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- ABSTRACT -

MICRORING RESONATORS IN SILICON-ON-INSULATOR

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SUMMARY

We present a variety of microring resonators in SOI with radii from 1 to 8µm, showing possibility of high finesse (120) or high extinction ratio and channel drop efficiency, and a 1-by-4 demultiplexer.

KEYWORD
microring resonator, Silicon-on-insulator, deep UV lithography, WDM

ABSTRACT

INTRODUCTION

Microring resonators in high refractive index contrast waveguides can be a building block for densely integrated wavelength selective filters, which can be used for WDM purposes and other applications.
The material system used here is Silicon-On-Insulator (SOI) which has both a very high lateral and vertical index contrast. This enables fabrication of bend waveguides with radii down to a few microns with low radiation loss. This in turn allows for very large free spectral ranges (FSR) which is important for the fabrication of add-drop filters. A large finesse and high extinction ratios are of utter importance too. To achieve good add-drop filters the line shape of the microring still needs to be altered. This can be done by higher-order filters. However, the study of single ring filters is a first step towards this goal.

Reliable fabrication of such devices is challenging however. In most cases, e-beam lithography is used to define patterns in a resist but the industrial application of this serial writing technique is limited. We present microring resonators in Silicon-on-insulator photonic wires fabricated using CMOS fabrication technology. These wires are strip-like waveguides with submicron dimensions. The resonators have radii up to 8µm and are laterally coupled to two waveguides for channel dropping purposes. We studied different coupling alternatives in order to achieve low crosstalk and high finesse while maintaining a large free spectral range.

SILICON-ON-INSULATOR PHOTONIC WIRES

Structures are defined in SOI with a 220nm thick Si top layer and a 1µm buried oxide. Pattern definition in resist is done using deep UV (DUV) lithography with an illumination wavelength of 248nm. The Si layer is then fully etched using a dry etching process. The fabrication process is described in detail elsewhere [1]. Optionally, a top cladding such as SiO_2 or polymer can be applied. Resulting waveguides have both a high lateral and vertical refractive index contrast and are called photonic wires. They are no wider than 600nm in order to keep them single mode. Earlier, we demonstrated propagation losses as low as 2.4dB/cm for a 500nm wide straight wire for TE-like polarisation [2]. These losses are due to substrate leakage and scattering at sidewall roughness. The propagation losses for TM polarisation are much higher than for TE polarisation. Therefore, in the remainder of the paper only TE polarisation is considered.

In- and outcoupling to chip is done via shallowly etched 1D vertical fibre coupling gratings [3]. These fibre couplers have an approximately Gaussian transmission spectrum with a maximum transmission efficiency of 20% and a 3dB bandwidth of 60nm. Due to their relaxed alignment tolerances compared to in- and coupling to a waveguide facet, they are very well suited for characterization of components. One drawback of the fibre couplers is that normalisation of measured spectra becomes more difficult if a broad wavelength range is considered. Transmission spectra plotted hereafter show the unnormalized transmission from laser to detector through the sample, thus including about 15dB coupling loss.

It is possible to reduce the polarisation dependency of straight wires by making them more squared. However, obtaining polarisation independent functional circuits is very difficult. By extending the principle of the fibre coupling gratings to 2D, polarisation diversity can be used in order to relieve polarisation dependency problems [4].

CIRCULAR RING RESONATORS

The first devices fabricated are circular ring resonators coupled to two straight waveguides. The gap between ring and straight waveguide is limited to about 200nm due to technological limitations. This makes coupling between the ring and waveguides difficult and smaller than 1%. This can be seen in Fig 1 which shows the power coupling coefficient for different gap widths for a 5µm radius ring. These are the results of simulations based on coupled mode theory [5].

With a 5µm radius ring, a FSR of 17nm is obtained but drop efficiency is very low due to the low coupling. Also, Fig. 2a shows that resonances are often split. This is due to coupling to the counterpropagating mode induced by the surface roughness. As explained in [6] this effect only appears if the coupling coefficient is sufficiently low. We applied a BCB top cladding in order to enhance the coupling. This polymer has a slightly higher refractive index (1.5) than the air cladding. The increase in the coupling coefficient is clear from simulations (Fig 1). The measurements also clearly show the increase of the coupling and the absence or large reduction in the splitting of the resonances (Fig 2b). Reduced waveguide dispersion also leads to a net increase of the FSR to 18.5nm.
Due to low coupling and high FSR the finesse of this kind of device is high, up to 120. However, for WDM purposes coupling should be increased. Therefore, we looked at other ring resonator configurations to enhance coupling between cavity and waveguides.

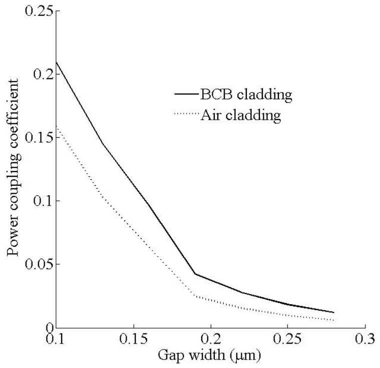

Figure 1: Simulation of the power coupling coefficient versus gap width

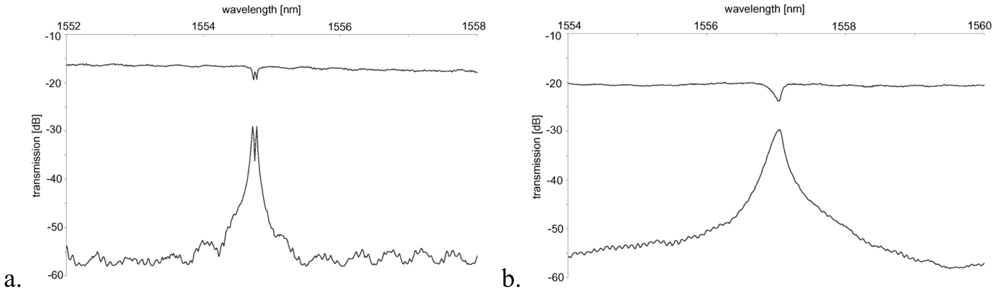

Figure 2: (a) detail of transmission spectra of a ring resonator with 5µm radius
(b) same ring with a BCB top cladding, resonance in the same wavelength range

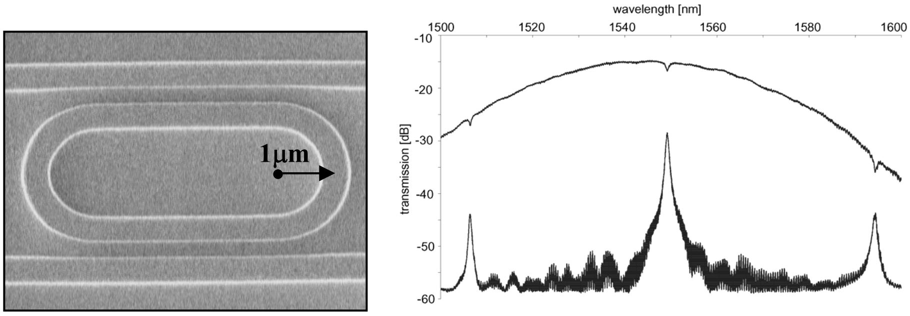

Figure 3: racetrack with 1µm radius (left) SEM picture (right) transmission spectra

RACETRACK RESONATORS

One option is to include a straight coupling section, leading to a racetrack form resonator (Fig. 3). We fabricated racetracks with radii of the bend section between 1 and 6 µm. Transmission spectra of a racetrack with 1µm radius are shown in Fig. 3. With 1µm radius, a Q of around 2100 is obtained but the drop efficiency is low. To our knowledge, it is the first time rings with such a small radius have been presented. For larger radii, the ring losses decrease quickly. With a 2µm radius, drop efficiency is already much larger and Q factors in the range 5000-9000 are obtained. We also fabricated racetracks with 5µm radius and larger coupling section. The larger coupling leads to a high add-drop extinction ratio of -20dB and 50-70% drop efficiency at Q factors still larger than 3000. This is illustrated in Fig. 4.

RING RESONATORS COUPLED TO BENT WAVEGUIDES

While racetrack resonators can clearly enhance coupling, their FSR is limited. Another option is coupling to bend waveguides [7]. The topology is illustrated by Fig. 5. By carefully choosing the widths of cavity and bus waveguides, a good phase matching can be obtained and coupling can be high without lowering the FSR as in the case of the racetrack resonator. We fabricated bend-coupled resonators with 5 and 8µm radius. The amount of coupling is varied by varying the angle over which both waveguides are coupled. Coupling is large enough to obtain a relatively high extinction ratio (-10 to -15dB) and high drop efficiency, although these first devices are still far from optimized.

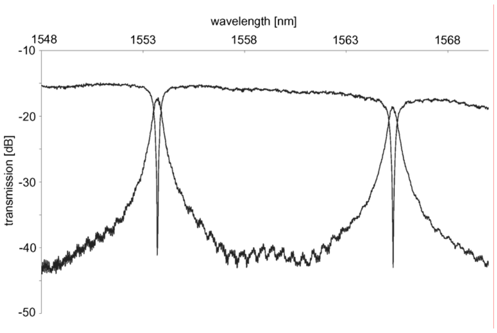

Figure 4: transmission spectra of a racetrack resonator with 5µm radius

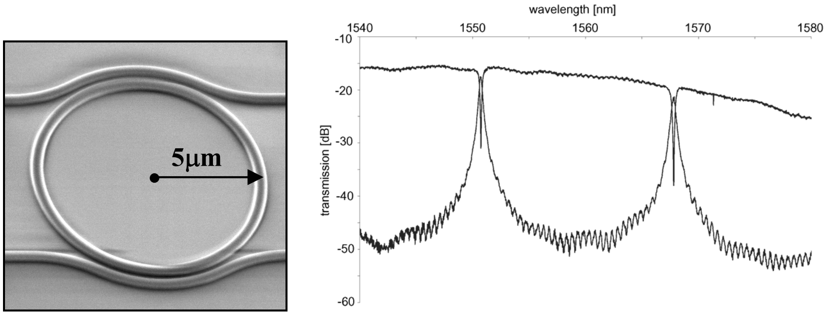

Figure 5: (left) SEM picture and (right) transmission spectra of a bend-coupled ring resonator with 5µm radius

FIRST-ORDER DEMULTIPLEXER

We fabricated a 4 channel add-drop filter with racetrack resonators with different radius. By varying the radius, the resonance wavelength is changed and each cavity is tuned to another set of dropped wavelengths. One must keep in mind that with this approach the FSR also varies. Figure 6 shows the overlaid transmission spectra for 4 resonators with 6, 6.02, 6.04 and 6.08 µm. A BCB top cladding was applied. We see that a large part of the FSR can be reached by changing the radius over only 80nm. However, better control over the exact resonance wavelengths is needed.

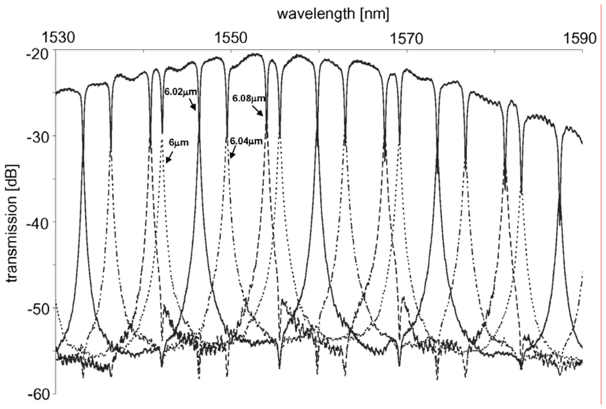

Figure 6: Overlaid transmission spectra of a 1-by-4 demux with 4 racetracks with varying radius (indicated)

CONCLUSION

We have presented various microring resonators in Silicon-on-Insulator fabricated with CMOS technology. The circular microring resonators coupled to straight waveguides exhibited very high finesse but low extinction ratio and drop efficiency due to low coupling. To increase the coupling racetrack resonators with a radius down 1µm were fabricated. These had a Q value of 2000. The racetrack resonators with radii of 5µm showed high extinction ratios of -20dB and high drop efficiencies. To increase the coupling but not decrease the FSR ring resonators coupled to bent waveguides were fabricated. These filters still have a relatively large finesse and a high free spectral range. We also demonstrated a 1-by-4 (de)multiplexer consisting of 4 racetracks with varying radius on a single input waveguide.

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