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Low-Crosstalk and Low-Loss Waveguide Crossings on InP with Small Dimensions

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With the increasing scale of integration, resulting in a higher on-chip complexity, waveguide crossings with good performance are becoming increasingly important. Worst-case paths contain a high number of crossings, depending on the number of channels being processed, in switching matrices [1], multiwavelength add drop filters [2] ~~(up to 15), and optical cross-connects~~ [3]. Crossings with very low crosstalk and loss can be realized in fiber-matched waveguide structures as used in lithium niobate or silica-based technology [4, 5]. In highly integrated semiconductor devices, crossings may contribute significantly to the loss and crosstalk performance. In this paper we present the results of a series of experiments for the design of high-performance semiconductor waveguide crossings.

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Design

For our experiments we used a ridge-type waveguide structure as depicted in Figure 1. Two methods have been used to analyze the performance of waveguide crossings realized in this structure, both in combination with a two-dimensional *Effective Index Method* (EIM), and both for TE and TM polarization. First, the theory of *Multiple Scattering Interaction* (MSI) [6] was used, from which it can be found that the crosstalk vanishes for specific values of the intersection angle. These angles are also referred to as "magic angles." For the analyzed waveguide structure, the MSI predicts a magic angle at 10 to 11 degrees and one at 30 to 35 degrees, as depicted by dashed lines in Figure 2 (*a*, *b*). For the second analysis, which was performed for comparison, a two-dimensional *Beam Propagation Method* (BPM) was used. The results are shown as solid lines in the same graphs. It can be seen from these graphs that at the predicted magic angle of 10 to 11 degrees the BPM shows a local decrease in the crosstalk, which is, however, less pronounced as the value predicted with the MSI theory. This is probably due to power conversion from the fundamental mode to the first-order mode, which we observed with BPM analysis and is not accounted for by the MSI theory.

The fabrication tolerance of the magic angle was investigated by analyzing the effect of a change in the width of the waveguide. A 0.2-μm change in the waveguide width results in a shift of the magic angle of 1 degree. The crossings were investigated experimentally in an interval of a few degrees around both predicted magic angles. For a more accurate measurement of the excess loss, five crossings were placed in series.

Fabrication

Waveguide crossings have been fabricated in a MOCVD-grown InP/InGaAsP (λ_g = 1.3 μm)/InP ridge waveguide structure. A 100-nm thick PE-CVD deposited SiN_x film was used as the masking layer, and waveguides were RIE-etched using CH_4/H_2 to a depth of 80 nm into the guiding layer employing an etch/descum

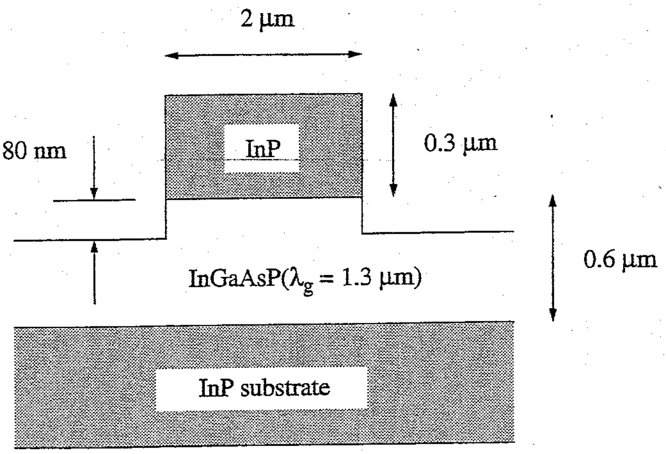
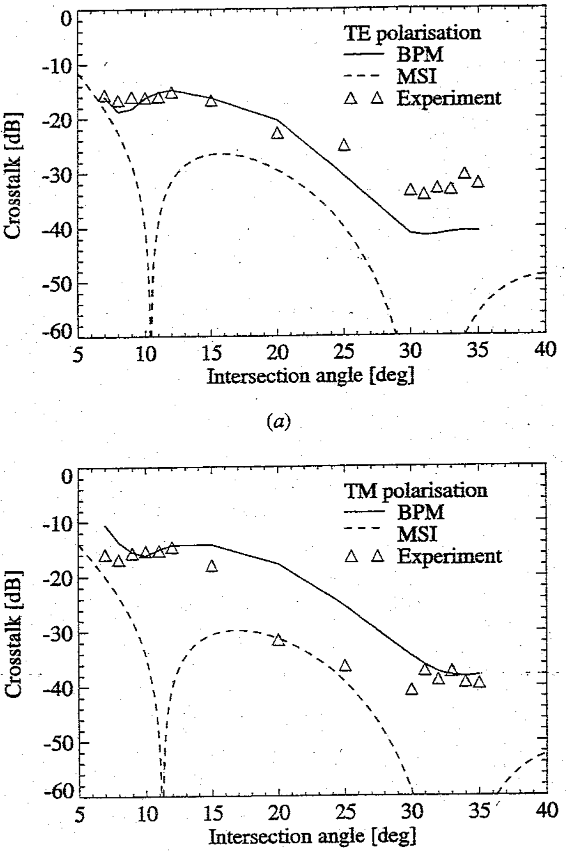


Figure 1. Schematic diagram of the used waveguide structure.



(*a*)

(*b*)

Figure 2. Crosstalk values versus intersection angles for (*a*) TE polarization and (*b*) TM polarization. Lines denote predictions: two-dimensional BPM simulations (solid line) and theory according to [4] (dashed line).

process to reduce the scattering losses [7]. Waveguide losses were measured 1.8 dB/cm for both TE and TM polarization.

Experimental Results

A Fabry–Perot laser operating at 1508 nm was used to measure the crosstalk and excess loss of the crossings. Measurement results of the crosstalk are shown in Figure 2(*a*), (*b*) for TE and TM polarization, respectively. Crosstalk values lower than −30 dB have been measured for angles greater than 30 degrees. As can be seen in both graphs, the MSI gives a good prediction of the position of the magic angles, whereas the BPM also gives a good quantitative prediction. Figure 3 shows the excess loss, which reduces to values of less than 0.3 dB for intersection angles greater than 30 degrees for both TE and TM polarization. As additional losses are easily obtained, it is noted that the best excess loss values follow the predicted curves within the estimated measurement accuracy of 0.2 dB.

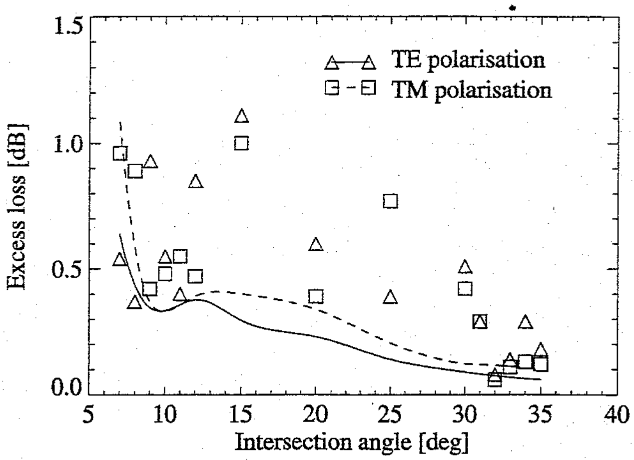


Figure 3. Excess loss of the crossings: lines denote two-dimensional BPM predictions.

Conclusion

Waveguide crossings with small intersection angles have been fabricated in a InP-based ridge waveguide structure. Crosstalk values of less than −30 dB and excess loss values of less than 0.3 dB have been measured for intersection angles down to 30 degrees, for both TE and TM polarization. It is shown that the MSI correctly predicts the magic angles, whereas a two-dimensional BPM gives a good quantitative fit to the experimental results. Further improving the performance of the semiconductor waveguide crossing will gain importance with increasing complexity of circuit designs.

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Biographies

Cornelis van Dam was born in Hague, The Netherlands, in 1967. He studied electrical engineering at the Delft University of Technology, receiving his master's degree in 1990. His thesis research was carried out in the integrated optics group of the Laboratory of Telecommunication and Remote Sensing Technology and concerned the development of a CAD-tool for the design and analysis of photonic integrated circuits using a microwave design system. In 1991 he was appointed to the scientific staff of the laboratory where he is currently carrying out his Ph.D research, which involves development of polarization independent integrated wavelength division demultiplexers.

Fokke H. Groen received the M.Sc. degree in electrical engineering from Eindhoven University of Technology, The Netherlands, in 1965. Until 1972 he was concerned with optical filtering and system theory at the Department of Electrical Engineering of this University. In 1972 he joined the Optics Research Group of the Department of Applied Physics, Delft Technical University. Since then his interests have been in lasers, nonlinear optics, digital holographic and speckle interferometry. During the last decade he was concerned with integrated optics on the basis of InP, mainly for telecom applications, with emphasis on process technology for passive waveguides, switches, and wavelength selective devices.

Jos J. G. M. van der Tol was born in Alphen a/d Rijn, The Netherlands, in 1956. He received the M.Sc., and Ph.D. degrees in physics from the State University of Leiden, Leiden, The Netherlands, in 1979 and 1985, respectively. His thesis treated the influence of magnetic fields on gasflows at very low pressures. In 1985 he joined PTT Research, where he worked on integrated optical components for use in advanced fibre optic communication networks. His research interests have covered modeling of waveguides, design of electro-optical devices on lithium niobate, and the realization of components. At present he is engaged in research on guided wave components on the III-V semiconductor material indium fosfide.

Meint K. Smit was born in Vlissingen, The Netherlands, in 1951. He studied electrical engineering at the Delft University of Technology (1969–1974), earning a masters degree (with honors) and a Ph.D degree (with honors). He started in 1974 as a research scientist with the NIWARS (Netherlands Interdepartmental Working Group on Application of Remote Sensing Technology). In 1976, he joined the Delft University of Technology as an assistant professor responsible for research in Microwave Remote Sensing and FM-CW radar development. He switched to optical communication in 1981, where he has set up facilities for fabrication of silicon-based integrated optical devices and invented the phased array wavelength demultiplexer, which is presently being widely applied. He worked on the design of multimode interference couplers, optical switches, the measurement and characterization of electro-optical devices, and the development of Computer Aided Design tools. From 1991 to 1992 he was on leave at the Institute of Quantum Electronics, ETH Zurich, where he worked on the development of a fast and compact polarization-independent optical switch.