Nanophotonic waveguides in Silicon-on-Insulator Fabricated with CMOS Technology

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Abstract— **We have made nanophotonic waveguides with low propagation losses in Silicon-on-insulator. The structures were fabricated with advanced CMOS fabrication technology including deep UV lithography at 248nm. We demonstrate photonic crystal waveguides with losses of 10dB/mm and single-mode photonic wires with propagation losses as low as 2.4dB/cm. We used these waveguides to construct compact racetrack and resonators in these waveguides with a Q of up to 8000.**

Keywords— **Silicon on Insulator, photonic crystal waveguide, photonic wire, deep UV lithography**

I. INTRODUCTION

Current photonic integrated circuits (PIC) are fairly large compared to their electronic counterparts. This is because the on-chip optical waveguides typically have a low index contrast, and therefore the light is weakly confined in the large waveguide core (core diameter >> 1μm). As a result, waveguides need a large bend radius, consuming valuable chip area only for interconnects. This is one of the reasons current PICs integrate only a small number of components onto a single chip, which is often many cm^2 in size.

Nanophotonic waveguides confine light into a submicron core area by using a very high refractive index contrast. So-called *photonic wires* are scaled-down versions of the conventional waveguides, with a much smaller core area and a higher refractive index contrast. Just as their large counterparts, they guide light by total internal reflection.

Alternatively, one can use photonic crystals [1]. These are periodic structures with a high index contrast. An example, consisting of air holes etched into a Silicon layer, is illustrated in the left part of figure 2. Because of their wavelength-scale periodicity, photonic crystals can have a photonic band gap, i.e. a wavelength region where no light can penetrate the crystal. A defect in such a photonic crystal, made by changing or removing a row of holes, can sustain a guided mode in the photonic crystal. Light in the photonic band gap is bound to the waveguide defect because it is not allowed to propagate through the areas of photonic crystal on both sides of the waveguide. In the structure in the left part of figure 2, called a photonic crystal slab waveguide, light is guided in-plane by the photonic crystal, and in the vertical direction by total internal reflection.

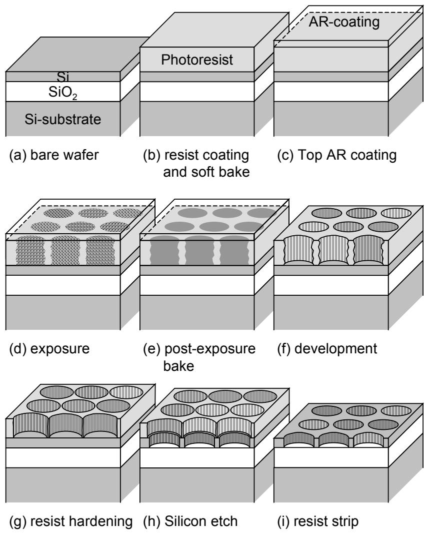

Fig. 1. The fabrication process based on CMOS Technology.

II. FABRICATION PROCESS

Semiconductors like GaAs and Silicon, with a refractive index of approximately 3.45, are exceptionally suited for nanophotonic waveguides. Also, there is a lot of experience in nanoscale fabrication for semiconductor platforms. In this work, we used Silicon-on-Insulator (SOI) as our base material. SOI is an ideal material for nanophotonic waveguides. The top layer, in our case of 220nm of Silicon, has a refractive index of 3.45. The layer below is Silica (SiO$_2$) with an index of 1.45. If sufficiently thick, this buffer layer optically isolated the top layer from the Silicon substrate. This makes it possible to make nanophotonic waveguides in SOI by etching only the top layer.

Because we use a Silicon-based material, we can use of processes compatible with CMOS technology. We demonstrated that with 248nm deep UV lithography, available in IMEC in Leuven, we can define the small features needed for nanophotonic waveguides.

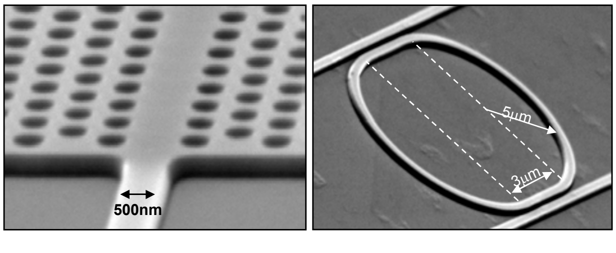

Fig. 2. A W1 photonic crystal waveguide and a photonic wire based racetrack resonator in Silicon-on-insulator.

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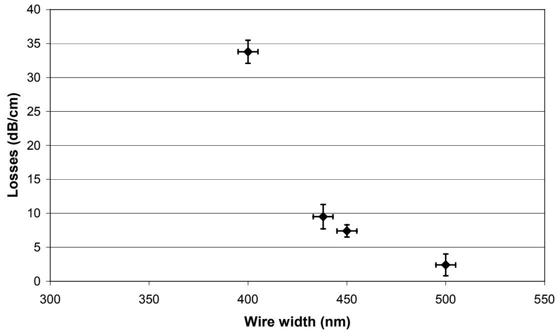

Fig.3. Propagation losses for photonic wires.

The fabrication process is illustrated in figure 1. First, the wafer is coated with photosensitive resist and an anti-reflective coating, after which it is illuminated by the deep UV stepper with designs on a mask. After development, the resisted is exposed to an optional plasma treatment, after which it is used as a mask for the Silicon etch. The process is described in more detail in [2].

III. FABRICATED STRUCTURES

We fabricated components based on both photonic wires and photonic crystal waveguides with deep UV lithography. These components were characterised using an end-fire technique. Light from a tunable laser source is coupled in a broad ridge waveguide in SOI using a lensed fibre. The broad ridge waveguide is then tapered down to a nanophotonic waveguide, either a photonic wire or a photonic crystal. The transmitted light is led out again through a taper and a broad ridge waveguide and collected by an objective onto a power detector. This way, we can measure the transmission of the component as a function of wavelength.

In order to measure the propagation losses, photonic wires and photonic crystal waveguides of various length were put on the mask. For photonic wires, we measured propagation losses as low as 2.4dB/cm, for wires that are still single-mode. When the wires get narrower, the effect of sidewall roughness increases the losses, as illustrated in figure 3. With propagation losses this low, nanophotonic interconnects of several cm become realistic, allowing to integrate a large number of components onto a nanophotonic IC.

We also made ring and racetrack resonators based on photonic wires. A racetrack resonator, as illustrated in the right part of figure 2, couples light from the input waveguide to the drop waveguide only for the resonating wavelengths, i.e when the wavelength in the material fits an integer number of times in the circumference of the ring. In the other cases, light just continues its way along the input waveguide.

Ring resonators can be used as wavelength selective filters. For a resonator of a certain size, the selectivity is mainly determined by the coupling efficiency between the waveguide and the ring and the losses in the ring. This is expressed in the quality factor. For wavelength-selective applications, Q of several thousands are required. Figure 4 shows the transmission spectrum of the drop and pass port of the racetrack resonator illustrated in the right part of figure 2. The drop port has a strong wavelength selectivity, with a Q of over 3000. With a similar ring resonator, which has a shorter coupling section, we have already attained a Q of 8000.

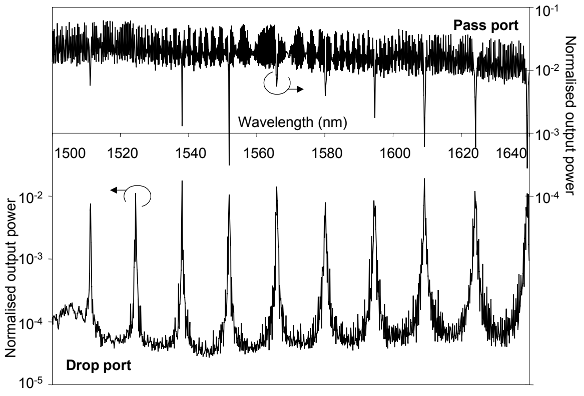

Fig.4. Transmission spectrum of a the racetrack resonator in figure 2. Top: pass port, Bottom: drop port.

For photonic crystal waveguides, propagation losses are still an order of magnitude larger. In figure 4 we can see a measurement indicating a propagation loss of 10dB/mm.

IV. CONCLUSION

We have demonstrated both photonic crystals and photonic wires in Silicon-on-insulator fabricated with deep UV lithography. For photonic wires, we have already attained record-low propagation losses of 2.4dB/cm, and ring resonators with a Q of up to 8000. For photonic crystal waveguides, we have measured losses of 10dB/mm.

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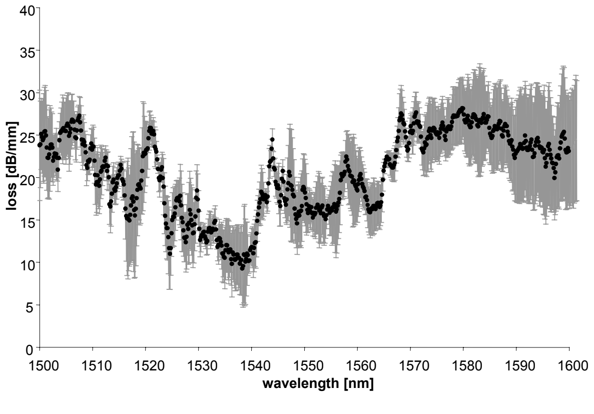

Fig. 5. Propagation losses as a function of wavelength in a W1 photonic crystal waveguide.