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1x2 Multimode interference coupler with ultra-low reflections in membrane photonic integrated circuits

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Multimode interference (MMI) couplers are basic building blocks in most photonic integration circuit platforms. Such devices are used as splitters and combiners. However, they are heavily affected by parasitic reflections, mainly because of the resonances due to the self-imaging properties of the structures and the abrupt transitions they comprise [1]. These reflections can compromise the expected performance of the integrated circuits.

In a splitter mode, the main source of the reflection is the limited imaging resolution of the device. This constrain allows some light to be imaged on the back edge of the structure, which will be reflected to the input. On the other hand, when the MMI is in combiner mode the reflections will be low when the two inputs are in phase. Nevertheless, when the inputs are out of phase, the optical field will be imaged on the black plane next to the output waveguide and then the reflection will be strong due to the imaging properties of the structure.

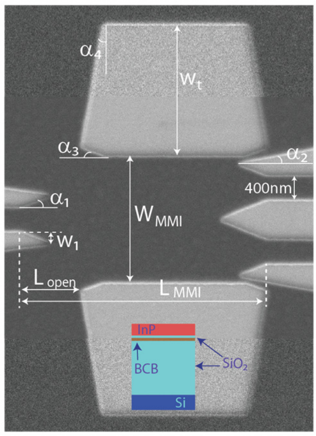

Fig. 1. SEM picture of the device on SiNx and the cross section of the chip.

In membrane platforms this problem is magnified due to the high contrast index regime. In order to alleviate this problem, we propose a butterfly geometry based on the design of E. Kleijn [2]. In this design, the areas next to the waveguides, where the parasitic reflections are originating but which do not play an important role in the MMI function, are removed. In the remaining structure angles are added so that light being reflected there is directed out of the main propagation path. In our case, we optimize the device for an InP membrane on Silicon (IMOS) platform of 300nm thick [4]. Figure 1 shows a SEM picture of the SiNx mask for the realization of the optimized device with all the parameters highlighted and a cross section of the IMOS chip included.

We design a 2 µm wide MMI. The length for a 1x2 MMI was calculated to be $L_{MMI} =$

$3L_\pi/8 = 4\mu m$, with $L_\pi = 4nw_{eff}{}^2/3\lambda$ [1]. We optimize the geometry in a combiner mode, since this gives the worst case situation. An evaluation function is chosen to maximize the output power and reduce the reflections. We define this function as $F_{eval} = 0.2[-10log_{10}(P_{reflection\ to\ 1} + P_{reflection\ to\ 2})] - 3P_{\ out}/(P_{\ out} - 0.8)$. The first term increases the value when the back reflected power reduces. The second term increases F_{eval} when more light is coupled to the output waveguide, but it penalizes drastically if the power is lower than 90%. We run a particle swarm optimization method for 16 generations with 20 elements each. We use as initial values similar parameters as in [2]. The optimized parameters are $\alpha_1 = 22.2°$, $\alpha_2 = 10°$, $\alpha_3 = 20°$, $\alpha_4 = 10°$, $w_1 = 183nm$, $w_t = 2\mu m$ and $L_{open} = 940nm$. With these parameters, a transmission of $-0.2255dB$ (94.94%) and reflections of $-49.9dB$ are obtained. In figure 2 (right) we compare this structure with standard square (left) and angled (centre) MMIs [3]. In the upper part, there is the electric field on the structure for the out of phase situation. It is clear that the reflections are minimized in the new structure as compared to the other geometries by allowing the field to escape from the structure. In the lower part, the transmitted power and the reflections to the input waveguides are plotted against the phase difference. It shows at the out of phase condition an improvement of 28 dB and 8 dB, respectively, with respect to the square and angled geometries.

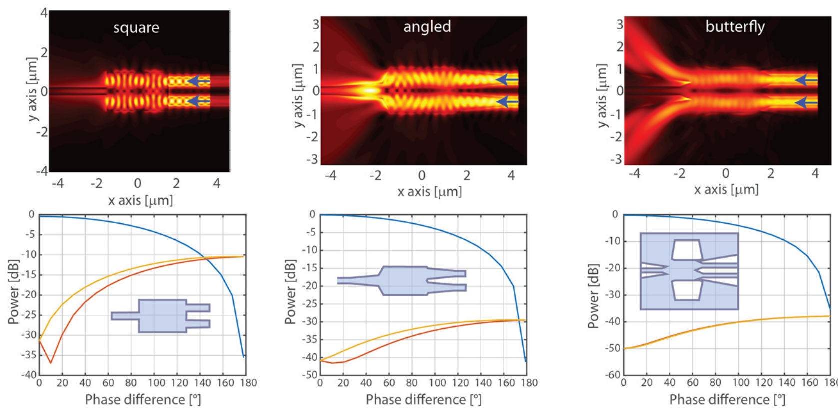

Fig. 2. Top: the electric field distribution of the different MMI geometries. Down: The transmission (blue line) and reflection to the upper (yellow) and low (red) waveguides

We have presented a new geometry for a MMI in membrane photonics. The predicted reflections are -38dB in a combiner mode with out of phase inputs (-50dB for in phase), 8 dB lower than the optimized angled corners MMI. The geometry is optimized for the IMOS platform, but can easily be implemented for SOI chips.

References

[1] E. C. M. Pennings *et al.*, *Reflection Properties of Multimode Interference Devices*, IEEE PTL, Vol. 6, No. 6, 1994.

[2] E. Kleijn *et al.*, *Multimode interference couplers with reduced parasitic reflections*, IEEE PTL, Vol. 26, No. 4.

[3] R. Hanfoug *et al.*, *Reduced reflections from multimode interference couplers,* Electronics letters, Vol. 42, Issue 8, 2006.

[4] J. Pello, Building up a membrane photonics platform in Indium phosphide, PhD thesis, TU Eindhoven, 2013.