A Multimode Interference coupler with low reflections

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A designed 3 dB Multimode Interference (MMI) coupler optimized for low reflections is presented. The MMI is designed, processed and measured. For comparison purposes, MMIs with an original non-optimized layout are included on the same wafer. The measured results from both devices are compared. The results show reflection suppression in the case of the optimized MMI of more than 10 dB. In the same way a design for 1x2 3 dB MMI is tested. The measured results also show reduced reflections.

Introduction

To insure the optimal performance of optical integrated circuits enclosing semiconductor optical amplifiers, parasite reflections must be suppressed. The reflections in integrated optical circuit can be internal and happen at interfaces where there is an effective index mismatch (i.e. shallow-deep transition, offsets, multimode interference coupler interfaces…) or from the facets of the chip. The latter can be minimized by tilting the output waveguides with a suitable angle and by application of anti-reflection coating. Removing the internal reflections needs a suitable design for every suspect reflection source. It is preferable that the design should be also tolerant for fabrication errors.

Due to its good characteristics (large operation bandwidth, fabrication tolerance, polarization independency) the MMI coupler is one of the extensively used devices in integrated optics [1]. However the device can suffer from reflections which may disturb the operation of the integrated circuit. The reflection properties of the MMI coupler are studied in [2] and experimentally determined in [3]. For back reflections suppression in MMI couplers, Gottesman *et all*. [4] propose a design with incorporation of a lossy waveguides. However their design is suitable only for deep etched 1x2 MMI couplers.

In this paper a different design is proposed. The back reflections are suppressed in the MMI coupler by tilting the walls on which those reflections may occur. The proposed design is suitable for shallow and deep etched MMI couplers. The new design is fabricated and measured for both 2x2 3 dB coupler and 1x2 3 dB couplers. Results are presented in this paper.

Design and fabrication

When the light enters the multimode waveguide it will diverge, propagate the length of the MMI coupler and converge to output spots at the other end of the MMI. By checking the beam propagation field of the MMI coupler it can be seen that the optical field is absent from the areas neighboring the access waveguides. However, those areas may become a potential source of reflections mainly when fabrication errors occur. In our proposed design, those areas are removed. The design is presented in figure 1. The dashed line represent the modification done on the original design in case of a 3 dB 2x2 MMI (Figure 1a) and a 3 dB 1x2 MMI (figure 1b). The sharp end of the area between the two access waveguides and the tilt on the walls on the other two sides of the waveguides will suppress the possible reflection in the device. The shape of the MMI coupler shown in figure 1 is obtained by the introduction after the access waveguide of a non-adiabatic taper. The taper angle (20°) is chosen to be larger than the divergence angle of the light, so that the multimodal interference properties are not affected. The length of the taper is calculated from the angle and the intersection with the straight part of the non-optimized MMI. The total length of the optimized MMI is the sum of the tapers lengths and the straight section length. In this work, the MMI length L_{mmi}=230 µm, the width W=12 µm and the offset O=2.2 µm.

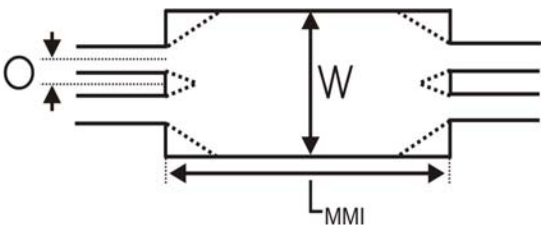

Fig. 1(a) schematic of 2x2 MMI coupler; dark line for non-optimized MMI, dashed line for the optimized MMI; W: width, L_{mmi}: length, O: offest

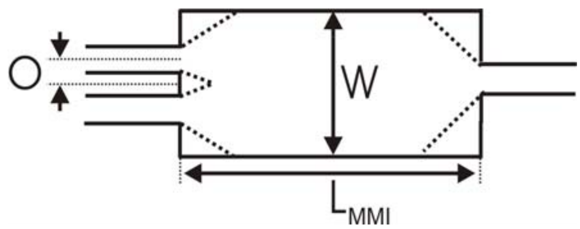

Fig. 1(b) schematic of 1x2 MMI coupler; dark line for non-optimized MMI, dashed line for the optimized MMI; W: width, L_{mmi}: length, O: offest

The structure used for the fabrication of the MMI couplers is a heterojunction InP/InGaAsP(Eg=1.25 µm)/InP grown by MOCVD. The guiding layer thickness is 0.5 µm, the top cladding thickness is 1.5 µm

The mask used for the fabrication of the MMI coupler contains both the new design (optimized MMI couplers) and non optimized ones. For processing the couplers a SiN_x layer, which will be used as an etching mask, is deposited. The coupler features are transferred to the SiNx layer by optical photolithography and dry etch. The structures are then etched in a reactive ion etch with a CH_4/H_2 plasma to a depth of 1.6 µm. In the end, the SiN_x layer is removed. The chip is cleaved in such a way that the MMI couplers are not positioned in the middle. This will help to distinguish the different reflections involving the two facets of the chip and the MMI coupler.

Measurement and discussion

The optical setup used for the measurement is presented in figure 2. An Erbium Doped Fiber Amplifier (EDFA) is used as the light source, from which TE polarized light is selected with a polarizer. The light is launched in one of the inputs of the MMI coupler by means of an objective. At the corresponding output of the MMI coupler a tapered fiber is used to collect and carry the light to the input of a High Resolution Optical Spectrum Analyzer (HR-OSA). The transmitted spectrum from the chip is recorded. A fast Fourier transform is used to extract the resonance cavities from the data of the recorded spectrum. The results are shown in the figure3.

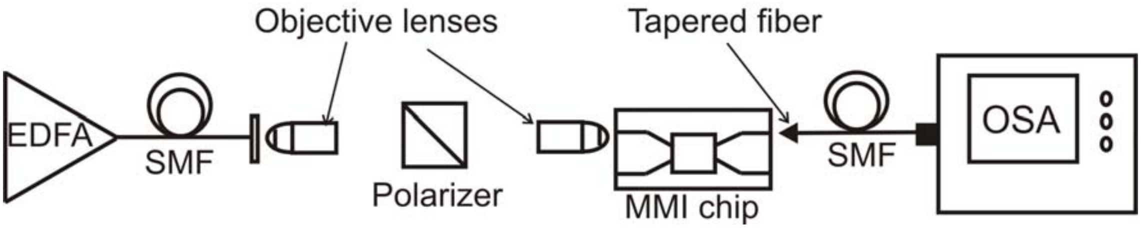

Fig. 2 Measurement setup used for the characterization of the MMI coupler chip.
SMF: Single Mode Fiber, OSA : Optical Spectrum Analyzer

First, a single passive waveguide (PWD) is measured; the analyzed data is presented in (figure 3-A). The only peak present on the graph is from the cavity formed by reflection of light on both facets of chip. This chip-peak is around 5.4 mm and matches the chip length. For the non-optimized MMI coupler (figure 3-B), besides the chip-peak, two extra peaks can be seen around lengths L_1 = 3.16 mm and L_2 = 2.55 mm. By analyzing the MMI coupler structure, it has been found that the L_1 corresponds to the cavity resulting from the reflections between the right hand facet of the chip and the left hand side of the MMI. For L_2 it corresponds to the cavity results from the reflections between the right hand side of the MMI and the left hand facet of the chip. In case of the optimized MMI coupler (Figure 3-C) these two peaks fade and the graph looks like the one obtained for the PWD. Also for the 1x2 optimized MMI coupler (figure 3-D) only the chip-peak is seen.

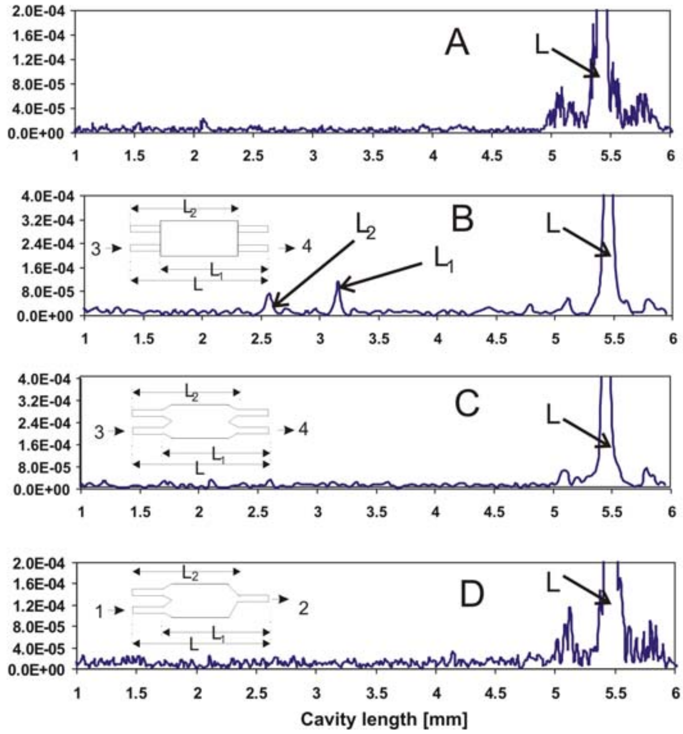

Fig.(3): Fast Fourier Transform of the recorded spectrums for; (A) a PWD device, (B) Non-optimized 2x2 MMI coupler, (C) Optimized 2x2 MMI coupler, (D) Optimized 1x2 MMI coupler

The fading of the peaks at the cavity lengths L_1 and L_2 is an indication of reflection suppression in the case of optimized MMI couplers.

The value of the reflection in case of the non-optimized MMI coupler is calculated by comparing the strength of the chip-peak and the peaks around L_1 and $L_{2,}$ using the

Fabry-Perot transmission equation. The value obtained for reflection is around R = -30 dB. For the optimized MMI couplers the reflection value is much lower and can not be estimated because the missing the peaks around L_1 and L_2. This implies that the reflection must be more than 10 dB suppressed with respect to the non-optimized MMIs.
The rather high reflection value obtained for the non-optimized MMI coupler in this work is due to deviation from design parameters (values better than -40 dB are reported in [3]). The etch depth of the fabricated MMI is 150 nm deeper than the design and the guiding layer (InGaAsP layer) is 50 nm thinner. These two effects lead to increased reflections. The new design still show reflection suppression even with the errors mentioned above, which shows that it very tolerant to fabrication errors.

Conclusion

An efficient MMI coupler design for back reflection suppression is presented. The design is suitable for shallow and deep etched devices and for 1x2 and 2x2 MMI couplers. The new design is fabricated and measured. A HR-OSA and Fast Fourier Transform are used to identify the resonant cavity. The results show clear reflection suppression in case of the optimized MMI coupler. The reflection value in case of non-optimized MMI coupler is found to be around -30 dB, for the optimized MMI the reflection value can not be estimated, which means it must be lower than -40 dB. The new design can be easily integrated since it does need any extra technology step or connecting element.

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