ARROW-Based AWG Demultiplexers

Yi-Hao Yang and Yang-Tung Huang
Department of Electronics Engineering and Institute of Electronics
National Chiao Tung University
1001 Ta-Hsueh Road, Hsinchu, Taiwan, Republic of China
TEL: 03-5712121 Ext. 54138, FAX: 03-5724361
E-Mail: huangyt@cc.nctu.edu.tw

Abstract

We investigate the ARROW-based AWG devices. A 16-channel ARROW-based AWG demultiplexer with 200-GHz spacing for 1550.92-nm operation on a Si substrate is designed. The losses for the central and outer wavelengths are 0.41 and 1.59 dB, respectively. The 3-dB bandwidth is 0.71 nm.

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1 Introducton

The arrayed-waveguide grating (AWG) based on planar lightwave circuit (PLC) is one of the key components in the construction of flexible and large-capacity WDM systems [1]. AWG offers the advantages of low loss, high port counts, and mass productivity.

Since 1986, the ARROW (antiresonant reflecting optical waveguide) has been proposed and demonstrated [2]. The light power guided in the ARROW is utilizing the Fabry-Perot cavities as the reflectors instead of total internal reflection. This new structure is promising and attractive for its advantageous feature of single mode operating with a large core size compatible to a single-mode fiber. In this presentation, we introduce the design of ARROW-based AWG demultoplexers.

2 Device Structure

The antiresonant reflecting optical waveguide (ARROW) is a novel waveguide, which utilizes the high reflectivity of the Fabry-Perot resonator to reach a low propagation loss. The Fabry-Perot resonator consists of a set of cladding layers, which supports destructive interference, inserted between the core and the substrate. The wave is constructive in the core and the optical power can be efficiently confined within the core region. The basic structure of a single planar ARROW waveguide ($n_a/n_g/n_h/n_l/n_s$) is shown in Fig. 1, which consists of a core layer (n_g) and two cladding layers (n_h/n_l) before air (n_a) and the substrate (n_s). The core layer of the ARROW waveguide is with a low refractive index of n_g and a thickness of d_g, which is placed above the two layer claddings. These interference cladding layers, which consist of the high index first cladding (n_h) with thickness d_h and the low index (n_l) cladding with thickness d_l, are sandwiched by the core and the substrate. To satisfy the transverse antiresonance condition for all cladding layers, the thicknesses must satisfy [3]

$$d_h = \frac{\lambda}{4n_h}\left[1-(\frac{n_g}{n_h})^2+(\frac{\lambda}{2n_h d_{eff}})^2\right]^{-\frac{1}{2}} \cdot (2P+1), \qquad P=0,1,2,\ldots \tag{1}$$

$$d_l = \frac{\lambda}{4n_l}\left[1-(\frac{n_g}{n_l})^2+(\frac{\lambda}{2n_l d_{eff}})^2\right]^{-\frac{1}{2}} \cdot (2Q+1), \qquad Q=0,1,2,\ldots \tag{2}$$

The AWG consists of regularly arranged waveguides that connect the two slabs. The lengths of adjacent waveguides differ by a constant value ΔL. This structure produces a wavelength-dependent phase shift and the arrayed-waveguide operates like a concave diffraction grating. From the phase match condition, the grating equation is given by

$$n_s d \sin\theta_i + n_c \Delta L + n_s d \sin\theta_o = m\lambda \tag{3}$$

where $\theta_i = i \cdot D/R_f$, $\theta_o = j \cdot D/R_f$, θ_i and θ_o are the diffraction angles in the input and output slab, respectively; d is the pitch of the arrayed waveguides, m is the diffraction order of the grating, and λ

is the wavelength; i and j are the numbers of the input and output waveguides, respectively; D is the spacing of the input and output waveguide along the slab waveguide edge; R_f is the focal length of the slab. The center wavelength is λ_c which satisfies

$$n_c \Delta L = m\lambda_c \tag{4}$$

The channel spacing ($\Delta\lambda$) and Free spectral range (FSR) can be obtained as [1], [4]

$$\Delta\lambda = \frac{D}{R_f}\frac{\partial\lambda}{\partial\theta_o} = \frac{Ddn_s n_c}{R_f m n_g} \tag{5}$$

$$FSR = \frac{c}{n_g \Delta L} = \frac{f_c n_c}{m n_g} \tag{6}$$

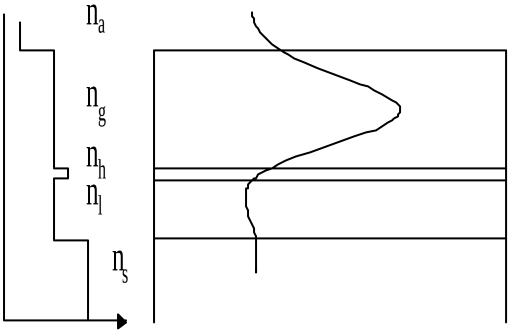

Fig.1: Single ARROW structure

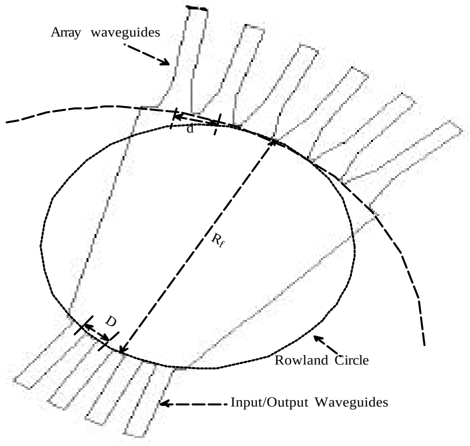

Fig.2: Enlarged view at free propagation region

3 Device Design and Characteristics

The structure of an ARROW-based waveguide is shown in Fig. 3. For Si substrate (n_s=3.5), SiO_2 with refractive index of 1.45 acts as both the core layer and second cladding layer (λ_0 = 1.55 μm). The larger refractive index of first cladding layer provides a lower loss, because of the higher reflection at the cladding-layer interface based on Fabry-Perot characteristics. In our design, the first cladding layer is Poly-Si with an index of 3.5 to obtain a low loss. We have investigated the performance of the ARROW devices with several core thicknesses. Here, we adopt the core thickness to be 7 μm as used in commercial AWG devices, and the optimum cladding layer thickness can be obtained from Eqs. 1 and 2 as d_h/d_l= 0.122/3.5 μ m. For this structure, low transmission loss can be achieved only for the fundamentional TE mode, which is below 0.035dB/cm.

To make the analysis the efficient and simpler, we convert the three-dimentional problem to a two-dimentional problem by the effective index method (EIM). The multilayer characteristic matrix method and effective index method are used to find acceptive d_{side} (the thickness of boundary). Typically, the diameter of single-mode fiber is 12.5 μm, and the difference between the core and cladding indices is 0.36%. In oeder to have efficient coupling to single mode fibers, we must let our structure to have larger core size and effective index difference. We chose the channel width to be the same as the core thickness of 7 μm. It is expected that the N_{eff} difference may be greater, which can have smaller channel waveguide separation, to reduce the device size and with acceptable loss. d_{side} is chosen as 4.8 μm with 0.29%-N_{eff} difference and 0.077 dB/cm loss, and single-mode guiding is maintained in the lateral y-direction.

After the design of the waveguide structure in the transverse xy-direction, we design the arrayed-waveguide grating structure in the yz-plane. We try to design a 16-channel AWG demultiplexer with 200-GHz spacing. The central wavelength of 1.55092 μm is chosen following the ITU-T standard grid. The FSR is chosen as 30 nm, and from Eq. (6) we obtain the diffraction order m as 52 by assuming $n_c = n_g$. In order to achieve sufficient isolation between neighboring output waveguides, the output channel waveguide separation is chosen as 13 μm. Therefore, the output channel waveguide pitch D is 20 μm with waveguide width of 7 μm. Considering the loss at the junctions between the Free Propagation

Region and the array waveguides, the gap between the array waveguide ends should be reduced. We use taps with input width 12 μm, output width 7 μm and length 500 μm connected with two ends of the array waveguides as shown in Fig. 2. We let the taps with pitch of 13.5 μm ($d = 13.5$ μm, as shown in Fig. 2). The focal length (R_f) of the slab can be given by Eq. (5) as 4692.67 μm. The input and output waveguides must be set on the Rowland Circle with half focal length radius ($1/2R_f$), and the array waveguides must be allocated on the circle with radius R_f. The array waveguide number (N_g) need to be large enough to reduce the crosstalk caused by the truncation of the field. The array waveguide number is 70 for our design. From Eq. (4), we can obtain the length difference ΔL between adjacent array waveguides as 55.79 μm.

After choosing suitable parameter values of our structure, we use a commercial semi-vectorial BPM software package Prometheus V4.3 by Kymata Inc. to simulate the performance of the designed AWG devices. The spectral response was calculated with a wavelength step of 0.16 nm and the result is shown in Fig. 4. The central wavelength loss is 0.41 dB, the outer channel loss is 1.59 dB, and the 3-dB bandwidth is 0.71 nm. The crosstalk level is lower than -30 dB.

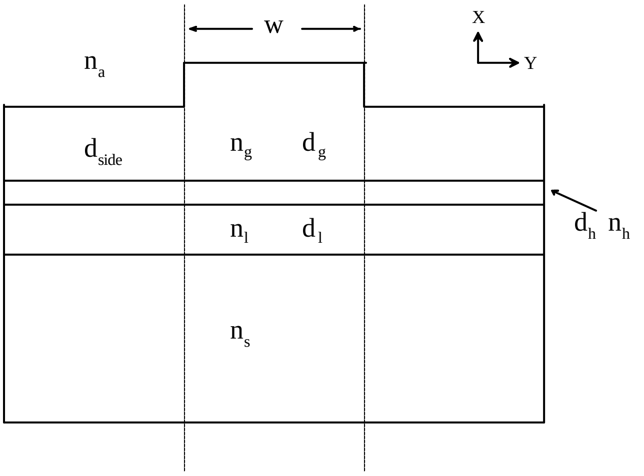

Fig.3: ARROW-based waveguide

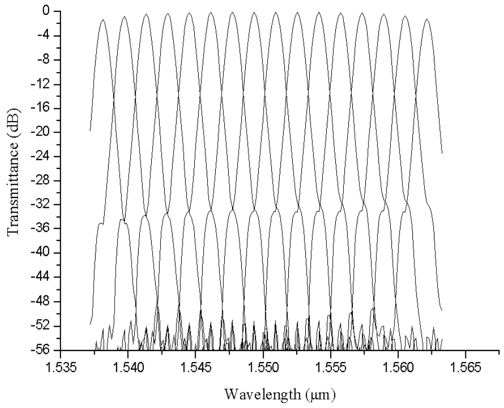

Fig.4: Spectral response of the simulation result

4 Conclusion

A 16-channel ARROW-based AWG demultiplexer with 200-GHz spacing for 1550.92-nm operation on a Si substrate is designed. The losses for the central and outer wavelengths are 0.41 and 1.59 dB, respectively. The 3-dB bandwidth is 0.71 nm. We successfully combine the ARROW structure and the AWG to design a demultiplexer. The results show that the ARROW-based AWG devices can be made of materials based on silicon substrates, and therefore compatible to IC process technologies.

References

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