Available online at www.sciencedirect.com
ScienceDirect
Optics Communications 266 (2006) 117–121
OPTICS COMMUNICATIONS
www.elsevier.com/locate/optcom

Effects of shaded facets on the performance of metal-coated etched diffraction grating demultiplexer

Ning Zhu *, Jun Song, Liyang Shao

Centre for Optical and Electromagnetic Research, State Key Laboratory of Modern Optical Instrumentation, Joint Laboratory of Optical Communications of Zhejiang University, Zhejiang University, Yu-Quan, 310027 Hangzhou, PR China

Received 14 August 2005; received in revised form 15 April 2006; accepted 21 April 2006

Abstract

A finite-difference time-domain (FDTD) method combined with a periodic boundary condition is used to analyze the diffraction efficiency of an etched diffraction grating (EDG) demultiplexer coated with a metallic film at the backside. The numerical results show that the diffraction loss is mainly due to the scattering effect of shaded facets of a metal-coated grating at both the polarizations. However, the same shaded facets can produce a higher loss for a TM polarization than that for a TE polarization, which induces a higher polarization dependent loss (PDL) of the demultiplexer.

Keywords: Finite-difference time-domain method; Etched diffraction grating; Perfectly matched layer; Diffraction efficiency

1. Introduction

Nowadays, dense wavelength division multiplexing (DWDM), a technology that simultaneously uses multiple lasers and transmits several wavelengths of light in a single optical fiber, is a reasonable solution to the increasing demand of bandwidth capacity. Integrated waveguide multi/demultiplexers are key elements in a wavelength-division multiplexed (WDM) optical communication system. Two types of planar waveguide demultiplexers have been extensively investigated and developed. One is arrayed waveguide gratings (AWGs) [1] and the other is etched diffraction gratings (EDGs) [2–5]. Compared to an AWG and other DEMUX devices, an EDG has higher spectral resolution and potentially larger number of channels available over its free spectral range in a very compact size, attributing to its huge number of teeth.

On the other hand, the application of an EDG is limited by its high insertion loss associated with imperfect fabrication. Deeply etched grating facets are required, and the verticality and smoothness of the facets can greatly affect the performance of the device. Coating the facets with a metallic film at the backside of the grating is a convenient and effective method for reducing the reflection loss and thus improving the diffraction efficiency.

In a ray approximation method (which is a high frequency method appropriate for use when the fine structure is much larger than the wavelength), the diffraction efficiency is approximately equal to the reflectance R. Assuming a groove infinite in width, the reflectance R on the interface between air and the dielectric medium (with refractive index n) is $[(n-1)/(n+1)]^2$. For n within 1.5–3, R is only about 4–25%. If the facets are coated with metallic films (such as aluminium), the reflectance R can reach to as high as 97%. However, this is not accorded with experimental results [2,5]. The method mentioned above neglects the diffraction effect of shaded facets (i.e., the facets without direct illumination of light). In the present paper, we propose a finite-difference time-domain (FDTD) method [9] combined with both PML [6] and periodic boundary condition [7] to simulate the diffracting

* Corresponding author.
E-mail address: zowie@coer.zju.edu.cn (N. Zhu).

0030-4018/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.optcom.2006.04.057

process. This method is based on a direct discretization of Maxwell's equations without any approximation, by which we can obtain accurate results. Particularly, a deep physical insight into the loss source for the metal-coated grating is achieved by using this method.

2. Numerical model

We introduce a 2D-FDTD method to calculate the diffraction efficiency. We only consider a two dimensional geometry and neglect the influence of the depth of the facets. Under 2D condition, assuming that all the components of electromagnetic fields are independent of coordinate z, they can be separated into two independent groups, E_z, H_x, H_y for TE polarization and H_z, E_x, E_y for TM polarization. These components are discretized using the mesh proposed by Yee [8], as Fig. 1 indicates.

i and j are integers. Discrete time expressions are at $t = n\Delta t$ (Δt is the time increment) for electric fields and $t = (n + 1/2)\Delta t$ for magnetic fields. For the present structure, the field component at any grid can be denoted by

$$A(x,y,t) = A(i\Delta x, j\Delta y, n\Delta t) = A^n(i,j) \quad (1)$$

For TE polarization, one can obtain the following discretized time-stepping formulas

$$H_x^{n+1/2}(i,j+1/2) = H_x^{n-1/2}(i,j+1/2) - \frac{\Delta t}{\mu\Delta y}[E_z^n(i,j+1) - E_z^n(i,j)] \quad (2)$$

$$H_y^{n+1/2}(i+1/2,j) = H_y^{n-1/2}(i+1/2,j) + \frac{\Delta t}{\mu\Delta x}[E_z^n(i+1,j) - E_z^n(i,j)] \quad (3)$$

$$E_z^{n+1}(i,j) = \frac{2\varepsilon - \sigma\Delta t}{2\varepsilon + \sigma\Delta t}E_z^n(i,j) + \frac{2\Delta t}{2\varepsilon + \sigma\Delta t}\left[\frac{H_y^{n+1/2}(i+1/2,j) - H_y^{n+1/2}(i-1/2,j)}{\Delta x} - \frac{H_x^{n+1/2}(i,j+1/2) - H_x^{n+1/2}(i,j-1/2)}{\Delta y}\right] \quad (4)$$

Similarly the formulas for TM polarization are as follows:

$$E_x^{n+1}(i+1/2,j) = \frac{2\varepsilon - \sigma\Delta t}{2\varepsilon + \sigma\Delta t}E_x^n(i+1/2,j) + \frac{2\Delta t}{(2\varepsilon + \sigma\Delta t)\Delta y} \times \left[H_z^{n+1/2}(i+1/2,j+1/2) - H_z^{n+1/2}(i+1/2,j-1/2)\right] \quad (5)$$

$$E_y^{n+1}(i,j+1/2) = \frac{2\varepsilon - \sigma\Delta t}{2\varepsilon + \sigma\Delta t}E_y^n(i,j+1/2) - \frac{2\Delta t}{(2\varepsilon + \sigma\Delta t)\Delta x} \times \left[H_z^{n+1/2}(i+1/2,j+1/2) - H_z^{n+1/2}(i-1/2,j+1/2)\right] \quad (6)$$

$$H_z^{n+1/2}(i+1/2,j+1/2) = H_z^{n-1/2}(i+1/2,j+1/2) - \frac{\Delta t}{\mu}\left[\frac{E_y^n(i+1,j+1/2) - E_y^n(i,j+1/2)}{\Delta x} - \frac{E_x^n(i+1/2,j+1) - E_x^n(i+1/2,j)}{\Delta y}\right] \quad (7)$$

After some time intervals, one can obtain stable field components at any grid to calculate the retro-diffraction efficiency.

Fig. 2 shows the schematic diagram of an etched diffraction grating demultiplexer based on a Rowland circle structure.

The field propagating from an input waveguide to the free propagation region (FPR) is diffracted by each grating facet. It is then refocused onto an imaging curve and guided into different output waveguides according to the wavelengths. Conventional dielectric echelle grating has a series of grooves, each groove consists of a normal-illuminated facet and a shaded facet. The length of the groove is designated by $a = m\lambda/2n_{\mathrm{eff}}\sin\theta$, where m is the blazing order, n_{eff} is the effective refractive index of the incident

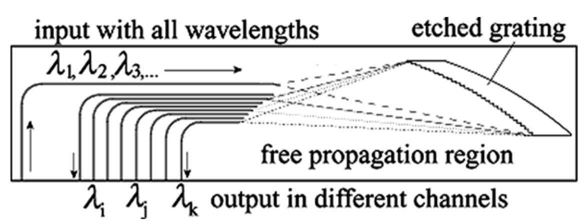

Fig. 2. Schematic diagram of an EDG.

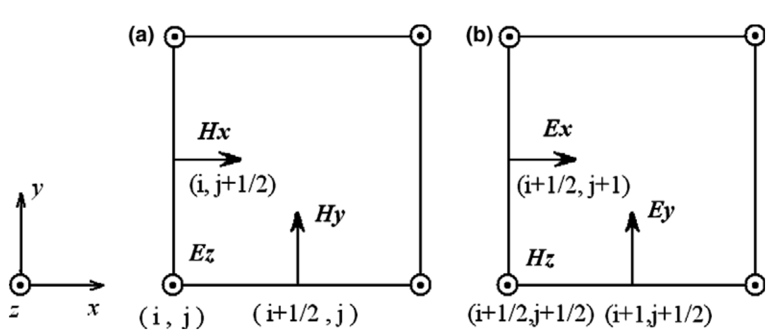

Fig. 1. Yee's cell for TE mode (a) and TM mode (b).