Manufacturing VCSELs on 150mm and 200mm wafer formats

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Outline

- Capability, background & motivation
- Device Structure & Fabrication
- Thinner substrates?
- 200 mm comparison
- High speed
- Conclusions

Cardiff University
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Institute for Compound Semiconductors

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ICS TRH Cleanroom

- **Pay for Use, Open Access**
- **Up to 200mm (8-inch) full wafer processing of III-Vs and III-Vs on Si**
- **1350m^2 clean space in Bay & Chase arrangement, with sub floor plenum**
- **ISO 5 (class 100) Lithography area 225m^2, ISO 6 (class 1000) elsewhere**
- **14 wet processing stations**
- **Capacity ~3k fab starts/year (includes pieces and full wafers)**
- **Industry relevant facility**
- **World class academic facility**

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Process Capabilities

Lithography,
Mask aligners, Mask-less projection, Laser, e-beam lithography

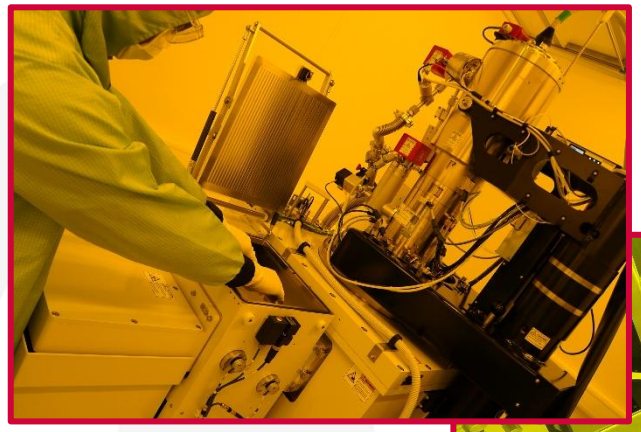
Plasma (Etch & Deposition),
ICP, RIE, PECVD, ALD

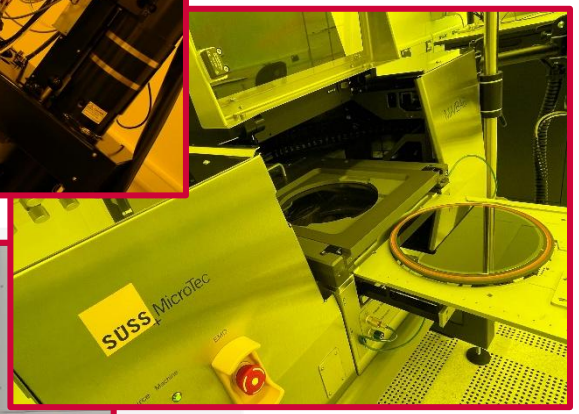
Physical Deposition (Metals & Dielectrics),
Evaporation (thermal & e-beam), sputtering (DC & RF)

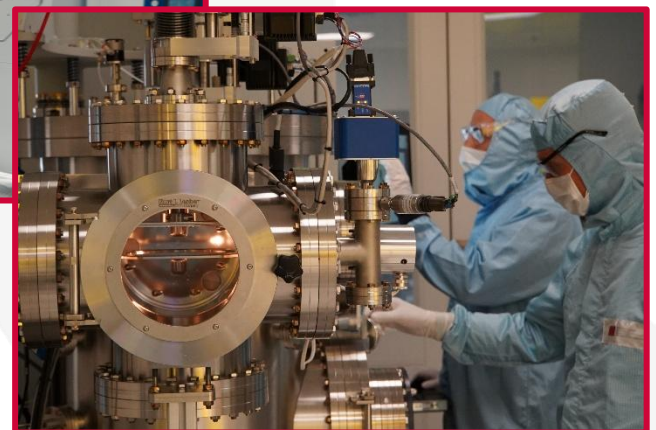
Thermal Processing,
RTP, Oxidation, Polymer curing

Metrology,
Hi-Res SEM, Ellipsometer, Profilometer, Wafer particle mapping, Focused Ion Beam

Back-End Processing
Lapping/polishing, Wafer dicing, Facet cleaving, Wire bonding







ICS Contact: Stephen Sutton ICS@cardiff.ac.uk https://www.ics-cardiff.co.uk/

Motivation

- Demand for VCSELs increasing rapidly due to 3D sensing and comms applications
- 150 mm now standard manufacturing platform
- Future 200mm and beyond?
- Issues:
  wafer bow,
  sustainability,
  supply chain risk

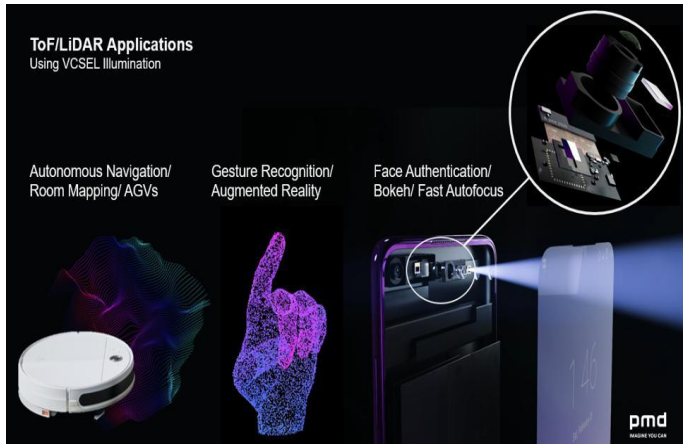


Image Source: Forbes/PMDTechnologies

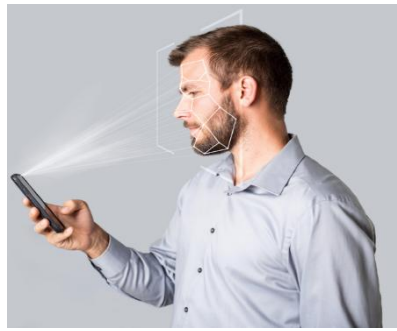


Image Source: Shutterstock/Megan Betterid

Note: VCSEL material available on 200mm GaAs since 2022

A. Johnson et al "First demonstration of high performance 940 nm VCSELs grown on 200 mm diameter substrates" Proc. CS Mantech (Monterey, USA, May 2022) DOI:10.1117/12.2583207)

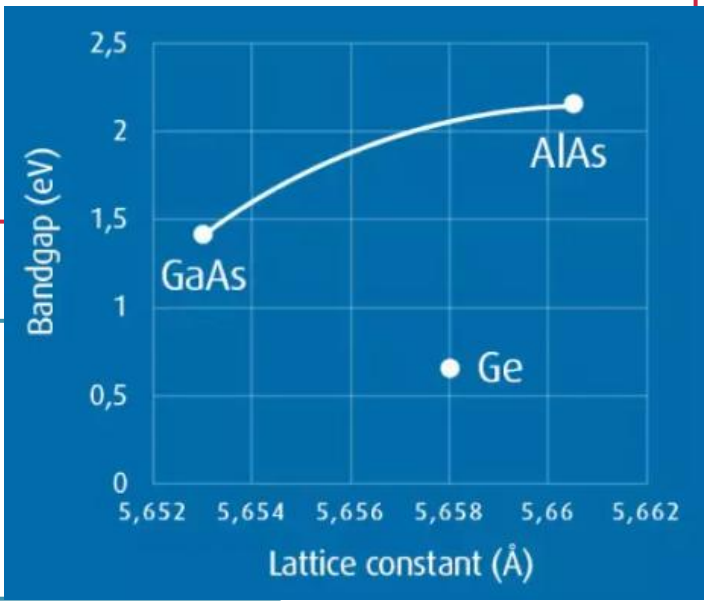
GaAs v Ge substrates

GaAs

- Lattice mismatch between thick DBRs and large area GaAs leads to extreme bow and warp
- Requires mitigation in epitaxy and fabrication to maintain yield and may increase cost
- Recycling of thick GaAs substrates difficult
- Supply chain issues 90% of Ga comes from China
- GaAs is the established technology
- GaAs cheaper than Ge substrates (factor 2)

Ge

- Ge lattice constant favourable – almost eliminates strain
- Ge robust and commercially available up to 300 mm diameter
- Recycling feasible
- 60% of Ge comes from China with distribution of other sources



Source: Umicore

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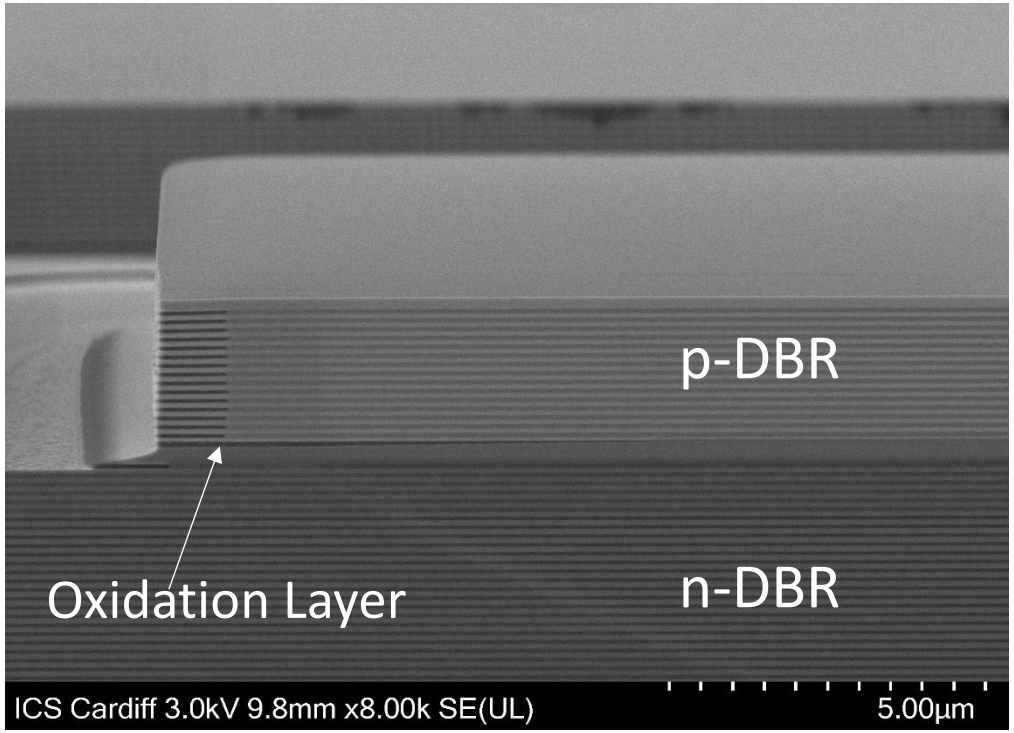
Epitaxial Design

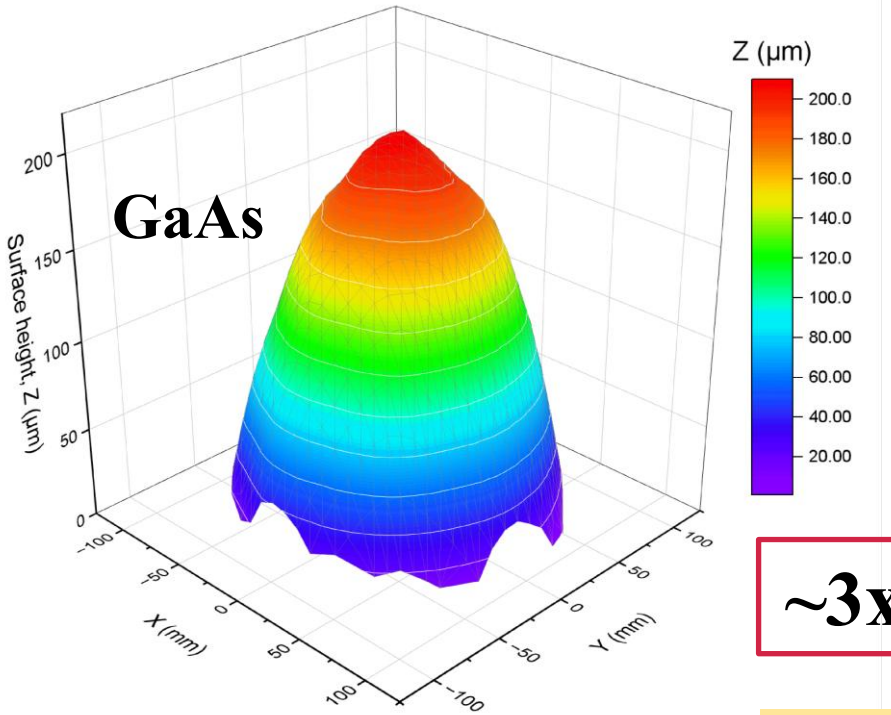
- Generic design for 940 nm emission wavelength
- AlGaAs/AlGaAs based p-DBR & AlAs/AlGaAs based n-DBR
- Single 98% AlGaAs oxidation layer
- Nominally identical design on n-doped GaAs- & Ge-substrate



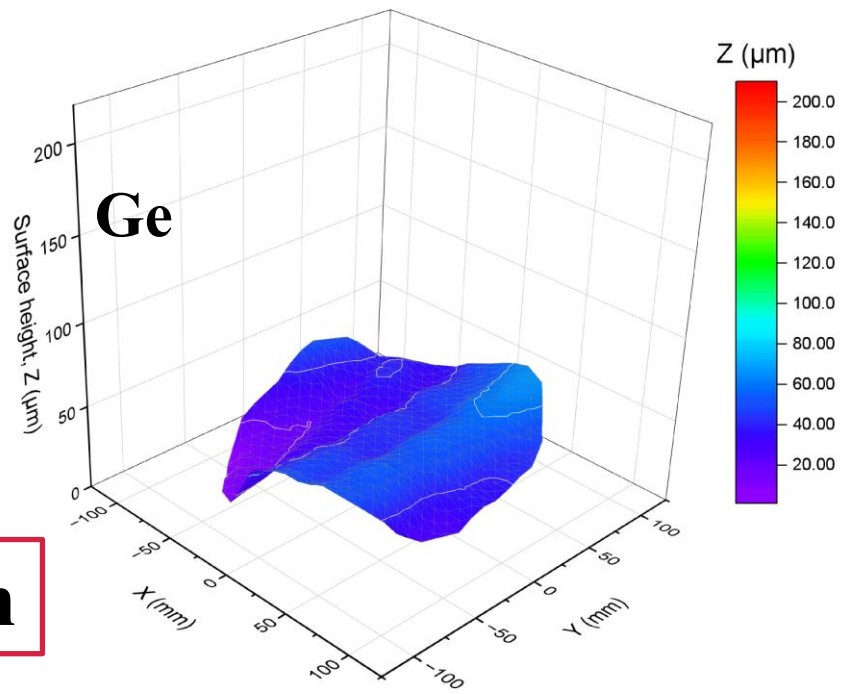
Wafer Bow

Wafer Size	Peak-to-valley Variation
150 mm	130 µm [1]
200 mm	**210 µm**

Wafer Size	Peak-to-valley Variation
150 mm	25 µm [1]
200 mm	**66 µm**



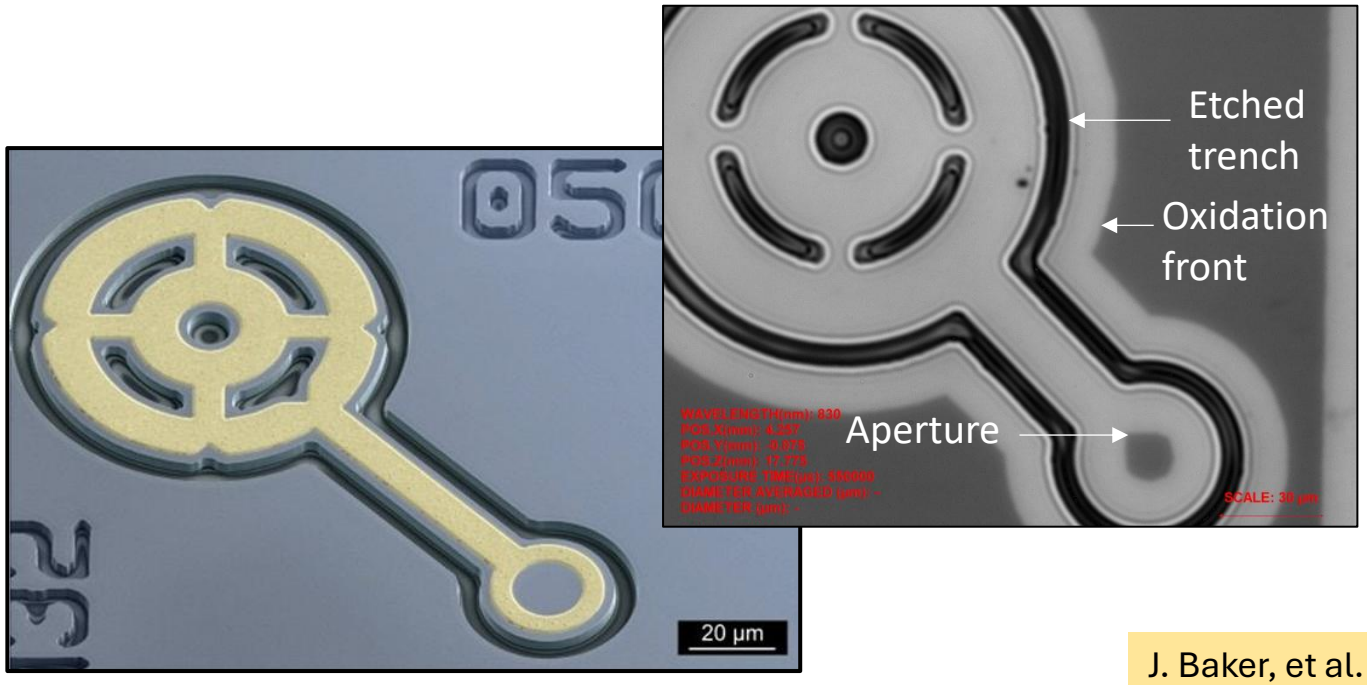
~3x reduction



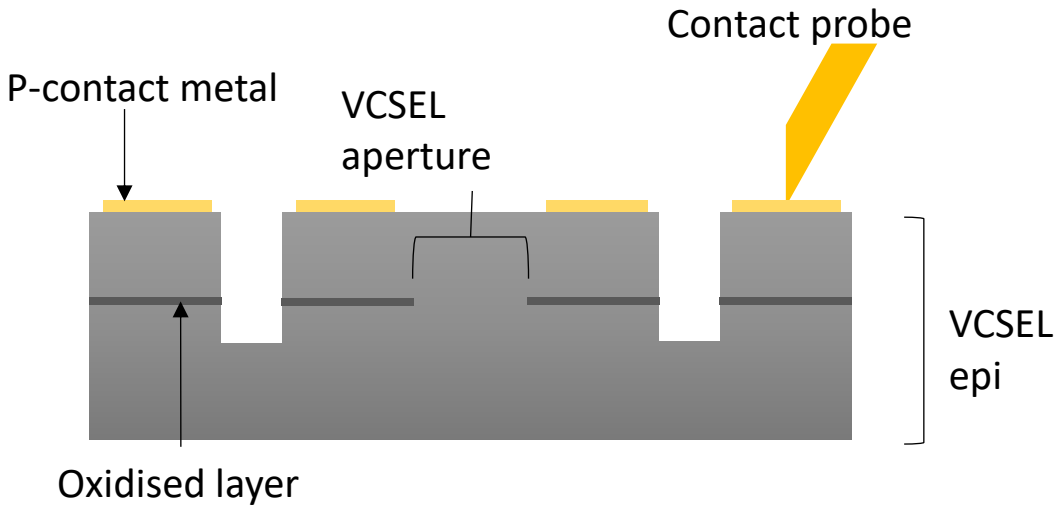
S.J. Gillgrass, et al. 2023. "Impact of thermal oxidation uniformity on 150 mm GaAs- and Ge-substrate VCSELs", Journal of Physics D: Applied Physics DOI: 10.1088/1361-6463/acc040

Device Structure

- VCSEL Quick Fab (VQF) devices
- A 4-step VCSEL fabrication process for direct probing;
  Etch – Oxidation – P-contact – N-contact



3D cross-section:



- Fast feedback for large area wafers
- Repeatable and comparable performance to typical, planarised devices [1]

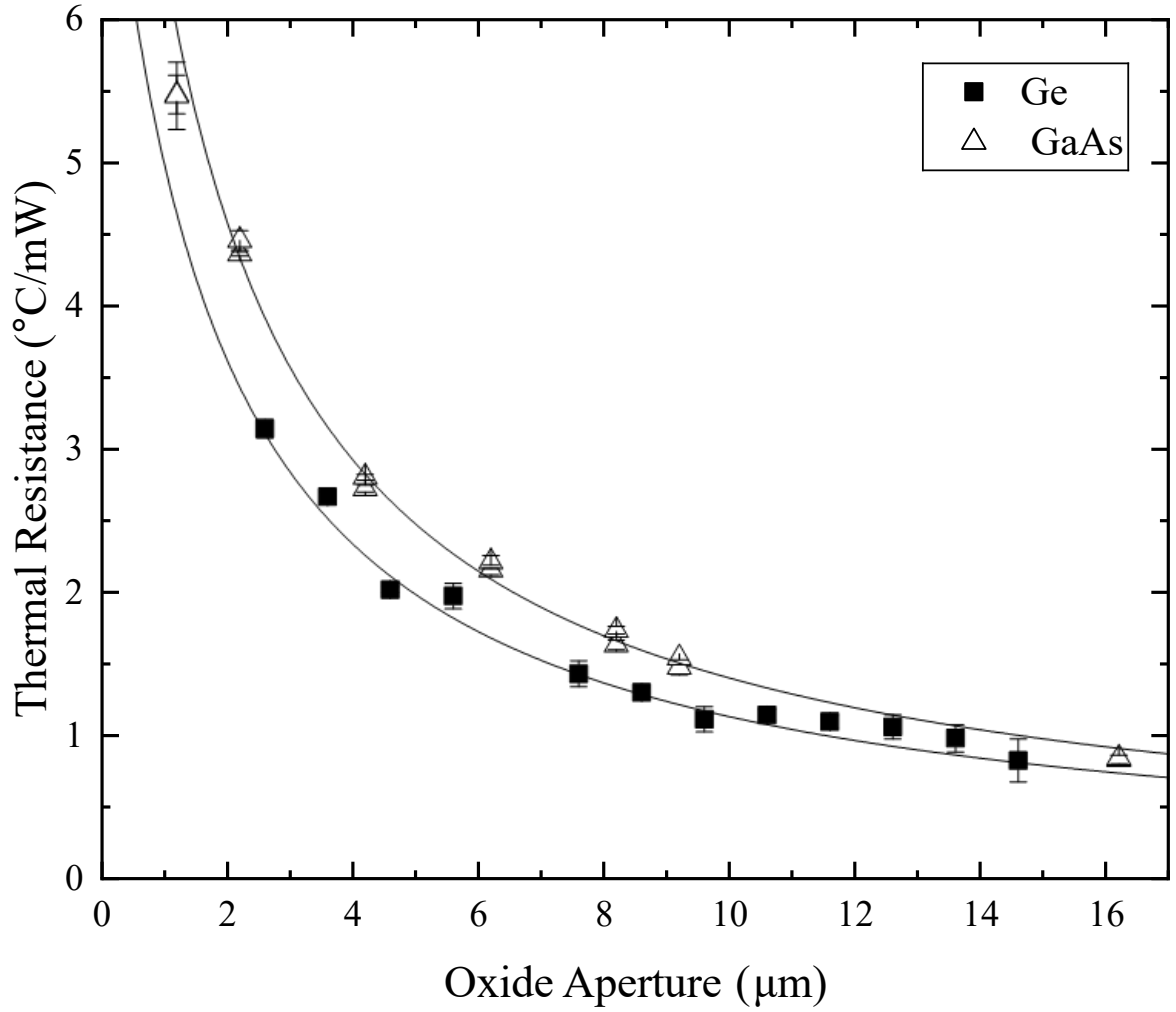
J. Baker, et al. "VCSEL quick fabrication for assessment of large diameter epitaxial wafers" IEEE Photonics Journal 2022 10.1109/JPHOT.2022.3169032

Device Fabrication

- Identical fabrication processes for both GaAs & Ge substrates except for global backside n-ohmics
- Oxidation performed in a single-wafer conduction furnace, equipped with vacuum chuck and IR camera for in-situ measurements
- Un-thinned substrates – 675 μm thick in both cases
- Each 150 mm (200 mm) wafer contains 150,000 (280,000) individual VCSEL devices

Fabricated 200 mm (8”) VCSEL wafer.

150mm substrates



- On average Ge devices have 18% better thermal impedance similar to relative performance of bulk substrates.

J. Baker et al, "Thermal Performance of 940 nm AlGaAs-Based VCSELs Grown on Germanium," IEEE Photonics Journal, 2025, doi: 10.1109/JPHOT.2025.3552951

- 150mm Ge devices comparable performance to 150mm GaAs

S.J. Gillgrass, et al. 2023. "Impact of thermal oxidation uniformity on 150 mm GaAs- and Ge-substrate VCSELs", Journal of Physics D: Applied Physics DOI: 10.1088/1361-6463/acc040

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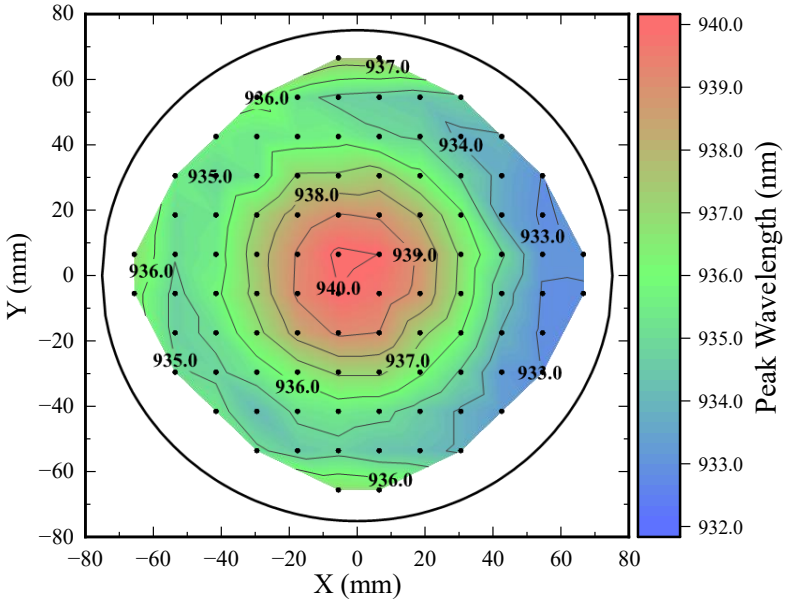
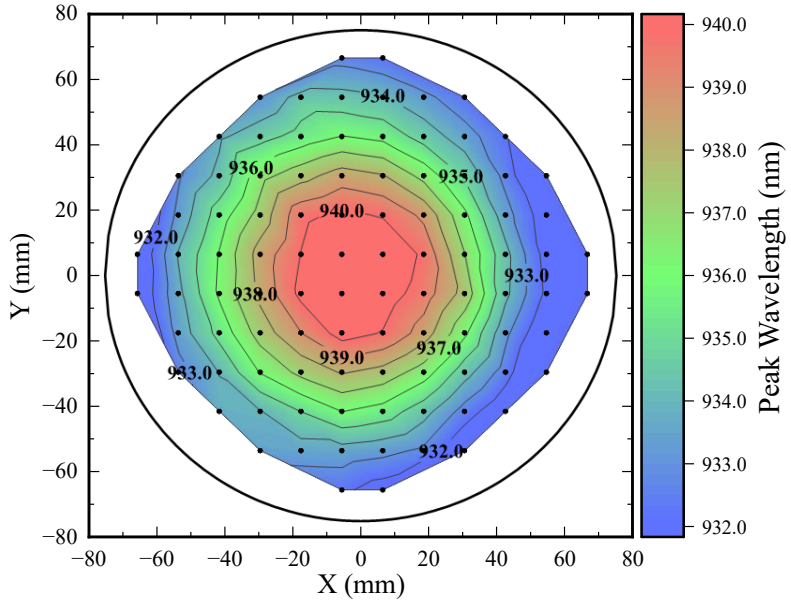
Results: Wavelength

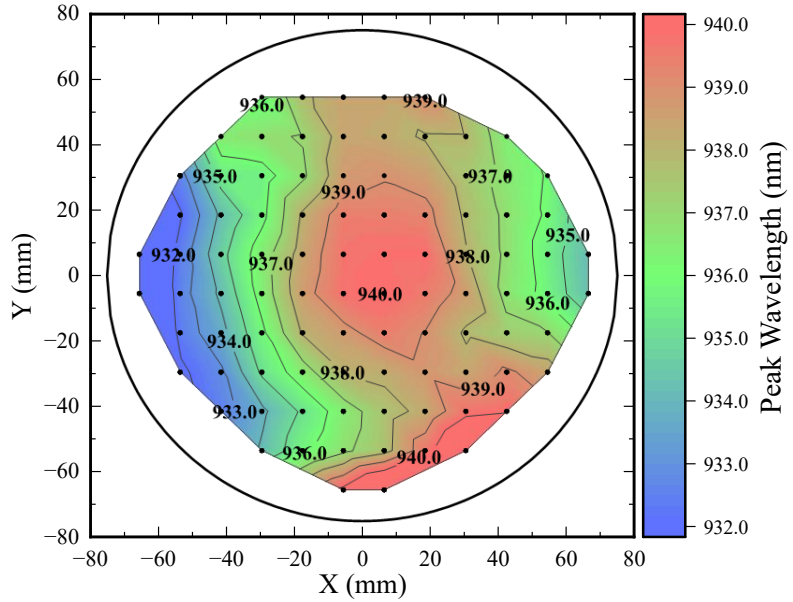
675 μm



450 μm



225 μm

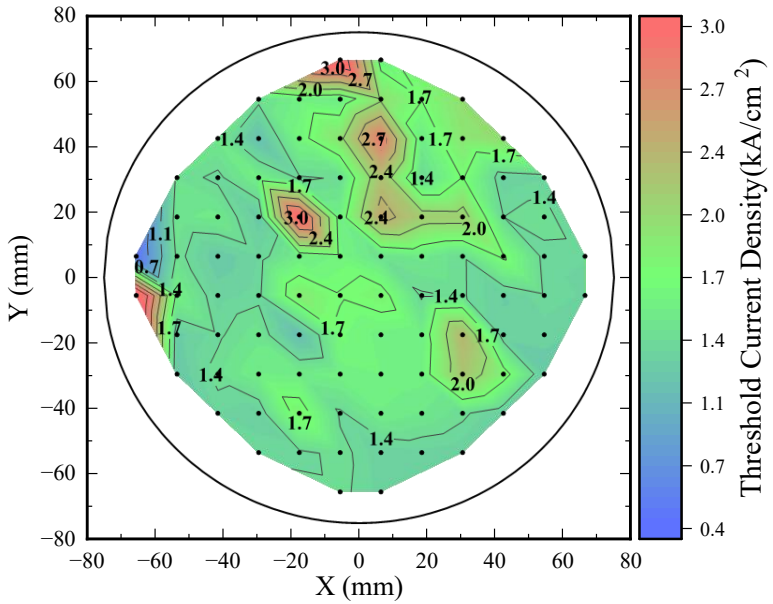


49 μm mesa diameter (~ 14 μm oxide aperture) VCSELs, at 5 mA

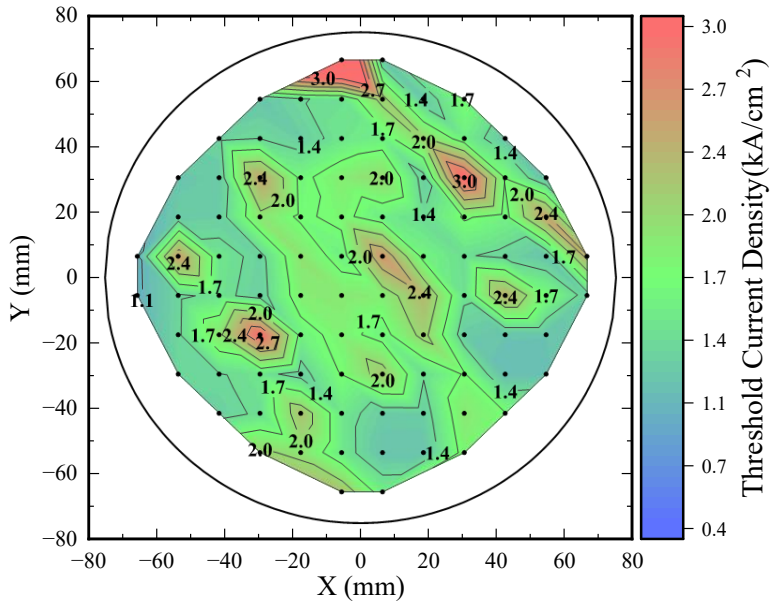
S.J. Gillgrass, et al. AlGaAs VCSELs grown on thin 150 mm germanium substrates. JPhys: Photonics 2025 DOI: 10.1088/2515-7647/adef1f

Results: Threshold current density

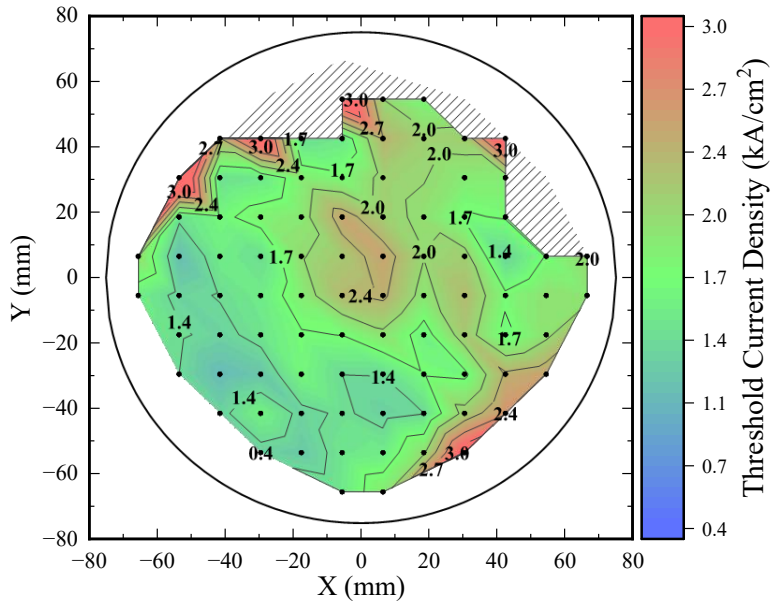
675 μm



450 μm



225 μm



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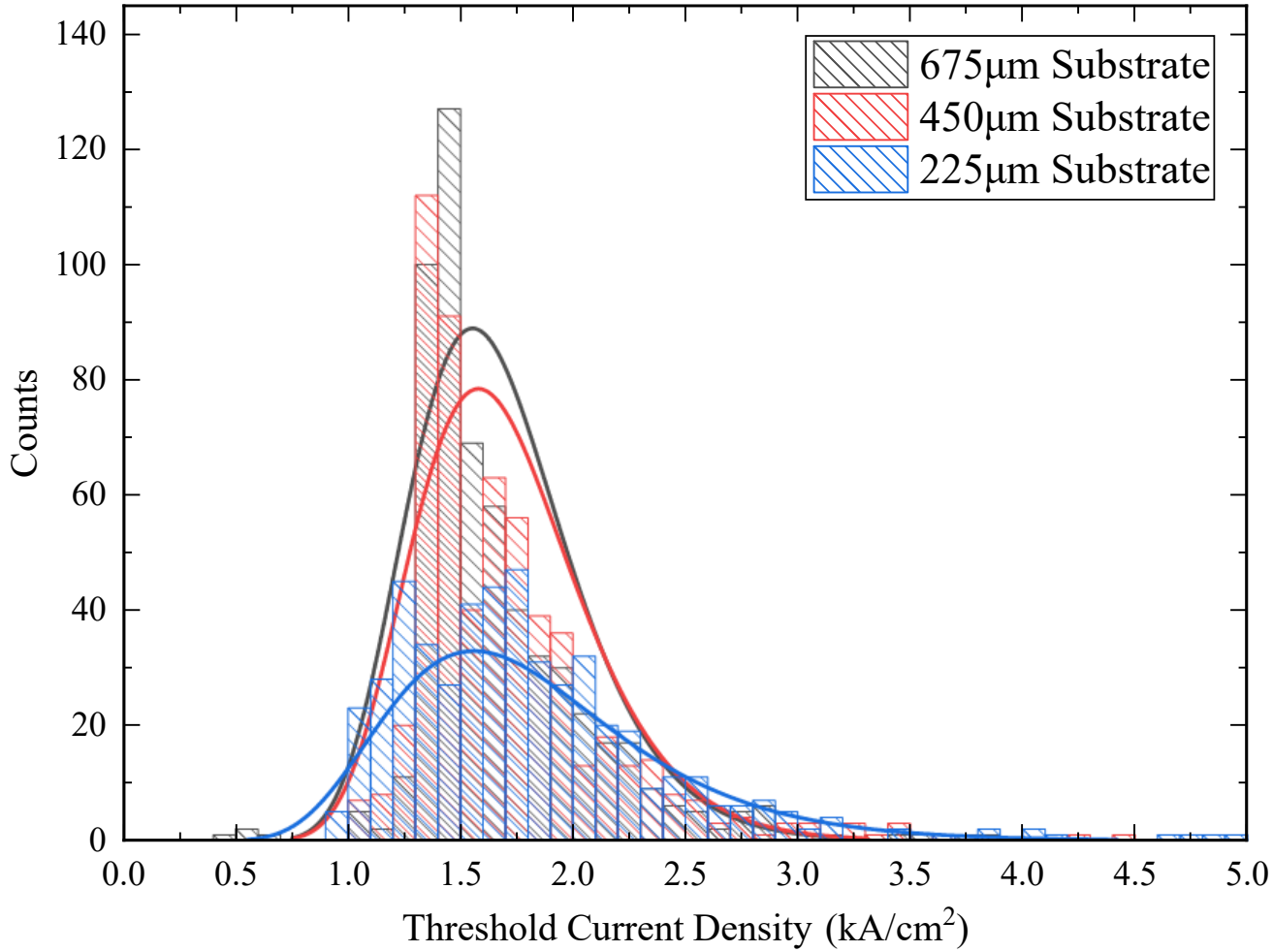

Variance 0.14, 0.15, and 0.35 kA cm^{-2}

225 um incomplete oxidation and leakage path (temperature variation of 1.2 ◦C too small to cause this)

S.J. Gillgrass, et al. AlGaAs VCSELs grown on thin 150 mm germanium substrates. JPhys: Photonics 2025 DOI: 10.1088/2515-7647/adef1f

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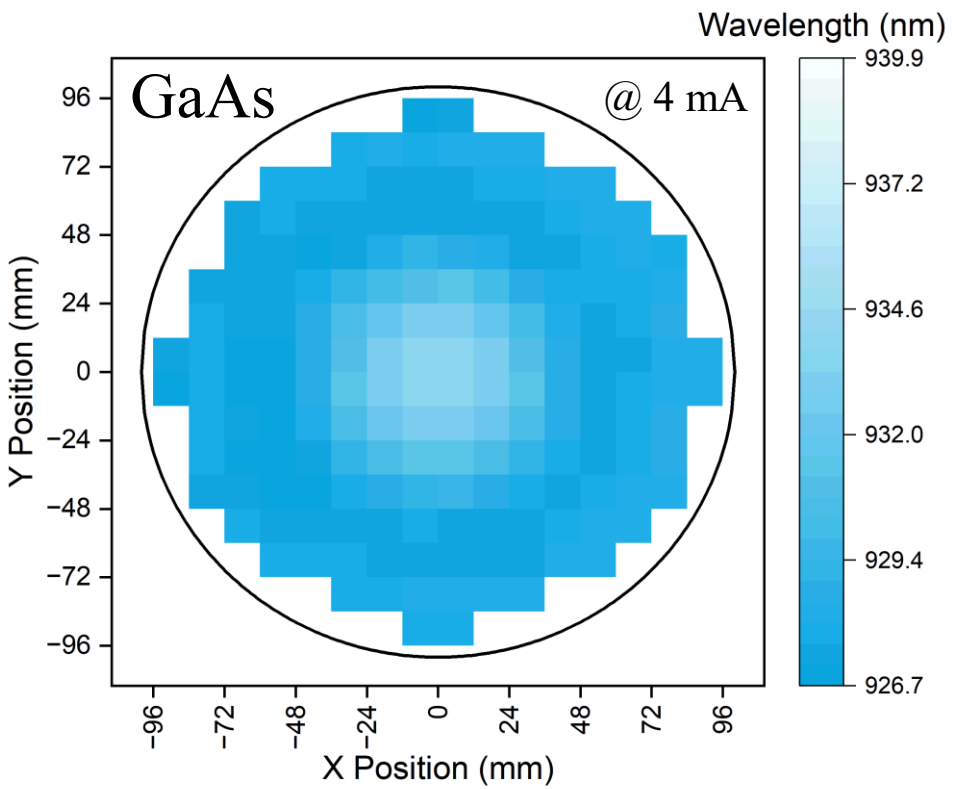
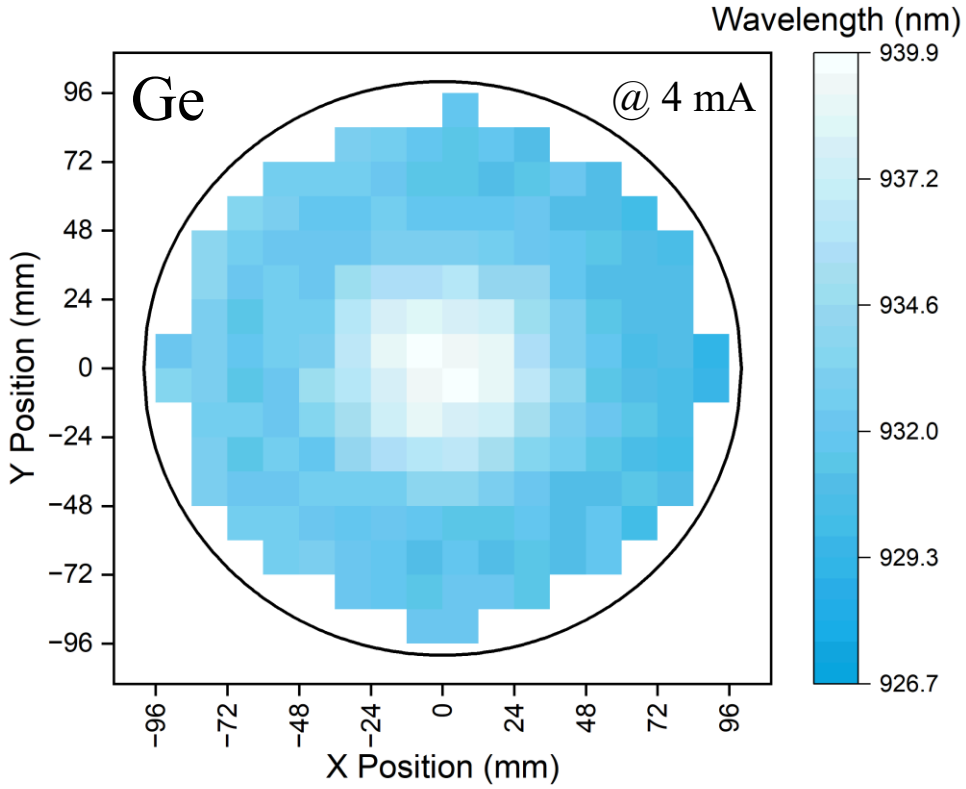
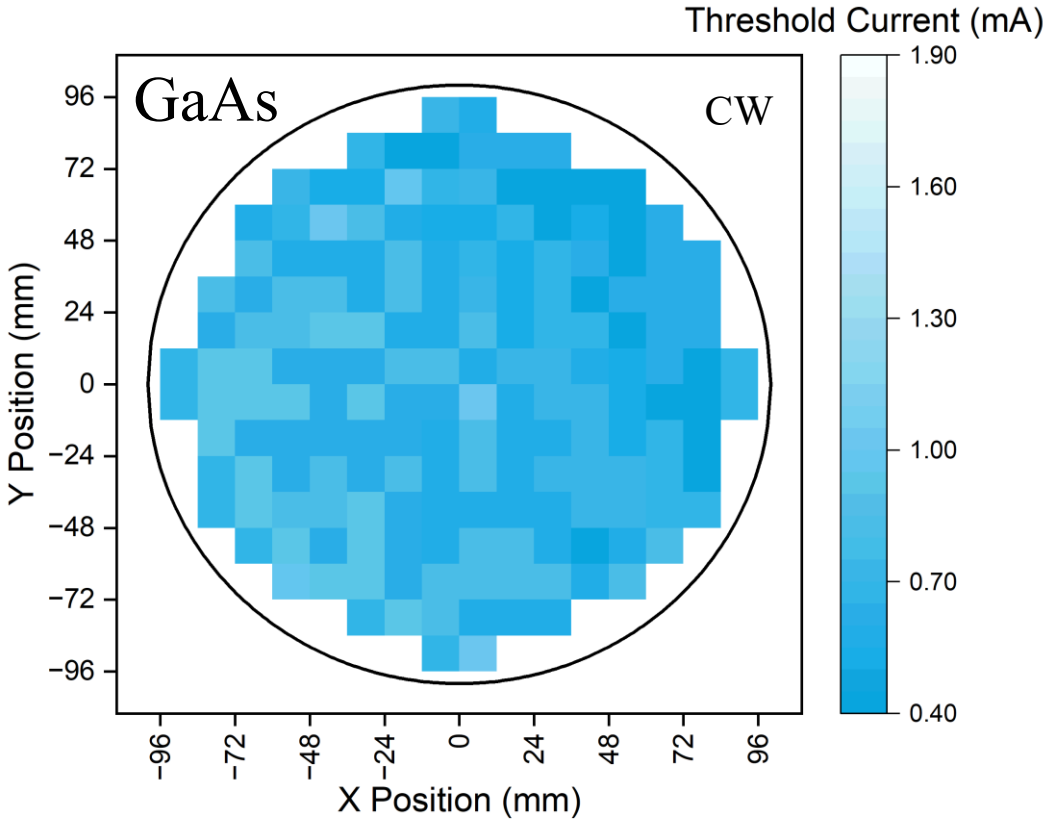


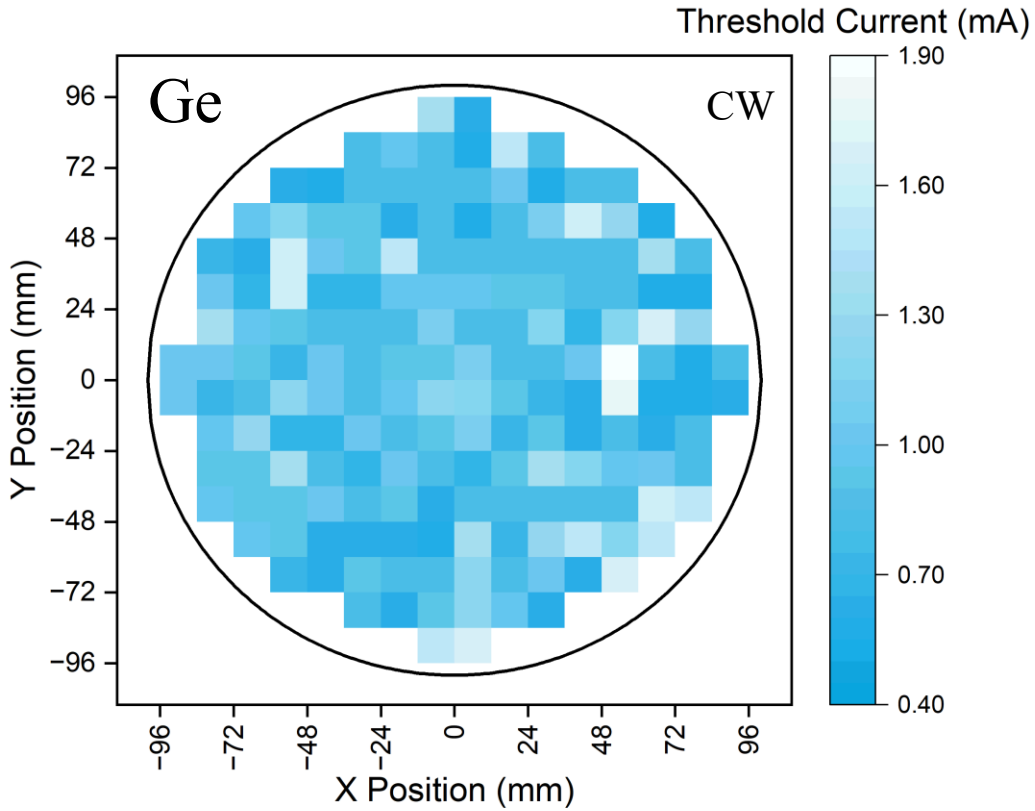
Central Peak Wavelength	934.0 nm
Range	7.2 nm



Central Peak Wavelength	939.5 nm
Range	10.6 mn

Results: Threshold current

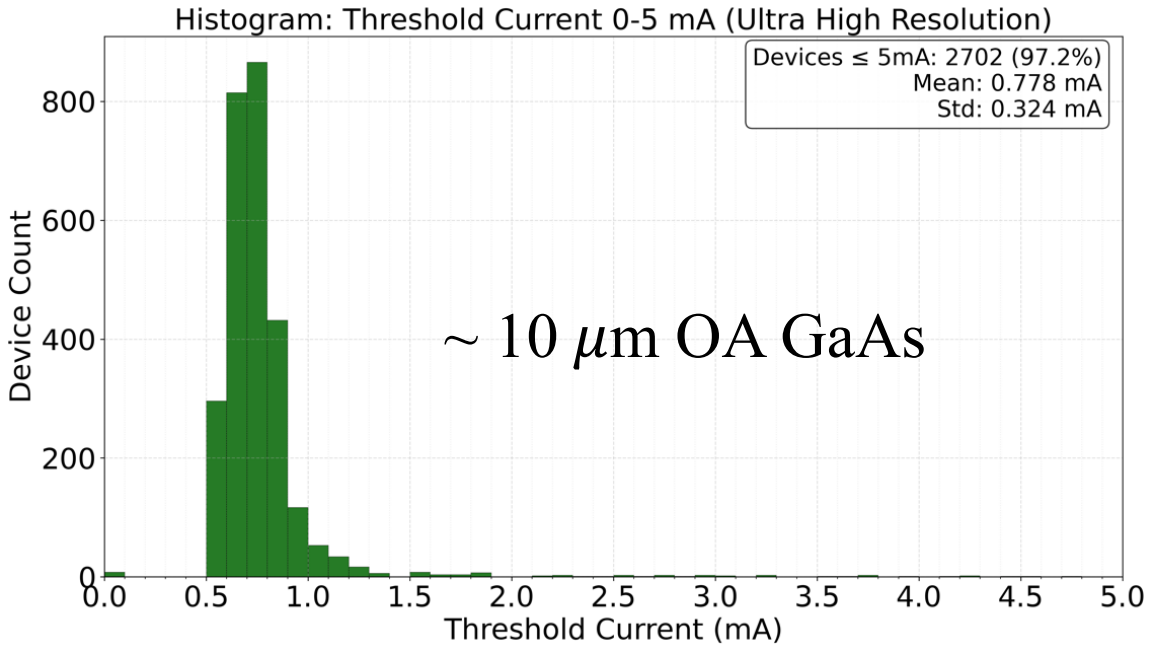


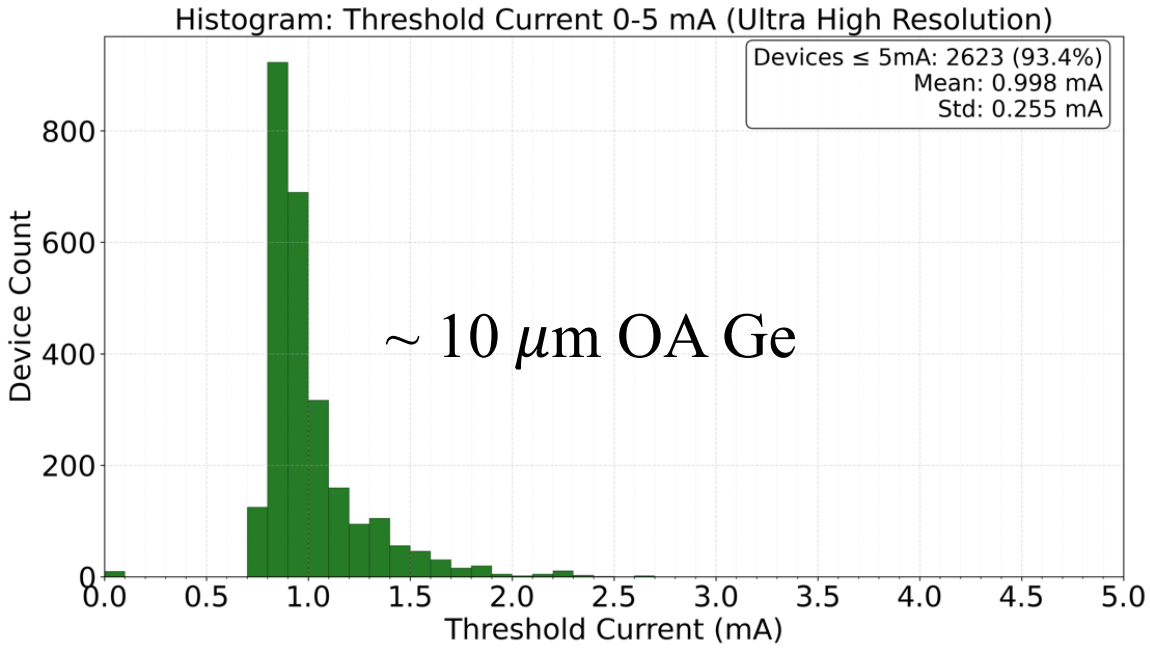


Mesa diameter = 40 um

OA = ~10 um

Results: Threshold current





Substrate	Mean (mA)	Std (mA)
GaAs	0.78	0.32
Ge	1.00	0.26

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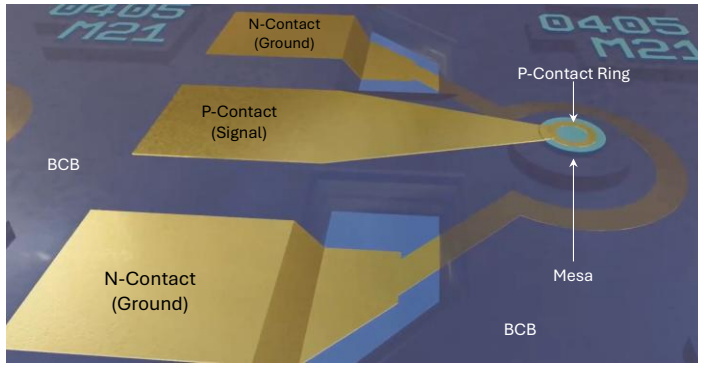
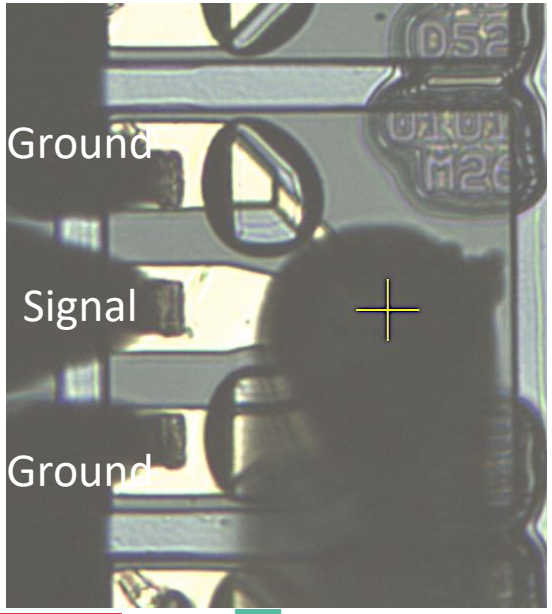
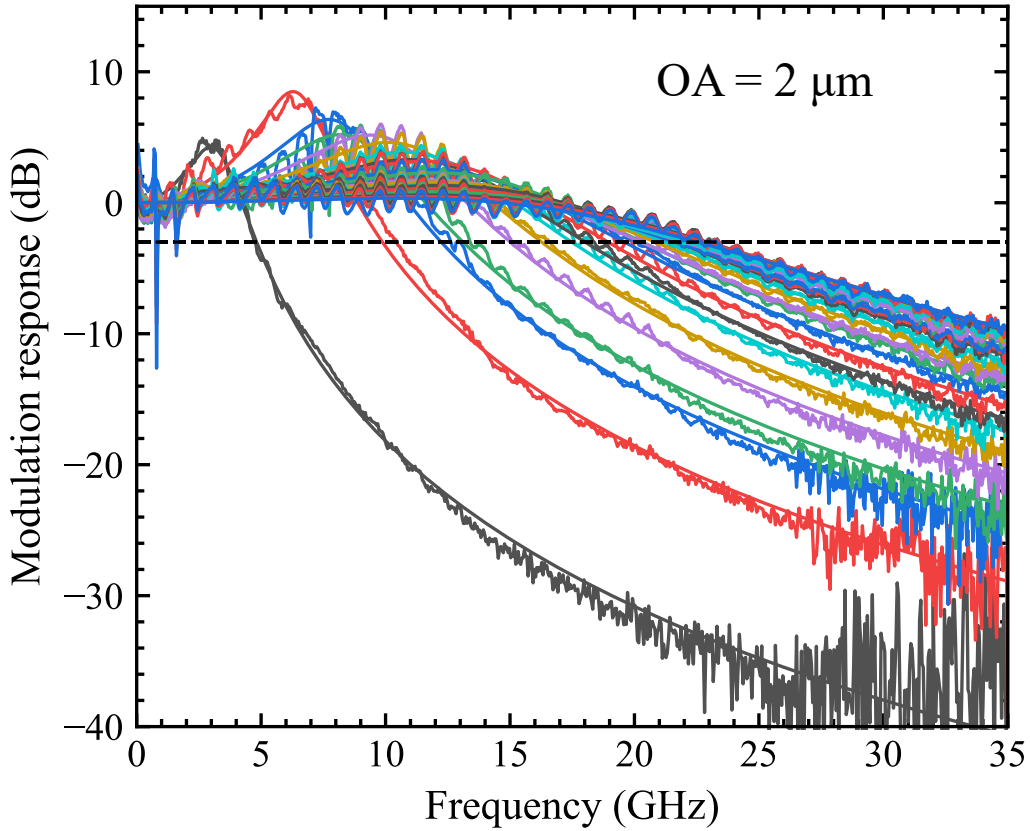
Dynamic Characterisation – Small-Signal Response

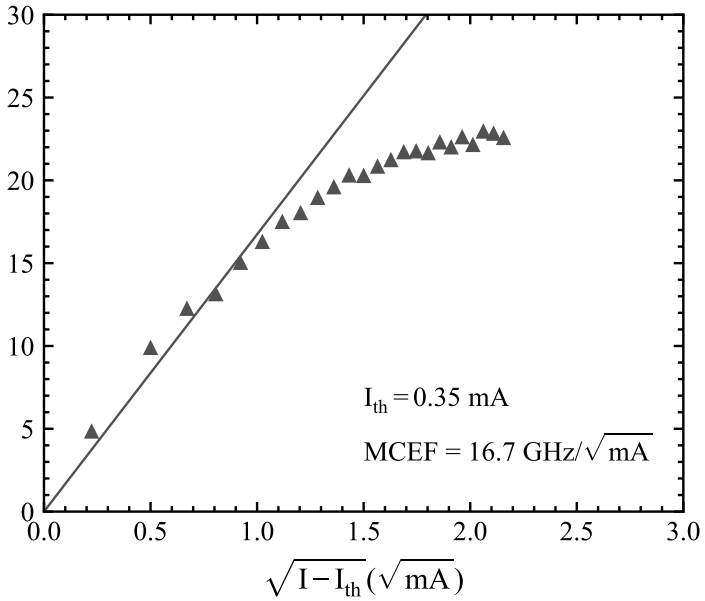




λ/2 cavity with two oxidised layers on GaAs



Bandwidth limited to
~ 23 GHz



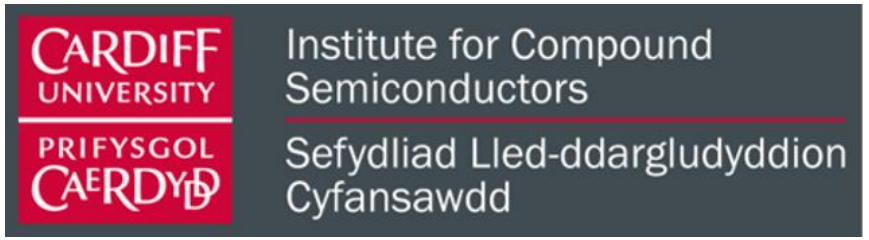
Conclusions

- Ge substrates offer potential advantages for VCSEL manufacture
- Thinner substrates can be used; 450um shows similar performance to 675um
- Growth conditions must be separately optimised for GaAs and Ge
- While 150mm substrates show similar performance, 200 mm Ge VCSELs have higher threshold currents and extended tail. Further work required!
- 2um OA on GaAs achieves bandwidth ~ 23 GHz

Acknowledgements

Epitaxial growth was carried out by

Device fabrication was carried out at:



Part of:

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