MBE growth facilities and capabilities

“Providing direct collaborative access to a comprehensive range of unique III-V research and development facilities”
MBE Achievements

• First observation of exciton complexes, first observation of a permanent dipole and first direct observation of the growth mechanism for InAs quantum dots (QDs)

• Lowest threshold, highest CW lasing temperature, highest output power and lowest noise for any semiconductor (QD) laser

• Amongst the first to demonstrate a GaAs based VCSEL, amongst the first to demonstrate a single QD emitter. Very high ‘Quality-factor’ for a semiconductor microcavity.

• Lowest threshold and amongst the highest $T_o$ reported for a GaInNAs laser. Longest wavelength emission PL from any GaInNAs QW

• First GaAs based & first As-Sb based Quantum cascade (QC) laser and the shortest wavelength QC emission
Epitaxial tools: Two V90 MBE Reactors

- Arsenides, phosphides and antimonides
- 2, 3 and 4 inch wafer capability. <1% variations in uniformity
- Fully automated system capable of batch growth
Epitaxial tools: V80 MBE Reactor

- Arsenides, phosphides, dilute nitrides and dilute bismides
- 2 inch wafer capability, < 5% variation in uniformity
- Manual system, suitable for individual wafer growth
In-situ characterisation facilities

- Staib RHEED, including image collection system
- In-house designed Laser light scattering
- Laytec Optical Reflectivity sensor with ‘true temperature’ pyrometry
Ex-situ characterisation facilities

- High-resolution X-ray diffractometry
- Photoluminescence and photoluminescence mapping
- Electrochemical CV profiling
- Atomic force microscopy
- Nomarski Optical microscopy
Collaboration

Supporting 22 external and 12 internal grants
19 different UK universities

Other key project funding: FP5,6,7EU Framework programme
Defence Technology Centres. Regional Development Agency
Existing Materials Capabilities

- GaAs based heterostructures: GaAs, AlGaAs, GaInAs, GaInP
- InP based heterostructures: InP, GaInAs, AlInAs, GaAlAsSb
- InAs/GaSb based heterostructures: InAs, GaAlSb, InSb
- InGaAs based quantum dots/quantum wires on GaAs and InP
- Optoelectronic devices: Laser, LED, photodetectors, APD, optical modulators, SOA, superluminescent LEDs
- Electronic device: HEMT, HBT, RTD
- Quantum cascade, QWIP, QDIP structures
- Dilute nitride: GaInNAs Bulk, QWs and QW lasers
InGaAs-GaAs quantum dots

- Quantum dot samples in a range of device configurations
- Extensive expertise and detailed characterisation
Very low-density QDs by growth interruption (<$10^9$ cm$^{-2}$) (R T Phillips et al, Cambridge)

PL spectrum dominated by QDs

PL spectrum dominated by the WL peak (medium dot density)

PL peak from the QDs (very low dot density)
Photonic crystals, R A Taylor, Oxford, F Brossard, Hitachi

Single dot strong coupling, APL 2010
Low density InAs/GaAs QDs at 1300 nm

- InAs/GaAs QDs with density of $2 \times 10^8$ cm$^{-2}$ (2 µm$^{-2}$) and emission wavelength of 1300 nm at 10 K
Optical Microcavity

- Quantum dot microcavity, VCSEL, Photonic band gap
Quantum dot lasers

- High density multilayer QD lasers, for 1000-1350nm emission
Quantum dot lasers

- Record low threshold of 17A.cm$^{-2}$
- True 1310nm operation
- Record CW power output at 1.3$\mu$m (>250mW) for single mode and record power density.
- Record low RIN noise (-159dB/Hz), 2 decades lower than equivalent QW lasers. Low chirp.
- Improved high temperature performance
Long-wavelength InAs/GaAs QD bilayers

- Stacked QD layers allowing independent control of density & emission wavelength
- InAs/GaAs QD devices with room temperature electroluminescence up to 1520 nm, lasing up to 1430 nm
Broadband QD Superluminescent diodes

• Developed with Thales under the EU program ‘Nano-UB sources’

• Applications in OCT, spectroscopy, telecoms
Other QD laser systems

- GaAsSb capped ‘type-II’ quantum dots
- InGaAs Quantum wires on InP substrates
Plasma nitride growth

Nitrogen passes into a pBN resonance chamber and diffuses out through pin-holes.

- Capable of N incorporation at the 0.1-6% level
- GaAsN, GaInAsN and InAsN extensively studied

N$_2$
GaInNAs quantum wells

- GaInNAs QWs with emission up to 1.6μm
- High quality GaInNAs multiple QWs

(detection semiangle=35-100mrad)
GaInNAs quantum well Optoelectronics

- Record low threshold (178 A/cm²) and transparency current (63A/cm²).
- Record characteristic temperature (T₀) of 189K over the range 20-50°C.
- Strong QC Stark effect in bulk GaInNAs.
Quantum cascade, QW/QD IR photodiode

- InGaAs/InAlAs and AlAsSb/ InGaAs Quantum cascade lasers
- QDIP/QWIP device development
Short-wavelength antimonide QCLs

- InP based InGaAs/AlAsSb, Deep well: $\Delta E_c = 1.6$ eV
- Multi-Watt RT pulsed power @ 3.3\,\mu m-3.7\,\mu m
- World record performance

![Graph showing peak optical power vs. current density](image)

- 10\,\mu m x 4 mm
- HR coating
- $\lambda \sim 3.5$\,\mu m
- $F = 125\,kV/cm$

![Photograph of a device](image)

- 1\,mm scale
Antimonide infrared detectors

- InAs/GaSb type II superlattice detectors
- InAs/AlAsSb bulk
Personnel/Contact

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