Silicon-on-Insulator Platform for WDM-components

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Abstract *The Silicon-on-insulator (SOI) platform allows to make ultra -compact photonic circuits by means of standard processes used for advanced CMOS. Various WDM-components (filters and demultiplexers) based on high-contrast nanophotonic waveguides in SOI are reported.*

Introduction

The implementation of photonic ICs for Wavelength Division Multiplexing (WDM) functions can be done by means of a variety of material systems. For passive functions such as filters and demultiplexers silica-based technologies have been very successful to meet the demanding requirements of WDM systems in terms of spectral behaviour (bandwidth, crosstalk…) and losses. However the low refractive index contrast in the silica system results in large dies, mainly because the waveguide bends need to have radii in the millimeter range.

In contrast, a Silicon-on-insulator (SOI) substrate offers the possibility to make waveguides with very high refractive index contrast, of the order of 2 to 1, in all directions of confinement. With such strong confinement the typical dimensions of the Silicon core are a few hundred nm in both transversal directions for single-mode behaviour. These waveguides – often called photonic wires - allow to reduce the bend radius down to a few micrometer. For many types of photonic circuits this means that the die size can be miniaturized by 10-1000 times. The price paid for this dramatic reduction in size is the fact that the geometrical precision of the topological layout needs to be of the order of 10 nm or better, so as to achieve a predictable and reproducible effective refractive index as well as to reduce the losses due to roughness.

E-beam lithography allows to meet these stringent requirements and a variety of photonic functions has been demonstrated in SOI by means of this technology [1-4]. One of the major advantages however of SOI-based nanophotonic circuits is the fact that they can be fabricated by means of standard technologies normally used for the industrial manufacturing of microelectronic ICs, such as deep UV lithography.

In this paper a variety of WDM-functions implemented in SOI by means of 248 nm deep-UV lithography are discussed. The fabrication technology and basic waveguide structures are discussed in [5] and [6] respectively. This technology has allowed to reproducibly make waveguides with losses of the order of a few dB/cm.

Ring resonator based add-drop filters

A variety of ring and racetrack resonators have been demonstrated with radii in the range 3-5 micrometer [7]. Depending on the coupling efficiency of the coupler the Q-factors ranged from a few 1000 to over 10000. The best devices have insertion losses to the drop port of 3 dB. Fig. 1 shows an example of the pass and drop transmission.

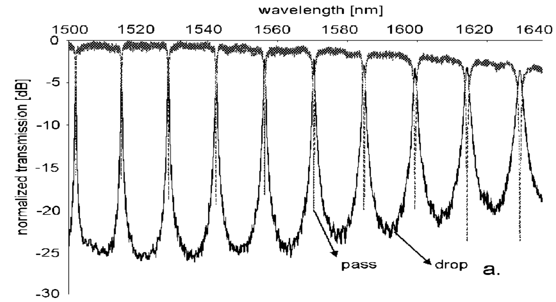

Fig.1 Pass and drop transmission spectra of a racetrack resonator with a bend radius of 5 micron.

The dimensions of these ring resonators are critical. The gap of the directional coupler is typically 200-250 nm wide and the coupling strength depends strongly on this value. The width of the waveguide in the ring has a strong influence on the resonance wavelength: a width change of 5 nm leads to a shift of about 15 nm.

This sensitivity calls for a thorough optimisation of the design and fabrication process including line bias effects and proximity corrections.

Arrayed Waveguide Gratings

We have designed and fabricated an 8-channel AWG, illustrated in Fig. 2. This device has a footprint of 380µmx290µm, or about 0.1mm^2. The insertion loss due to the star coupling sections is approximately 8dB. The channel spacing is 3nm, with a free spectral range of 24nm. However, the crosstalk is still significant, between 6dB and 9dB [8].

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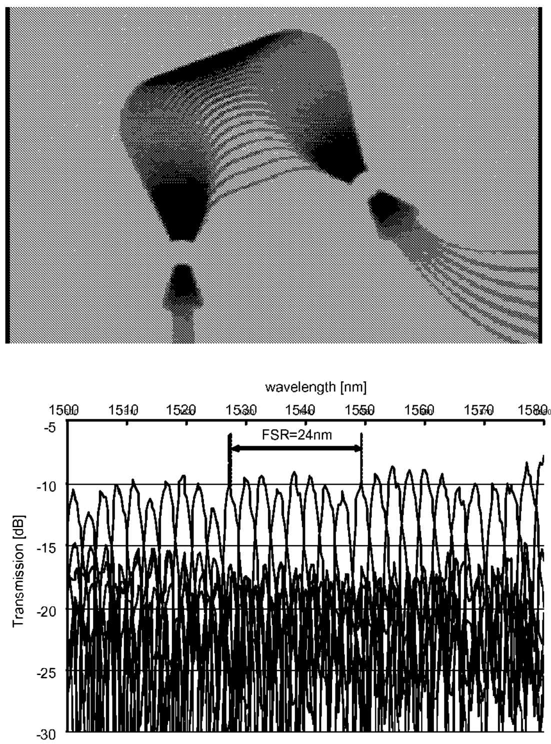

Fig. 2 Microscope image of the 8channel AWG and superimposed plot of the 8 transmission spectra.

Cascaded Mach-Zehnder (CMZ) add-drop multiplexers
A CMZ is a 2 x 2 port device allowing for Chebychev-type filter behaviour with low sidelobe levels. Figure 3 shows an example of a 5-stage CMZ, consisting of 6 directional couplers and 5 delay sections. The isolated waveguides have a width of 565nm while the waveguides in the coupling sections are only 535nm wide due to optical proximity effects. The gap width itself is 220nm.

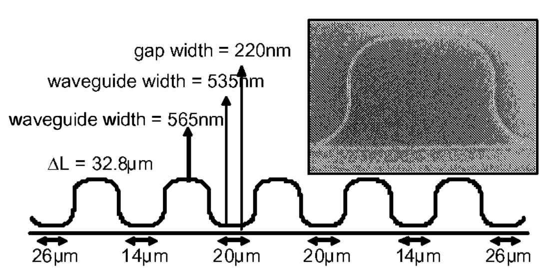

Fig. 3 Design of a 5-stage CMZ

Figure 4 shows the transmission characteristic of this component in both the pass and the drop port normalized to the transmission of a simple straight waveguide. We can see a well-defined filter characteristic with a bandwidth of 2.6nm, a free spectral range of 17nm and a coupling efficiency of almost 100%. The crosstalk of 10 dB is still relatively high.

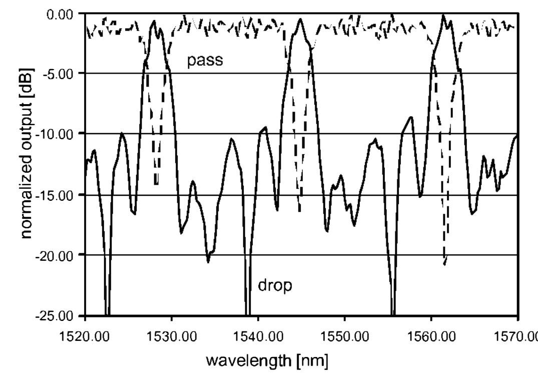

Fig. 4 Transmission characteristic of the five-stage CMZ from figure 3.

Conclusion
The results shown here demonstrate that a variety of passive WDM-functions can be implemented on Silicon by means of CMOS-compatible processes. While the performance of these first devices is promising, there is certainly a lot of room for improvement by refining the designs and optimising the technology. This should result in predictable control of geometry at the nanometer level, as needed for these nanophotonic circuits.

Acknowledgements
Part of this work was supported by the European Union through the IST-PICCO and IST-PICMOS project and by the Belgian IAP-PHOTON network project. P. Dumon and W. Bogaerts thank the Flemish Institute for the industrial advancement of scientific and technological Research (IWT) for a specialization grant. D. Van Thourhout and P. Bienstman acknowledge the Belgian Federal Office for Scientific, Technical and Cultural Affairs and the Flemish Fund for Scientific Research (FWO) respectively.
The authors would also like to thank D. Vangoidsenhoven, Rudi de Ruyter and Johan Mees.

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