

Passive SOI devices for the Short-wave-infrared

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Abstract—In this paper we report on passive silicon-on-insulator devices for the short-wave-infrared wavelength region. Substantial improvements are achieved for grating couplers, waveguides and ring resonators.

Keywords – short-wave-infrared; silicon-on-insulator

I. INTRODUCTION

Silicon-on-insulator has attracted a lot of attention in the last decade for photonic applications. At first mainly driven towards telecom applications, the research on SOI optical devices is extending more and more to other applications such as nonlinear optics and gas sensing. In both cases, extending the basic SOI structures to cover the short-wave infrared and Mid-IR region would be highly beneficial. For sensing, the main reason is that many molecules have distinct absorption bands in this region [1]. This allows for unambiguous detection of the presence and concentration of certain molecules. In nonlinear optics, working at longer wavelengths reduces the parasitic nonlinear absorption in silicon, the two-photon absorption (TPA), enormously. Without TPA it is possible to fully benefit from the record nonlinear parameters obtained through the combination of the high linear index leading to high confinement and the high nonlinear index of silicon. This has been recently confirmed by implementations of highly efficient nonlinear optical devices enabling high parametric gain [2] and efficient supercontinuum generation [3]. In this paper we report on highly efficient grating couplers, low loss waveguides and high finesse resonators for the 2.2 μm region.

II. GRATINGS

Grating couplers for the short-wave-infrared have been recently reported by our group [4]. Here we present a more thorough experimental investigation of these gratings. These gratings are fabricated in the 200 nm CMOS pilot line at imec with 193nm DUV lithography. We refer the reader to [4] for more details on the fabrication. The gratings have been measured using standard single mode fibers under an angle of 10 degrees. First the grating period dependence was studied, allowing to reach a record -3.8 dB coupling losses around 2080 nm, with a period of 970 nm (not shown).

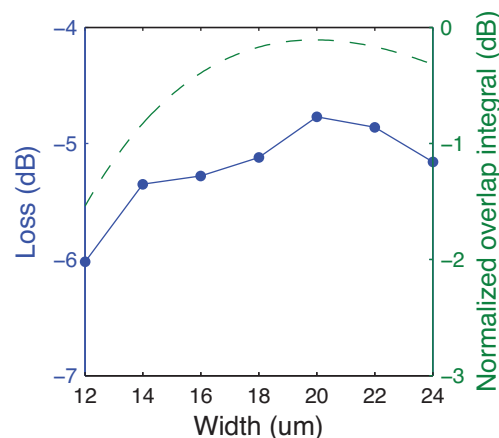


Fig. 1 : Influence of the waveguide width on the attainable fiber-to-chip coupling efficiency

In order to reach such values for longer wavelengths, we then fabricated gratings with different width to study the effect of the transversal overlap between the SOI mode and the fiber mode. The grating under investigation has a period of 1050 nm and a 35% fill factor. The lowest coupling losses are measured at 2240 nm. Fig. 1 shows the evolution of the coupling losses at 2240 nm for different waveguide widths (blue line). It is compared with the theoretical dependence (dashed green line), obtained by calculating the overlap between the mode in the grating and the mode in the fiber. The $1/e^2$ -width of the latter was taken to be 13.6 μm . We see a good agreement, showing that varying the width has significant impact on the coupling losses. However, it didn't allow reaching such low values than the one measured at 2080 nm with a shorter period. The reason for this is still under investigation.

III. WAVEGUIDES

In this section we report on record low losses of 0.6 dB/cm for single mode waveguides in the short-wave infrared region. The silicon photonic wires used are fabricated in a CMOS pilot line, using 200 nm SOI wafers consisting of a 220 nm silicon waveguide layer on a 2 μm buried oxide layer. The wires are 900 nm wide with no top cladding and are etched through the 220nm silicon waveguide layer. The losses are

measured using a cutback technique. The light is coupled in and out of the waveguides through grating couplers. Fig. 2 shows the measured losses over the grating coupler optical

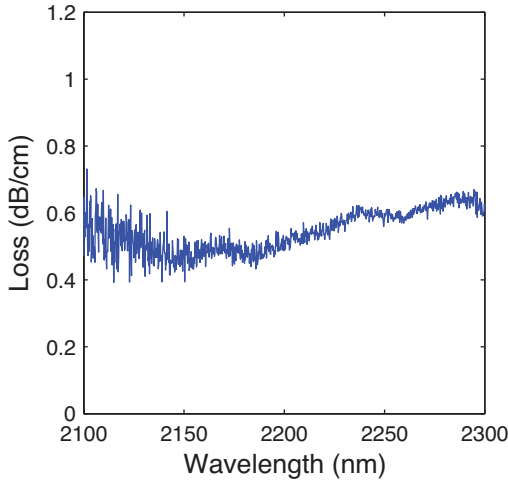


Fig. 2 : Waveguide loss as a function of wavelength for 900nm wide silicon wire waveguides

bandwidth. Let us point out that the strong optical confinement of such waveguides results in a very high effective nonlinearity parameter. It has been estimated to be $150 (\text{W}\cdot\text{m})^{-1}$ [3].

IV. RINGS

Fabry-Perot cavities are essential to the fields of nonlinear optics and sensing as they allow increasing both the propagating power and the interaction length (see e.g. [5]). In particular, there is recently a lot of interest in integrated frequency combs [6]. These are equally spaced spectral lines generated from parametric frequency conversion in a high Q microresonator. Integrated combs have been experimentally generated in many different configurations, such as silica toroidal microcavities [7] and Si_3N_4 ring resonators [8], but remain to be observed in silicon. The applications of such a comb lies in precision spectroscopy, atomic clocks and molecular fingerprinting. A silicon microresonator could potentially allow for the integration of such a frequency comb. Here we report on the fabrication of resonators with a finesse of 130, corresponding to a loaded Q of 75000. A microscope picture of the ring is presented on Fig. 3. The ring circumference is $350 \mu\text{m}$, the gap is 450 nm and the coupling length is $20 \mu\text{m}$. The waveguides are 900nm wide. By injecting the ASE of our laser source through a grating coupler and by looking at the outcoupled spectrum on a SWIR optical spectrum analyzer, a FSR of 3.9 nm can be observed. The changes in depth of the different resonances is due to the limited resolution of our OSA (50 pm). To measure the full width at half maximum we work at one single wavelength and tune the chip's temperature. We measured a finesse of 130,

which corresponds to a FWHM of 30 pm. Moreover, we found an on-resonance extinction of more than 13dB showing that our ring is very close to critical coupling.

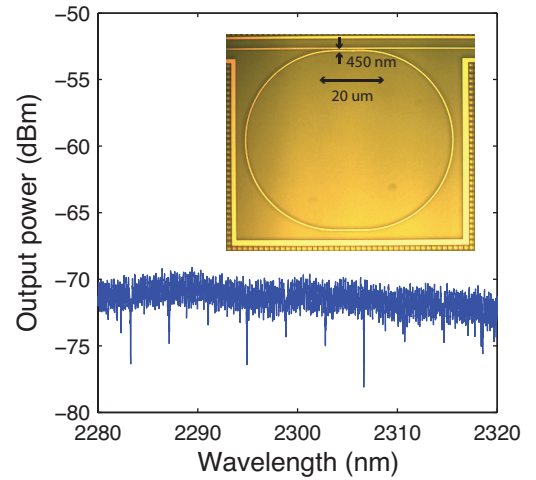


Fig. 3 : Observed transmission spectrum of high-Q ring resonators for the short-wave infrared.

V. CONCLUSION

While silicon photonics has mostly been used for 1.3 μm and 1.5 μm applications, we highlight the potential of this platform for longer wavelengths. This observation could lead to the use of SOI waveguide circuits for a new range of applications, including spectroscopic sensing and nonlinear optics.

ACKNOWLEDGMENT

This work was carried out in the framework of the ERC-MIRACLE and the ERC-InSpectra project

REFERENCES

- [1] Crowder *et al.*, "Infrared methods for gas detection," in Mid-infrared semiconductor optoelectronics, Springer 2006
- [2] B. Kuyken *et al.*, "50 dB parametric gain in silicon photonic wires," *Optics Letters*, 36(21), pp. 20172-20181 (2011)
- [3] B. Kuyken *et al.*, "Mid-infrared to telecom-band supercontinuum generation in highly nonlinear silicon-on-insulator wire waveguides," *Optics Express*, 19(22), pp. 4401-4403 (2011)
- [4] B. Kuyken *et al.*, "Highly efficient broadband silicon-on-insulator grating couplers for the short wave infrared wavelength range," *Integrated Photonics Research, Silicon and Nano-Photonics (IPR)*, Canada, p.IMB6 (2011)
- [5] N.A Yebo, P. Lommens, Z. Hens, R. Baets, 'An integrated optic ethanol vapor sensor based on a silicon-on-insulator microring resonator coated with a porous ZnO film', *Optics Express*, 18(11), pp 11859-11866 (2010)
- [6] T.J. Kippenberg, R. Holzwarth and S.A. Diddams, "Microresonator-based optical frequency combs, *Science*, 332(6029), pp 555-559 (2011)
- [7] P. Del'Haye *et al.*, "Optical frequency comb generation from a monolithic microresonator", *Nature*, 450(7173), p.1214-1217 (2007)
- [8] J.S.Levy *et al.*, "CMOS-compatible multiple-wavelength oscillator for on-chip optical interconnects," *Nat. Photon.* 4(1), 37-40 (2010)