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Novel Optical Power Splitter Based on Nonperiodic Subwavelength High-Index-Contrast Grating

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Abstract A novel optical power splitter (OPS) based on a nonperiodic subwavelength high-index-contrast grating (HCG) is proposed. The OPS can split the reflected light into two beams while maintaining a high reflectivity. In order to achieve a specific phase-shift distribution for the application mentioned above, a rigorous coupled-wave analysis (RCWA) is used to calculate the reflectivity and phase shift of a periodic subwavelength HCG while changing the grating period and duty cycle to obtain the proper structural parameters of the HCG. The properties of the two-port OPS are numerically studied with a finite element method (FEM), which exhibits a 3.27 dB insertion loss and a wavelength varying from 1.50 to 1.60 μm. The presented OPS can be easily integrated with a semiconductor device.

Key words optical device; optical power splitters; high-index-contrast grating; subwavelength; phase shift

基于非周期高折射率差亚波长光栅的光功分器

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摘要 提出了一种新的基于非周期高折射率差亚波长光栅(HCG)的光功分器(OPS)。该光功分器在实现光功率均分的同时保持高反射率。为实现上述功分器,通过严格耦合波理论分析(RCWA)周期性亚波长光栅在不同的周期和占空比下的反射率和相位分布,从而挑选合理的参数用于设计非周期亚波长光栅以获得特定的反射相移。最后借助于有限元法(FEM)进行数值分析,经计算光功分器的插入损耗为3.27 dB,波长变化范围为1.50~1.60 μm,且很容易与半导体器件集成。

关键词 光学器件; 光功分器; 高折射率差光栅; 亚波长; 相移

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1 Introduction

An optical power splitter (OPS) is one of the most fundamental components in an optical communications network. An OPS, as a key element in an optical metropolitan area network (MAN), fiber to the home (FTTH), and optical cable TV, has been widely used to resolve the last "one mile" problem. Traditionally, an OPS is fabricated by fusing a biconical taper using ion-exchange technology[1-2], which is difficult to integrate with a semiconductor device.

In recent years, subwavelength high-index-contrast gratings (HCGs)[3-7] have been widely studied for their high reflection properties, low loss, and easy integration, which makes HCGs a promising alternative to some traditional lenses[8-9]. More importantly, a HCG with nonperiodic features can be designed to support a specific phase-shift distribution for a specific application while maintaining a high reflectivity[8-11].

In this paper, we present a new OPS based on a nonperiodic subwavelength HCG. The relationship between x axis and phase $\Phi(x)$ of the reflected light is given. On this basis, we propose an approach for designing an

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HCG-OPS. The properties of the proposed HCG-OPS are numerically studied with a finite element method (FEM)[12]. Simulation results show that the insertion loss of the splitter is 3.27 dB, and the wavelength varies from 1.50 to 1.60 μm. The presented OPS should be easily integrated with a semiconductor device.

2 Theoretical background

When light is incident upon a chirped HCG, the reflected beam develops a phase shift along the x axis owing to the lateral dimensional chirp along the x axis[9]. If the phase-shift distribution along the x axis is chosen properly, the plane wave is split. In this letter, the phase-shift distribution of the designed HCG satisfies

$$\Phi(x)={}^{2\pi}\!/_{\lambda}\left[\sqrt{(x-x_0)^2+f^2}-f\right]+\varphi_0 . \qquad (1)$$

In Eq. (1), λ is the incident wavelength, f is the focal length, x is the coordinate of the grating center, and φ_0 is the phase shift of the reflected light at the position x_0. If we select x_0 as 0, according to Eq. (1), the phase shift $\Phi(x)$ is then a parabola, and the reflected light will be focused at (x_0,f). We select just half of the phase from x_1 to x_N and then mirror the structure; thus, we obtain the phase shift by which the reflected light can be split into two equal parts.

A schematic of the OPS based on a nonperiodic HCG is shown in Fig. 1. The parameters depicted in Fig. 1 determine the phase shift and reflection properties of the grating. These parameters are the grating thickness t_g, grating periodicity p, and duty cycle η (the ratio of the bar-width w to the period p). By changing these structural parameters of the HCG, the phase front will change accordingly. Thus, we can obtain the specific phase-front profiles of the reflected light for a nonperiodic HCG to realize beam splitting by collecting the individual HCG units together in a specific way corresponding to a nonperiodic HCG. In this work, we change the period and duty cycle while the thickness remains constant.

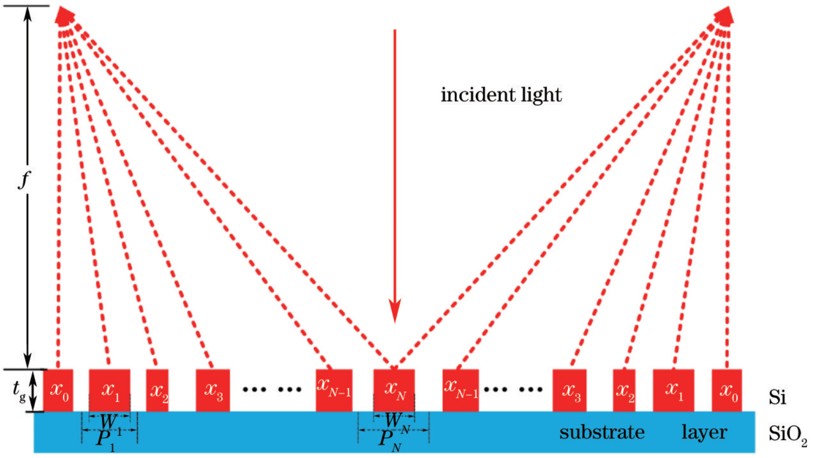

Fig.1 Schematic of the OPS based on a nonperiodic HCG

3 Design process

The design of an HCG-OPS element is straight forward. Given the requirements, e.g., the focal length and structure length, the ideal phase-shift distribution of the reflected light can be obtained according to Eq. (1). The next step is to determine the proper grating units that can conform to the expected phase profile. As an example, we design an HCG-OPS with a focal length of 30 μm for the TM polarization (the E-field vector is perpendicular to the grating bars) at an incident wavelength of 1550 nm. The reflectivity and phase shift can be obtained as a function of the grating period and duty cycle using a rigorous coupled-wave analysis (RCWA)[13] simulation method. Here, the HCG bars on the silica substrate are made of silicon and surrounded by air. The thicknesses of the HCG bars and substrate are both 0.5 m. The refractive indices of the HCG bars and substrate are 3.48 and 1.47, respectively. The calculation results are shown in Fig. 2. A series of (p,η) is selected, which can achieve a high reflectivity (such as $|r|^2 > 80\%$) and a gradually changing phase-shift range from 0 to 2π rad. The achievement of a full 2π rad is important because it can make phase to be arbitrarily controlled control[8]. These data will be the map for selecting a grating unit to meet the target phase-shift distribution. According to the map, we select the proper grating parameters (p,η) one by one for the different grating units and obtain an HCG-OPS, in which the introduced phase adapts to Eq. (1).

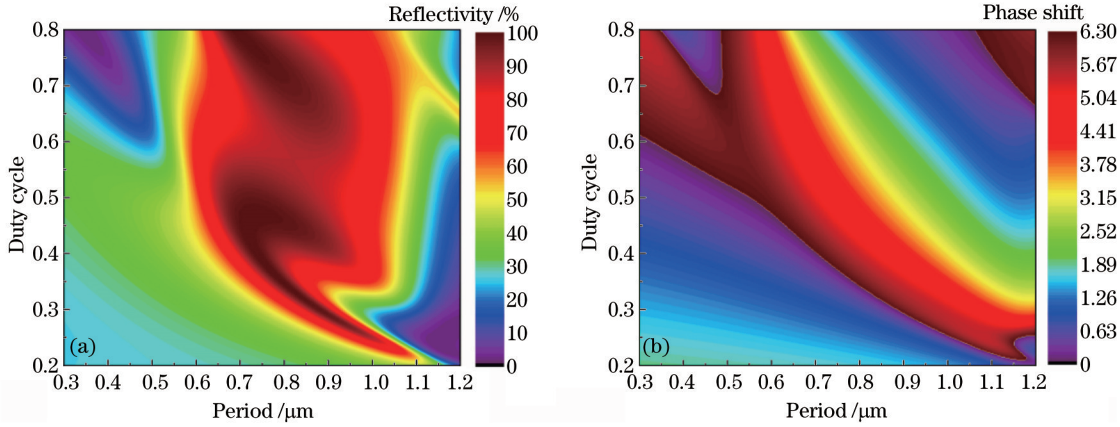

Fig.2 Maps of the (a) reflectivity and (b) phase shift of a periodic bar-type HCG at the reflected plane

The related literature has demonstrated that an HCG reflector with a discrete and stepped phase distribution can achieve a high focus power when the grating period is smaller than the incident wavelength. Further, the electric-field distribution is much closer to the ideal case. This principle is applicable to the HCG-OPS as well. Notably, although the reflection and phase maps are calculated for periodic HCGs, their use in the design of a nonperiodic HCG-OPS is excellent.

Fig.3 shows the detailed structural parameters, including the corresponding discrete phase distribution and the reflectivity of the designed HCG-OPS. In Fig. 3 (a), the blue squares and red triangles denote the period of the grating and the duty cycle, respectively. In Fig. 3 (b), the red triangles represent the reflectivity, the blue line is the ideal phase distribution we want to achieve, and the blue dots are the designed discrete phase-shift values that correspond to (p,η).

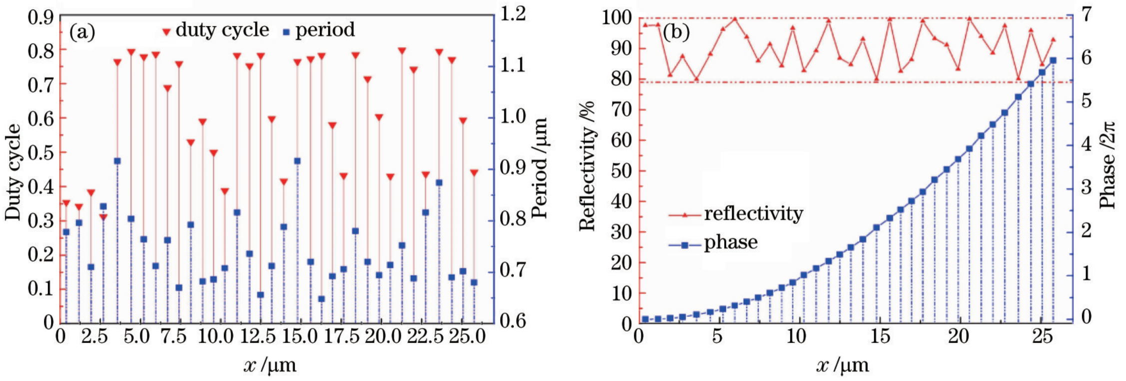

Fig.3 Detailed structural parameters of the HCG-OPS. (a) Distribution of (p,η);

(b) reflectivity and $\Phi(x)$ compared with the ideal phase distribution

4 Numerical simulation and discussion

The properties of the designed HCG-OPS are numerically studied using an FEM with TM-polarized light at a wavelength of 1550 nm. The simulation results are shown in Fig.4 (a). The TM polarized light has normal incidence upon the surface of the HCG-OPS, and most of the light is reflected and isolated into two parts, which agrees with our expectation. The insertion loss of the designed splitters is 3.27 dB, mainly owing to the inevitable transmission of the grating.

When the incident wavelength varies from 1.50 to 1.60 μm, the corresponding power distribution of the OPS changes slightly, as shown in Fig. 4 (b). In this figure, we calculate the relative light energy in the specific focus area in which the beam is mainly concentrated. The ratios of the energies at different wavelengths to that at 1.55 μm are all higher than 80%. Thus, the designed OPS has broadband wavelength properties.

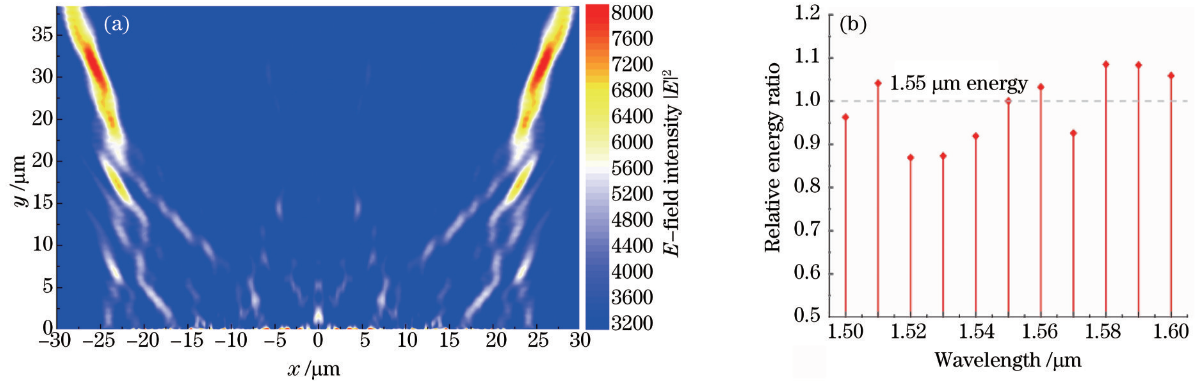

Fig.4 (a) Distribution of the E-field intensity; (b) relative energy ratio to 1550 nm incident light

5 Conclusions

In this paper, we presented an OPS using nonperiodic subwavelength HCGs. Such structures are simple to fabricate with standard photolithography and may be readily incorporated into a variety of integrated electronic and photonic platforms. An OPS can be designed by varying the HCG dimensions to achieve the desired reflection phase distribution. By FEM numerical simulation, the results show that the insertion loss of the splitter is 3.27 dB, and wavelength varies from 1.50 to 1.60 μm. In the same way, a two dimensional (2D) blocky subwavelength HCG-OPS can also be obtained.

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