Prism Coupling of Light in Optical Waveguides

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Abstract: We report the results of simulation showing light coupling in waveguides through prism coupling method. Prism coupling method of light coupling in waveguides is a dominant method adopted by photonic device fabricators. It is necessary to understand the effect various parameters on light coupling in such processes. We used industry standard PDE solver COMSOL Multiphysics to study and analyze the results. It is assumed that light enters at one of the input coupling prism and is decoupled via another prism. Various parameters such as air gap between the prism and waveguide, angle of prism, misalignment between the prism and waveguide, effect of epoxy used to bind prism with waveguide, etc are analyzed. Also the effect of index mismatch between the prism and waveguide also understood. Wave equation obtained from Maxwell's equations are employed which are solved using COMSOL.

Keywords: Waveguide, light coupling, waveguide losses, optical communication.

1. Introduction

Optical communication dominates over all existing types of communication modalities. Light coupling and losses occurring while coupling through various types of waveguides still is an important issue. Looking into the recent progress on optical computing, ultrafast communication methods, as well as nanolasers, etc. requires appropriate lossless methods of light coupling. Light coupling through prism is not new, and is widely used over the years [1-3].

Prism couplers are also used to measure the refractive index/birefringence and thickness of dielectric and polymer films. Since refractive indices of a material depend upon the wavelength of the electromagnetic radiation transmitted, a monochromatic laser is used in conjunction with a prism of known refractive index. The laser beam is directed through a side of the prism, bent, and is normally reflected back out the opposite side into a photo detector. However, at certain values of the incident angle θ, the beam does not reflect back out, but instead is transmitted through the base into the film sample. These angles are called mode angles. The first mode angle found determines the refractive index, and the angle difference from one mode to the next determines the sample thickness.

Prism couplers also allow for coupling light in and out of a waveguide without exposing the cross-section of the waveguide (edge coupling). The prism coupling methods was first introduced by Ulrich and Tien [4]. To achieve phase matching condition, it is required between the propagation constant of the *m*th mode in the waveguide β_m and the incident light at an angle θ_m normal from the waveguide surface.

$$\beta_m = \frac{2\pi}{_0} n_p \sin\theta_m \qquad \text{.....(1)}$$

where n_p is the index of refraction of the prism. Major difference between prism coupling and butt-coupling is mode selection. Prism based methods are couples modes especially, if they are transverse modes. Figure 1, depicts common structure used for light coupling through prism.

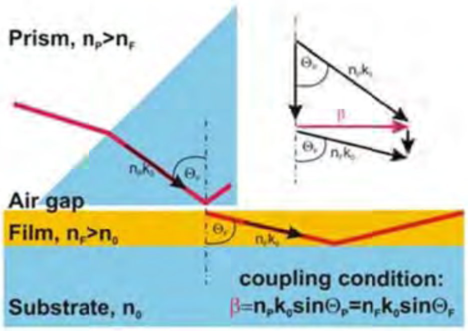

Figure 1. schematic of light coupling in waveguides through prism.

Coupling of light directly from air (without the prism) into a waveguide is not possible. It can be shown that the phase matching condition is:

$$\beta_m = kn_1 \sin\theta_m \quad .....(2)$$

where n_1 is the index of air (~1) and β_m is the propagation constant of the waveguide. In order to have a guided mode, $\beta_m > kn_1$. This would imply that $\sin\theta_m > 1$, which is not possible.

2. Methodology

We assumed that a circular symmetric Gaussian beam is coupled through the face of a prism. Basic diagram used is shown in figure 2.

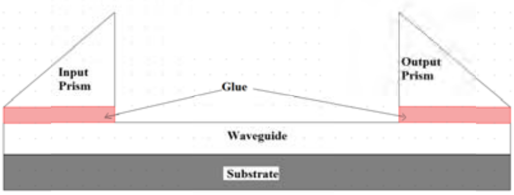

Figure 2. Basic template used for prism coupling. The strip between prism and the waveguide is glue.

Numerous literature are available on the theoretical aspects of light coupling through waveguides. We used the standard method available in Ref. 2 and 5. The simulations are carried out using COMSOL. We considered the following to optimize for maximum coupling through waveguide devices; (i) Effect of prism angle and (ii) effects optical properties of glue and substrate.

3. Use of COMSOL Multiphysics *(Optional)*

A layout similar to the one as given in Fig. 2 is drawn using COMSOL editor. Electric field amplitude of 5V is applied along the boundary 6 (that is the input plane of prim 1). The subdomain settings used are given in Table 1. After creating appropriate fine mesh results are found.

TABLE 1 : Subdomain (SD) settings used.

Setting	SD1	SD2,4	SD3	SD5
n	2	1	2.05	1.92

4. Results

In a integrated optical (IO) circuits as well as in IO elements light coupling to waveguide is major source of loss. Also decoupling of light and recoupling the same light another components leads multiplied losses. The coupler in the present case is a right angle prism which is fixed on the waveguide using transparent epoxy. The epoxy in turn adds its own loss.

Accordingly, to understand the various sources of losses, due to the nature of epoxy, angular mismatch in fixing the prism and thickness of epoxy, we used COMSOL Multiphysics and the results are summarized in Figures 3, 4 and 5.

4.1. Case I: Refractive Index of Epoxy

As evident from figure 3, if butt coupling is used (no epoxy; only in the presence of air), we could find that the light is coupled through the waveguide, however the coupling efficiency changes dramatically when the refractive index (n_e) of epoxy reaches a value in between the refractive indies of either the waveguide (n_W) or prim (n_p). Maximum coupling is noticed when the $n_e = n_W$. However, maximum decoupling occurs when $n_e = n_p$.

4.2. Case II: Angle of Prim

The effect of mismatch in alignment of prism is demonstrated in Fig. 4. As expected maximum coupling occurs when perfect alignment (mismatch = 0 deg) is achieved. Interestingly, best decoupling is noticed when mismatch is nearly equals to 1 deg.

5. Conclusions

Using COMSOL multiphysics RF module, we studied the effect of epoxy on prism coupling of light through waveguides. Best coupling is achieved when the refractive indies of prism and epoxy are of the same order, while maximum decoupling is notices for $n_e = n_p$ and when an angular deviation of one degree is given to the prism decoupler.

6. Acknowledgements

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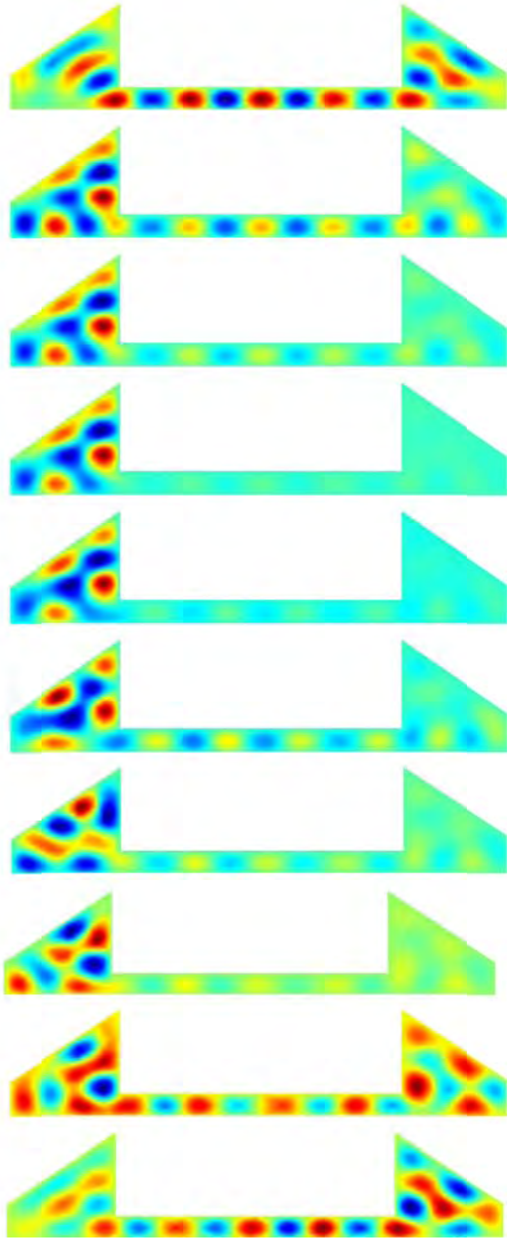

Figure 3. Effect of refractive index of adhesive on light coupling is demonstrated. From the top image to bottom the change in refractive index of glue is changed from 1.0 (air) to 2.0 (prism). The refractive indies of prism and waveguide are assumed to be 2.05 and 2.0, while the thickness of the waveguide s assumed to be 150nm. It is very clear that maximum coupling occurs when the refractive index of glue is nearly equals to that of prism or waveguide.

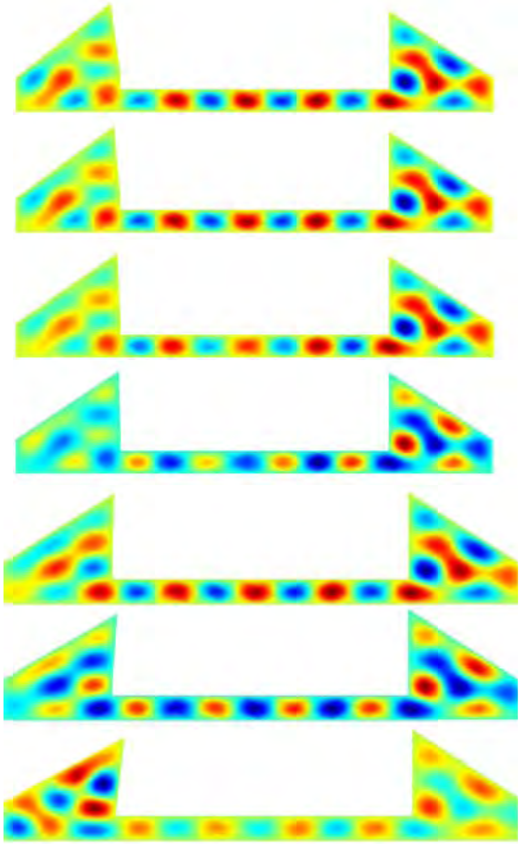

Figure 4. Effect of angle mismatch on coupling and decoupling losses in optical waveguide. In Figures 2 and 3, same optical parameters are used, however, the ref. index is adhesive is fixed at 2.0 while the angle of the prism is varied from +5 deg to -5 deg. It is interesting to note that maximum coupling occurs for prism orientation of ±1deg with respect to the substrate. However, maximum decoupling occurs for 0deg. Detailed analytical and numerical understanding is required to understand this anomaly.

7. References

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