SOI Photonic Crystal components fabricated with deep UV lithography

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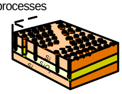
Rationale

- Photonic components >> electronic components
- Need for compact photonic buidlding blocks to integrate with electronics
- Need for suitable mass-fabrication
  - → e-beam litho = too slow
  - → classic optical litho = too coarse

Deep UV lithography

Silicon-on-insulator

- Base material for advanced CMOS
- Good base material for high-contrast photonics
  - → Low material loss at 1.55µm
  - → Top (guiding) layer: n_{Si}=3.45
  - → Buffer (cladding) layer: n_{SiO2}=1.45
- Compatible with standard CMOS processes
- Available in 200mm (8") wafers
- Our choice: SOITEC Unibond®



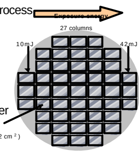
Deep UV Lithography at IMEC

- Deep UV stepper: ASML PAS5500/300 (being replaced by a PAS5500/750 step-and-scan)
- Wavelength: 248nm (KrF excimer laser)
- Field size: 2 x 2 cm² on wafer
- Reduction mask → wafer: 4X
- Wafer size: 200mm (8")
- Future planning: 193nm

Wafer layout

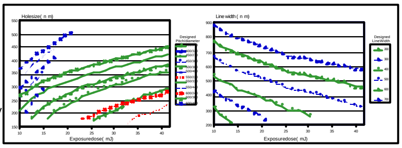
- Multiple dies on 1 wafer
  - → Use different lithography conditions for each die
  - → Characterise fabrication process
- e.g. Exposure sweep
  - → Increasing energy
  - → different feature sizes

Large parameter space on 1 wafer



Fabrication tolerances and reproducibility

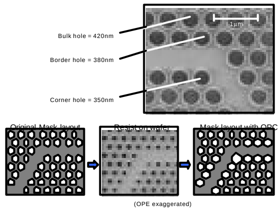
- Feature size ~ exposure energy
  - → wide variety of sizes possible (±30% of the design size)
  - → adequate budget for reproducible manufacturing (2-3 mJ)
- Holes and lines together?
  - → Hole size increases with energy
  - → Line width decreases with energy
  - → Difficult to get both right together

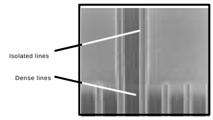


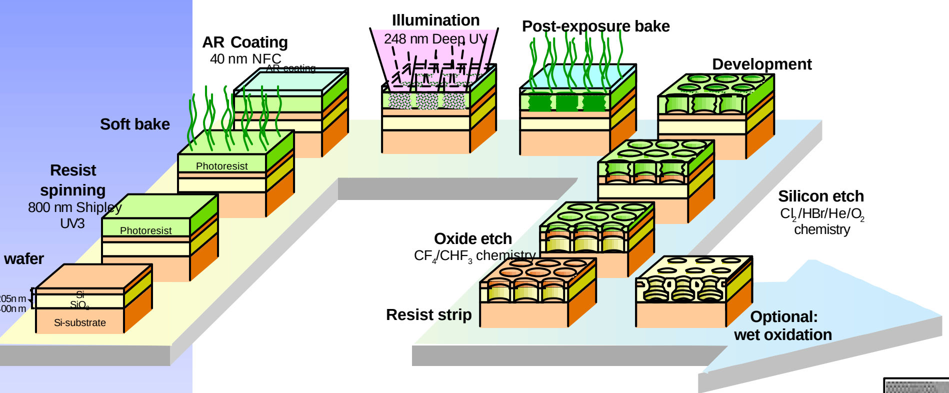
Optical proximity effects

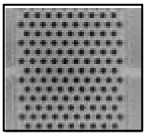
- Dense structures (e.g. photonic crystal lattices)
  - → neighbouring structures influence each other
  - → structures at the boundaries and near defects print different than structures in the bulk of the lattice
  - → effects are coherent
  - **= Optical proximity effects**

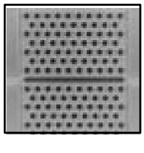
Corrections should be applied during the mask design stage (optical proximity corrections)

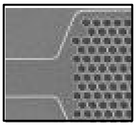


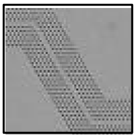


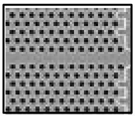


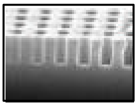


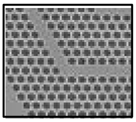


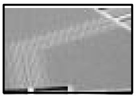


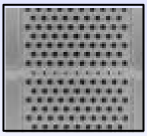


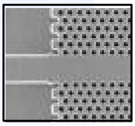












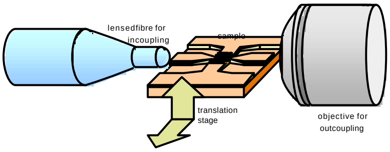
Abstract

Today's photonic ICs (PIC) are large, especially when compared to ULSI electronic circuits. To increase the level of integration in photonic components, compact building blocks to perform the elementary functions are required. These building blocks should be of the same length-scale as the basic CMOS elements. Photonic Crystals offer a way to this reduction in size. However these structures are very difficiult to fabricate at the most popular telecom wavelengths of 1.55µm and 1.3µm. For research purposes, these structures are therefore fabricated with e-beam lithography, a very accurate yet extremely slow pattern definition technique. While this produces good structures, it is too slow to be used for commercial fabrication. Manufacturing technology similar to that of state-of-the art CMOS components is needed to achieve both the accuracy and the throughput for mass fabrication of ultra-compact PICs.

We demonstrate the use of deep UV lithography for the fabrication of wavelength-scale photonic structures, including photonic crystals. We do this in Silicon-on-Insulator, a material system well suited for optical waveguiding. Deep UV lithography, as used today in the high-end CMOS industry, promises to deliver both accuracy as large capacity. We will discuss the fabrication process, and how the differences of these structures with typical CMOS structures make the application of this technology anything but straightforward. Still, the fabricated structures are well defined, with little sidewall roughness. Optical measurements on the fabricated photonic crystal waveguides show guiding of light, both through straight waveguides and a double 60-degree bend.

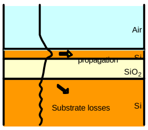
Measurement Setup

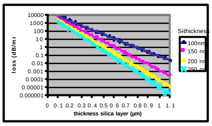
- Incoupling with lensed fibre into broad waveguide
- Outcoupling to high-NA objective
- Adiabatic tapering into photonic wire (500nm wide)



Substrate losses

- Light leaks through oxide buffer
  - → Current wafers: d_{SiO2} = 0.4µm: 8dB/mm loss
  - → New wafers: d_{SiO2} = 1µm: 10^{-5} dB/mm loss
- Calculations are for slab waveguide: Situation is (much) worse for narrow waveguides



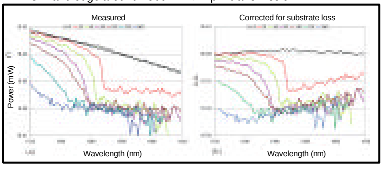


Conclusions

- Deep UV lithography is suitable for photonic IC fabrication
  - → Large throughput
  - → Adequate resolution
- Process characterisation is needed
  - → Print different structures together
  - → Optical proximity corrections
- Good wafer structure required
  - → Buffer layer should be thick enough

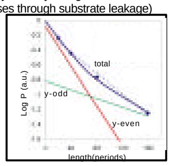
Measurements

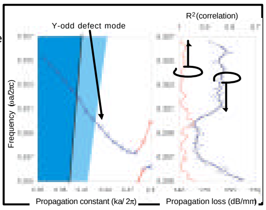
- Spectrum should be corrected for substrate losses
- This measurement: a = 432 nm, Ø = 232 nm
- Very high overall losses
- PBG: Band edge around 1560nm → Dip in transmission



Interpretation

- Very high propagation losses:
  - → Main mode: y-even mode above light line (very lossy coupling to radiation modes)
  - → Secondary mode: y-odd guided Bloch mode (only losses through substrate leakage)





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Acknowledgements

Part of this work was carried out in the context of the IST-PICCO project supported by the European Union

Part of this work was carried out in the context of the IAP-PHOTON project supported by the Belgian Government

Wim Bogaerts en Bert Luyssaert acknowledge the Flemish Institute for the Advancement of Scientific and Technological Research in the Industry (IWT) for a specialisation grant.