electromechanical system (MEMS) devices for applications in certain areas, such as wavelength selection and optical filtering, among others^[12,13]. SG lacks a substrate, and thus, it can easily be tuned using a MEMS actuator. In this letter, a single-layer suspended germanium grating is used as a wide band polarizer to fabricate the optical device. The calculated results by using RCWA show that the proposed polarizer is tolerant to the deviations of structure parameters, making it easy to fabricate using current integrated circuit (IC) technology.

Figure 1 shows the proposed structure that consists of a single-layer suspended germanium grating. The incident and substrate media were assumed to be air ($n_{\text{inc}} = n_{\text{sub}} = 1$), and germanium material with a refractive index of 4 was the material used for the grating ridge. The structure was illuminated from the top with a normal incident angle, and only the zero-order reflection was considered in the proposed design. For simplicity, the material of the device was assumed to be loss- and dispersion-free.

To design a wide band polarizer over the spectrum band of 1.5–1.6 μm , RCWA together with particle swarm optimization (PSO) were used to calculate and optimize the device. Lee *et al.* first used PSO, which was a robust and evolutionary strategy, for the optimization design of GMR grating. The most

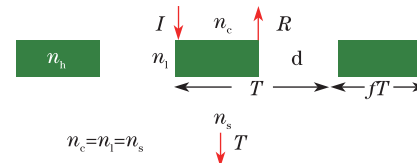


Fig. 1. Structure of a single-layer suspended grating under TE and TM illuminations at a normal incident angle. The high and low refractive indices of the grating structure are labeled as n_h and n_l , respectively. The refractive indices of the cover and substrate are denoted as n_c and n_s , respectively. The depth of the grating structure is expressed as d .

distinctive advantage of PSO lies in its powerful global searching ability to handle different design problems with multiple parameters. For the structure, the refractive indices of the substrate, incident layer, and grating ridge were fixed as constants, and thus, they were not optimized in the calculations. Period (T), grating thickness (d), and fill ratio (f) were chosen as the optimizing parameters. RCWA was used to calculate the diffraction efficiency (DE) of the structure with each optimized parameter over a wide spectrum band.

The PSO algorithm was used for the optimization design of the proposed polarizer. The merit function (MF) was taken to be a RMS error function as

$$MF = \left\{ \frac{1}{M} \sum_{\lambda_i} [R_{\text{desired}}(\lambda) - R_{\text{design}}(\lambda)]^2 \right\}^{1/2}, \quad (1)$$

where $R_{\text{desired}}(\lambda)$ is the desired reflection of zero order in the corresponding wavelength range for the TE and TM polarizations, $R_{\text{design}}(\lambda)$ is its PSO-designed counterpart, and M is the number of wavelength points. RCWA was used to calculate the DE. All parameters included in the proposed design were arrayed as (T, d, f) . The minimum and maximum values of each parameter were set to (200, 10, 0.1) and (2000, 2000, 0.9), respectively, where the units of measurement of the first two parameters are in nanometers. The optimized wavelength ranged from 1300 to 1900 nm, and the wavelength interval was 2 nm, corresponding to $M = 300$ in Eq. (1). The structure parameters were (1016, 249, 0.16) after 2000 iterations, and the design process took approximately 60 min using an ordinary PC.

Figure 2(a) shows the reflection spectra of the polarizer for both TE and TM polarizations. The reflection over the spectrum band of 1.35–1.9 μm for TE polarization is greater than 90%, whereas the reflection is extremely low for the TM polarization light in the same wavelength region. On the other hand, the reflection and transmission for TE and TM polarization light are both greater than 99% in the wavelength band of 1.4–1.7 μm , as shown in Figs. 2(b) and (c), respectively. Therefore, an extraordinarily wide spectrum band polarizer with extraordinary extinction can be obtained using this kind of structure.

The transmission was plotted on a logarithmic scale to clearly illustrate the high reflection and large bandwidth of the TE polarization light. The TE polarization contained two transmittance dips at wavelengths 1425 and 1603 μm , each of which corresponds to a leaky mode resonance, as shown in Fig. 3^[14]. The transmittance dips show that the broad reflection band is caused by the co-existence and interaction of the TE leaky modes. Therefore, the simultaneous co-existence and interaction of the leaky modes of the TE polarized waves resulted in extremely high reflection properties.

Figures 4(a) and (b) show the relationships between grating depth and bandwidth with high reflection and high transmission for TE and TM polarizations, respectively. The reflection was kept greater than a very high

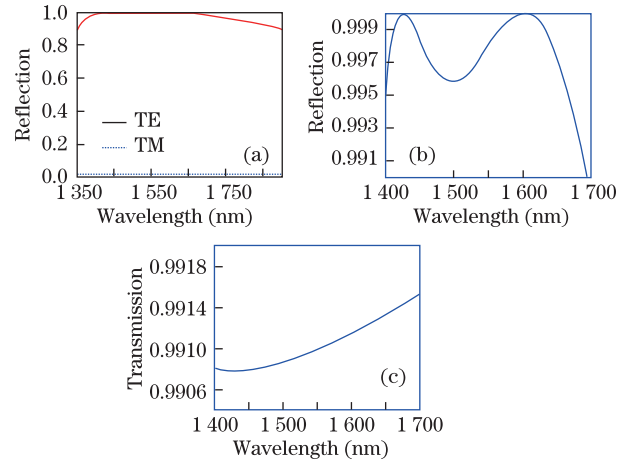


Fig. 2. (a) Reflection spectra of the polarizer illuminated with normal incidence for TE and TM polarizations over the spectrum band of 1.35–1.9 μm and (b) reflection and (c) transmission spectra for TE and TM polarizations in the wavelength band of 1.4–1.7 μm , where the parameters are denoted as $d = 249$ nm, $T = 1016$ nm, and $f = 0.16$.

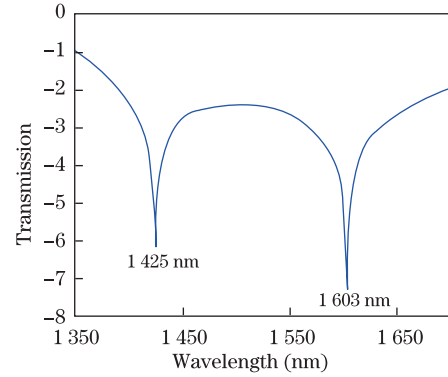


Fig. 3. Transmission on log scales. The TE polarization contains resonance wavelengths of 1425 and 1603 μm .

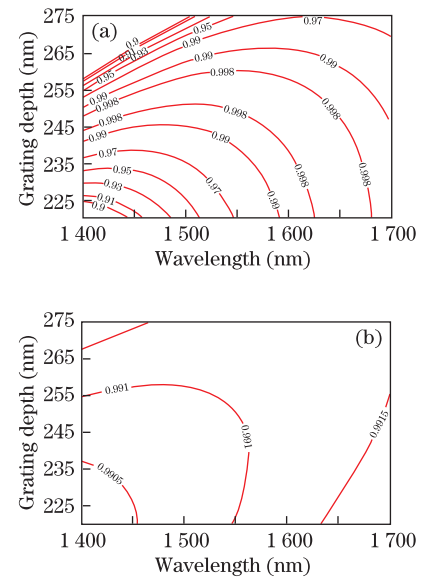


Fig. 4. DE of the polarizer as a function of grating depth and incident wavelength for (a) TE and (b) TM polarizations, respectively.

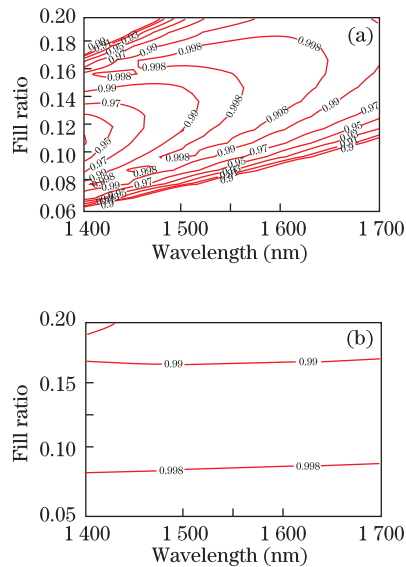


Fig. 5. DE of the polarizer as a function of fill ratio and incident wavelength for the (a) TE and (b) TM polarizations, respectively.

value ($R > 90\%$) over the entire wavelength band of 1.4–1.7 μm even as the groove thickness was increased from 225 to 260 nm for TE polarization. Moreover, a much large groove thickness tolerance in the optical communication wavelength band that provides a favorable advantage for the fabrication process was obtained. For the TM polarization, the transmission was kept at a very high value ($R > 99\%$) in the corresponding wavelength band and grating thickness. The transmission spectrum in the entire wavelength band was very flat compared to the reflection spectrum of the TE polarization when the grating thickness was varied. Therefore, the range of grating thickness required to acquire the high optical property of polarizer is mainly decided by the TE polarization light. In general, grating fabrication has an extraordinarily large fabrication tolerance regardless of whether the etching is shallow or deep. Thus, an excellent wide band polarizer can be obtained in the telecommunication wavelength band by using the parameters in the proposed design.

Figures 5(a) and (b) show the DE of the polarizer as a function of fill ratio and incident wavelength for the TE and TM polarizations, respectively. In general, variations in the fill ratio play an important role in the reflection of TE polarization light and they have a minor effect on the transmission of TM polarization in the corresponding

wavelength range. The DE of the polarizer can maintain very high values (above 90%) if the fill ratio is changed from 0.1 to 0.2.

In conclusion, a wide band polarizer over the telecommunication wavelength band by using PSO and RCWA is designed. The polarizer based on a single-layer suspended grating has a simpler structure than other designs. In addition, the proposed polarizer is capable of offering high reflection ($R > 99\%$) for TE polarization light and high transmission ($T > 99\%$) for TM polarization over the 300-nm wavelength range, as well as large tolerance for fabrication in the spectrum band of 1.5–1.6 μm , making it easy to fabricate using current IC technology.

This work was supported by the Natural Science Foundation of Shanghai Committee of Science and Technology under Grant No. 10ZR1433500.

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