GAAS NANO-RIDGE LASERS ON SILICON

OUR OPTION #1: TRANSFER PRINTING

III-V-ON-SI WIDELY TUNABLE LASER WITH μTP
OUR OPTION #2: DIRECT EPITAXY ON SILICON

- Why?
  - Ultimate scalability: selective growth using MOCVD on 300mm wafers
  - It’s fun

HETEROEPITAXY- CHALLENGES

- LATTICE MISFIT
  - Lattice mismatch results in unwanted defects

ASPECT-RATIO-TRAPPING (ART)

- Basic processing scheme
  - Si
  - SOI
  - GaAs
  - InGaAs
  - InGaP

ASPECT-RATIO-TRAPPING (ART)

- Reference sample
ASPECT RATIO TRAPPING (ART)

- High-AR SiO$_2$ trenches enable trapping of threading dislocations.

NANO-RIDGE ENGINEERING (NRE)

Control growth rate on different crystal planes to obtain well-defined nano-ridge profile.
Higher growth rate facets disappear, whereas facets with lower growth rates define the nano-ridge profile.

Increasing trench width: shape and volume of nano-ridge changes.
BASIC CHARACTERIZATION
OPTICAL PROPERTIES

ROOM TEMPERATURE PHOTOLUMINESCENCE

NANO-RIDGE GALLERY

HIGH QUALITY DOES NOT COME FORE FREE!

Selectivity problems
Insufficient diffusion
Varying ridge shape

Rough nano ridge surface

XSEM images: GaAs NRs

Si
GaAs
QWs

TOP-VIEW SEM
FRONT-VIEW SEM
CROSSECTION TEM
LATERAL CUT TEM

600nm
1µm
2µm
500nm
1µm
500nm

532nm optical excitation

PL spectra for reference sample

photoluminescence

PL spectra for reference sample

300K

532nm optical excitation

PL spectra for reference sample

photoluminescence

532nm optical excitation

PL spectra for reference sample

photoluminescence

PL spectra for reference sample

photoluminescence

PL spectra for reference sample
TIME RESOLVED PHOTOLUMINESCENCE (TRPL)

Cryo only used in LT measurements

TRPL FOR REFERENCE STRUCTURE

Reference structure:
- 3 x InGaAs QW
- InGaP passivation-layer

No Passivation
- 50nm & 100nm InGaP

InGaP passivation layer is critical to suppress surface recombination

TRPL : EFFECT OF InGaP PASSIVATION LAYER

InGaP barrier suppresses leakage to defective trench

TRPL : EFFECT OF InGaP BARRIER
TRPL: LOW TEMPERATURE (80K)

With/without passivation layer

(Pump in QWs)

TRPL: EFFECT OF DOPING

Collaboration with Nils Gerhardt, Bochum University

Doping decreases lifetime: defects or more efficient recombination?

OPTICAL GAIN FROM VSL-MEASUREMENT

Variable strip length

PL power vs pump length

Modal gain

KEY MESSAGES MATERIAL QUALITY

- The GaAs nano-ridges emit at 1 \( \mu m \).
- Narrow trenches (<150nm) can efficiently traps defects.
- Surface recombination is a dominant carrier loss mechanism.
  - passivation of the surface with InGaP strongly suppresses the loss.
  - Recombination in the defective trenches is another carrier loss mechanism: inserting InGaP carrier-blocking layer suppresses the loss and improves the lifetime up to 2.5ns.
- The material gain was estimated to be above 5000cm\(^{-1}\).
- High-quality GaAs nano-ridge on Si can be obtained.
1μM-WAVELENGTH NANO-RIDGE LASER

TE-LIKE GROUND MODE
• highest confinement in QWs
• lowest leakage loss towards Si substrate
is believed to be the dominant waveguide mode.
Higher optical gain due to the strain effect

n_eff is increasing for nano-ridges with wider trench

4/2/20
Trade-off between coupling factor and loss results in optimal duty cycle of 40%
**APPROACH 1**
- Increase Indium content in QW’s to 45%

Huge strain leads to new threading dislocations appearing at QW-layers

**APPROACH 2**
- Replace GaAs buffer by InGaAs Buffer

**CHARACTERIZATION  OPTICAL PROPERTIES**

**OPTICAL PUMPING \(\lambda/4\)-SHIFTED CAVITY**

Lasing?
FUTURE: COUPLING WITH SILICON WAVEGUIDES?

PROPOSED INTEGRATION FLOW

(a) SOI wafer with 300nm silicon layer
(b) STI-process defines trench and waveguide
(c) KOH etch to open trench. Waveguide is protected
(d) III-V epitaxy

1ST GENERATION: DIRECTIONAL COUPLER

<table>
<thead>
<tr>
<th>PROPOSED CONFIGURATION</th>
<th>CROSS SECTION</th>
<th>PHASE MATCH CONDITION</th>
</tr>
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</table>

100% coupling
Sensitive to variation

2ND GENERATION: LINEARLY TAPERED COUPLER

<table>
<thead>
<tr>
<th>PROPOSED CONFIGURATION</th>
<th>TOP VIEW</th>
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98% coupling
Long footprint

L=310 µm
Standalone WG mode
Supermode
CONCLUSION AND PERSPECTIVES

CONCLUSION

- Aspect Ratio Trapping combined with nanoridge engineering allows to grow excellent material on 300 mm wafers
- We demonstrated:
  - PL-lifetime > 1 ns
  - Material gain > 4000 cm\(^{-1}\)
  - Optically pumped lasing with high SMSR at 1.05 \(\mu\)m
    - With both index and loss coupled gratings
  - Emission at 1.3 \(\mu\)m
  - Efficient coupling scheme to silicon waveguides

The European Silicon Photonics Alliance

**5th ePIXfab Silicon Photonic Summer School**
Ghent University (Belgium)

**DATE:** 15 – 19 June 2020

**KEY FEATURES**
- Learn all about silicon photonics: from technology to applications
- Geared towards industrial and academic participants
- A perfect blend of learning and networking

**MORE INFO:**
e-mail: info@ePIXfab.eu

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**Upcoming Activities**

**Training Program**
ePIXfab trainings are designed to address the needs of both industrial and academic workforce with the mindset to enable seamless entry into the field of silicon photonics.

- **China-Europe Silicon Photonics Symposium**
  26-30 May 2020, Chongqing, China
- **Silicon Photonics School, 5th edition**
  15-19 June 2020, Ghent University, Belgium
- **Design Course, 3rd edition**
  8 - 12 June 2020, Ghent University, Belgium
- **Hands-on design software training**
  23 June 2020, EOS2 Conference, Paris, France
- **European Photonic Integration Forum**
  September 2020, Brussels, Belgium

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**Prof. Dries Van Thourhout**
PHOTONICS RESEARCH GROUP

E: dries.vanthourhout@ugent.be
T: +32 9 264 34 38

www.photonics.intec.ugent.be

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Ghent University

@DThourhout

Ghent University

**meec**
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GaAs nano-ridge lasers on silicon (Conference Presentation)

Deen Van Thourhout, Xueling Shi, Marina Bay, Volker, Yannick De Keza, Marina Pantazaki, Anuk Van Campenhout, Bernard De Keizer

Author Affiliations:

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Abstract

The silicon photonics platform is still missing a native source. Therefore, using a novel epitaxial process based on aspect ratio trapping and nano-ridge engineering we demonstrated an powerful approach to fabricate GaAs-GaAlAs lasers directly on a standard silicon substrate. In depth morphological and optical characterisation confirms the high quality of the material. We demonstrated lasing from DFB-type devices with etched gratings and with metal gratings. In the presentation we will also discuss the possibility for coupling to standard silicon waveguides and for extending the emission to longer wavelengths.