High Index-Contrast Silicon-On-Insulator Nanophotonics

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ABSTRACT
We will present recent progress in several devices based on silicon-on-insulator nanophotonics using deep-UV lithography. We will report on high efficiency grating couplers, ultra-compact arrayed waveguide gratings and ring-resonator based biosensors.
Keywords: nanophotonics, arrayed waveguide gratings, ring resonators, biosensors.

1. INTRODUCTION

Silicon-on-insulator offers a very interesting platform for nanophotonics because of the high-index contrast and the possibility of integration with CMOS. We report here on several devices fabricated with deep-UV lithography, which opens the way for mass fabrication of these components. We will discuss three types of devices: high efficiency grating couplers using a metal mirror, ultra-compact arrayed waveguide gratings and ring-resonator based biosensors.

2. GRATING COUPLERS

Coupling to fiber remains a severe issue in optical communication networks. The ongoing trend to make components smaller in order to integrate them on one chip makes the problem even more difficult. The large difference in dimensions between fiber and waveguides on chip causes high insertion losses and high packaging cost. Key features of effective solutions are compactness, broadband operation, and low insertion loss. Using an inverse taper approach can meet these requirements [1, 2]. Another attractive solution are grating couplers, since they open the prospect of wafer-scale testing. Light is coupled out-of-plane from fiber to waveguide, and in- and outcoupling can occur anywhere on the chip. When using high index contrast material, these gratings can be made very compact and relatively broadband [3].

We have fabricated such grating couplers in Silicon-on-Insulator with a measured coupling efficiency of 69%. The gratings have a footprint of 10x10 μm^2 and the 1 dB bandwidth is 40 nm. The high coupling efficiency is achieved by adding a gold bottom mirror to an existing SOI-grating coupler using BCB wafer-bonding [4]. In this way, coupling to the substrate is avoided, and all the light can be coupled upwards by the grating. The coupling efficiency can be further increased by using a non-uniform grating to a theoretical value of more than 90%.

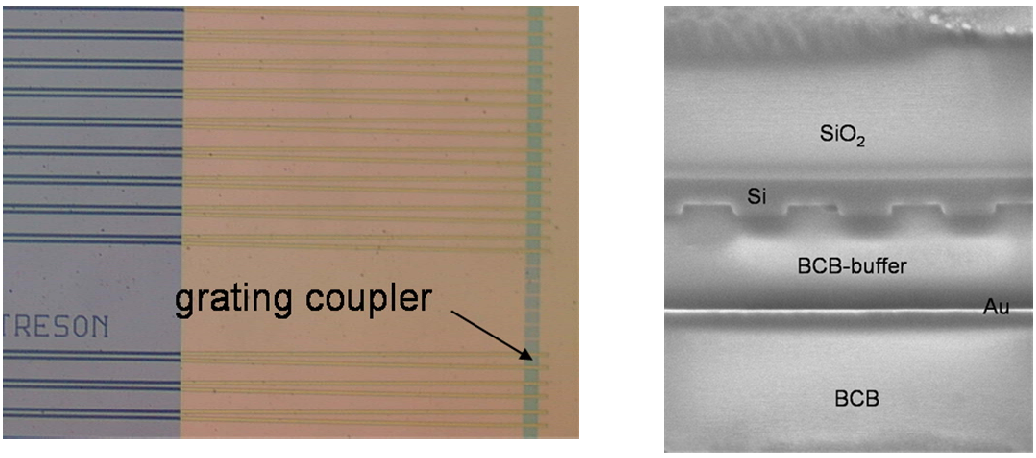

Figure 1. Left: picture of a fabricated structure. Right: SEM-picture of a FIB cross-section.

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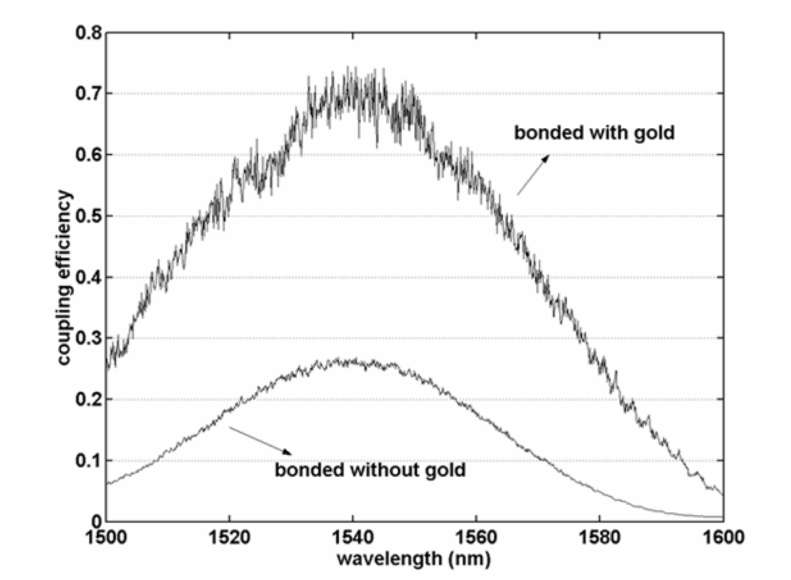


Figure.2. Measurement result for bonded SOI-grating couplers with and without bottom mirror.

3. COMPACT ARRAYED WAVEGUIDE GRATING

Silicon wires are very attractive to implement passive linear wavelength filters for WDM purposes, such as arrayed waveguide grating (AWG) routers, multiplexers or demultiplexers. With lower index contrast systems, the size of an AWG is limited by the bend radius. The use of Silicon wires, with a bend radius of just a few µm exhibiting negligible losses, overcomes this problem. The size of an AWG is then limited by design parameters such as the desired free spectral range and the number of wavelength channels.

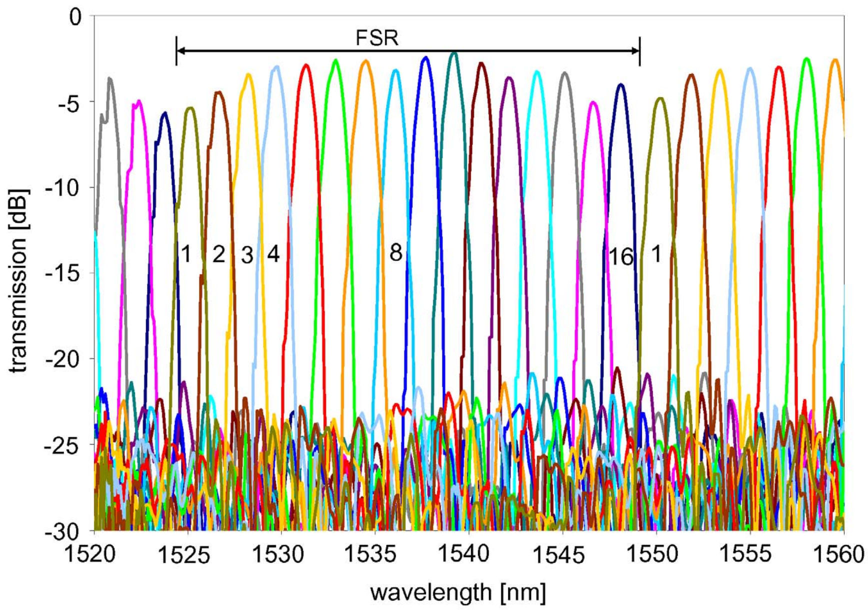
One of the major sources of loss in an AWG, and even more pronounced in a high index contrast material system, is scattering at the gaps between the array waveguides. We reduced the scattering loss by using a lower index contrast for the star coupler. This was done through a double etch scheme, where the waveguides around the star coupler were etched only 70 nm deep in the 220 nm thick Si layer. A double taper approach converts between the 220 nm deeply etched waveguides at the inputs, outputs and in the array.

The second point tackled is the crosstalk, arising from multiple sources. The high index contrast, submicron size waveguides are very sensitive to small waveguide width variations such as random roughness and longer scale variations or more systematic mask digitization errors. This gives rise to phase errors which can be very significant, up to a considerable fraction of π. We lowered this sensitivity by using broader waveguides, for which the effective index changes less with waveguide width. As these waveguides are multimode, more narrow waveguides are still used for the bends and near the tapers at the star couplers. Other contributions to the crosstalk are the truncation of the field due to the finite array aperture and other aberrations which can be stronger in this high index contrast, wide angle system.

Here we present a 16 channel AWG for routing purposes, with a 200 GHz channel spacing. The AWG has 36 arrayed waveguides. The gaps between the (shallowly etched) array waveguide apertures are 190 nm. The device has an insertion loss of 2 to 3 dB, and a side lobe level (giving rise to crosstalk) of -15 to -20 dB.

4. RING RESONATOR BASED BIOSENSOR

Sensing of biomolecules is gaining interest due to its applications in many areas such as bacterial and virus detection, medical diagnostics, drug development, food and environmental control. Most commercialized biosensors rely on detection of labeled molecules. However, there is a growing need for label-free detection methods for fast, sensitive and quantitative sensing. We propose a highly miniaturized label-free biosensor based on optical microcavities in Silicon-on-Insulator (SOI). SOI offers a high refractive index contrast suitable for the fabrication of nanophotonic circuits including micron- and submicron sized optical cavities of very high quality. The shift of resonance wavelength that occurs when the dielectric surroundings of such a cavity is changed, can be used for sensing.



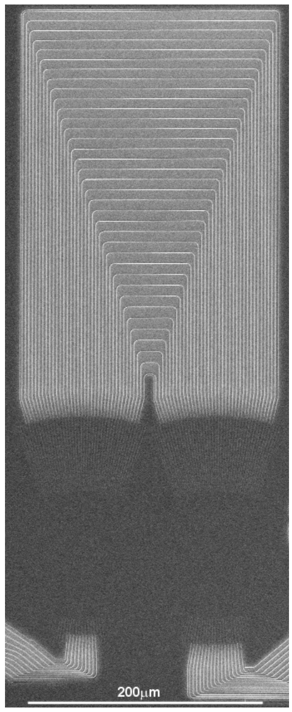


Figure 3. 16 channel (200GHz) AWG (left) transmission spectra from central input to all outputs (right) SEM picture.

We demonstrate a sensor based on an SOI optical microring resonator with radius 4 micron. We find our device capable of detecting bulk refractive index changes of $7 \cdot 10^{-5}$ using salt concentrations (see figure 4). The silicon surface has been chemically modified allowing for immobilization of biotin molecules. We test avidin/biotin affinity sensing by flowing an avidin solution over the modified microring using a microfluidic system and observe the corresponding resonance wavelength shift. Moreover, we demonstrate easy and alignment tolerant coupling of light into and out of our device. The sensor is fabricated by means of standard technologies, in particular deep-UV lithography, used for the fabrication of very large scale integrated (VLSI) electronic circuits. These technologies allow for high levels of integration indicating the potential of multiparameter analysis and lab-on-chip applications. Moreover, they allow for high-throughput fabrication as needed for high volume applications.

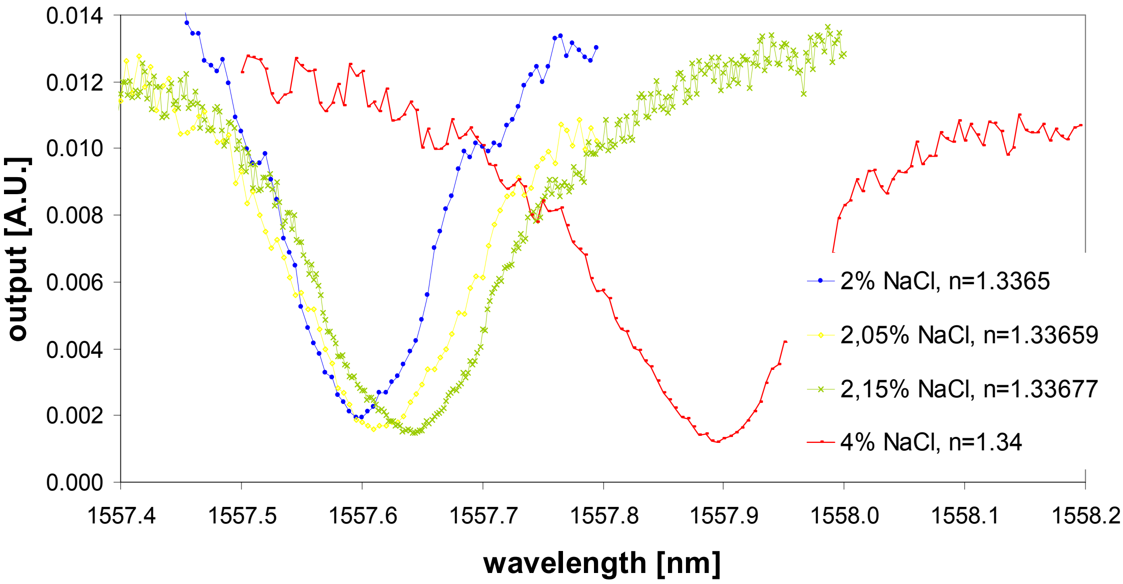


Figure 4. Resonance shift of biosensor for different salt concentrations.

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CONCLUSIONS

We presented recent progress in several devices based on silicon-on-insulator nanophotonics using deep-UV lithography. We reported on high efficiency grating couplers, ultra-compact arrayed waveguide gratings and ring-resonator based biosensors.

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