ESSCIRC/ESSDERC 2020 Presentation

"Merging of photonics and micro-electronics: Photonics in the UK"

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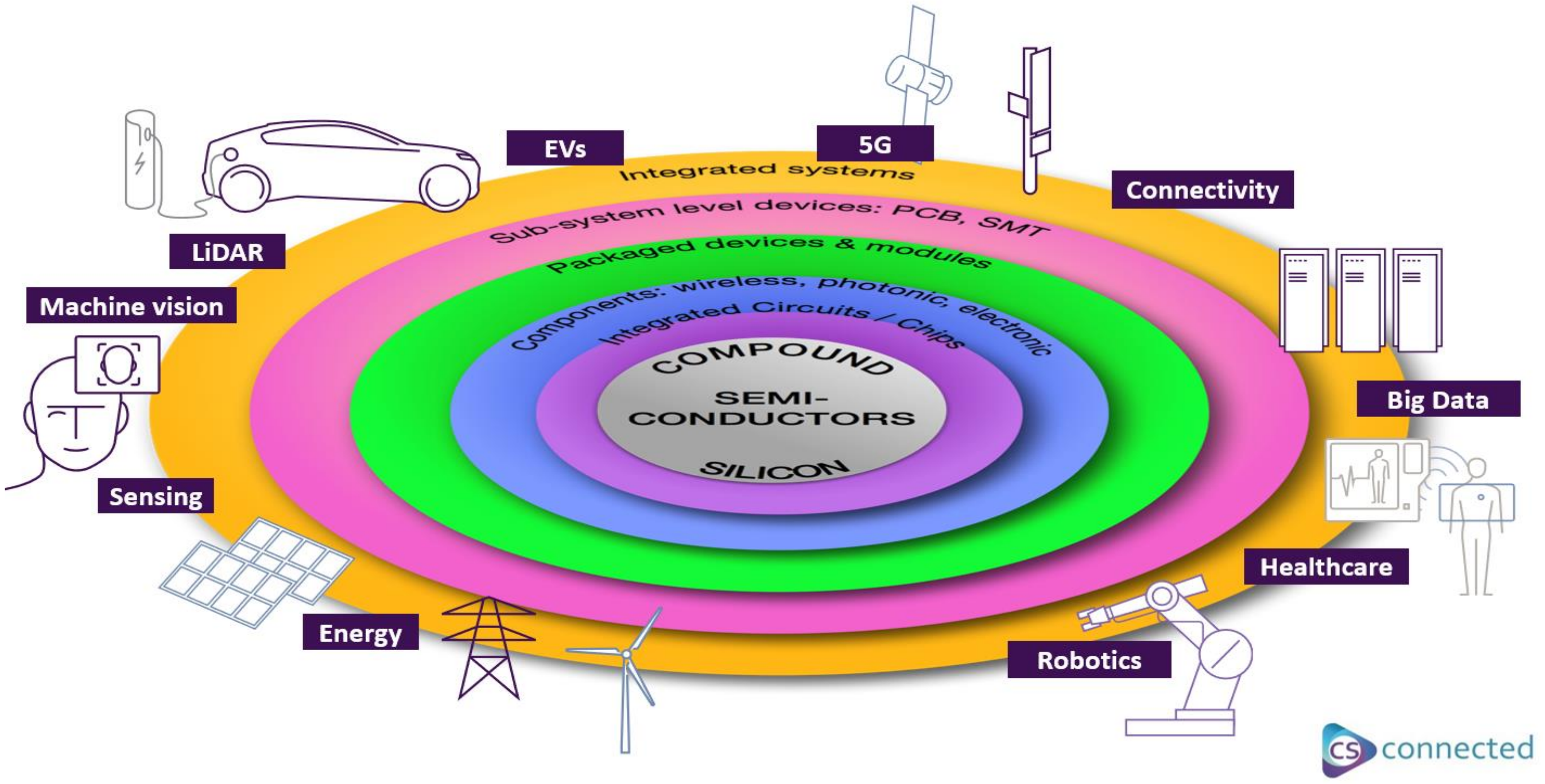
September 14-18, 2020

Global Supply Chains



The nucleus of the Global CS Cluster in the Cardiff Capital Region

The Entities

Cardiff University / Prifysgol Caerdydd
Institute for Compound Semiconductors
£75m

CISM
Centre for Integrated Semiconductor Materials
£90m

Compound Semiconductor Centre (CSC)
£42m

IQE

SPTS

Newport Wafer Fab

Technology Readiness Level

TRL 1-3
R&D

TRL 4-6
Prototyping

TRL 7-9
Production

Catapult Compound Semiconductor Applications
£50m+£100m

Cardiff Capital Region City Deal
£40m+£80m

IPCEI on Microelectronics

Horizon 2020 European Union Funding for Research & Innovation

IPCEI Partners

IPCEI Cooperation Partners

The economic benefits to the region

- Global CS Wafer & Chip Foundries
- European CS Prototyping & Development Centre
- Centres of Academic Excellence
- Magnet for international workshops and conferences
- Formation of 25-50 new SMEs
- Creation of 2,500 to 5,000 high value jobs (equivalent to 20,000 new jobs)
- Europe's 5th and newest Semiconductor Cluster
- World's First Compound Semiconductor Cluster

Overview of "Strength in Places" – major underpinning RD&I for IPCEI

"The Strength in Places Fund (SIPF) will bring together research organisations, business and local leadership to drive significant economic impact, job creation and regional growth"

UK Govt. funded

HM Government

UK Research and Innovation

Research England

2019 Bid submission (£43M)

Q4 2020 Project start

2025 5,000 projected jobs

3.1: Next generation optical comms and sensing

Package includes high capacity data-centres and LIDAR sensing for autonomous vehicles.

5G

Collaborators on RD&I for this section of the "Strength in Places" project included in this presentation

NEWPORT WAFER FAB

CARDIFF UNIVERSITY PRIFYSGOL CAERDYD

IQE

Rockley PHOTONICS

Cardiff Univ. - Active component design, modelling, prototyping (fab) and testing

CSC - Indium Phosphide epitaxial materials development

IQE - Indium Phosphide epitaxial materials scale up to 6" for volume manufacturing

NWF - passive device manufacture and PIC process devel.

Rockley Photonics - Active/passive component spec. and design, sub-system integrator to transceiver and sensor level.

The co-integration of III-V and Si: options

Direct growth III-V epitaxy on silicon:
Defect formation (e.g. threading dislocations, antiphase domains).

Novel IQE approaches:
III-V on Ge-on-Si – novel buffer technologies to reduce TDD
Patented cREO approach on Si – rare earth oxides on <111>Si for III-V overgrowth

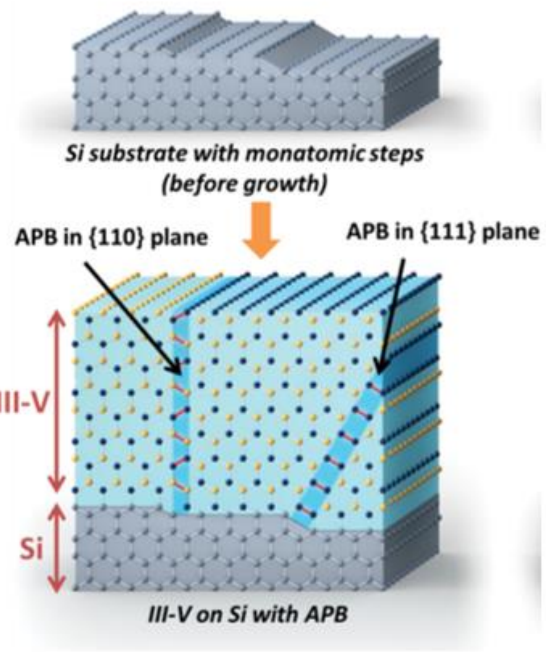
Wafer bonding and Transfer printing - Fabrication issues, Low light coupling efficiency.

Nanowires growth on silicon - significant progress, electrical pumped lasers challenging .

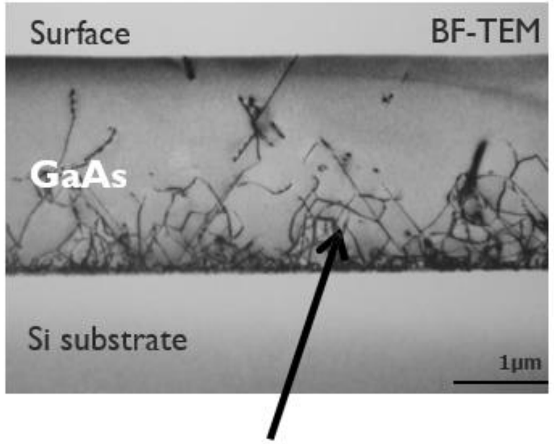
Quantum Dot (QD) offer great potential:
Less sensitivity to material defects and temperature variations.
Broad optical gain spectrum.
GaAs-based 1.3µm InAs QD lasers grown on silicon have been achieved.
Direct growth of 1.55µm InAs QD lasers on silicon is difficult, but not much work done.

III-V epitaxy on Si: fundamental challenges

- Polar/non-polar interface: Antiphase Domain(APD)
- Lattice mismatch: Misfit/threading dislocations, twins/stacking faults
- Thermal mismatch

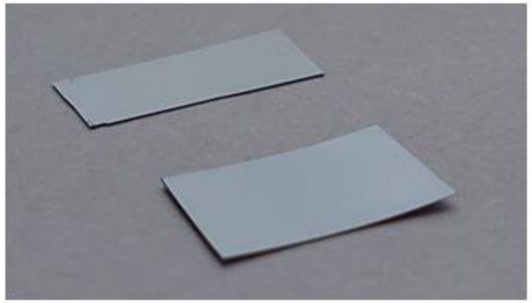


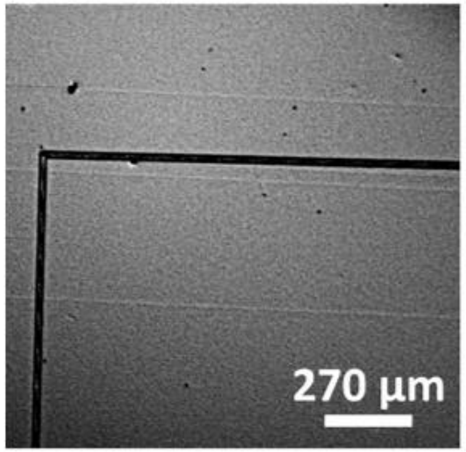
*IEEE Spectrum



Threading dislocation network: High defect density!

*B. Kunert, Pulse School 2015



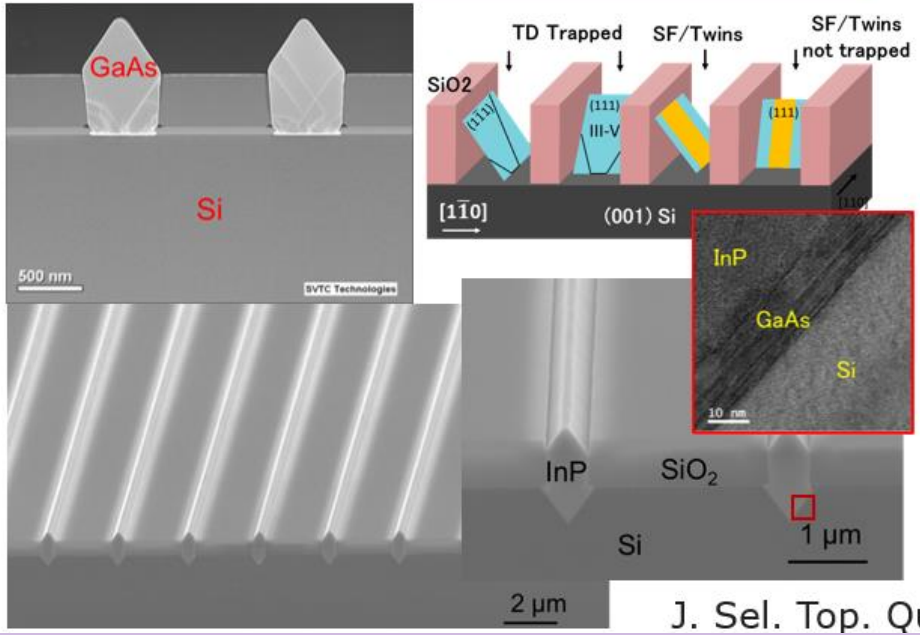


Bowing or cracking of GaAs films on Si

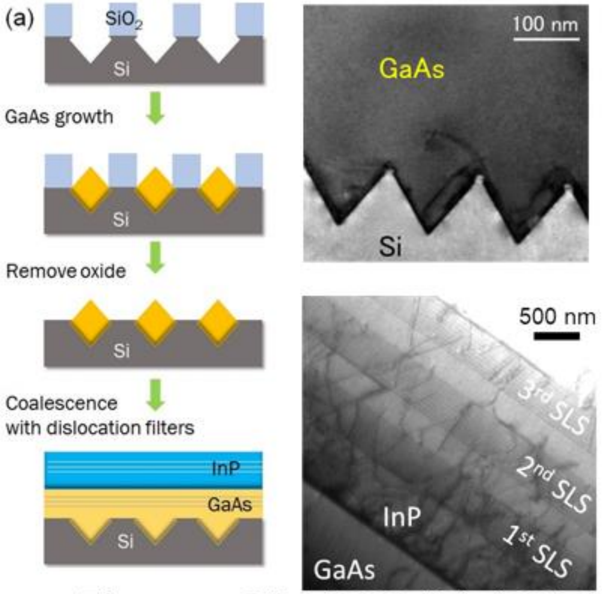
MOCVD growth of InP on CMOS-compatible (100) Si

- GaAs/InP on V-grooved Si: Overcome Antiphase Domains, no offcut Si, no Ge buffer
- Enabling low defect density nano-ridges and coalesced thin films
  - Low temperature grown GaAs stress relaxing layer (<10nm)
  - Aspect ratio trapping effect
  - Superlattices dislocation filtering layers plus thermal cycle annealing

Aspect Ratio Trapping + V-groove epitaxy



Coalesced V-groove epitaxy



GaAs on Si:

AFM rms < 1nm
TDD: $6x10^6$/cm2

InP on Si:

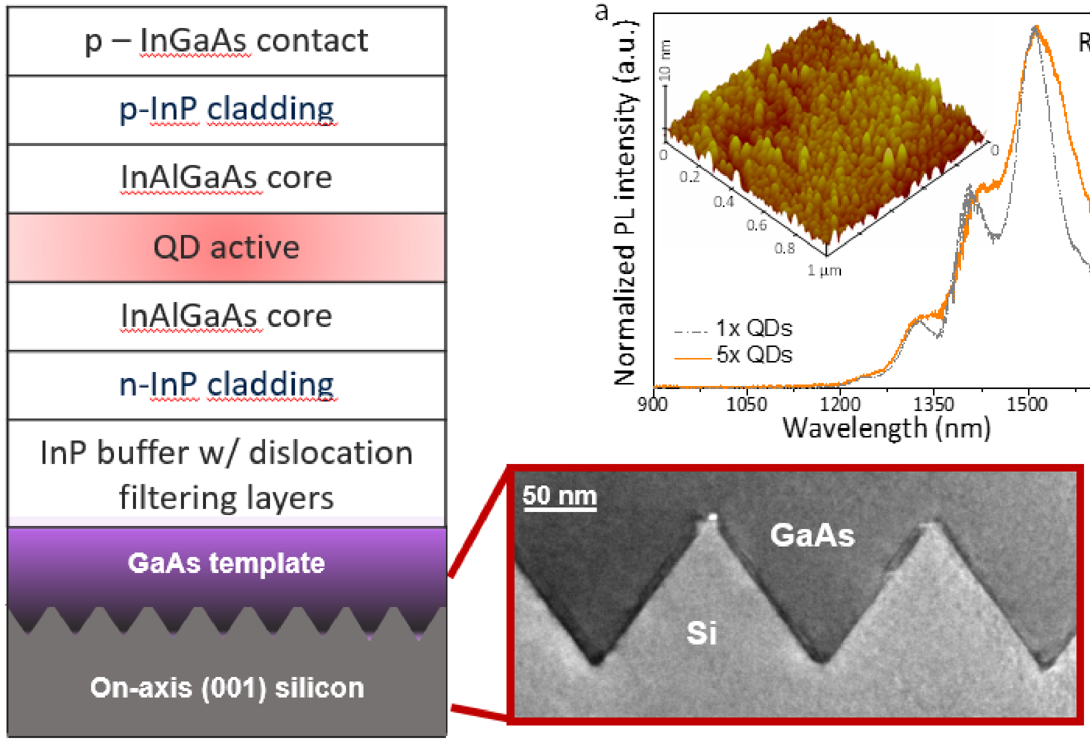
AFM rms ~2nm
TDD ~
1E8/cm2

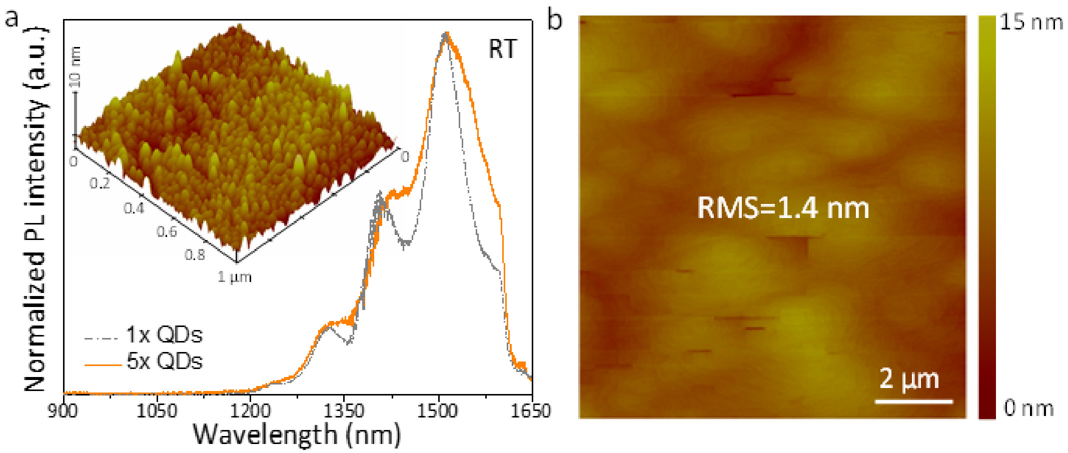
J. Sel. Top. Quantum Electron 25, 1900711 (2019)

1550-nm InAs/InP QD lasers on Si

- 3x InAs quantum dot layers by MOCVD (HKUST), less sensitive to defects
  - 510 ℃, 3 ML InAs, V/III=0.2
  - Dot density ~ 5 x10^{10} cm^{-2} per layer

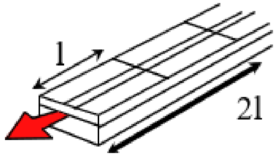
CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD   HKUST



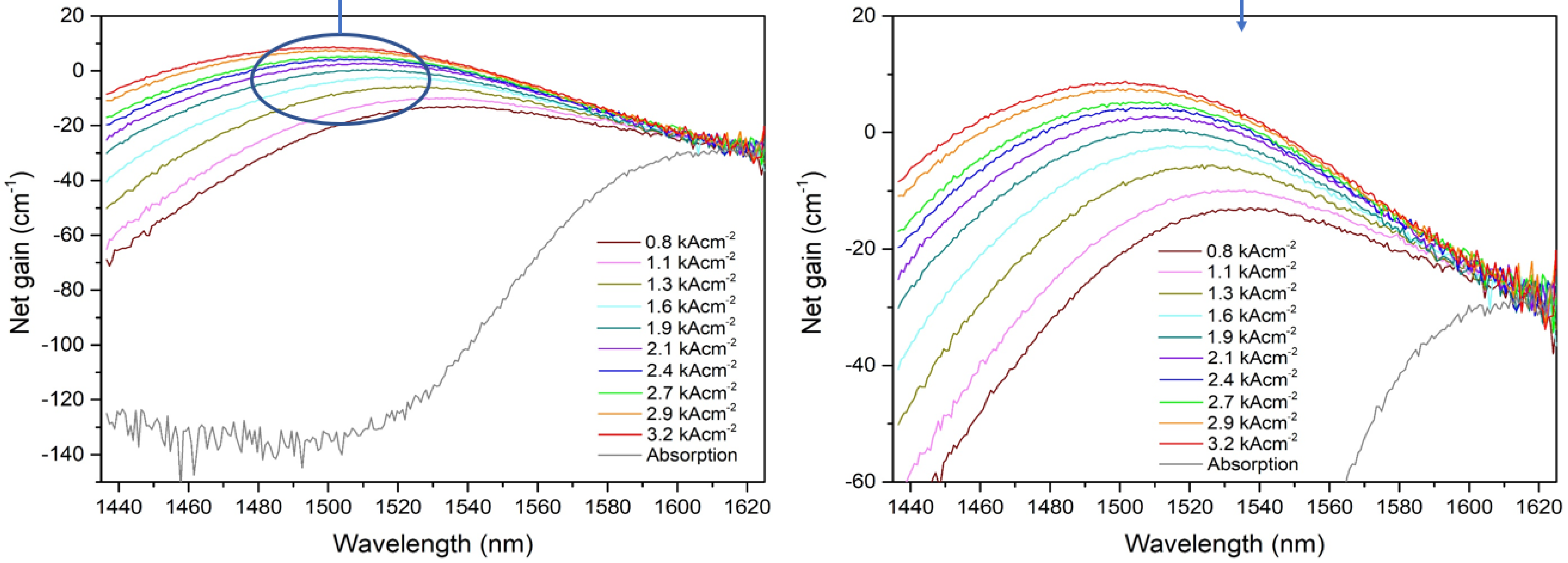


Appl. Phys. Lett. 113, 221103 (2018)

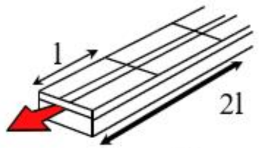
Basic Characterisation of InP substrate at 40°C



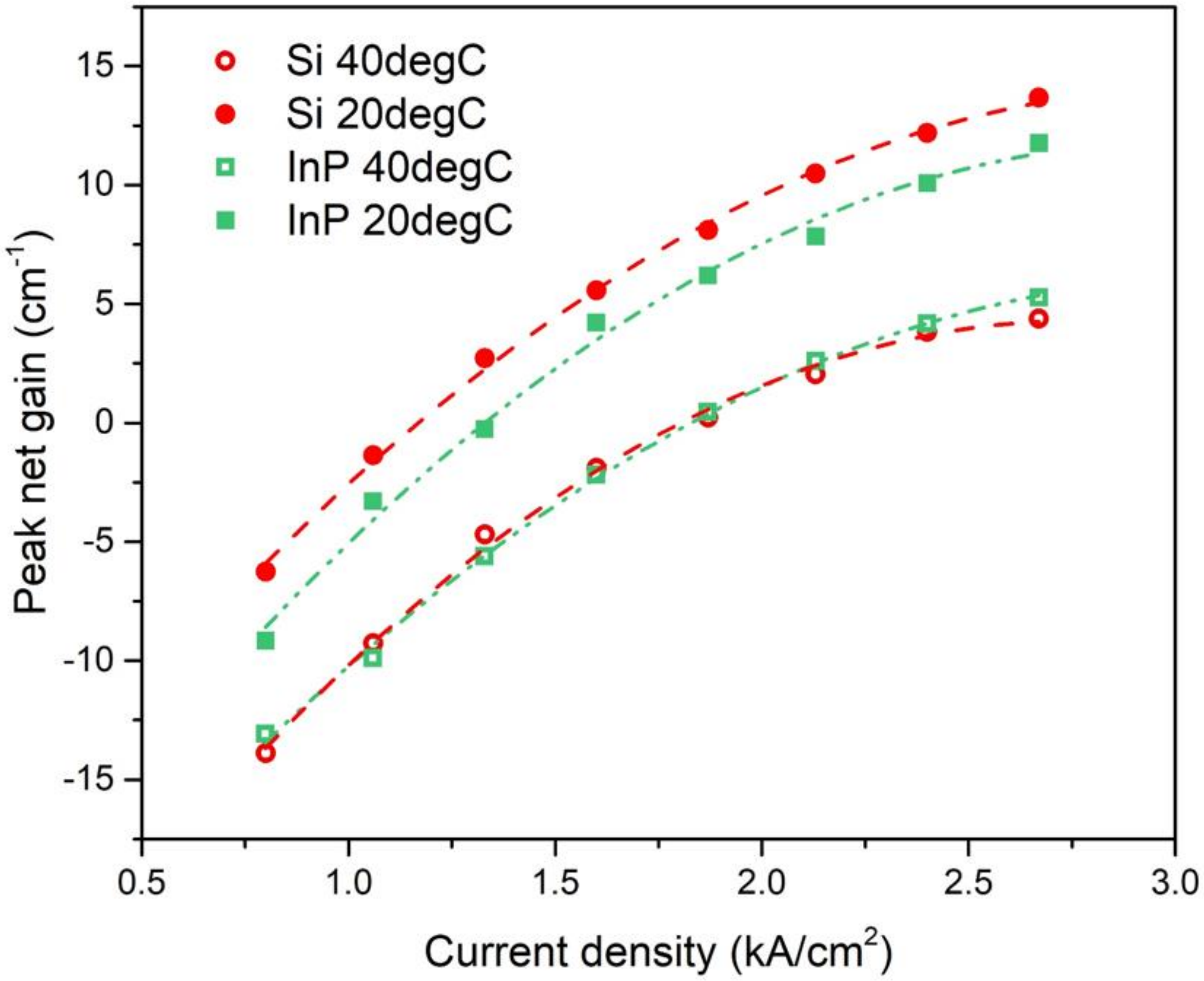
$$G-\alpha_i=\frac{1}{l}ln\left[\frac{I_{1,2}}{I_1}-1\right]$$



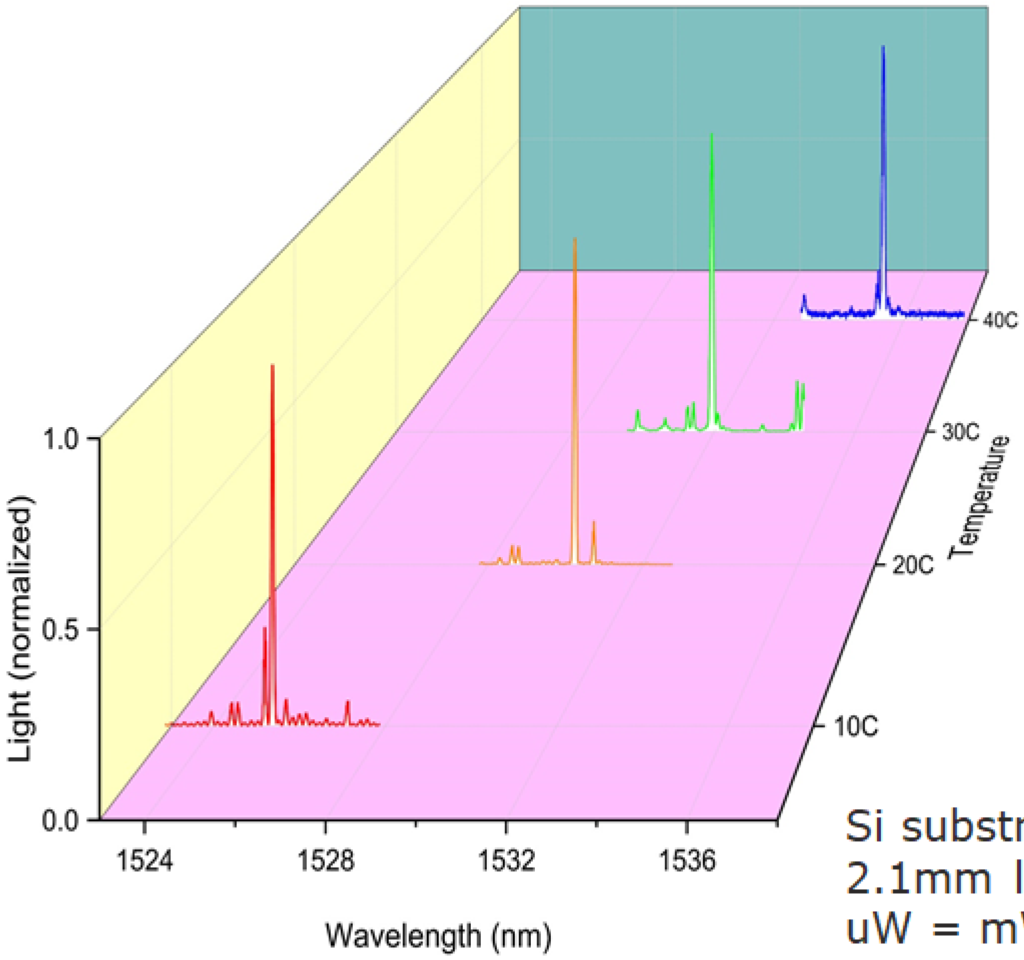
Basic Characterisation InP vs Si substrate

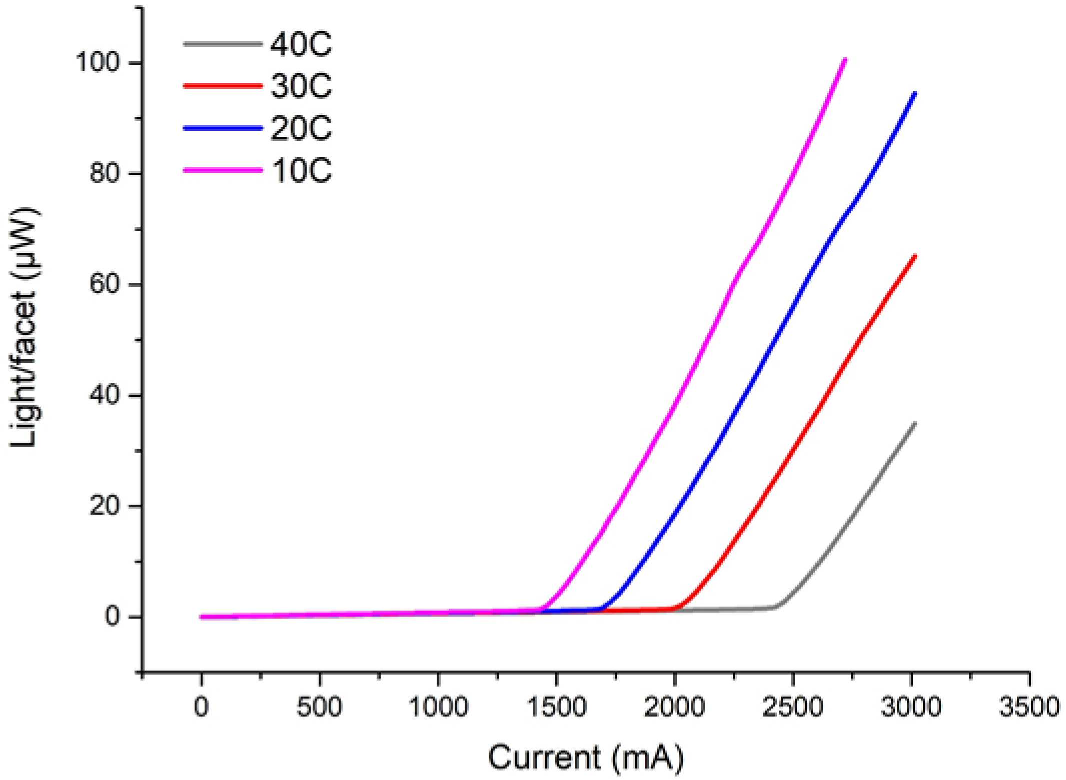


$$G-\alpha_i = \frac{1}{l} ln\left[\frac{I_{1,2}}{I_1}-1\right]$$



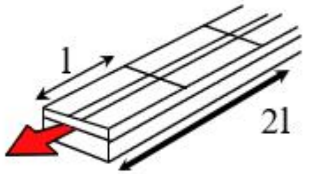
1550nm lasers electrically driven on Si





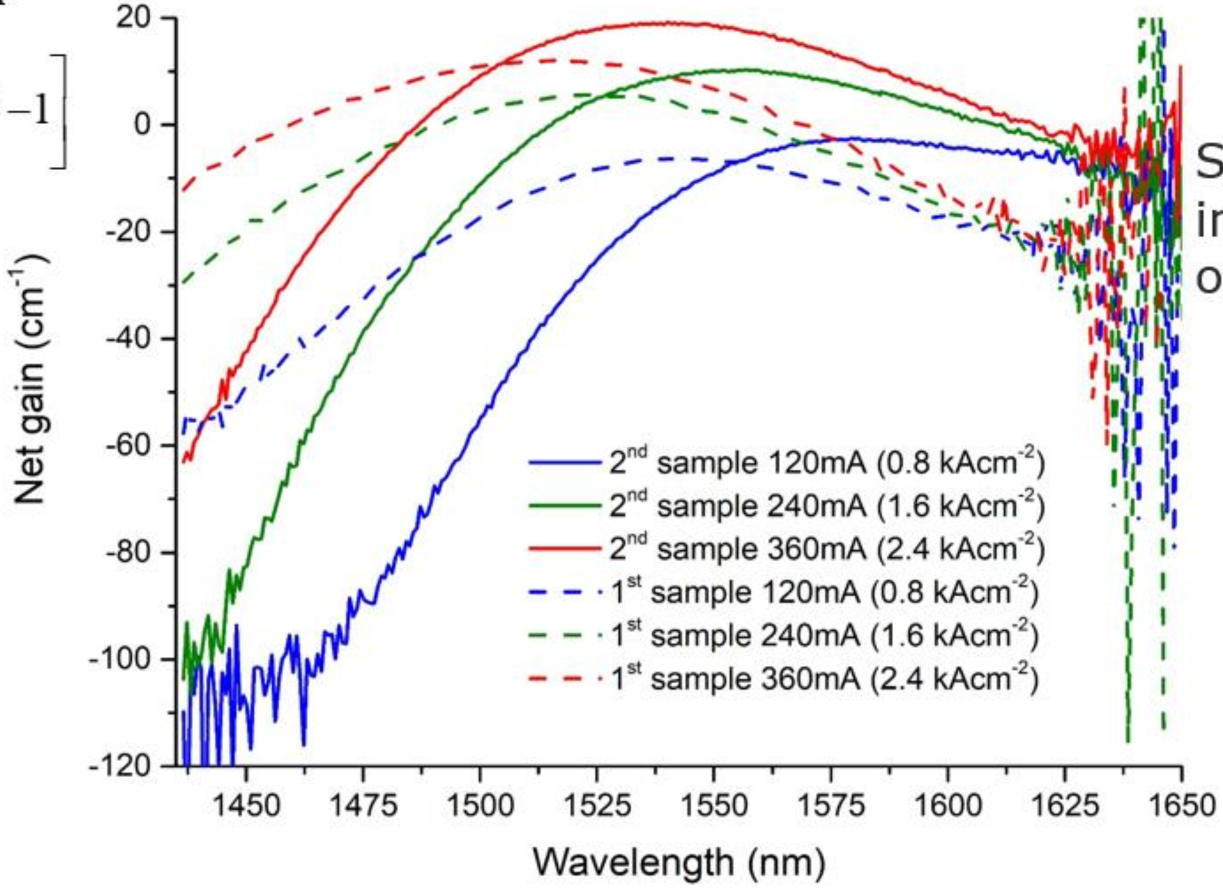
Si substrate, lasing spectra & L-I curves 10C-40C
2.1mm long cavity, pulsed driven 0.1% duty cycle average
uW = mW
Lasing spectra at 10% above I_{th}

Improved waveguide design sample 2 vs sample 1



$$G - \alpha_i = \frac{1}{l} ln\left[\frac{I_{1,2}}{I_1} - 1\right]$$

Improved optical gain



Significant improvement in optical loss

Initial laser results

Threshold current density 500-700 A cm^{-2}

1550nm wavelength

Summary

- Electrically injected 1550nm lasers grown on silicon feasible
  - further design iterations should improve performance
- Approach consistent and compatible with existing technology
- Further advances required in quantum dot technology at 1550nm and in the InP-to-Si interface

Acknowledgements

This work is funded by the UK Govt through UK Research & Innovation, (Research Councils and Innovate UK) as underlying RD&I, in the frame of the:

Important Project of Common European Interest (IPCEI).

IPCEI on Microelectronics

The IPCEI is funded by Public Authorities from Germany, France and Italy