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A design method based on photonic crystal theory for Bragg concave diffraction grating

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ABSTRACT

A design method based on one-dimensional photonic crystal theory (1-D PC theory) is presented to design Bragg concave diffraction grating (Bragg-CDG) for the demultiplexer. With this design method, the reflection condition calculated by the 1-D PC theory can be matched perfectly with the diffraction condition. As a result, the shift of central wavelength of diffraction spectra can be improved, while keeping high diffraction efficiency. Performances of Bragg-CDG for TE and TM-mode are investigated, and the simulation results are consistent with the 1-D PC theory. This design method is expected to be applied to improve the accuracy and efficiency of Bragg-CDG after further research.

1. Introduction

Wavelength Division Multiplexing (WDM) devices are key components in large capacity optical communication networks [1]. There are a number of competing technologies available in the WDM devices, such as interference filters, Bragg grating filters, planar integrated devices, etc. [2,3]. In these technologies, the planar integrated devices are promising [17]. Concave diffraction grating (CDG), a typical planar integrated WDM device, is more attractive due to its advantages of being compact, time reliability, cost effective, and channel spacing accuracy [4,5]. Unfortunately, traditional CDGs need a deep etching process which may result in both complex processing and large insertion loss [6]. In order to improve the performances of CDGs, metallic facets, V-shaped retro-reflecting facets and high refractive index contrast material systems are introduced to reduce the insertion loss [7,8]. However, they cannot get rid of constraints of the deep etching process, strict tolerances on facet verticality, additional processing steps or reflection Fresnel loss.

To solve the problems of traditional CDGs, Bragg-CDGs with Bragg mirrors reflecting mechanism and shallow etching process, are proposed [9–13]. J.Brouckaert et al. develop a four-channel SOI Bragg-CDG demultiplexer whose wavelength ranges from 1.5 μm to 1.6 μm: the on-chip loss can be reduced down to −2.4 dB with a second-order Bragg reflector [9]. However, the etching strips between adjacent Bragg facets in this structure are not successive, which will result in extra scattering loss. Amir Jafari et al... improve the structure and propose a Bragg-CDG with the continuous Bragg facets that reduce the scattering loss [10]. However, the device also has larger insertion loss due to using a higher order Bragg reflector. Additionally, the input waveguide is placed in the middle of the output waveguides, therefore a gap occurs in the middle of the output spectrum, resulting in channel nonuniformity. Pottier et al. propose a continuous elliptical Bragg-CDG structure and a design method thereof [11–13], which improve the diffraction efficiency up to 90% (−0.46 dB). Whereas, the period of Bragg facet derived from diffraction grating condition can not match with the period calculated by the quarter-wavelength method exactly, as the refractive index of materials cannot be arbitrarily chosen practically. This drawback may cause problems of channel nonuniformity, material, and process limitations.

In a case that the materials are selected, we propose a grating design method based on one-dimensional photonic crystal (1-D PC) theory to match reflection condition with diffraction condition. This allows the central wavelength of Bragg facet to be consistent with that of CDG. The remaining part of the paper is organized as follows. 1-D PC theory based design process is presented in section II. In section III, a Bragg-CDG is designed, and TE and TM-mode of Bragg-CDG are discussed. In section IV, the difference between the 1-D PC theory based Bragg-CDG and the quarter-wavelength method based Bragg-CDG is discussed. Finally, conclusions and possible extensions are introduced in section V.

2. Principle and design method

The layout of the Bragg-CDG based on the Rowland circle config-

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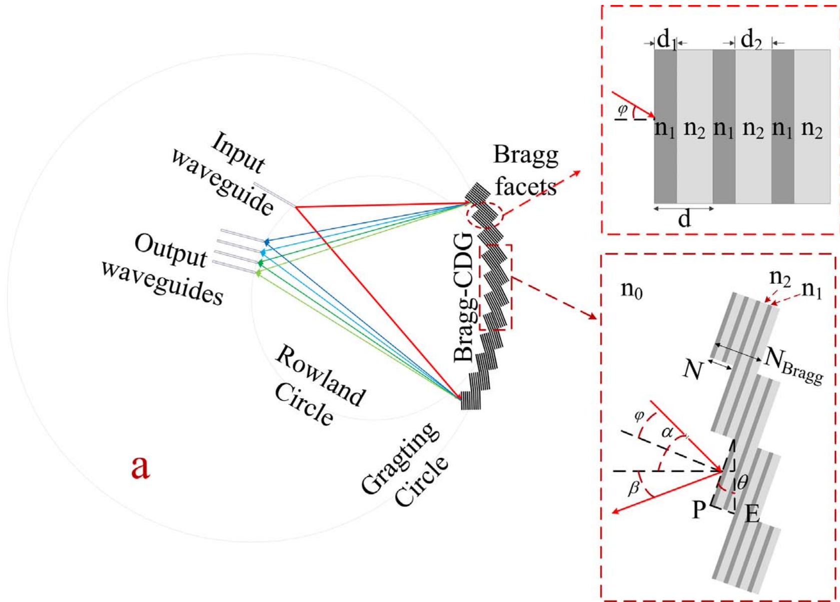

Fig. 1. Schematic diagram of Bragg-CDG based on Rowland geometry in which the facets consist with an array of alternating dielectric (n_i and d_i are the refractive index and width of layer i, respectively).

uration is shown in Fig. 1. Input and output waveguides are positioned on the Rowland circle of radius R_{rc}. The radius of curvature of the grating, internally tangent to the Rowland circle, is 2 R_{rc}. With the input light propagating to the Bragg-CDG, different wavelengths are diffracted and focused on the respective output waveguides. Insertion loss can be greatly reduced in the Bragg-CDG, because the conventional deep etching facets are replaced with Bragg reflectors having high reflection efficiencies in operating waveband. In Bragg-CDGs, the Bragg reflection condition determines the performances of Bragg-CDGs together with the grating diffraction condition..

2.1. Reflection condition of Bragg facet

The inset of Fig. 1b shows a schematic diagram of a Bragg facet which consists of periodic dielectric layers. It is noted that Bragg facet with dielectric periodically arranged, essentially, is a kind of PC structure, which can reflect light in a certain frequency efficiently. Thus we can calculate reflection band in the design of Bragg facets by 1-D PC theory. Where d is the periodic width of the PCs. The width of a dielectric layer and an etched layer are d_1, and d_2 with indices of n_1 and n_2, respectively. The propagation characteristics of light waves through one period of Bragg facet are related to a unitary 2×2 translation matrix [14]. The wave vector (Bloch wave number) is given by:

$$K = \frac{i}{d} \ln\left(\frac{1}{2}Tr(U) \pm \left\{\frac{1}{4}[Tr(U)]^2 - 1\right\}^{1/2}\right). \tag{1}$$

With the Bragg facet, light can be reflected or propagated, corresponding to imaginary or real Bloch wave numbers, respectively. As a result, the boundary between evanescent status and propagating is:

$$\frac{1}{2}Tr(U) = 1, \tag{2}$$

and the exact expression of Eq. (2) for the band edges is:

$$\left|\frac{1+A}{2}\cos(B_1 + B_2) + \frac{1-A}{2}\cos(B_1 - B_2)\right| = 1, \tag{3}$$

where $B_i = k_i d_i \cos(\varphi_i) = 2\pi n_i \varpi h_i \cos(\varphi_i)$, k_1 and k_2 are the wave number of dielectric layer and the etching layer, respectively. h_1 and h_2 are the width ratio of dielectric layer and the etching layer with the indices of n_1 and n_2, respectively. α is the angle of incidence of the light with respect to the grating normal, θ is the grating tilted angle, φ_1 is the angle of incident light with respect to the facet normal. ϖ is the normalized frequency, and the frequency $\omega = \varpi \cdot 2\pi c/d$, where c is the speed of light in vacuum, and d is the width of Bragg period.

Solutions of Eq. (1) define the band structure $\varpi(K, h_1)$ for the Bragg facet. It is convenient to display the solutions of the Bragg facet by projecting the $\varpi(K, h_1)$ function onto the $\varpi - h_1$ plane. An example of such projected structures is shown in Fig. 2. The ordinate indicates the frequency ϖ (unit:$2\pi c/d$), and the abscissa indicates the dielectric layer width ratio h_1. The light gray areas are in the propagating states, where K is strictly real; the bright areas are in the reflecting states, where K is imaginary. With h_1 (black dashed longitudinal linear in Fig. 2) selected, light with a frequency ranging from $\varpi_L$to ϖ_H will be reflected..

The central wavelength can be expressed as:

$$\lambda_0 = \frac{1}{2}(\lambda_L + \lambda_H), \tag{4}$$

according to the equation:

$$\lambda = \frac{2\pi c}{\omega} = \frac{d}{\varpi}, \tag{5}$$

the periodic width of Bragg facet is obtained from,

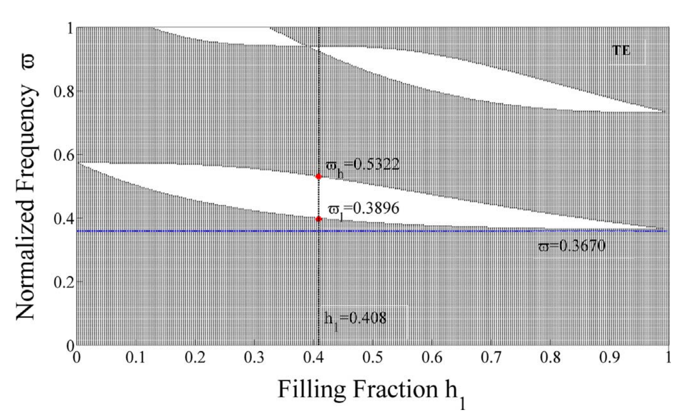

Fig. 2. Projected band structure of a Bragg structure for TE-mode, showing the photonic band gap of Bragg facets with n_1=1.45, n_2=1, and φ_1=20°. Propagating state, gray; reflecting state, white.