COST-216 COMPARATIVE STUDY OF S-BEND AND DIRECTIONAL COUPLER ANALYSIS METHODS

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Abstract

Modelling methods for the calculation of the insertion loss of S bends and for the design of a directional coupler are compared. Accurate experimental data are available for the analysed waveguide structures.

1. Introduction

The COST (European Cooperation in the Field of Scientific and Technical Research) project 216 consists in studying the technology and characterization of advanced devices for optical switching and routing. Within the Working Group "Device Modeling" attention is focussed on the modeling of optical waveguide switches. As a first effort the group compared various modeling techniques for the eigenmode analysis of integrated optical ridge waveguides [1,2]. This paper reports on a comparative study of analysis methods to calculate the insertion loss of S-bends and to design a directional coupler. In the case of the S-bends the total loss is calculated as function of the radii of the bends and the effect of a transverse offset between the two curved sections of the S-bend is investigated. For the directional coupler the coupling length of the parallel guides is calculated and the influence of the S-bends on the overall coupling of the device is investigated. In order to make a sound comparison between the numerical and experimental results, much attention was paid to a careful selection of accurate experimental data. The working group acknowledges the Technical University of Delft and the Heinrich Hertz Institute for providing these data.

2. Analysed structures and compared modeling techniques

Two types of ridge waveguides are considered: a weakly guiding one (the HHI guide, Fig. 1) and a strongly guiding one (the RNL-TUD guide, Fig. 3). S-bends were fabricated for both types. The directional coupler is based on the HHI guide (Fig 2). The waveguide parameters for both types are given in Table 1. For the HHI guide the quasi-TE fundamental mode is used and for the RNL-TUD guide the quasi-TM modes EH_{00} and EH_{01} are considered.

For the directional coupler the power ratio at B with respect to the input power at A is calculated with h = 25. mm, r = 40. mm, a gap g = 2.5 µm, and for lengths of the straight guides x = 1., 2., 3., and 4. mm (hereafter refered to as task I).

For the HHI S-bend the total insertion loss is calculated with height h = 25. mm, offset s = 0. µm and for radii r = 10., 15., 25., and 40. mm (task II.1). The same calculation is done with h = 25. mm, r = 15. mm and for offsets s = 0., 0.5, 1., and 1.5 µm (task II.2).

This calculation is repeated with the RNL-TUD S-bend (Fig. 4) for the following 5 cases: r_2 = 50 µm, s = 1.53 µm; r_2 = 75 µm, s = 1.20 µm; r_2 = 100 µm, s = 1.05 µm; r_2 = 150 µm, s = 0.85 µm; r_2 = 200 µm, s = 0.73 µm and with fixed parameters: h = 410 µm, r_1 = 200 µm (task III).

The compared modeling techniques [2] are: the effective index method (EIM), either on its own or in conjunction with the beam propagation method (BPM), the corrected effective index method (CEIM), the discrete sine method (DSM), the domain integral method (DIM), the coupled mode theory (CMT), the method of lines (MoL), conformal mapping to straighten out the bends, the leaky mode method (LMM) and a perturbation method (PM). The reader is referred to [2] for more details about most of those methods. Figs. 5-7 indicate which method or combination of methods was used by each research group.

waveguide parameters (in µm):	w	t	dt	λ
task I: HHI directional coupler:	3.	1.1	0.225	1.286
task II: HHI S-bend:	2.	1.3	0.300	1.286
task III: RNL-TUD S-bend	ws = 2.5 wc =3.5	0.240	0.100	0.6328

Table 1: Waveguide parameters

3. Numerical results

Task I. Fig. 5 represents the power ratio P(B)/P(A) for the four lengths z of the parallel section as obtained by each research group. From coupled mode theory, it follows that the cross-coupling between two straight parallel guides is given by $P(z) = P(0)\sin^2[K_c z]$, where the coupling constant $K_c = (\pi/2)/L_c$, and L_c is the coupling length. By defining y = arcsin $[\sqrt{(P(z)/P(A))}]$, and z as the length of the straight guides of the coupler, the obtained data can be converted to a linear y(z) graph. This graph has the form $y(z) = K_c\,(2l_{add} + z)$, where $2l_{add}$ stands for an additional physical length representing the coupling between the S-bends at the beginning and end of the coupler. The coupling in the physical coupler is then equivalent to the coupling between a pair of parallel guides with physical length $z + 2l_{add}$.

Task II. A comparison of the calculated and measured values for the S-bend loss will be presented.

Task III. Figs. 6 - 7 show the computed and measured total insertion loss of the RNL-TUD S-bend structure. The differences between the calculated results increase sharply with the curvature of the bend. For the fundamental mode, the mean of the calculated value is about 0.5 - 1.0 dB below the measured figure (except at r_2 = 50 µm), but shows the same general behavior as the measurements. Due to the use of different widths for the straight and curved parts of the guide and of a transverse offset, low insertion losses can be obtained for rather high curvatures with this type of waveguide (< 1 dB for r_2 = 150 µm). By optimizing this technique a bending loss of 0.6 dB for a radius of 50 µm was recently reported [3]. For the second mode, the differences between the calculated and measured values is much larger. Since a mode of a higher order is more difficult both to model and to measure this could be expected.

4. Conclusions

Most of the available numerical methods to analyse realistic passive device structu such as S-bends and directional couplers, have been reviewed. In this way both the accur of the different methods and the way they are actually implemented by the different resea [illegible] could be compared. We refer the reader to the oral presentation of this paper for a more extensive discussion of the results. Some general conclusions are given here.

From Fig. 5, it can be seen that there is a good agreement between the different implementations of the EIM+BPM combination and between the EIM, CEIM and an exact method such as the DIM. The small differences between the different BPM results are due to differences in discretization and parameters such as the propagation step size and absorber conditions. For some methods such as the DSM, the MoL and CMT the difference with the other methods grows slightly with the length of the device.

For the RNL-TUD S-bends there is less agreement between the simulations, as can be seen from Figs. 6 - 7. Between the different implementations of the EIM+BPM+conformal mapping schemes the agreement is good for small curvatures and offsets. However, they increase rapidly with the curvature and the offset of the bend. The other methods show larger differences.

5 References

[1] P. Lagasse et. al., "COST-216 comparative study of eigenmode analysis methods for single and coupled integrated optical waveguides", 14th ECOC, Sept. 1988.

[2] P. Lagasse et. al., "Comparison of different modeling techniques for longitudinally invariant integrated optical waveguides", IEE Proc.,J. Optoelectronics, 136,Pt. J, no. 5, Oct 1989.

[3] E. Pennings et. al., "Reduced bending and scattering losses in a new optical 'double ridge' waveguide", Electronics Letters,25(11),1989.

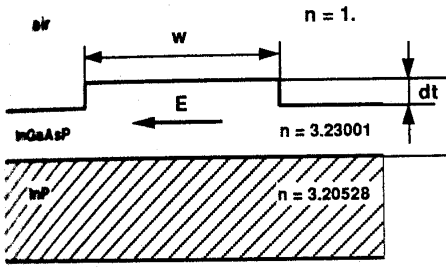


Fig. 1. HHI ridge waveguide: cross section.

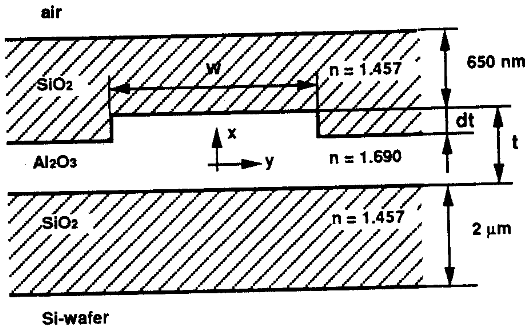


Fig. 3 RNL-TUD rib waveguide: cross section.

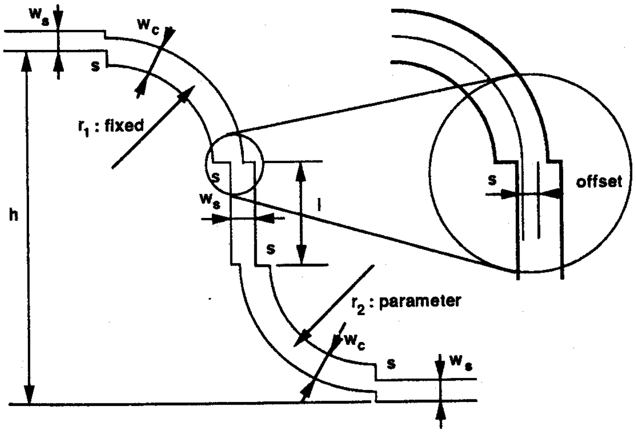


Fig. 4 RNL-TUD S-bend.

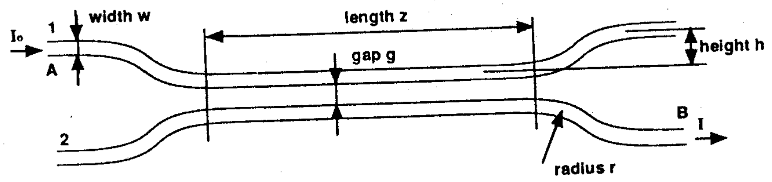


Fig. 2 HHI coupler.

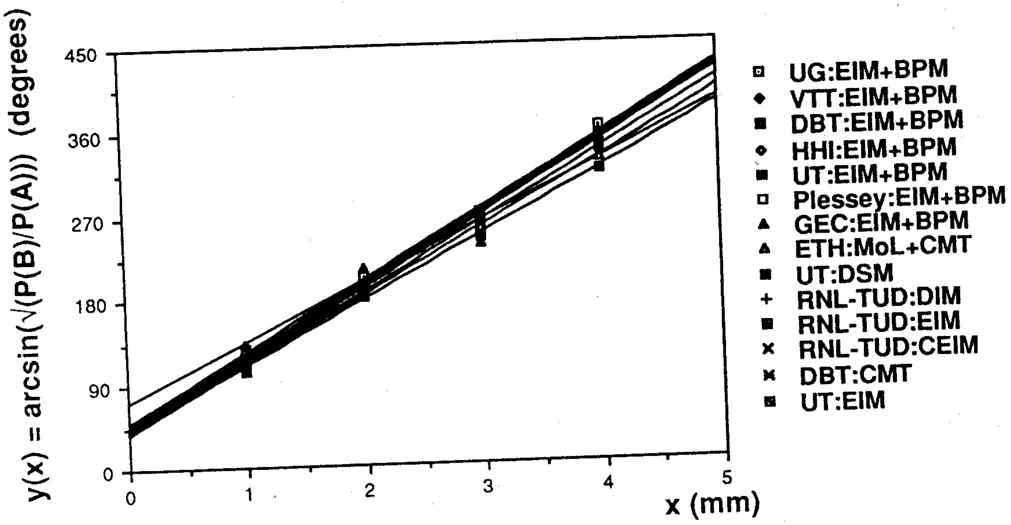
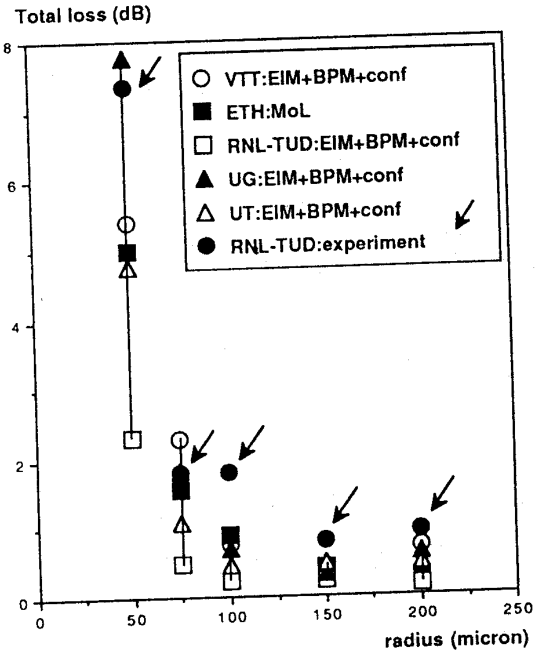


Fig. 5 Task I: HHI coupler.



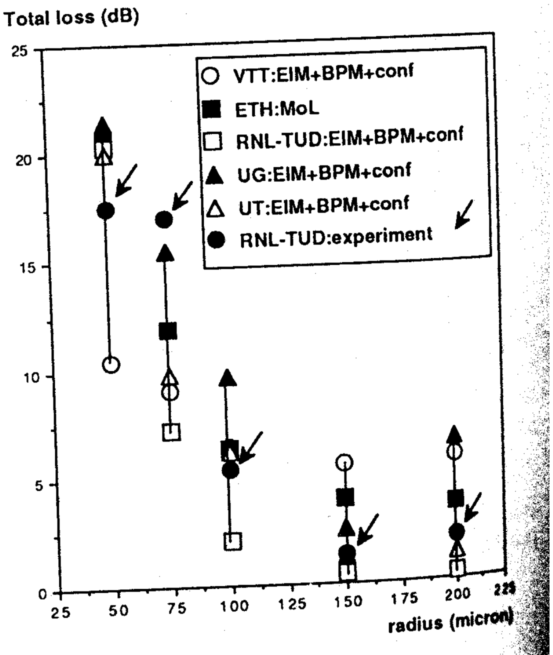


Fig. 6 Task III.1: RNL-TUD S-bend, EH(00)-mode.

Fig. 7 Task III.1: RNL-TUD S-bend, EH(01)-mode.