Fabrication tolerant silicon MZI filter

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Abstract— **A compact fabrication tolerant MZI filter is demonstrated. The measured device shows a 20-fold improved tolerance to systematic waveguide linewidth variations, with a wavelength shift of less than 60 pm/nm linewidth change.**

I. INTRODUCTION

One of the most pronounced weaknesses of silicon nanophotonics is the need for extremely precise fabrication, especially for passive wavelength filter devices. The high index contrast and submicron waveguide dimensions will translate any change in waveguide width and height into a strong change in refractive index [1]. When used in an interferometric wavelength filter, a 1nm change in width can easily result in a 1nm change in the filter response.

While fabrication technology is systematically improving, the required fabrication control will ultimately dictate the yield of larger circuits. Fabrication variations can be actively compensated (e.g. with thermal tuning), but this will drive up power consumption and complicate the device with active control circuitry. Pre-fabrication or post-fabrication trimming [2] of the components can be used to correct the effects of the "last nanometer" fabrication offsets. However it comes with a significantly increased cost of the whole fabrication process.

In this paper we demonstrate a technique to make a wavelength filter tolerant to linewidth variations by design, without changing the fabrication process itself. We show that indeed it is possible to get a fabrication tolerant MZI filter by using different mode confinement in the arms of the filter. The technique can be applied to more complex filters, and extended to include tolerance to other effects, such as waveguide thickness and temperature [3].

II. DESIGN AND FABRICATION

The most simple wavelength filter we can construct is the Mach-Zehnder interferometer (MZI). The device, pictured in Fig. 2, uses a shallow-etch multimode interference coupler (MMI) as a 50/50 1×2 power splitter, and the same is used as a combiner [4]. The sensitivity of the spectrum position to width deviation $d\lambda/dw$ for a conventional MZI implemented in 450 nm×220 nm strip waveguides [1] with air top cladding at a wavelength of 1550 nm is shown in Fig. 1. The device has
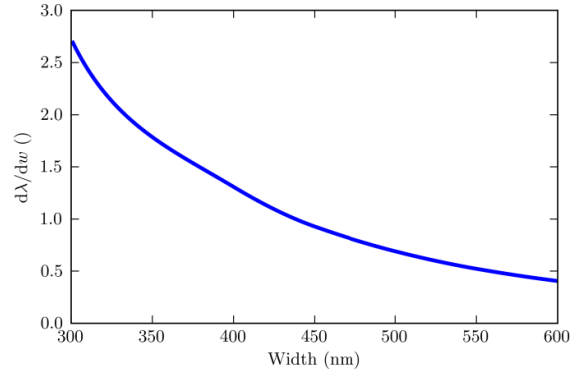

Fig. 1. Sensitivity of spectrum position to width deviation, $\frac{d\lambda}{dw}$, for conventional MZI with air top cladding at 1550 nm.

around 1nm wavelength shift for a 1nm change in waveguide width. The graph also shows that this sensitivity decreases for larger width since the mode confinement in a wider waveguide is larger and converges to that of the slab waveguide. The shift of the spectrum due to a width deviation of -2 and +2 nm for this MZI is shown in Fig. 3(a) for a designed free spectral range (FSR) of 5 nm.

Basically, we can write the wavelength sensitivity of the device to any parameter X as

$$\frac{d\lambda}{dX} = \frac{\lambda_m}{n_g} \frac{dn_{eff}}{dX} \qquad (1)$$

where X could be replaced by the waveguide width (w), height (h), temperature or any other influence. λ_m is the center wavelength and, n_g is the group index.

To compensate for this effect in our device we use different waveguide widths in the 2 arms, introducing not a single set of optical parameters, but two. The modified expression for the sensitivity becomes

$$\frac{d\lambda}{dX} = \frac{1}{M} \left(L_1 \frac{dn_{eff1}}{dX} - L_2 \frac{dn_{eff2}}{dX} \right) \rightarrow 0 \qquad (2)$$

which we now try to minimize. M is the modified interference order which takes into account the dispersion for a given FSR of the filter. For a device tolerant to width variations the condition for zero sensitivity becomes

$$\frac{L_1}{L_2} = \frac{\frac{dn_{eff2}}{dw}}{\frac{dn_{eff1}}{dw}} |\lambda_0 \qquad (3)$$

It means that, for the filter to be width tolerant the length ratio of the arms should be inversely proportional to the change in effective refractive index of the waveguides of the corresponding arms. The assumption we make here is that the linewidth variation induced by the fabrication process is similar for the waveguides in the two arms. This is generally true if the linewidth change is caused by a lithographic dose variation or a change in etch time, and the device is sufficiently compact.
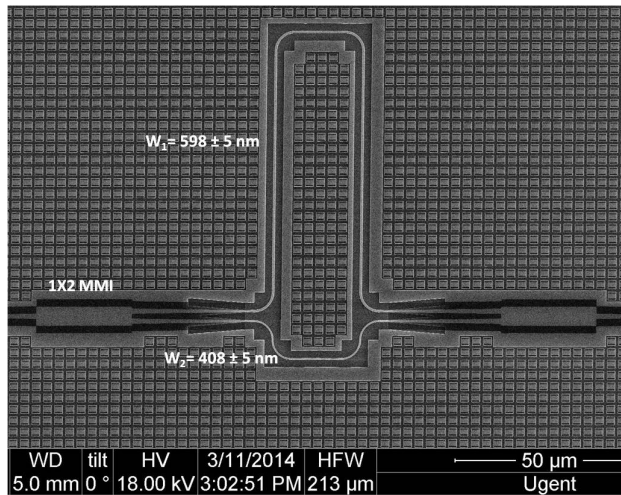

Fig. 2. SEM image of fabricated MZI filter with shallow etch MMI.

III. EXPERIMENT

We designed the devices using the IPKISS parametric design framework [5]. We chose a nominal linewidth of 400 nm in the lower arm and 600 nm in the upper arm of the MZI. To demonstrate the tolerant behavior we replicated the device with deliberate variations in the linewidth in both arms over a 20 nm range: A ±10 nm width variation can be considered as controllable for an optimized, stabilized fabrication process. The simulation of this device is plotted in Fig.3 (b), and to compare the response a conventional, non-compensated MZI is plotted in Fig.3 (a), but with only a ±2 nm linewidth change. The simulations were performed using the circuit simulator Caphe [6].

The devices were then fabricated in IMEC's standard passive platform using the ePIXfab MPW service. This process uses 200mm SOI wafers with nominally 220 nm of silicon and 2 µm of buried oxide. The measured thickness of the silicon waveguide in the presented devices is 218±3 nm. The measured arm width is 598±5 nm in the upper arm and 408±5 nm in the lower arm approximately, as shown in SEM image of device in Fig. 2. The calculated length of the upper and lower arm is 172 µm and 45 µm respectively.

The experimental measurements are shown in Fig. 3(c) and matches very well with the simulation. The devices show an extinction ratio of more than 25 dB and an insertion loss of less than 0.3 dB throughout the C band. The measured FSR of the filter is around 5 nm.
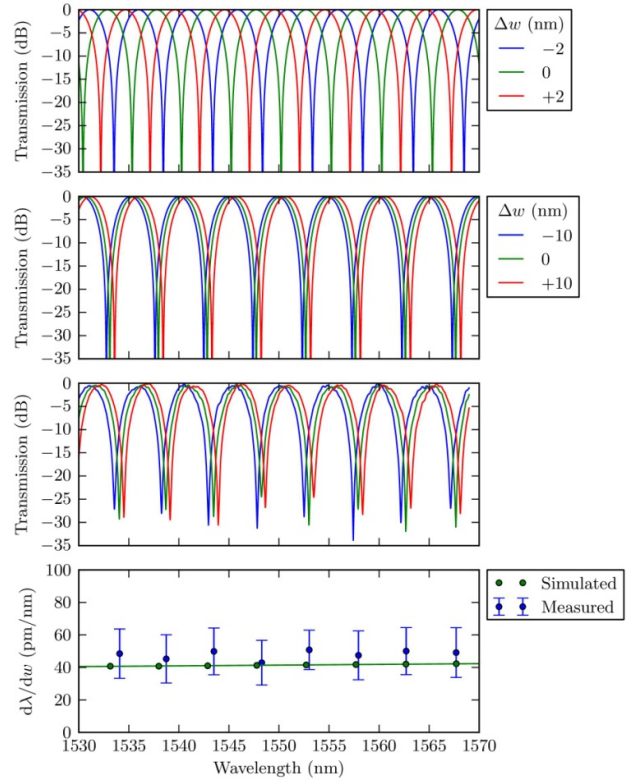

Fig. 3. (a) Simulated spectra of a conventional MZI for 0, -2 and +2 nm width offset. (b) Simulated spectra of the optimized design for 0, -10 and +10 nm width offset (c) Measured transmission and (d) dλ/ dw variation with wavelength.

The extracted sensitivity to linewidth $d\lambda/dw$ is shown in Fig.3(d). The measured width sensitivity is reduced from 1nm/nm to less than 60 pm/nm over the entire spectrum with standard deviation of 15 pm/nm which is measured over four devices with width offsets of ± 5 nm and ± 10 nm.

IV. CONCLUSION

We demonstrated a compact fabrication tolerant filter on SOI. The measured results show a reduced linewidth sensitivity of less than 60pm/nm over a wide band which is an almost 20 - fold improvement compared to conventional devices. This technique can also be extended to reduce sensitivity to a number of other effects and ultimately to designs with an intrinsically improved yield.

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