Reducing MMI imbalance in compact PIC design

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In photonic integrated circuits (PICs) multimode interferometers (MMIs) are often the preferred method of power splitting due to their low insertion loss and compact form factor. However, we show that in compact circuits the impact of tight bends feeding splitters can have a surprisingly large impact on the imbalance of these devices. We demonstrate that by properly designing the feeding circuit to the MMI the problem can be greatly alleviated by using small offsets between the bend and the MMI or inserting mode strippers.

1 Introduction

In recent years, photonic integrated circuits have been applied for a wide variety of applications. These applications rely on robust passive and active photonic components, which are not only highly tolerant to inevitable fabrication variations, but are also as compact as possible to reduce chip cost. Power splitters are key components in PICs and can be realized in different ways, such as Y-splitters, MMI couplers and evanescent directional couplers. MMI couplers are often the component of choice for power splitting, as they combine compactness and low insertion loss with a broadband optical response that is quite tolerant to fabrication variations.

In applications that require many subsequent levels of splitters it is critical that the power splitting is well balanced both in amplitude and phase, as even small imbalances on the individual splitter level will result in dramatic variations at the final stage of the splitter tree. Hill et al [1] reported the improvement in the imbalance of 2x2 MMI power splitter by optimizing the input waveguide width. For these devices a significant cause of imbalance is the phase error induced by odd and even modes when deviating from the optimum design due to fabrication variation. If the application allows it is preferable to use a 1x2 MMI splitter, where the fact that the input waveguide is placed along the symmetry axis of the MMI means that only the odd modes of MMI will be excited. Therefore any fabrication variation only results in changes in insertion loss and does not impact the imbalance.

In this work we show that care should be taken when using 1x2 MMIs in a compact circuit, since a surprisingly large amount of imbalance can be observed when there is mismatch between the bend mode and the feeding section of a 1x2 MMI. We show that even for small radii bends balanced power splitting can be maintained by choosing the correct feeding length after the bend, by mode-matching the bend and input taper of the splitter, or by introducing a mode stripper section to remove any higher order components.

Results and discussion

The circuits demonstrated in this work are fabricated in imec's SiN platform [2]. This platform makes use of a low temperature plasma-enhanced chemical vapor deposition (PECVD) to deposit a SiN film on a 200mm wafers, which is then patterned with 193nm optical lithography and etched with reactive ion etching. The low processing temperatures allow photonic circuits to be processed on top of standard CMOS wafers.

SiN is transparent in the visible-NIR, enabling a large range of applications. The film thickness used in this paper is 220nm.

We designed and fabricated 1x2 3dB MMI power splitters at the wavelength of 638nm for the fundamental TE mode. Figure 1(a) and Table 1 outline the geometrical parameters and values of the MMI design. We compare the simulated response for a MMI fed with a straight waveguide to one that is fed from a 15µm bend ($L_{straight} = 0$, see Figure 1(b)). It can be clearly seen that the bend causes a large imbalance between the outputs.

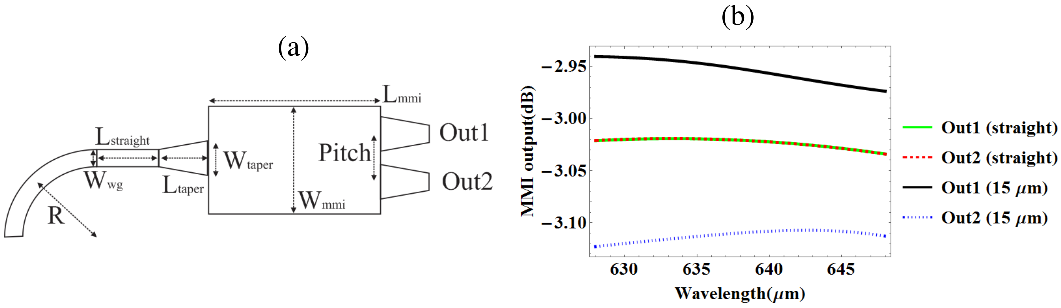

Figure 1: (a) Schematic overview of MMI design parameters. (b) Spectral response of the two 1x2 3dB MMI power splitters, fed with a straight segment and a 15 µm bend respectively.

Table 1 Design parameters of 1X2 3-dB power splitter operating at the wavelength of 638nm.

Parameter	W_{wg}	*Thickness*	W_{taper}	W_{mmi}	L_{mmi}	L_{taper}	*Pitch*
Value (µm)	0.34	0.22	1.2	3	13.45	30	1.58

Power splitters are commonly preceded by a bend section in PIC applications. When the mode propagates in the bend section it is pushed to outer part of waveguide [3]. This mode displacement causes a mode mismatch between the bend and the MMI input section. This mode mismatch not only results in insertion loss, but also in the excitation of the second order mode in the MMI input section. Although the second order mode is not supported in a single mode waveguide and therefore decays quickly, it can still propagate a significant distance, causing a beating pattern between the fundamental and second order modes. The modes beating results in the small displacement of modes perpendicular to propagation direction. From the simulated and meaured results in Figure 2(b) it is clear that the maximum imbalance increases exponentially as the radius decreases. While it is possible to achieve perfect MMI balance if the MMI geometry and the feeding network are designed to be on a node (black squares in Fig. 4(b)) where the mode displacement due to the beating pattern is zero, such method is vulnarable to fabrication variations. Any variation will change the propagation constants of the modes and therefore impact the beating pattern.

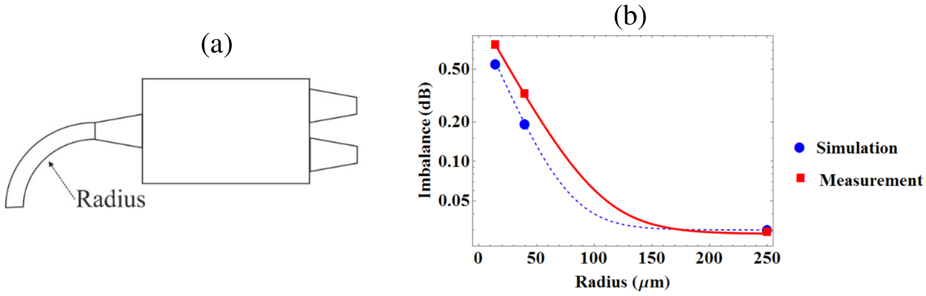

Figure 2: (a) Schematic overview of a bend feeding an MMI. (b)Measurement and simulation results of imbalance for three bends, 15, 40 and 250 μm. Lines indicate the modeled exponential relation to the results.

A simple solution to avoid the mode beating is to offset the bend section compared to the straight section to cancel the mode mismatch and thus to minimize the transition loss between bend and straight section [3]. Here we used the same principle to remove the mode mismatch between the bend and the MMI input taper (Fig. 3(a)), allowing to balance the output power of the MMI as well. A set of test structures with offsets between 0 nm and 23 nm were fabricated, and results are presented with red squares in Fig 3(b). Clearly, the imbalance drops linearly as function of the offset and reaches a value as small as 0.02 dB for the offset of 23 nm. A linear fit allows us to extrapolate that zero imbalance would be achieved for an offset of 25 nm.. Similar observations can be made in different simulation tools, but small variations are seen on the slope and the optimum point for zero imbalance.

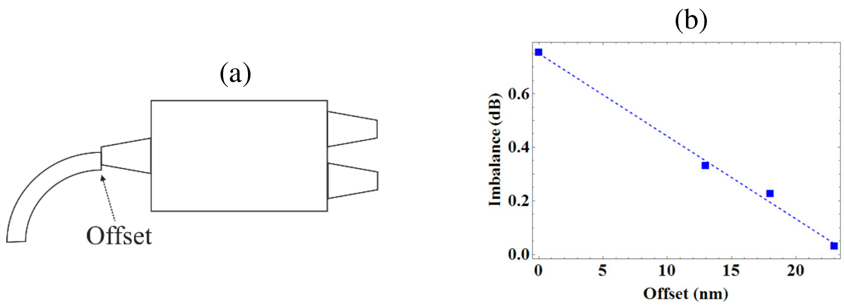

Figure 3: (a) Schematic illustration of the test structure for feeding the MMI with an offset. (b)Measurement and simulation results of imbalance for a bend radius of 15 μm.

A third method to reduce the imbalance is to introduce a mode stripper section between the bend and the MMI input (see Fig. 4(a)). This is achieved by tapering down to a narrow waveguide segment where the decay length of the second order mode is significantly decreased. The measurements (see Fig. 4(b)) clearly show that these mode strippers are very efficient in removing the MMI imbalance, but they will slightly increase the insertion loss of the circuit as the power that was coupled to the second order mode is lost. However, in cases where very low levels of imbalance are required, we recommend using a mode stripper to remove any remaining imbalance.

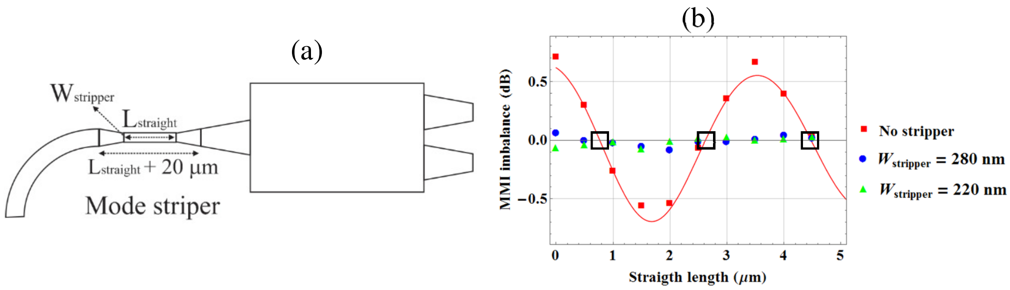

Figure 4: (a) Schematic illustration of the test structure for feeding the MMI with a mode stripper. (b)Measurement and simulation results of imbalance for a bend radius of 15 µm.

Note that for both stripper cases the imbalance has nearly totally vanished, which can likely be attributed to the fact that the tapers from the mode stripper already sufficiently strip the higher order modes.

Conclusion

Using compact bend radii in a MMI feeding circuit can result in significant power imbalance between the output ports. Designing an appropriate straight length between bend and MMI can minimize the effect, but results in a larger footprint and is vulnerable to processing variation. The preferred technique is to offset bend and straight sections mode to avoid coupling to the second order mode, as this method does not increase the footprint and minimizes the loss caused by the mode mismatch. With fabrication variation the optimum offset will shift slightly, so when very low levels of imbalance are required, a mode stripper can be used to remove any remaining imbalance from the system.

References

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