Conditions for optimum performance of unbalanced MMI couplers

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Unbalanced Multi-Mode Interference (MMI) couplers are optical integrated components widely used in photonic integrated circuits. Couplers with two fixed coupling ratios: 85/15 and 15/85 are studied in this paper. Low loss MMI couplers are designed and fabricated. Excitation of the first-order mode in access waveguides of MMI couplers can influence the excess losses and the coupling ratio of these components. The effect of the first-order mode excitation was simulated and confirmed by the experimental results, which are presented in this paper.

Introduction

One of the widely used passive components in photonic integrated circuits is the optical coupler. For several applications an unequal distribution of the input light signal is required, e.g. over the branches of a Mach-Zehnder interferometer [1,2] or to implement a monitoring function. Multi-Mode Interference couplers are well known candidates for this because of a compact design and polarization independence of these devices [3]. They use the self-imaging property of a multimode waveguide: an image of the input field occurs after a certain distance. Multiple images appear after fractions of that distance.

MMI couplers are optical integrated components that are sensitive to technological deviations. The length of the multimode waveguide L_{MMI} (further in this paper *coupler length*) depends on the square of its width W_{MMI}. Photolithography and the etching process of ridge waveguides can introduce certain deviations to the waveguide width. Consequently, the coupler length becomes very dependent on these processes.

The dimensions of access waveguides are such that they are often supporting not only the zero-, but also higher order modes. This can for example be because of lithographical limitations. The first-order mode can deteriorate the performance of the couplers. Performance of the MMI couplers with unequal power distribution (further in this paper *unbalanced MMI couplers*) and the influence of the first-order mode on their operation are discussed in this paper.

Design of 85/15 and 15/85 MMI couplers

The layout of an unbalanced MMI coupler is schematically presented in figure 1. Two sets of MMI couplers with two different coupling ratios and consequently different lengths – 85/15 and 15/85 – were designed. In each of these sets, all couplers have identical access waveguides and a fixed width but varying coupler length. From this set, the optimal components could be chosen and influence of the lithographical deviations on the losses and splitting ratio could be investigated. The access waveguides have a width of 3 µm and bent with a radius of 500 µm. They are placed at $\frac{1}{4} W_{MMI}$ and $\frac{3}{4} W_{MMI}$ with respect to the edge of the multimode region. Their position is optimized with the optical circuit simulation program MDS [4]. The multimode region has a width of 10 µm.

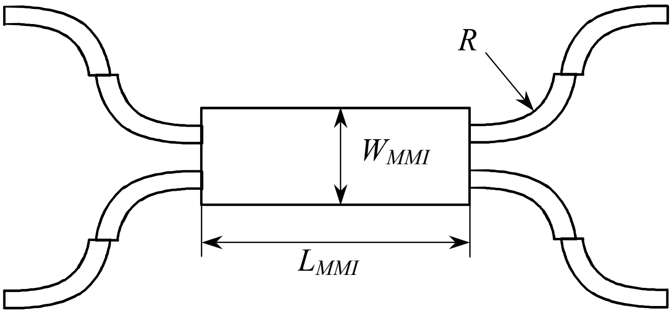

Fig. 1. Schematic layout of a MMI coupler

First-order mode influence

Excitation of the first-order mode in an access waveguide becomes significant when the input light source is not centered with respect to the middle of the waveguide. The first order mode can also be excited in bends. Influence of the lateral input displacement on the couplers performance and splitting ratios is presented below. The analysis of the devices described above is performed with a simulation program based on the Film Mode Matching method [5]. The simulation results for the coupler with a coupling ratio of 85/15 are presented in figure 2.

Fig.2a shows that a contribution of the first-order mode to the output power detected at the 85% output port is negligable. At the 15% output port (fig.2b), the first-order mode begins to play a dominant role after an input displacement of 0.65 µm and gets its maximum value at a displacement of 1.1 µm. Similar results we can obtain for the 15/85 couplers.

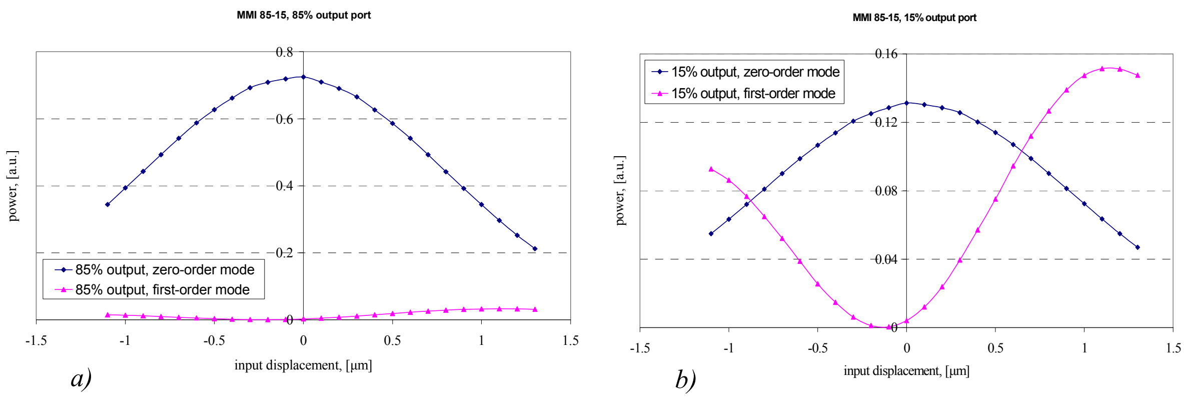

Fig. 2. Power in the zero- and first-order modes vs lateral displacement for 85/15 MMI coupler: a) at 85% output port, b) at 15% output port

Fabrication

The couplers were realized in an InGaAsP / InP layerstack grown by JDS Uniphase, The Netherlands. For the waveguide masking, a SiN_x-layer with a thickness of 100 nm was used. The ridge waveguides were etched employing an optimized $CH_4/H_2/Ar$ Electron Cyclotron Resonance etching process [6] alternated with steps of oxygen plasma process for removing polymers depositions. The etching depth into the film layer is 100 nm.

Measurement results

An Erbium-Doped Fiber Amplifier (EDFA) and a tunable filter (at λ=1550 nm) were used as a light source for characterisation (fig. 3). This was to avoid instability problems during measurements, mainly caused by the Fabry-Perot resonances in the chip as the facets of the chip were not anti-reflection coated. Such an input signal has a broader spectrum that allows to neglect the Fabry-Perot peaks. Coupling of light into the input waveguide and detecting light at the output was done with microscope objectives (MO). The objectives were maintained on the stages controlled by piezzoelectrical drivers. That allows to position an objective with a high degree of accuracy. Both output ports could be visualised with an infrared camera.

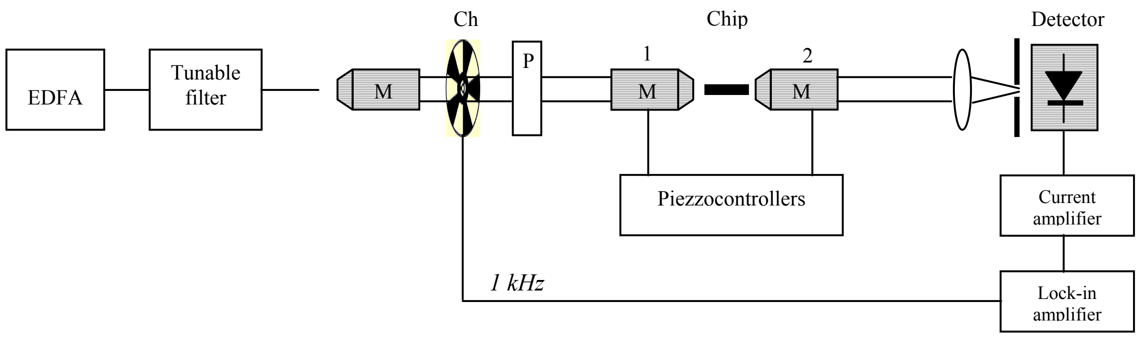

Fig. 3. Measurement setup for characterization of the couplers without AR-coatings. P: Polarizer, MO: Microscope Objective, Ch: Chopper.

For a correct alignment, positions of the input/output microscope objectives were adjusted in such a way, that the power detected from the output port had a maximum value. For a straight waveguide that implies excitation of the zero-order mode only: the input objective is then positioned in the middle of the input waveguide (zero lateral displacement). For unbalanced MMI couplers, as follows from the simulations, the correct alignment of the input/output microscope objectives can only be done for the high power output port (in our case 85%). Then the maximum power corresponds to the excitation of the zero-order mode in the access waveguides.

The measured excess loss corresponding to the optimum alignment is better then 0.6 dB for the 85/15 MMI coupler with the measured coupling factor of 0.156. The measured excess loss corresponding to the optimum alignment is better then 1 dB for the 15/85 MMI coupler with the measured coupling factor of 0.851. The losses were determined by comparing the measured transmission with that from a straight waveguide. Optimum lengths for these couplers are 724 μm and 234 μm respectively. The influence of the lateral input displacement, and consequently of the first-order mode, on the device performance was determined using stages controlled by piezzoelectrical drivers. Measurements show that with 1.1 μm displacement for the 85/15 MMI coupler, coupling ratio degradates down to 0.188 with 1.1 dB excess loss. For the 15/85 coupler, however, influence of the lateral displacement was less evident. That can be explained by relative phase difference between the zero- and the first-order modes, since the length of the access waveguides is different for the two couplers.

Conclusions

Excitation of the first-order mode in access waveguides can significantly deteriorate the coupling ratio of unbalanced MMI couplers and increase the excess losses. Care, therefore, should be taken in coupling light into the access waveguides, as well as in the circuit design (e.g. using bends in front of the MMI) to avoid this effect. Another option for this, as measurement results suggest, is controlling the relative phase difference.

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