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Optimal design for a flat-top AWG demultiplexer by using a fast calculation method based on a Gaussian beam approximation

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Abstract

Passband broadening of an AWG (array waveguide grating) demultiplexer with an MMI (multimode interference) coupler connected at the end of a tapered input waveguide is considered. An explicit formula based on the field propagation of an approximate Hermit–Gaussian beam is used to calculate quickly and reliably the spectral response of the AWG demultiplexer. The widths of the input waveguide, the output waveguides and the MMI coupler are optimized. The optimal design is verified with the experimental measurement.

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Keywords: Arrayed waveguide grating; Flat top; MMI; Gaussian beam

1. Introduction

The explosive growth of internet traffic is pushing the rapid development of dense wavelength division multiplexing (DWDM) systems. An arrayed-waveguide grating demultiplexer [1], which is based on the planar waveguide technology, has played an important role as a key optical component in a DWDM system. A flat-top AWG is insensitive to the laser wavelength shift (due to e.g. temperature change) and is especially desirable in a high speed DWDM system. Several techniques have been proposed to obtain a flattened spectral response, such as using a multimode output waveguide [2], two cascaded grating devices [3] multiple gratings [4], multiple Roland-circles [5], a multimode interference (MMI) coupler [6], and a Y-junction [7].

Putting an MMI section at the end of the input waveguide is a simple and effective way of realizing a flattened spectral response. In the present paper, we connect an MMI section at the end of a tapered input waveguide to broad the spectral response of an AWG demultiplexer. The paper is organized as follows. In Section 2, the basic principle of the AWG demultiplexer with an MMI coupler connected at the end of the input waveguide is discussed, and an explicit formula for the spectral response of an AWG demultiplexer is derived. This formula is efficient for calculating the spectral response of a flat-top AWG demultiplexer. In comparison with some other fast calculation methods (such as 1:1 imaging method [8]) the present formula is more accurate (particularly when the total number of the arrayed waveguides is not large). With such a fast and reliable method, the widths for the MMI section, the input waveguide and the output waveguides are optimized in Section 3. Section 4 gives a comparison of the simulation results and the measured results for a fabricated flat-top AWG demultiplexer.

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2. Basic principle and formulas

The structure of an AWG demultiplexer is shown in Fig. 1(a). An AWG demultiplexer consists of an input waveguide, many output waveguides, two free propagation regions (FPRs), and N arrayed waveguides (AWs) with a constant length difference (ΔL) between two adjacent waveguides. The input and output waveguides are tapered in this paper. In order to broad the spectral response of an AWG demultiplexer, an MMI coupler is connected at the end of the tapered input waveguide. The input light is radiated to the first FPR and then excites the arrayed waveguides. After traveling through the arrayed waveguides, the light beam interferes constructively at one focal point in the second FPR. The location of the focal point depends on the wavelength [1]. The adiabatically tapered sections for both the input and output waveguides are shown in the enlarged view of Fig. 1(a).

Fig. 1(b) shows an enlarged view of the first FPR including the MMI section and the adiabatically tapered section of the input waveguide. Below we give a formula for the flattened spectral response by using the propagation theory for an approximate Gaussian beam.

The field propagation of the fundamental mode (of Gaussian beam leaving a waveguide) in an FPR can be described approximately by the following normalized Gaussian field distribution (subscript "i" is for the first FPR and "o" for the second FPR)

$$E_{\mathrm{F}}(x,z) = A_{\mathrm{norm}} \exp\left\{-\mathrm{j}\left(kz - \tan^{-1}\frac{\lambda z}{\pi\omega_{\mathrm{F}}^2}\right) - x^2\left[\frac{1}{\omega_{\mathrm{F}}^2(z)} + \frac{\mathrm{j}k}{2R_{\mathrm{F}}}\right]\right\}, \quad \mathrm{F} = \mathrm{i}, \mathrm{o}, \tag{1}$$

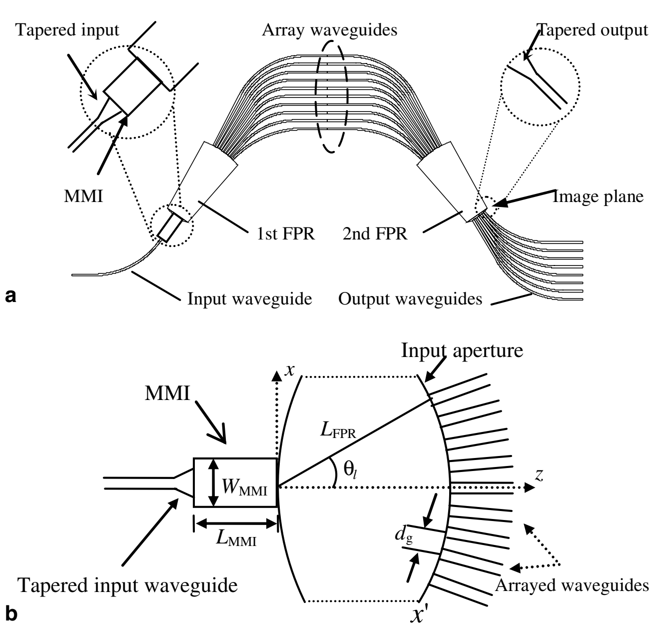

Fig. 1. (a) An AWG demultiplexer; (b) enlarged view of the first FPR.

where

$$A_{\mathrm{norm}} = \left(\frac{2}{\pi}\right)^{1/4}\frac{1}{\sqrt{\omega_{\mathrm{F}}(z)}},$$

$$\omega_{\mathrm{F}}(z) = \omega_{\mathrm{F}}\sqrt{1 + \left(\frac{\lambda z}{\pi\omega_{\mathrm{F}}^2}\right)^2},$$

$$R_{\mathrm{F}}(z) = z\left[1 + \left(\frac{\pi\omega_{\mathrm{F}}^2}{\lambda z}\right)^2\right],$$

where λ is the wavelength in the FPR, A_{norm} is the normalized constant, $k = 2\pi/\lambda$ is the wavenumber, ω_{F} and $\omega_{\mathrm{F}}(z)$ are the beam waist at $z = 0$ and the beam width at distance z, respectively, and $R_{\mathrm{F}}(z)$ is the wave-front radius of curvature. Note that ω_{F} depends on the width w_{F} of the waveguide [1],

$$\omega_{\mathrm{F}} = \frac{W_{\mathrm{wg}}}{2}\left(1 + \frac{2}{v}\right),$$

where W_{wg} is the width of the waveguide and $v(= k_0 W_{\mathrm{wg}}\sqrt{n_{\mathrm{eff}}^2 - n_{\mathrm{c}}^2})$ is the normalized transverse attenuation constant (here k_0 is the wavenumber in vacuum, n_{eff} and n_{c} are the effective refractive index and the refractive index for the cladding, respectively).

To broad the spectral response of the AWG demultiplexer, an MMI (1×2) section (with length L_{MMI}) is connected at the end of the tapered input waveguide. With an appropriately chosen length (L_{MMI}), the MMI section converts its input field into a two-fold image. The separation Y between the two peaks of this two-fold image determines the 3 dB passband width and is directly related to the width W_{MMI} of the MMI [9]

$$2Y = W_{\mathrm{e}} = W_{\mathrm{MMI}} + \frac{\lambda}{\pi}\left(\frac{n_{\mathrm{c}}}{n_{\mathrm{r}}}\right)^{2\sigma}(n_{\mathrm{r}}^2 - n_{\mathrm{c}}^2)^{-1/2}, \tag{2}$$

where $\sigma = 0$ (for TE) and 1 (for TM), and n_{r} and n_{c} are the refractive indices for the core and cladding, respectively. L_{MMI} is related to the effective width W_{e} by the relation [8],

$$L_{\mathrm{MMI}} = \frac{4n_{\mathrm{r}}W_{\mathrm{e}}^2}{3\lambda}. \tag{3}$$

The two-fold image field distribution at the end of the MMI section is given by [8]

$$E_{\mathrm{MMI}}(x) = CA_{\mathrm{norm}}\left\{\exp\left[-\frac{(x+Y/2)^2}{\omega_i^2}\right] + \exp\left[-\frac{(x-Y/2)^2}{\omega_i^2}\right]\right\}, \tag{4}$$

where

$$C = \frac{1}{\sqrt{2}}\frac{1}{\sqrt{1+\exp[-2Y^2/(2w_i)^2]}}.$$

The field distribution at the end of the MMI section is shown in Fig. 2 for different values of Y (directly related to the width of the MMI section). Obviously $Y = 0$ corresponds to the conventional AWG design. The field at the input aperture ($E_{\mathrm{IAP}}(x)$) is given by (see Fig. 1(b))