Novel materials and nanostructures for advanced optoelectronics

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Outline

◆ Brief introduction to
  ✴ Lancaster University
  ✴ Department of Physics
  ✴ Research group - Semiconductor Physics and Nanostructures

◆ III-V compound materials and Nanostructures from MBE
  ✴ QDs (self-assembled, V group exchange & droplets)
  ✴ Nanowires
  ✴ Dilute nitrides

◆ Summary
Lancaster University
Established 1964
Close to the Lake District
17,500 students
2,250 staff
Ranked in top 10 universities in UK
Ranked 131 in the World (THEWUR)
Top ranked Physics Department in UK in RAE 2008
semiconductor physics and nanostructures

◆ Academic staff
  ✴ Qiandong Zhuang (molecular beam epitaxy)
  ✴ Manus Hayne (physics & applications of QDs)
  ✴ Oleg Kolosov (scanning probe microscopy)
  ✴ Tony Krier (Mid-infrared optoelectronics)
  ✴ Three Fellowships

◆ Main research facilities
  ✴ Epitaxial growth – 3 MBE
  ✴ Photoluminescence (PL)
  ✴ Magneto-PL up to 17 T
  ✴ AFM & SEM
  ✴ X-ray
  ✴ **Class 100 clean room for nano-fabrication**
Growth facilities

- MBE-1&3 (VG V80H):
  - III: Ga, Al, In
  - V: As, Sb, N plasma
  - Dopant: GaTe, Be

- MBE-2:
  - Wide bandgap nitride nanowires
  - *Graphene on BN*

- Research focuses on III-V semiconductors ranging from *MBE growth* to *fundamental studies, optoelectronic devices* (telecom lasers, MID emitters & detectors, solar cells, thermophotovoltaic, next generation QDs flash memories)
Self-assembled GaSb QDs

Why GaSb/GaAs QDs?
- Type II: flash memories

Schematic band-gap diagram of GaSb/GaAs including band bending. z is the growth direction.

Type-II QDs (Leuven, Berlin, LNLS Brazil)
[PRB, APL, PRB, PRB]

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Self-assembled GaSb QDs

Scanning tunnelling microscope image of a quantum ring cross-section; brighter regions indicate high Sb content.

Strong As-Sb exchange and Sb segregation during capping

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InSb/InAs QDs by exchange

- InAs-based QDs for mid-infrared light emitters
- Fabricate through an exchange technology

Currently developing InSb/InAs MIR Lasers on InP

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GaAs/AlGaAs QDs by droplets

Why droplets for QDs?
- No strain is required

More flexible in materials design
More suitable for fundamental studies

Ga droplets

Expose to As4 to crystallize

Cap with GaAs or AlGaAs

Sensitive to growth conditions

5 ML Ga droplets
Diameter: 71 nm; height: 25 nm
Density: 6.5±0.5x10^9 cm^{-2}
GaAs/AlGaAs QDs by droplets

- Sharp PL emission
- Persists up to room temperature
- Geometry of buried dots to be studied by TEM
- Aim to transfer to antimonide QDs
Nitride nanowires on Si(111)

Advantages of NWs?
- Devices: Solar cells, lighting & water splitting – H₂ generation

Requirements:
- Bandgap must be 1.6-1.7 eV
- straddle H₂O redox potentials
- Rapid charge transfer
- Stable in aqueous solution

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Nitride nanowires on Si(111)

InN grains

InN Nanowires

- Monocrystalline
- Strain-free

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Dilute nitrides

A few percent of nitrogen
- reduces lattice constant
- reduces band-gap
- Reduced Auger recombination

Ga(In)AsN: 1.3 ~1.5 um emission on GaAs

Possible for MIR optoelectronics?
Physics of bandgap bowing

Dilute nitrides

- Develop GaAs-based dilute nitride lasers operating at 1.55 um up to a temperature of 85°C through optimising valence band offset
  - Adding Sb
  - Embedded AlGaAs barrier

- Oclaro studentship
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Dilute nitrides

**InAsNSb on InAs or GaSb:** covers MIR and far-infrared with suppressed Auger recombination

Sb as surfactant improves the dilutes

Developing nitride MIR lasers on InP in collaboration with Wisconsin University

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Summary

- Top 10 universities in the UK, top ranked Physics in RAE 2008

- MBE growth facilities - most of arsenic and antimonide materials and

- Active in MBE grown novel materials and nanostructures
  - GaSb/GaAs QDs/Quantum Rings
  - InSb/InAs QDs by exchange
  - GaAs/AlGaAs QDs by droplets
  - Novel dilute nitride materials
  - Wide bandgap nitride NWs on Si

- New materials & structures: graphene + BN