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Numerical Analysis of Grating-Assisted Waveguide Couplers
(Grating-Assisted 도파관 커플러의 수치 해석)

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Abstract

The wavelength selectivity in grating-assisted optical waveguide couplers is studied using a matrix method to analyse optical filter characteristics. The matrix method is extended to both 2-system modes and all guided system modes. The influence of fundamental design parameters on the performances of the optical filters by waveguide couplers is discussed.

In integrated optics, the optical waveguide couplers are often used to realize the optical filters [1]. These waveguide couplers usually consist of the parallel waveguide coupled each other by means of the overlap of the evanescent fields between these waveguides. The filter characteristics of the optical waveguide coupler can be calculated by several numerical methods such as a matrix method [2,3], a coupled mode theory [4], and so on.

A matrix method is here employed to analyse the grating-assisted waveguide couplers [5] for the purpose of the filter operations. The basic structure of a grating-assisted waveguide coupler is shown in Fig. 1. The calculation is here restricted by the two system modes. There are the forward traveling system modes b_o^+ and b_1^+ on the left side of the interface A. At the same time, the backward traveling system modes b_0^- and b_1^- are also appeared. The mode amplitudes in the forward and the backward traveling waves on the right side of interface A can be determined by the boundary conditions of the electric fields and the orthogonal relation.

$$
\begin{aligned}
c_o^+ = \; & b_0^+ \frac{\int_{-\infty}^{+\infty} E_0 E_0' \, dy}{\int_{-\infty}^{+\infty} E_0'^2 \, dy} \cdot \frac{\beta_0' + \beta_0}{2\beta_0'} \; + \\
& b_0^- \frac{\int_{-\infty}^{+\infty} E_0 E_0' \, dy}{\int_{-\infty}^{+\infty} E_0'^2 \, dy} \cdot \frac{\beta_0' - \beta_0}{2\beta_0'} \; + \\
& b_1^+ \frac{\int_{-\infty}^{+\infty} E_1 E_0' \, dy}{\int_{-\infty}^{+\infty} E_0'^2 \, dy} \cdot \frac{\beta_0' + \beta_1}{2\beta_0'} \; + \qquad (1)
\end{aligned}
$$

$$b_1^- \frac{\int_{-\infty}^{+\infty} E_1 E_0' \, dy}{\int_{-\infty}^{+\infty} E_0'^2 \, dy} \cdot \frac{\beta_0' - \beta_1}{2\beta_0'}$$

$$= M_{00} b_0^+ + M_{01} b_0^- + M_{02} b_1^+ + M_{03} b_1^-$$

$$c_o^- = b_0^+ \frac{\int_{-\infty}^{+\infty} E_0 E_0' \, dy}{\int_{-\infty}^{+\infty} E_0'^2 \, dy} \cdot \frac{\beta_0' - \beta_0}{2\beta_0'} +$$

$$b_0^- \frac{\int_{-\infty}^{+\infty} E_0 E_0' \, dy}{\int_{-\infty}^{+\infty} E_0'^2 \, dy} \cdot \frac{\beta_0' + \beta_0}{2\beta_0'} +$$

$$b_1^+ \frac{\int_{-\infty}^{+\infty} E_1 E_0' \, dy}{\int_{-\infty}^{+\infty} E_0'^2 \, dy} \cdot \frac{\beta_0' - \beta_1}{2\beta_0'} + \quad (2)$$

$$b_1^- \frac{\int_{-\infty}^{+\infty} E_1 E_0' \, dy}{\int_{-\infty}^{+\infty} E_0'^2 \, dy} \cdot \frac{\beta_0' + \beta_1}{2\beta_0'}$$

$$= M_{10} b_0^+ + M_{11} b_0^- + M_{12} b_1^+ + M_{13} b_1^-$$

The mode amplitudes c_l' and c_l^- can be analogously obtained by replacing $\beta_1'$and E_l' with β_0' and E_0'. The matrix for the transition at the interface A is represented by

$$\underline{M_A} = \begin{pmatrix} M_{00} & M_{01} & M_{02} & M_{03} \\ M_{10} & M_{11} & M_{12} & M_{13} \\ M_{20} & M_{21} & M_{22} & M_{23} \\ M_{30} & M_{31} & M_{32} & M_{33} \end{pmatrix} \quad (3)$$

The matrix for the phase shift in the area 1 is given by

$$\underline{P_A} = \begin{pmatrix} e^{-j\beta_0 l} & 0 & 0 & 0 \\ 0 & e^{-j\beta_0 l} & 0 & 0 \\ 0 & 0 & e^{-j\beta_1 l} & 0 \\ 0 & 0 & 0 & e^{-j\beta_1 l} \end{pmatrix} \quad (4)$$

The entire matrix for the coupler is expressed by the multiplication of each separate matrixes for each transitions

$$\begin{pmatrix} a_0^+ \\ a_0^- \\ a_1^+ \\ a_1^- \end{pmatrix} = \underline{M_1} \cdot \underline{P_1} \cdot \cdot \cdot \underline{M_n} \cdot \underline{P_n} \begin{pmatrix} d_0^+ \\ d_0^- \\ d_1^+ \\ d_1^- \end{pmatrix} \quad (5)$$

This method can be also extended to more system modes. The fundamental calculations are not still changing even though the formulas become accordingly more extensive.

In the first place, a grating-assisted waveguide coupler shown in Fig. 2 is calculated. This coupler has a structure with symmetrical refractive index, i.e. both waveguides have the same refraction index of n_2=n_4=3.5, and the refractive index of n_1=n_3=n_5=3.2 of the substrate is chosen. The width of the both waveguides is 1.0μm. The average distance d between waveguides is 0.5 μm and the grating thickness t of the waveguide 1 is 0.1μm. The optical filter characteristic of this structure has been calculated at the wavelength of 1.50μm. It is known by solving the wave equation that the five system modes can be guided in this coupler. The results obtained by the matrix method with two system modes and five system modes are compared each other. The optical coupler should be excited by the high guided two system modes at the grating waveguide. In this case, Fig. 3(a) shows the guided energy along the grating waveguide (dotted line) and the cross coupled energy to the straight waveguide (solid line) as a function of the filter length. The energy losses are appeared during the wave propagation. When the five system modes are launched at the beginning of the grating waveguide, it is obvious that the energy loss is eliminated by the considering the effect of the higher order modes (Fig. 3(b)). The results of the matrix method with five system modes have been explained as entire energy can be maintained without losses.

The filter properties of a contra-directional coupler shown in Fig. 4 is also calculated. The refractive index of the waveguide is chosen as n_2=3.5 and the the other index values are as n_1=n_3=3.2. The thin width w_1 of the filter is

$0.1\mu m$ and the thick width w_2 of that is $0.3\mu m$. The filter characteristics for this coupler with the 200 transitions are calculated and then the results are compared with those of the coupled mode theory. The clear discrepancy could be found in the width of the main maximum and the strength of the beside maximums (Fig. 5). The calculated filter properties by the matrix method (solid line) have a bandwidth of about 60nm, whereas the bandwidth of 22nm for the contra-directional coupler is obtained using the coupled mode theory (dotted line).

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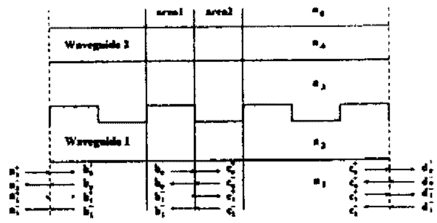


Fig. 1. The forward and backward traveling waves at each interface

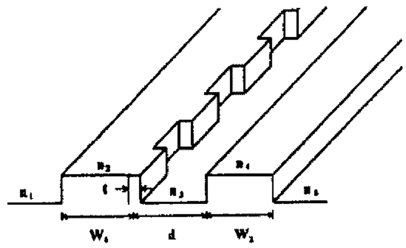
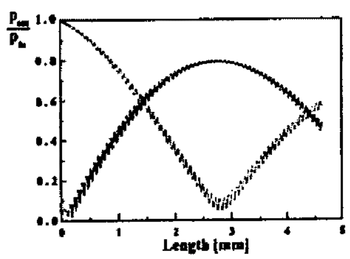
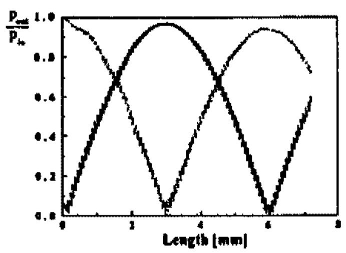


Fig. 2. Structure of a grating-assisted waveguide coupler



(a)

(a) two system modes



(b)

(b) five system modes

Fig. 3. Power ratio by launching

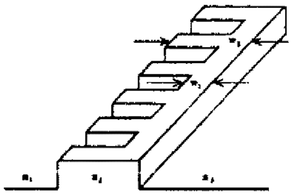


Fig. 4. Structure of a contra-directional coupler

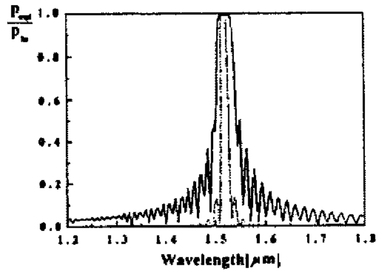


Fig. 5. Filter characteristics of a contra-directional coupler