6. Waveguide Input and Output Couplers

Some of the methods of coupling optical energy into or out of a waveguide were mentioned briefly in Chap. 5. In this chapter, we shall consider in more detail the various coupling techniques that can be used. The methods that are employed for coupling an optical beam between two waveguides are different from those used for coupling an optical beam in free space to a waveguide. Also, some couplers selectively couple energy to a given waveguide mode, while others are multimode. Each type of coupler has its attendant set of advantages and disadvantages; none is clearly best for all applications. Hence, a knowledge of coupler characteristics is necessary for the OIC user, as well as for the designer.

Coupler fabrication is generally accomplished by using techniques such as photoresist masking, sputtering and epitaxial growth, which have been described in Chap. 4; thus, a separate chapter devoted to coupler fabrication is not required. However, certain specialized methods, such as holographic exposure of photoresist to make grating couplers, are discussed in this chapter.

6.1 Fundamentals of Optical Coupling

The principal characteristics of any coupler are its efficiency and its mode selectivity. Coupling efficiency is usually given as the fraction of total power in the optical beam, which is coupled into (or out of) the waveguide. Alternatively, it may be specified in terms of a coupling loss in dB. For a mode-selective coupler, efficiency can be determined independently for each mode, while multimode couplers are usually described by an overall efficiency. However, in some cases it is possible to determine the relative efficiencies for the various modes of a multimode coupler. Thus, the basic definition of coupling efficiency is given by

\[
\eta_{cm} = \frac{\text{power coupled into (out of) the } m\text{th order mode}}{\text{total power in optical beam prior to coupling}} \quad (6.1.1)
\]

and coupling loss (in dB) is defined as

\[
\mathcal{L}_{cm} = 10 \log \frac{\text{total power in optical beam prior to coupling}}{\text{power coupled into (out of) the } m\text{th order mode}}. \quad (6.1.2)
\]
If the power in each mode cannot be separately determined, overall values of \( \eta_{cm} \) and \( \mathcal{J}_{cm} \) are used.

Coupling efficiency depends most strongly on the degree of matching between the field of the optical beam and that of the waveguided mode. This principle can be best illustrated by considering the case of the transverse coupler.

## 6.2 Transverse Couplers

Transverse couplers are those in which the beam is focused directly onto an exposed cross-section of the waveguide. In the case of a free space (air) beam, this may be accomplished by means of a lens. Transverse coupling of two solid waveguides may be done by butting polished or cleaved cross-sectional faces together.

### 6.2.1 Direct Focusing

The simplest method of transverse coupling of a laser beam to a waveguide is the direct focusing or *end-fire* approach shown in Fig. 6.1. The waveguide may be of either the planar or channel type, but we assume a planar waveguide for the moment. The transfer of beam energy to a given waveguide mode is accomplished by matching the beam-field to the waveguide mode field. The coupling efficiency can be calculated from the overlap integral [6.1] of the field pattern of the incident beam and the waveguide mode, given by

\[
\eta_{cm} = \frac{\left[ \int A(x) B_m^*(x) \, dx \right]^2}{\int A(x) A^*(x) \, dx \int B_m(x) B_m^*(x) \, dx},
\]

where \( A(x) \) is the amplitude distribution of the input laser beam, and \( B_m(x) \) is the amplitude distribution of the \( m \)th mode.

![Fig. 6.1. The transverse coupling method, which is sometimes referred to as *end-fire* coupling](image)