WDM filters in Silicon-on-insulator photonic wires

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Abstract— **We demonstrate compact integrated optical wavelength filters in Silicon-on-insulator nanophotonic waveguides. These filters can be used for wavelength division multiplexing in the infrared telecommunication wavelength range. The structures are fabricated in a CMOS line using deep UV lithography and dry etching techniques. We fabricated ring resonators with 8μm radius showing sharp resonances, an 8-channel arrayed waveguide grating with a footprint of about 0.1mm^2 but still high crosstalk between channels, and 5-stage cascaded Mach-Zehnder filters with high drop efficiency and -10dB crosstalk level.**

I. Introduction

For long-distance optical fibre communication, signals are transmitted using wavelength division multiplexing (WDM) in the 1550nm wavelength range. Optical (de)multiplexer components combine or seperate wavelength channels at the input and output of the fibre without electro-optic conversions. Today's commercially available wavelength (de)multiplexers still have footprints of tens of cm^2, mainly because the low-index-constrast waveguides require large (mm) bend radii to keep the light confined and keep radiation losses within bounds. To fit more functionality on the same or even much smaller die size, waveguides with sharp bends are a necessity. The confinement can be increased by using a higher refractive index contrast between the waveguide core and cladding.

Here, we present components in Silicon-on-insulator (SOI) waveguides. Waveguides are created in a Silicon top layer, shielded from the Si substrate by a SiO2 cladding layer. Due to the high index contrast between the Silicon core (3.47) and the silica cladding (1.44), bends with radii as small as 3μm are possible. To keep these waveguides single-mode (necessary for high-performance optical communications), the waveguide width needs to be submicron. The accuracy of the dimensions of these 'nanophotonic' structures must be as small as 10nm or less. One advantage of SOI is its compatibility with CMOS fabrication processes. We made use of deep UV lithography and dry etching processes, which can deliver the resolution and accuracy needed for submicron optical waveguides.

We will briefly describe the fabrication process (section II) and then discuss some measurement results in section III.

II. Fabrication

We used 200mm Silicon-on-insulator wafers with a top Si layer thickness of 220nm and a 1μm thick burried oxide layer. The processing was done in the advanced CMOS research environment of IMEC, Belgium. The fabrication process is illustrated in Fig. 1 and described in detail in [1]. After applying and baking the photoresist, a deep UV stepper with an illumination wavelength of 248nm is used to define the patterns. After development of the resist, resist patterns are smoothened using a plasma treatment. The resist is then used as an etching mask for the Silicon etch, which uses an ICP-RIE etch technique.

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III. Results

A. Waveguide losses and bends

Low-loss waveguides are a prerequisite for high-performance components. Losses in our waveguides arise from scattering at sidewall roughness and leakage to the substrate. While substrate leakage can be reduced by using a thicker oxide layer, a good fabrication process is needed to keep sidewall roughness within bounds. We already reported very low propagation losses of 2.4dB/cm for straight SOI waveguides [2]. In a bend, excess losses arise from radiation. These losses increase with decreasing radius. We characterized bend losses by measuring curled-up waveguides with many bends. For 500nm wide waveguides we measured excess bend losses of around 0.03dB/90^o for 3μm bend radius.

B. Arrayed Waveguide Gratings (AWG)

In an AWG (Fig. 2a), a multi-channel signal is fed into an array of delay lines. The ends of the delay lines act as a phased array antenna, focussing the light on one of the output waveguides. As the phase delay differs for each wavelength, one can seperate the incoming wavelength channels [3]. We fabricated 8-channel AWG's with 5 input and 8 output waveguides. Because the bend radius was still quite large (75μm) in these first designs, the footprint is around 0.1 mm^2. Figure 4 shows the transmission to the 8 output channels of the AWG shown in Fig. 3a. While the AWG functionally works, the crosstalk is still significant, between -6dB and -9dB.

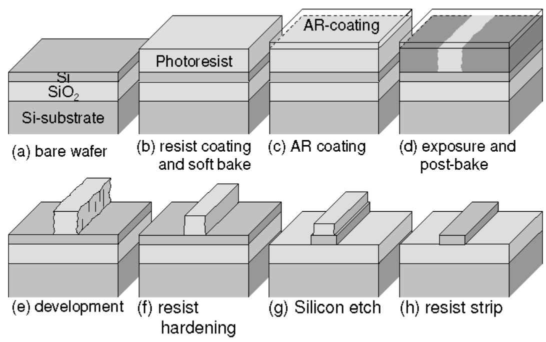

Fig. 1. The fabrication process for nanophotonic waveguide structures in SOI

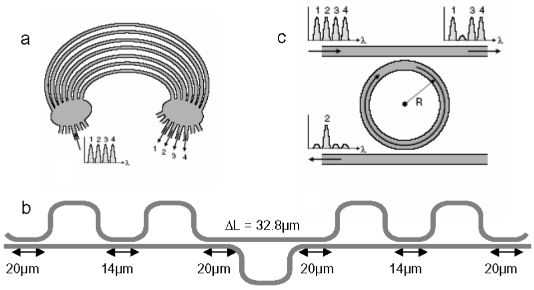

Fig. 2. Schematics of (a) an arrayed waveguide grating (b) a measured 5-stage cascaded Mach-Zehnder (c) a ring resonator

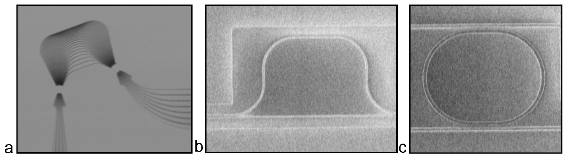

Fig. 3. SEM pictures of (a) an arrayed waveguide grating (b) one stage of a cascaded Mach-Zehnder with 10μm bend radius (c) a ring resonator with 8μm radius

C. Cascaded Mach-Zehnder filters (CMZ)

Figure 2b illustrates a cascade of Mach-Zehnder interferometers, consisting of coupling sections and delay lines. By carefully designing the coupling ratios of the couplers, one can obtain a higher-order channel drop filter with low crosstalk. Figure 3b shows part of a fabricated device, while the measured spectrum of a 5-stage CMZ is shown in Fig. 5. The channel drop efficiency is nearly 100%, but the sidelobe level of -10dB is relatively high, giving rise to crosstalk.

D. Ring resonator add-drop filters

While the AWG and CMZ are non-resonant devices, resonator-based filters have intriguing properties too. A ring resonator, weakly coupled to two waveguides, is illustrated in Fig. 2c. At the resonance wavelengths, the incoming signal is dropped to the output waveguide, while other wavelengths are transferred to the pass port. Figure 6 shows the transfer to the pass and drop ports of a measured ring resonator. The loaded Q factor is as high as 12700, with a 3dB bandwidth of 0.12nm and a free spectral range (period of the transfer function) of 16.5nm. There is significant add-drop crosstalk. We also demonstrated ring resonators with lower Q but lower crosstalk [2].

IV. CONCLUSIONS

We demonstrated compact integrated optical filters based on Silicon-on-insulator photonic wire technology. The structures were fabricated with CMOS technology. Functional arrayed waveguide grating and cascaded Mach-Zehnder filters were measured but still have large crosstalk levels. Ring resonator add-drop filters with high Q-factors but large crosstalk are demonstrated, while lower crosstalk was obtained using ring resonator filters with lower Q factors. While next generations of the devices are needed to show better performance, these first designs already show the potential of the technology.

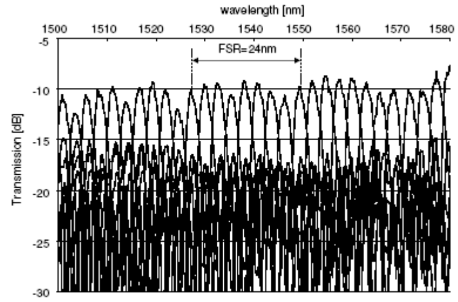

Fig. 4. Transmission to the 8 output channels of the AWG in Fig. 3a

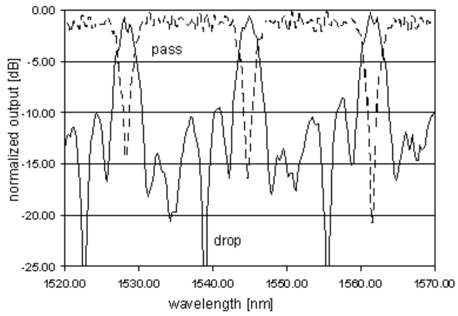

Fig. 5. Transmission to the pass and drop output ports of the CMZ in Fig. 2b

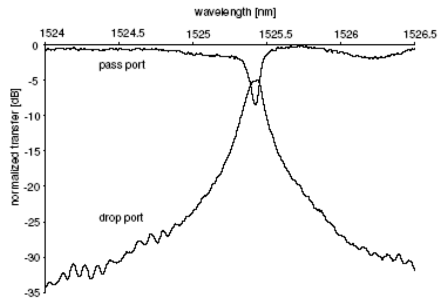

Fig. 6. Transmission to the pass and drop output ports of the ring resonator in Fig. 3c

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