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Double groove silicon grating polarizer in telecommunication wavelength band

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In this paper, we propose an ultra broad band polarizer operating in the telecommunication wavelength band, this device consisting a double groove silicon grating is designed with using the inverse mathematical method and rigorous vector diffraction theory. It is shown from our calculations that the device presents extremely high reflection ($R > 95\%$) for TE polarization light and high transmission ($T > 95\%$) for TM polarization over ~400 nm wavelength range, moreover, the extinction ratio is ~30 in the central wavelength 1550 nm. Furthermore, it is found with rigorous coupled wave analysis (RCWA) that the extremely wide band property for TE polarization is due to the excitation of strong modulation guided modes in the design wavelength range.

1. Introduction

Polarizer is an extremely important optical element in the telecommunication and photonic system which can convert the un-polarized light into specific polarized state. In actually applications, metal grid grating (MGG) and dielectric multilayer stacks (DMS) are the most commonly used polarizes [1,2]. Based on the polarization absorption, MGG is studied for several decades owing to its simple structure and compactness, in order to overcome the absorption of metal material, DMS polarizes are proposed and fabricated with using the thin film technology [3,4]. However, DMS polarizes require many layers with precious control of layer thickness and refractive indices although they can provide wide band width and large extinction ratio, more important drawback of these polarizes is that the element can only be used in oblique incident angle. To accommodate the important case of normal incidence, sub-wavelength grating in combination with dielectric thin-films can be used [5,6].

A new type of sub wavelength elements based on guided mode resonance (GMR) effect of dielectric grating can exhibit versatile spectra properties. Based on this effect, we can design all kind of optical elements such as broadband reflector [7], polarizer [8], narrow band filters [9] etc. Magnusson research group fabricated a silicon-based GMR polarizer in 2008, the experimental extinction ratio of ~97 at a central wavelength of 1510 nm over a ~40 nm wavelength range [8]. In 2011, they report an improved silicon-based GMR polarizer with ~200 nm bandwidth around optical communication wavelength band [10].

In this paper, based on the physical mechanism of GMR effect, we introduce an excellent wide band double groove silicon polarizer (DSP) operating in the telecommunication spectrum band with using the global optimization technique and rigorous coupled wave method (RCWA) [11]. Silicon material is the most common used optical IR material in terms of modern nano-device processing technology. The properties of high refractive index contrast and low optical absorbance make it very easy to be integration in other optical devices. DSP Grating is widely used in the micro-electromechanical system (MEMS) devices for the applications in the area such as wavelength selection, optical filtering etc. [12,13]. It is owing to double groove structure, the kind of polarizer have more freedom to be designed and used in the MEMS field, in our design, we give a single layer double groove silicon grating as a wide band polarizer with the purpose that this optical device can be fabricated and put forward to the MEMS fields. In fact, calculations with RCWA shown that the polarizer proposed here is tolerant to the deviations of structure parameters, which make it very easy to be fabricated with current IC technology.

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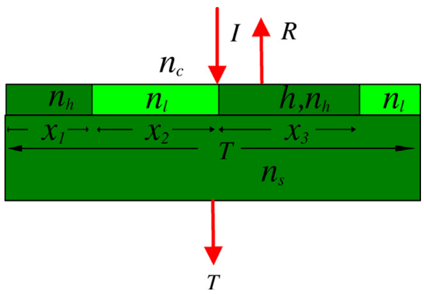

Fig. 1. Structure of single layer double groove grating under TE and TM illumination at normally incident angle. The high and low refractive indices of grating structure are labeled as n_h and n_l, respectively. The refractive indices of cover and substrate are denoted to be n_c and n_s, respectively. The depth of grating structure is expressed as d. The corresponding distances is labeled as x_1, x_2, x_3.

2. Numerical analysis and simulation

The structure proposed here consists of single layered double-groove silica grating which is illustrated in Fig. 1. The incident and substrate medium are assumed to be air and silica ($n_{inc} = 1$, $n_{sub} = 1.45$), the grating ridge is silicon material and the grating thickness is labeled as h. x_1, x_2, x_3 are the corresponding distances. The structure is illuminated from the top side with normal incident angle. For simplicity, the material of the device is assumed to be losses and dispersion free.

In order to design a wide band polarizer over the spectrum band 1.5–1.6 μm, the rigorous coupled wave analysis (RCWA) in association with particle swarm optimization (PSO) is adopted to calculate and optimize this device. PSO is a robust and evolution strategy firstly used in the optimization design of guided mode resonance grating by Magnusson et al. The most distinctive advantage of this method lies in its powerful global searching ability handling different multiple parameters design problems. As for our structure, the refractive indexes of substrate, incident layer, grating ridge are fixed as constants and cannot be optimized in our calculations. The period (T), grating thickness (h) and the corresponding distances (x_1, x_2 and x_3) are chosen as the optimizing parameters. The well known method RCWA is used to calculate the diffraction efficiency (DE) of this structure over a wide spectrum band with each optimized parameters.

PSO algorithm is employed for the optimization design of polarizer device in our paper. The merit function (MF) is taken to be an *rms* error function:

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

where $R_{\mathrm{desired}}\,(\lambda)$ is the desired reflection of zero order in the corresponding wavelength range for the TE and TM polarization, R_{design} (λ) is its designed counterpart by PSO. M is the number of wavelength points. RCWA is used to calculate the DE. All parameters included in this design are arrayed as (T, h, x_1, x_2, x_3). The minimum and maximum values of each parameter are set as (200, 10, 10, 10, 10) and (3000, 3000, 500, 500, 500), respectively. The units of the parameters all are nanometer. The optimized wavelength range is from 1300 nm to 1800 nm, and the interval of the wavelength is 2 nm, which means $M = 250$ in Eq. (1). The structure parameters after 2000 iterations is (823, 502, 54, 288, 175), and the design process takes about 60 min with common PC.

Fig. 2(a) shows the reflection spectra of the polarizer for both TE and TM polarizations, as can be seen that the reflection over spectrum band 1.4–1.7 μm for TE polarization are more than 95%, while for TM polarization light, the reflection is extremely low in this wavelength region. Meanwhile, in the wavelength band 1.5–1.65 μm, the reflection and transmission for TE and TM polarization light are all above 95%, which are illustrated in Fig. 2(b) and (c), respectively. Therefore, extraordinary wide spectrum band polarizer with extraordinary extinction can be obtained with this kind of structure.

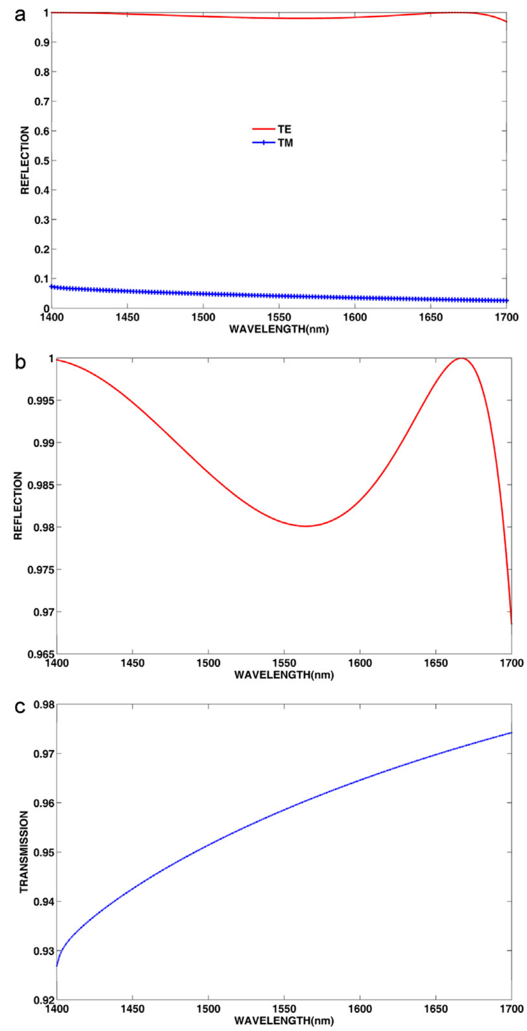

Fig. 2. Reflection spectra of polarizer illuminated with normal incidence for TE and TM polarizations (a), reflection (b) and transmission (c) spectra for TE and TM polarizations in the wavelength band of 1.4–1.7 μm, the parameters are denoted as $d = 502$ nm, $T = 823$ nm, $x_1 = 54$ nm, $x_2 = 288$ nm, $x_3 = 175$ nm.

In order to clearly illustrate the high reflection and large bandwidth of TE polarization light, we plot the transmission on a logarithmic scale. As can be seen from Fig. 3, for TE polarization, there are two transmittance dips (at the wavelength 1.387 μm and 1.667 μm) in the range of 1.4–1.7 μm, each of which corresponds to a leaky mode resonance [14]. This shows that the broad reflection band results from the co-existence and interaction of the TE leaky modes, therefore, the simultaneous co-existence and interaction of leaky modes of TE polarized waves result in the extremely high reflection properties. Therefore, the extraordinary wide spectrum band with high reflection can be obtained with the simultaneous excitation of resonant modes in the design wavelength range.

The relations between the grating depth and bandwidth with high reflection and high transmission for TE and TM polarization are illustrated in Fig. 4(a) and (b), respectively. It can be seen that the reflection is kept above a very high value ($R > 95\%$) over the whole wavelength band 1.4–1.7 μm even the groove thickness is increased from 450 nm to 530 nm for TE polarization. Therefore, we