A novel coupling structure for antiresonant reflecting optical waveguides

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ABSTRACT

A novel coupling structure between antiresonant reflecting optical waveguides (ARROW's) is proposed. In this structure, the separation thickness between dual ARROW's is chosen for destructive interference in the decoupling section, and changed to an efficiently coupling value in the coupling section. The coupling length is about 710 μm for InP/InGaAsP materials, which is very promising for practical applications.

1. INTRODUCTION

Directional couplers are key integrated optical components for many applications.[1] For these devices, it is important for designers to determine the coupling efficiency and coupling length between two waveguides. If the coupling coefficient is enough strong, the coupling length becomes short and the dimension of devices can be small as well. However, the coupling strength of conventional waveguide structures is decreasing as an exponential function of the separation between waveguides. This fact limits the design tolerance of waveguide separation in practical applications.

A directional coupler consisting of two coupled identical ARROW's (antiresonant reflecting optical waveguides) was recently proposed.[2–5] In comparison with conventional structures, ARROW waveguides utilize antiresonant reflection as the guiding mechanism instead of total internal reflection. With this structure, ARROW devices can have large core sizes and provide efficient connection to optical fibers. In addition, the great advantage of an ARROW-based coupler over a conventional waveguide coupler is that its coupling-length is not increasing but varies as a periodic function with increasing waveguide separation. Therefore, a remote coupler can be realized.

For the previously proposed ARROW-based coupler, the waveguide separation is constant and the energy transfers alternately from one to another. To efficiently couple the energy, the waveguide length is strictly defined and depends on the operating wavelength. Furthermore, the large value of the coupling length requires a large device size. These characteristics limit its practical applications and can be improved by our dual-ARROW coupling structure proposed in this presentation. Our dual ARROW waveguides in the propagation regions are decoupled with a designed separation thickness for destructive interference.[3] In the coupling region, the thickness of the high-index medium of the input ARROW is modified such that the energy can be efficiently transfers to the output channel. After complete energy transfer, the thickness is changed back to the decoupling original value and the energy keeps propagation in the output channel.

0-8194-1615-0/94/$6.00

2. ANALYSIS OF COUPLING STRUCTURE FOR ARROW-TYPE DIRECTIONAL COUPLERS

The basic structure of an ARROW-type directional coupler is shown in Fig. 1. It consists of two ARROW waveguides and a separation layer. The core layer of each ARROW waveguide is with a low refractive index (n_c), and sandwiched between two high index (n_h) cladding layers. The separation film with a low refractive index (n_s) is sandwiched between two ARROW waveguides. Light coupled into the core layer undergoes very high reflections from the antiresonant Fabry-Perot resonator when propagating in the waveguide. Under this antiresonant condition, ARROW-type guided modes (leaky modes) can be confined in the low index core layer and propagate with relatively low loss. In this case, the thickness of the cladding layers for destructive interference has been obtained as[2]

$$d_h = \frac{\lambda}{4n_h}\left[1 - \left(\frac{n_c}{n_h}\right)^2 + \left(\frac{\lambda}{2n_h d_c}\right)^2\right]^{-(1/2)} (2P+1), \quad P = 0,1,2,3,\cdots, \qquad (1)$$

and the thickness of separation layer for destructive interference is given as[5]

$$d_s = \frac{\lambda}{4n_s}\left[1 - \left(\frac{n_c}{n_s}\right)^2 + \left(\frac{\lambda}{2n_s d_c}\right)^2\right]^{-(1/2)} (2Q+1), \quad Q = 0,1,2,3,\cdots. \qquad (2)$$

The effective index of this dual-ARROW waveguides is calculated as the function of the separation thickness based on transverse resonance method.[5] Figure 2 shows the dispersion curves of the structure in Fig 1 for InP/InGaAsP material system. In this example, $\lambda = 1.55\ \mu m$, $n_c = 3.16$, $n_h = 3.55$, $d_c = 4\ \mu m$, and $d_h = 0.237\ \mu m$.[6] The dispersive (graded) regions represent that the constructive interference is formed in the separation layer. The nondispersive (flat) regions represent that the constructive interference is not formed in the separation layer, but in the ARROW waveguides. This nondispersive characteristics indicate a high optical confinement in the ARROW core layers.[5]

In order to achieve the maximum power exchanges between two ARROW waveguides, a pair of perfect symmetric and antisymmetric normal modes are required, i.e., the effective indices of two neighboring normal modes must be very close to each other in the nondispersive region. The coupling length is in verse proportion to the difference of these two mode indices.[4,5] In the structure we propose, the refractive index n_s of the separation layer for efficiently coupling is suitably adjusted to reduce the coupling length in the flat nondispersive region, and the configuration is shown in Fig. 3. Our dual ARROW waveguides in the propagation regions are decoupled with a designed separation thickness for destructive interference.[3] In the coupling region, the thickness of the high-index medium (n_{h2}) of the input ARROW is modified such that the energy gradually transfers from the input channel to this output channel. After complete energy transfer with the coupling length, the thickness is changed back to the original value to keep decoupling and the energy keeps propagation in the output channel.

3. DESIGN EXAMPLE AND SIMULATION RESULTS

In the first design example, we adopted the InP/InGaAsP material system, and the operation wavelength is 1.55 μm. The refractive index of $In_{1-x}Ga_xAs_yP_{1-y}$ depends on the wavelength and the material composition.[6] The material of the core layers is InP, and the material of the cladding and separation layers is InGaAsP. The corresponding indices are $n_h = 3.55$, $n_c = 3.16$, and $n_s = 3.4$, respectively. In the coupling region as shown in Fig. 3, the guide and cladding layer thicknesses are $d_{h1} = 0.2370$ μm, $d_c = 4$ μm, $d_{h2} = 0.71$ μm. The dispersion relation is shown in Fig. 4. Based on these characteristic curves, the separation thickness d_s was chosen as 2.0 μm, and the coupling length is given as $L_c = \lambda/(2\Delta N) \cong 710$ μm (ΔN is the index difference between two neighboring normal modes). The electric field distributions of these two normal modes for this structure are illustrated in the Fig. 5. The simulation result performed by beam propagation method (BPM) is shown in Fig. 6, which shows the same coupling length. This short coupling length is promising in practical applications.

4. SUMMARY

In this presentation, we propose a novel coupling structure for dual-ARROW directional couplers. Suitably selecting the refractive index of the separation layer, varying the separation thickness can determine the decoupling or coupling state between two waveguides. In the coupling region, the coupling length is about 710 μm in the InP/InGaAsP material system, which is promising for practical applications. The design for minimizing the coupling length and design for Si substrate are still under investigation. The experiments are in progress.

5. REFERENCES

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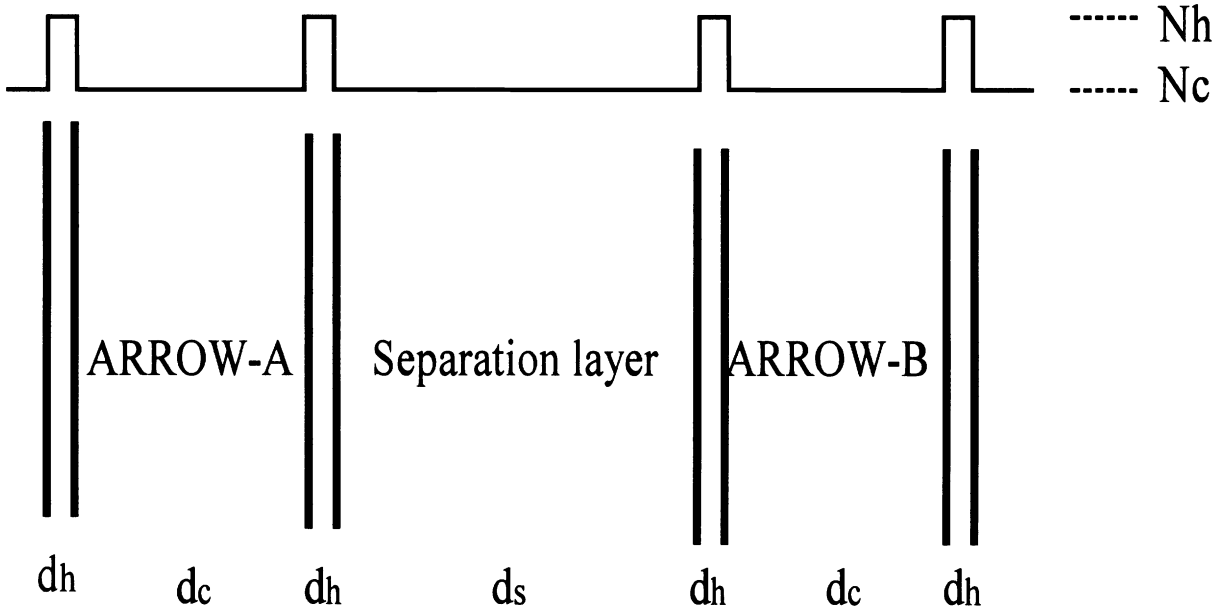

Fig. 1. The basic structure of an ARROW-type direction coupler.

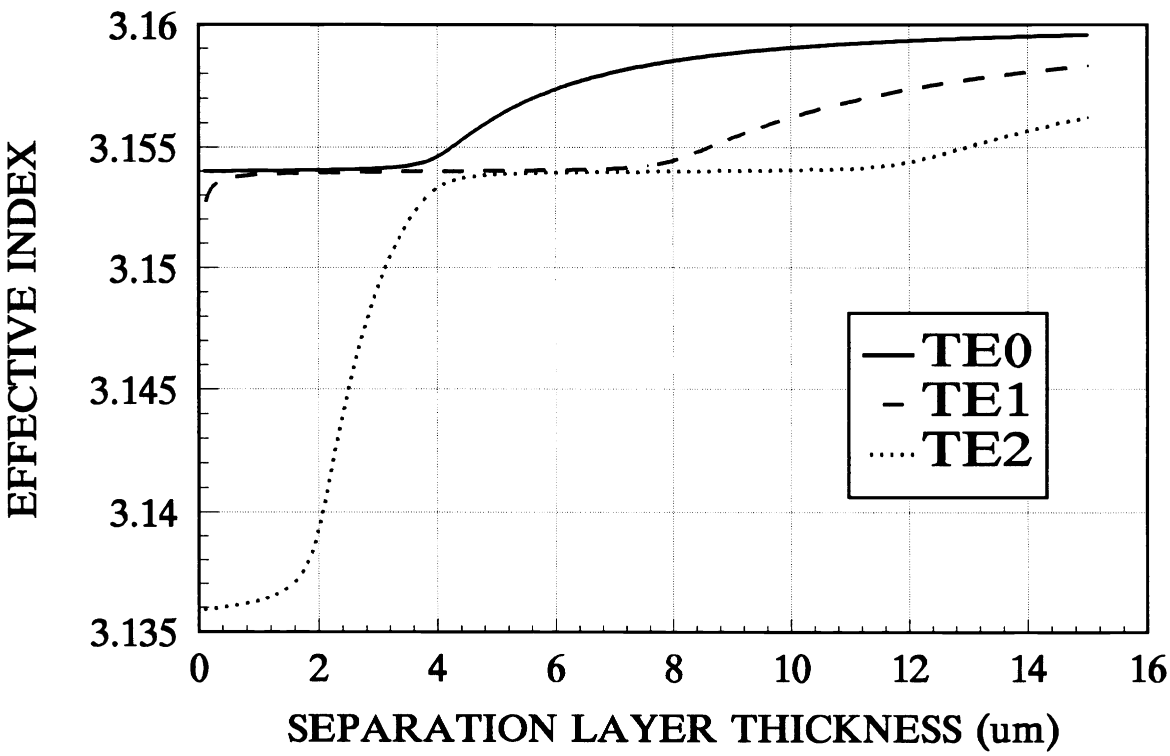

Fig. 2. The dispersion curves of the structure in Fig. 1.

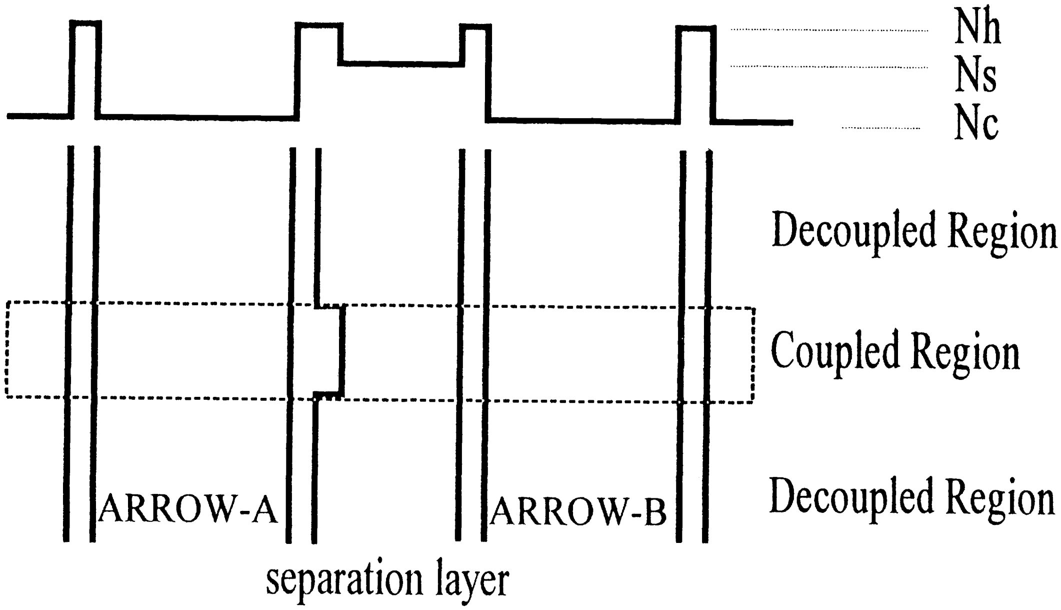

Fig. 3. The structure of the our dual-ARROW waveguides.

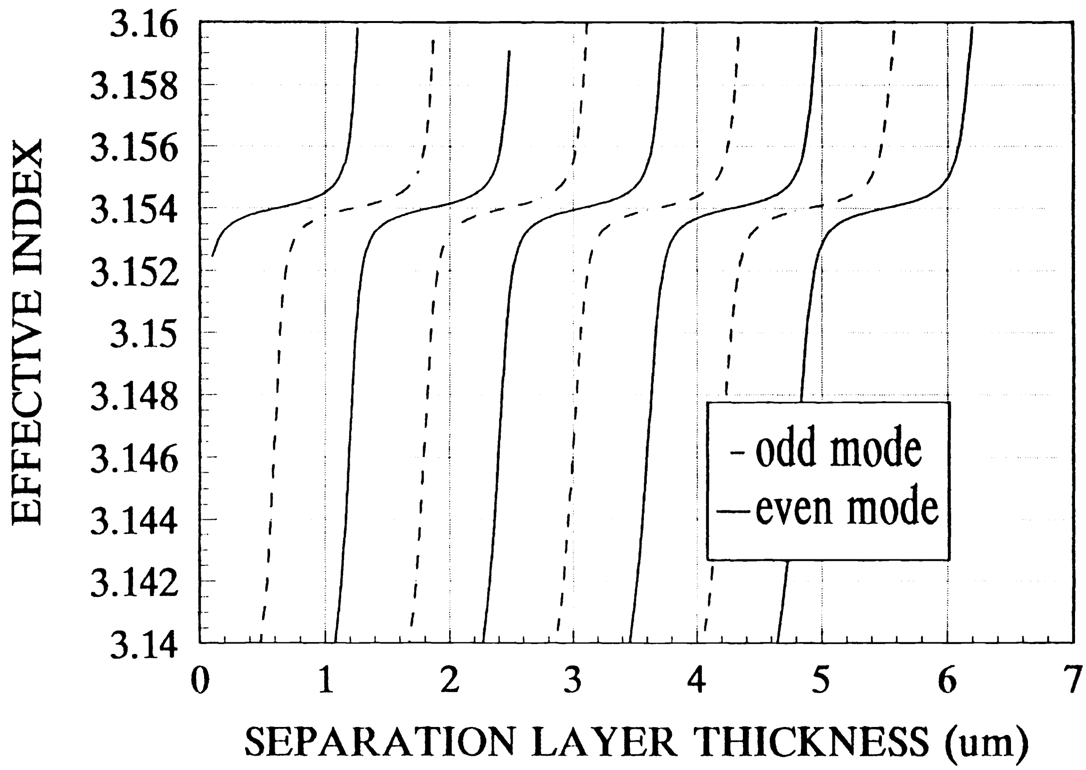

Fig. 4. The dispersion relation of the structure in Fig. 3.

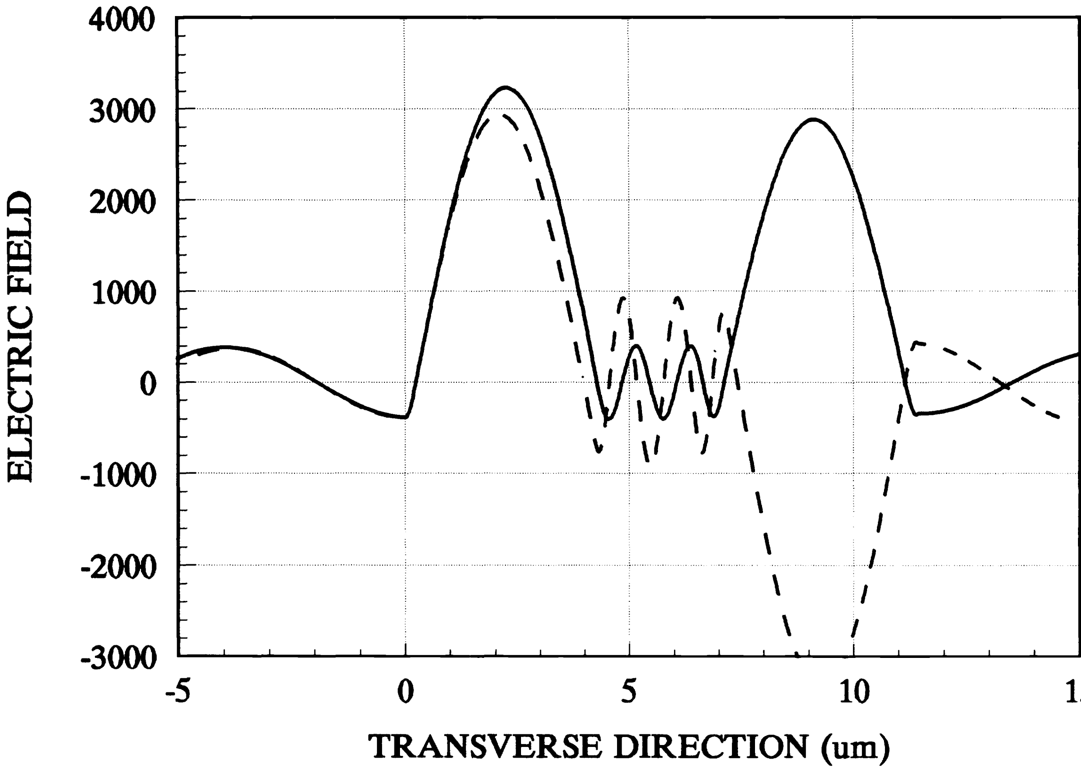

Fig. 5. The electric field distribution of two normal modes.

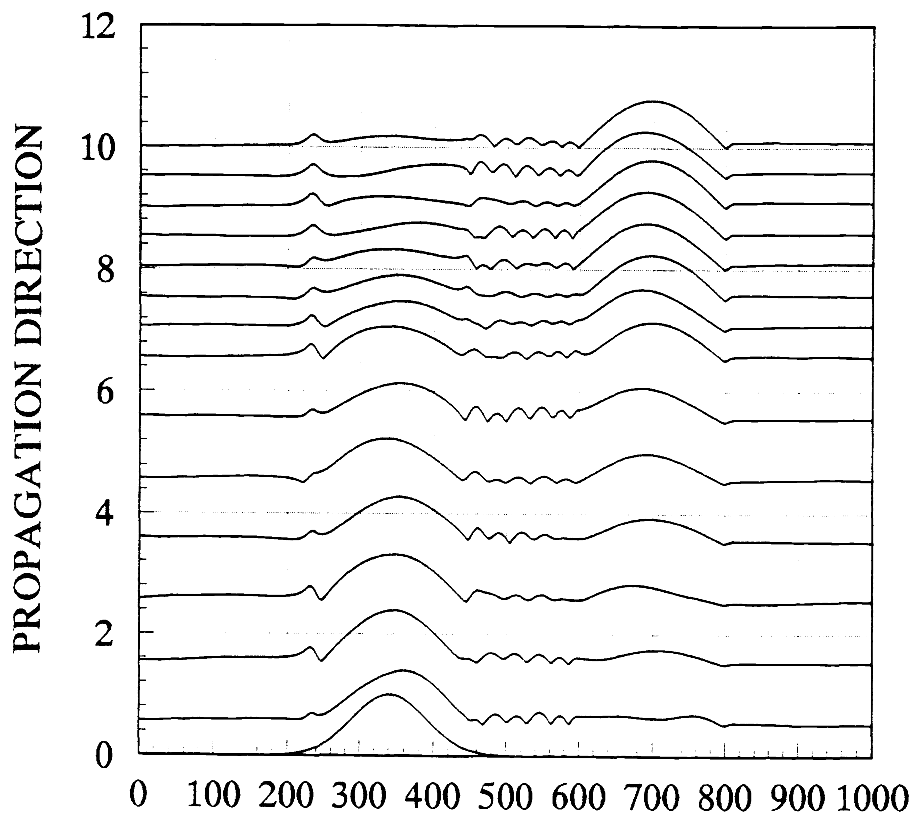

Fig. 6. The simulation result performed by beam propagation method.