Improved multi-mode interferometers (MMIs) on silicon-on-insulator with the optimized return loss and isolation

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In many integrated photonic circuits on silicon-on-insulator (SOI), e.g. integrated laser Doppler vibrometers, the return loss and isolation of multi-mode interferometers (MMIs) should be optimized. Several improvements, such as tilting the end-walls and increasing the taper lengths of the input and output ports can be done for the optimization. The return losses and isolations of different improved MMIs are simulated and compared by using the finite-difference time-domain method. MMIs with better return loss and isolation are predicted by the simulation.

Introduction

Multi-mode interferometers (MMIs) are important components for optical signal routing and processing, and they have been widely used in the integrated photonic devices on platforms like silicon-on-insulator (SOI). In SOI, the core of MMIs are normally surrounded by shallowly etched silicon layers with low effective refractive index (see in Figure 1), in order to avoid deterioration due to the high index contrast between silicon and cladding [1]. However, the excess waveguides are normally deeply etched waveguides. Deeply etched walls will be formed on both sides of the MMI, and they could introduce certain amount of spurious reflections back to the source side (port 1 and port 3).

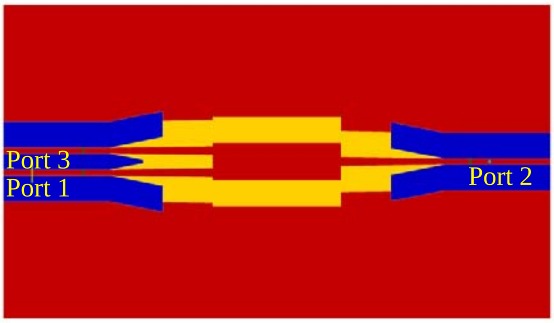


Figure 1. A commonly used 2x1 MMI on SOI. In the red area, a silicon layer with a thickness of 220 nm is covered on top of the silica buffer layer. In the yellow area the silicon is etched down to 150 nm. The silicon layer is etched away in the blue area, and this area is used as the trench for wire waveguides.

An MMI can be used to split light in an on-chip laser Doppler vibrometer (LDV) to measure velocities from a vibrating surface, as is shown in Figure 2(a). The principle of the integrated LDV is described in [2]. When the LDV is working, coherent light is coupled out from the chip through a grating coupler and sent to a vibrating surface. Some of the reflected light is coupled back to the chip via the same grating coupler. With the Doppler shift information carried by the reflected signal, the instantaneous vibration velocity of the target can be retrieved and sent to the user. However, the reflection back to the chip is 20 dB lower than the light sent out. According to simulation results, the isolation between port 1 and port 3 (see Figure 1) of the MMI should be larger than 40 dB so as to make sure that the average error (deviation between original and measured velocity values) of the he LDV output is less than 5%.

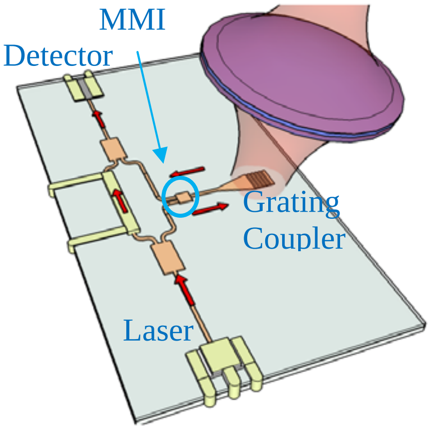
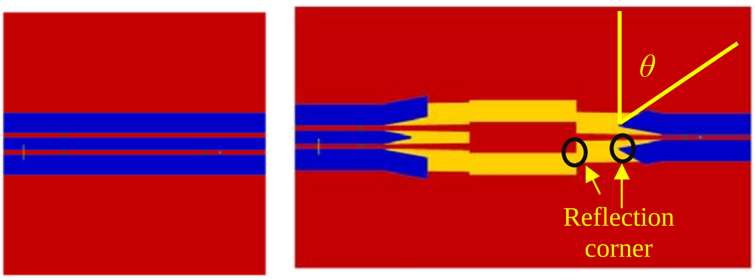


Figure 2. Schematic show of an on-chip LDV with an MMI as the splitter.

To reduce the increase the isolation and reduce reflection, one possible way is to tilt the walls at each end of the MMI [3]. Reflections are reflected away from the MMI and thus less reflection is sent back to the ports from the source side. In this paper, we report the simulation of reflections and isolations of the different type of MMI devices on SOI using the finite-difference time-domain (FDTD) method, and discuss the improvement by the tilted end walls in reflection and the isolation.

Simulation method

Simulations were performed with the finite-difference time-domain (FDTD) method, using a freely available software package [4,5]. The MMI structure is loaded from a python script. The source is put on the lower left input waveguide (port 1), with the field profile set as the fundamental TE mode of the input waveguide. A pulse of with a center frequency of 1550 nm is generated and sent to the MMI from the source. By detecting energy flux, transmissions from port 1 to the other ports are calculated. The isolation value is related to the transmission between port 1 and port 3. A design (shown in Figure 3(a)) with the reflection totally suppressed is also simulated, and it is used to retrieve the reflection and isolation of a normal MMI.



(a) (b)

Figure 3. (a) A reference design with suppressed reflections. (b) A design with the deeply etched walls titled angle θ.

Results and Discussions

The simulation results shown in Figure 4 are the reflection and isolation of MMIs with different tilting angles of the deeply etched walls. It is seen from Figure 4(a) that the isolation is increase by more than 5 dB when you increase the angle to 60°. This is because more light is reflected to the other directions rather than back to the source side. However, increasing the angle even further won't help more for the isolation. Light reflections are also decreased as the increase of the angle, as is seen from Figure 4(b). It can be found that the relative reflected flux could be less than zero. It might be due to the problem introduced by the source, which is not transparent to the reflection. One can also tilt the end walls of the MMI core (with 220 nm silicon layer), but the corresponding improvements of isolation is not very large.

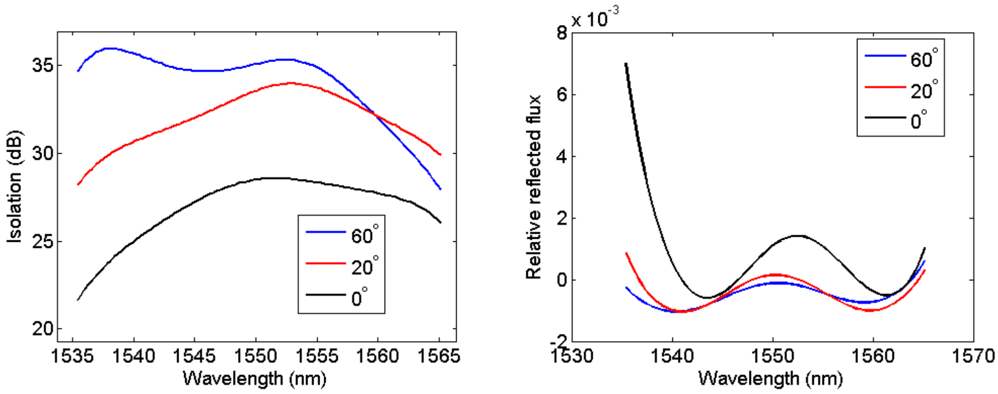


Figure 4. Isolation and relative reflection of MMIs with different tilting angles of the deeply etched walls.

Since strong reflections can occur at the deeply etched wall corners and the corner of the MMI core (see in Figure 3(b)). MMIs with their deeply etched corner titled by 60° and moved 8 μm away from the MMI core (using a longer taper) are also simulated and shown in Figure 5. The red curve stands for the MMI with its core walls also tilted outward by 20°. It is shown that only moving the deeply etched corners (blue curve in Figure 5) didn't improve the isolation and reflection. However, with tilted walls of the MMI core, the isolation is increased to 40 dB. That's because the reflections from the deeply etched walls does not dominate in the case. The retroreflection effect in corner of the MMI core dominates instead. Tilting the end wall of the MMI core helps reducing the retroreflections from the corner and thus improves the isolation.

Tilting of the deeply etched walls on 2x2 MMIs also improves the isolation. However, since the reflection and isolation problems of 2x2 MMIs are already better than those of 2x1 MMI, the improvements are not very huge.

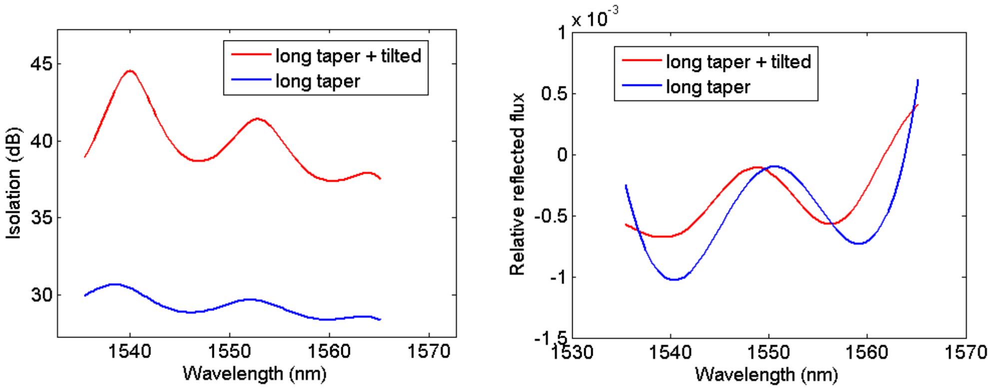


Figure 5. Isolation and relative reflection of MMIs with longer tapers. The blue curve in an MMI with the deeply etched walls titled by 60°, and moved 8 μm away from the MMI core using a longer taper. The red curve has the same deeply etched walls, but has its MMI core walls also tilted outward by 20°.

Conclusions

The isolation between port 1 and port 3 of a 2x1 MMI can be as high as 40 dB by tilting the deeply etched walls, increasing the distance between the deeply etched walls and tilting the walls of the MMI core. This value is good for its usage in an integrated LDV on SOI, and other applications requiring large isolation. The average reflection back to the port 1 is also decreased, and it can be used in some applications that need less spurious reflections.

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References

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