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COUPLING RESPONSES TOWARDS WAVELENGTH AND COUPLING GEOMETRIES FOR SYMMETRIC AND ASYMMETRIC DIRECTIONAL COUPLERS

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ABSTRACT

The coupling responses towards wavelength and coupling geometries for symmetric and asymmetric directional couplers are discussed. Their behaviors were studied using beam propagation method (BPM). 50% ± 5% wavelength flattened coupling characteristics over a wide range from 1.33 µm to 1.55 µm are obtained for directional coupler with waveguide asymmetric width in the coupling region. Symmetric structure was finding its application in wavelength division multiplexer/demultiplexer and asymmetric structure has the capability for 3 dB directional coupler for broadband region.

INTRODUCTION

A directional coupler is a fundamental passive optical component for planar lightwave circuits (PLC) where it performs the function of splitting as well as combining wavelengths and power. Understanding of the fundamental components will benefit and enable us to manipulation and construct advance components for applications such as optical switches, modulator and filters. The single-mode optical directional couplers has an intrinsic wavelength dependence in their coupling ratios and very sensitive to coupling parameters such as guide width, separation between two guides, refractive index difference and parallel interactive length.

This paper describes coupling behavior towards simple symmetric and asymmetric directional coupler waveguides. A symmetric directional coupler and asymmetric directional couplers are intensively studied. These couplers can be classified into several typical patterns with respect to their wavelength insensitivity.

In section II we dealt with the operating principle of broadband waveguide coupler. Meanwhile in the paper, section III describes details on symmetric and asymmetric directional couplers waveguides and the relationship of the structures and their wavelength insensitivity is discussed. We conclude our study on symmetric and asymmetric directional coupler waveguides in section IV.

DESIGN AND SIMULATION DETAILS

The symmetric coupling region was equipped with two identical uniform waveguide and asymmetric coupling region was equipped with a tapered waveguide and a uniform waveguide for easy coupling to single mode optical fibers. According to coupled mode theory [1], the coupling power between two parallel lossless optical waveguides of interaction length, *L* can be expressed by the following:

$$I_1 = 1 - (\kappa^2/\delta^2)\sin^2(\delta L) \tag{1}$$

$$I_2 = (\kappa^2/\delta^2)\sin^2(\delta L) \tag{2}$$

where κ is the coupling coefficient and δ is given by

$$\delta = \sqrt{\left(\frac{\Delta\beta}{2}\right) + \kappa^2} \tag{3}$$

and $\Delta\beta = \beta_1 - \beta_2$, where β_1 and β_2 are the propagation constants of uncoupled waveguides 1 and 2, respectively.

The amplitude terms (κ^2/δ^2) and phase term (δL) in (1) and (2) represents the maximum power transfer and the location of the position of maximum power, respectively with wavelength. If width *w1* of guide 1 is equal to the width *w2* of guide 2, so that, $\beta_1 = \beta_2$, then $\kappa = \delta$ in (3) and $(\kappa^2/\delta^2) = 1$ in (1) and (2). It is clear from (2) that the coupling ratio $I_1/(I_1+I_2)$ will reach 100% at a particular wavelength. On the other hand, if $\beta_1 \neq \beta_2$, the maximum coupling ratio cannot transfer completely. Such condition is easily realized by designing $w1 \neq w2$.

In general, the amplitude term (κ^2/δ^2) and phase term (δL) are influenced by several waveguide parameters such as guide width *w1* and *w2*, guide gap *d*, refractive index difference Δn between core and cladding and parallel coupling length, *L*, which determine the coupling characteristics. Thus, design of directional couplers especially at the coupling regions should be planned very carefully so that the practical wavelength-functional waveguide couplers can be realized.

In the next section, we discuss the wavelength responses towards coupling parameter for symmetric and asymmetric directional coupler waveguide. For clear understanding of the coupler behavior, we adopt the beam propagation method (BPM) which is useful for the analysis of waveguides optic [2]. This method uses finite difference methods to solve the well-known parabolic or paraxial approximation of the Helmholtz equation. The BPM has been thoroughly analyzed in several papers. [3], [4], and therefore the method in general will not be discussed in this paper.

RESULTS AND DISCUSSION

Figure 1 shows the top view of the designed uniformity symmetric type directional coupler, where it parameters were assigned as guide width, *w1*, length of interactive region, *L*, length of *S*-shaped bend, *sL*, guide gap between two arms at the interactive region, *d* and separation between two input and output arms due to fiber butt coupling, *fd* = 250 μm, refractive index difference, Δn and wavelength, λ.

Figure 2 shows the sinusoidal response at wavelength where the power transfer rises and falls completely with wavelength from 100% to 0 at certain wavelength. Such a coupler can be applied to wavelength-division multi/demultiplexers (WDM) with two signals of 1.31 μm and 1.55 μm. However, this design is not favorable for 50%-50% signals branching irrespective of the wavelength.

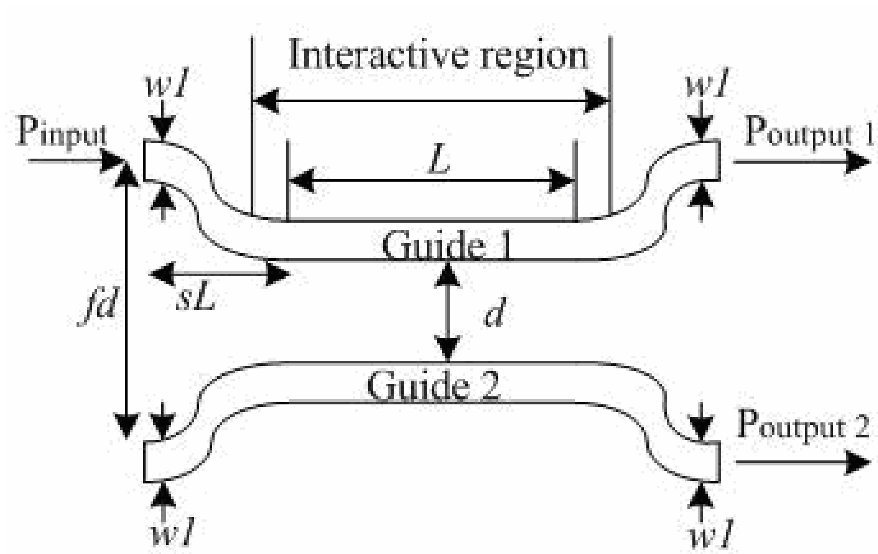


Figure 1: Top view of the uniformity symmetric directional coupler design for wavelength-divisionmulti/demultiplexer with two signals of 1.31 µm and 1.55 µm

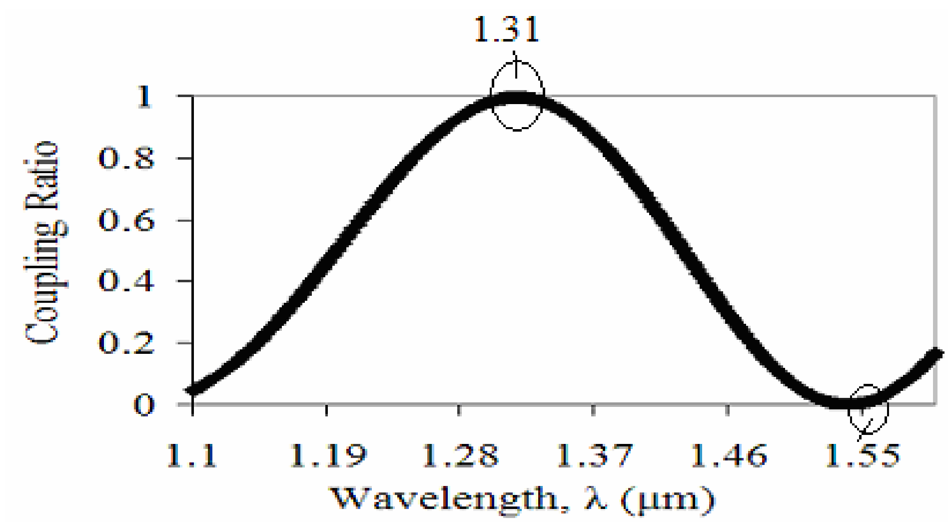


Figure 2: Typical sinusoidal wavelength response for a uniformly symmetric (conventional) coupler. Result obtain using BPM with parameter values are width, $w1$ = 3.5 µm, separation, d = 1.7 µm, L = 1.22 mm and Δn = 2.71%

Figure 3 shows the top view of designed asymmetric directional coupler consists of tapered waveguide and uniform waveguide at guide 1 and guide 2, respectively. We will call this type as T-S type directional coupler. In this analysis, three parameters has been varied, which is central coupling length, L, guide gap, d and identical values of Δn = 1.96% and sL = 5 mm.

Figure 4 shows a typical wavelength flattened response calculated by BPM for a T-S type directional coupler. The solid and dotted curves are calculated by varying the parallel coupling length L under the following conditions; $w1$ = 4.0 µm, $w2$ = 4.5 µm, Δn = 1.96% and d = 3.0 µm for figure 4 (a) and d = 3.5 µm for figure 4 (b).

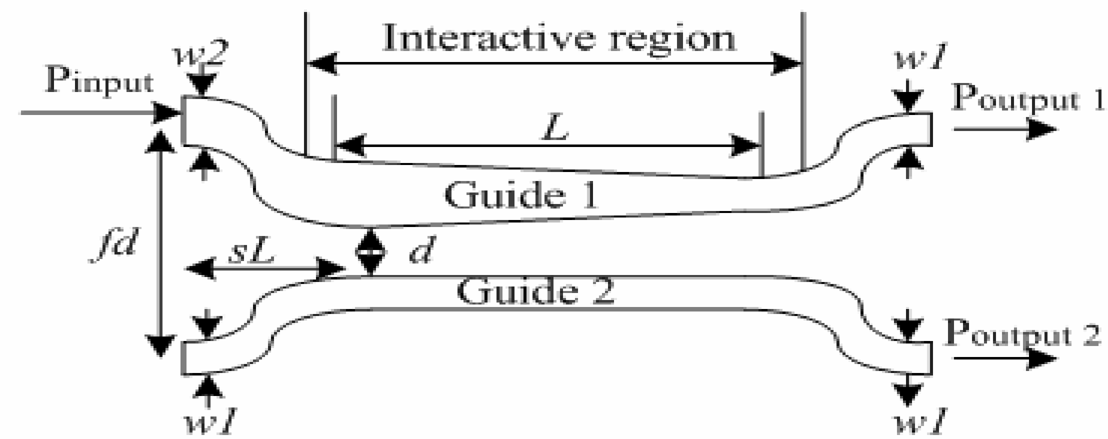
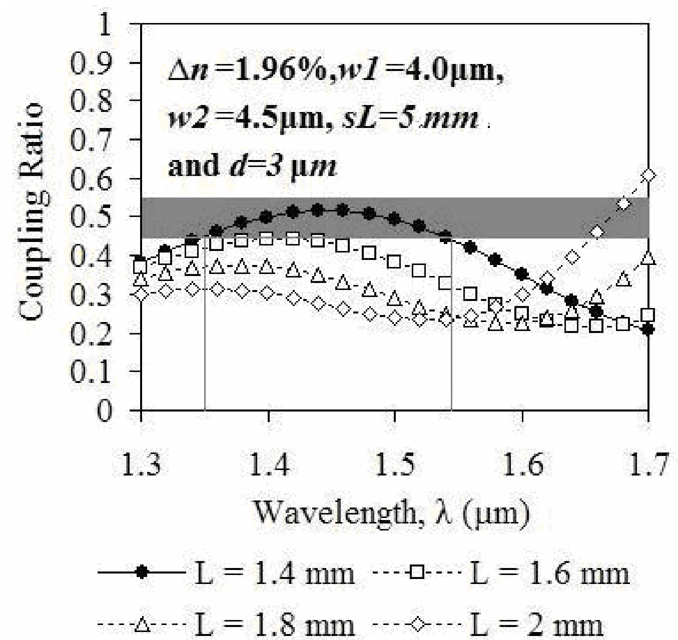


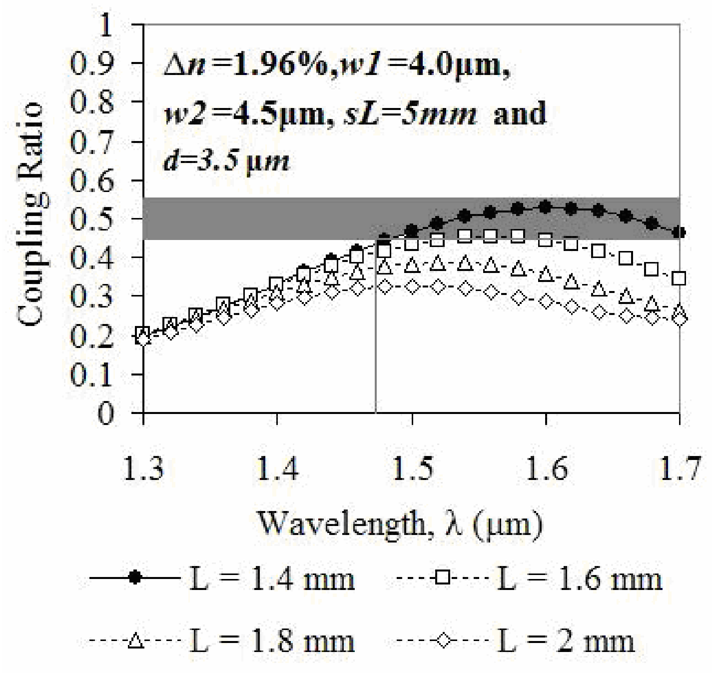
Figure 3: Top view of the T-S asymmetric directional type designed with a tapered and uniform waveguide.

Figure 4 (a) which the guide gap, d = 3 µm shows that for all L, the wavelength is flattened over 1.33 µm to 1.55 µm but at different coupling ratio. The coupling power change drastically after 1.55 µm especially for L = 1.8 mm and L= 2.0 mm. When the two guides are brought into proximity, the field of each guide will be perturbed in some manner by the presence of the other dielectric waveguide. In the case of d = 3 µm, the perturbation will be high, thus the coupling ratio is drastically change over the wavelength. The solid line with closed circled is the most 50% ± 5% wavelength flattened compared to other curves at 1.33 µm to 1.55 µm. Mode enter the front of guide 1 will stays longer inside the core of guide 1 because the width of front guide is wider compared to the end of guide 1. Thus mode stays longer inside the core 1 and slowly transfers its power into core 2.

Figure 4 (b) shows the coupling ratio versus wavelength with same parameter as figure 4 (a) but at d = 3.5 µm. We can see clearly the coupling ratio change smoothly over the entire wavelength. At d = 3.5 the perturbation will be small, thus the coupling ratio is not change drastically over the wavelength. The power transfer in the core is suppressed to 50% ± 5% coupling ratio over a wide range of 1.48 µm-1.70 µm at L = 1.4 mm. This can be realized due to mode which enters core 1 has long duration to transfer it power to core 2 because the separation between two guides is far and it makes the wavelength flattened region as shown in figure 4 (a) shifts towards longer wavelength as shown in figure 4 (b).



(a)



(b)

Figure 4: (a) Simulated results of T-S type asymmetric directional coupler. The closed circled shapes with solid line were found to be 50% ± 5% flattened over the range of 1.33 μm – 1.55 μm. (b) The parameter values is same as (a) but at different *d*, which the closed circled shapes with solid line represent 50% ± 5% flattened over the range of 1.47 μm – 1.7 μm.

CONCLUSION

In this paper the performance of coupling ratio towards wavelength for symmetric and T-S asymmetric directional couplers were described.Coupling responses towards wavelength have direct influenced with coupling parameters such as interactive region length, *L*, waveguide separation, *d*, guide width *w* and refractive index difference, Δn. It is concluded that the parallel coupling length *L* is the most controllable of all parameters.

It is found that the symmetric structure is more suitable to be used in wavelength division demultiplexer/multiplexer (WDM) application. This is due to its ability to transfer power from 0% to 100% at certain wavelength. Obviously this structure is not suitable for 3 dB coupler.

The asymmetric structure can be seen as wavelength flattened coupling ratio over wide range by selecting the proper asymmetric strength. A T-S type directional coupler obtained a 50% ± 5% wavelength flattened at 1.33 μm to 1.55 μm and 1.48 μm to 1.70 μm for d = 3 μm and d = 3.5 μm respectively. Coupling responses towards 50% ± 5% wavelength flattened made the asymmetric structure suitable for 3 dB directional couplers.

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