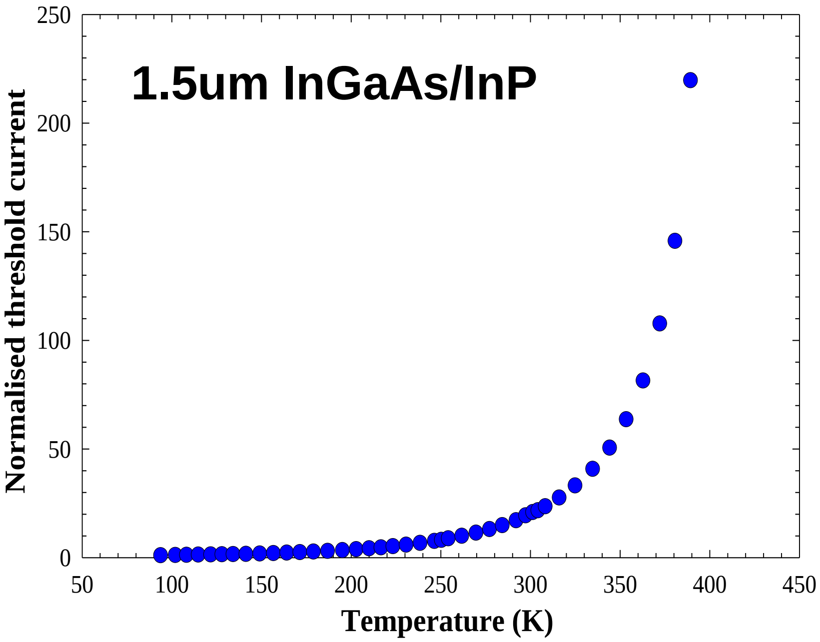
The Potential of III-Bismides for Near- and Mid-IR Photonic Devices

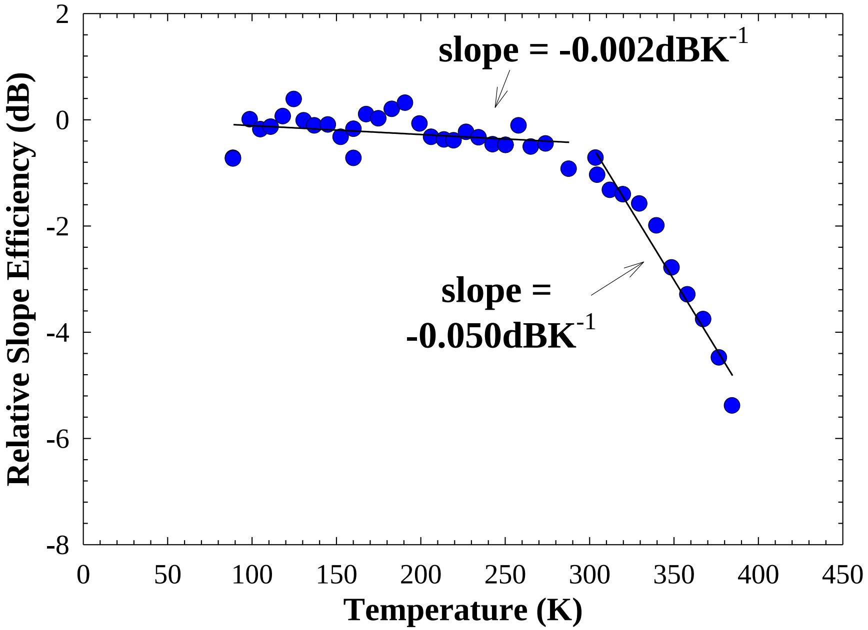
Stephen J. Sweeney, Zahida Batool, T. Jeff C. Hosea and Shirong R. Jin

Advanced Technology Institute and Department of Physics
University of Surrey, Guildford, GU2 7XH, UK

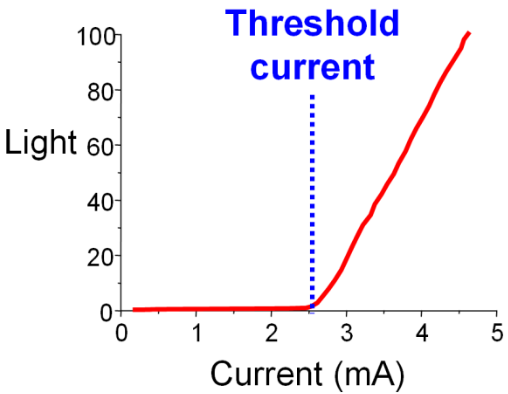
www.surrey.ac.uk

The problem with InP-based near-IR lasers



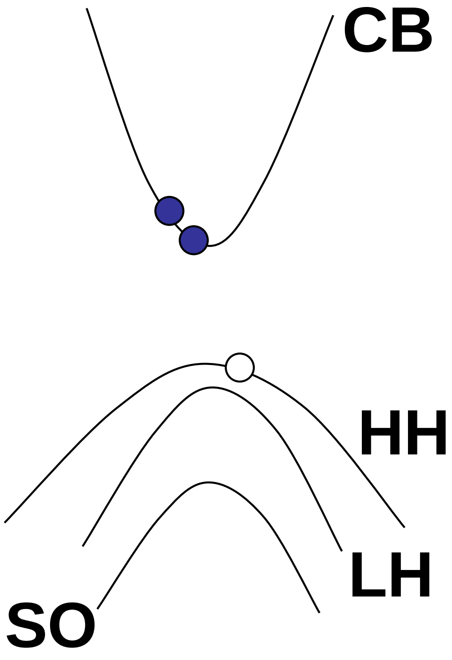


- Threshold increases by a factor of 20 from 100K to 300K and increases by a further factor of 11 from 300K to 380K
- Strong decrease in slope efficiency only above 300K
- Both degrade high temperature performance



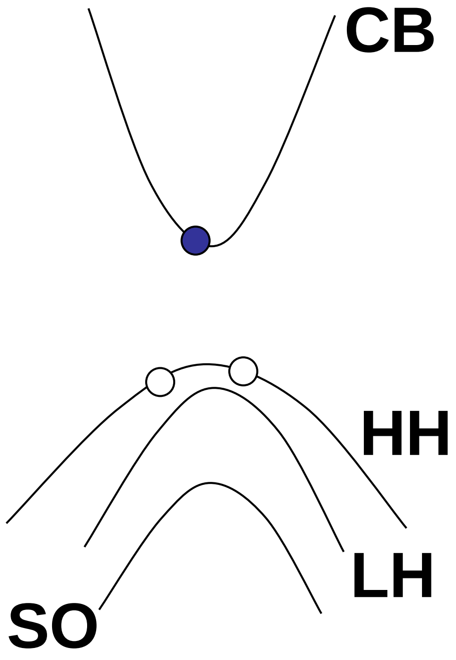
Auger recombination: two basic types

CHCC $\propto n^2p$



➡ **Hot electrons**

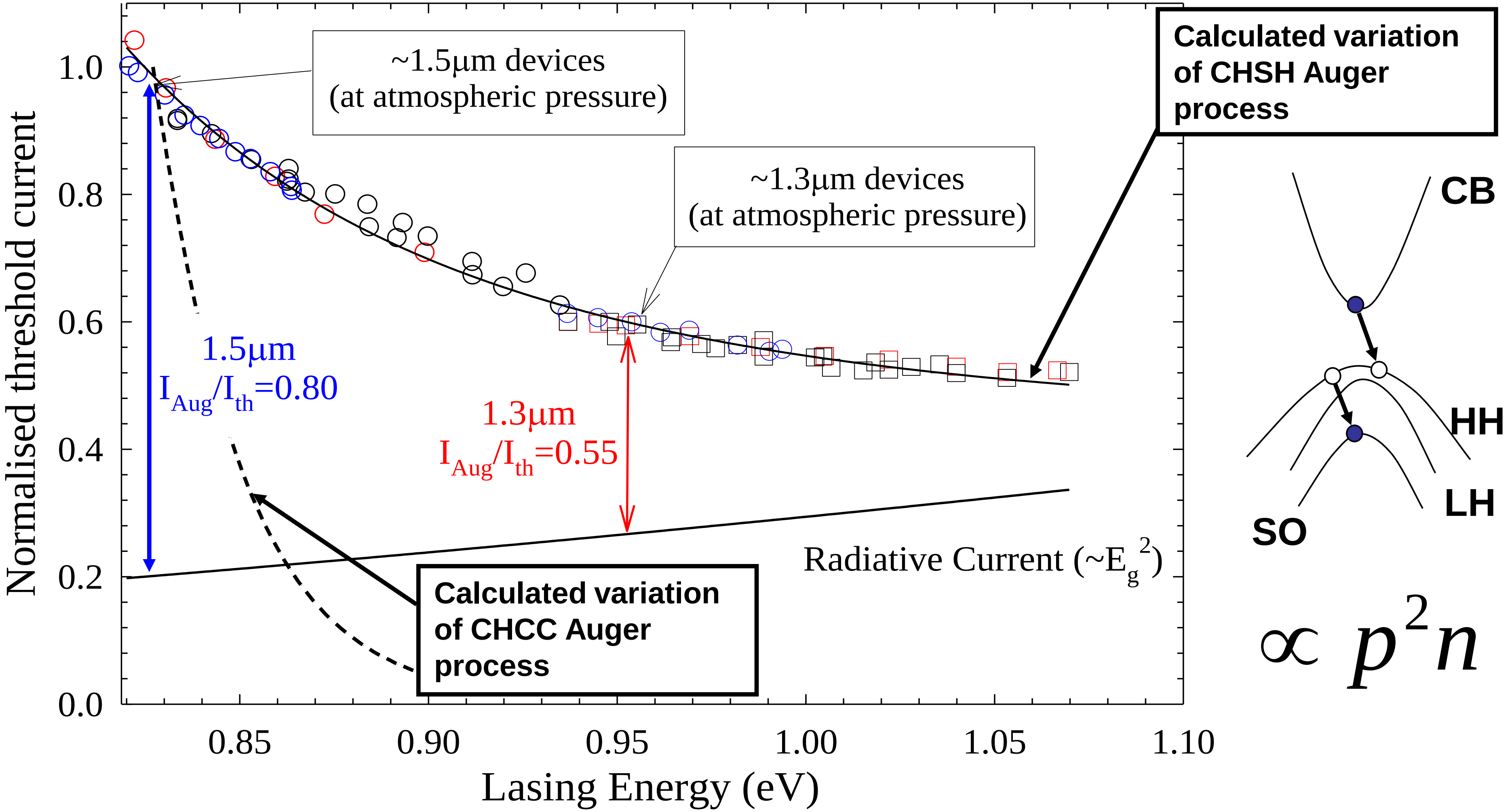
CHSH $\propto p^2n$



⇨ **Hot holes**

Band gap dependence of threshold current

(from pressure measurements)



~1.5µm devices (at atmospheric pressure)

~1.3µm devices (at atmospheric pressure)

1.5µm $I_{Aug}/I_{th}=0.80$

1.3µm $I_{Aug}/I_{th}=0.55$

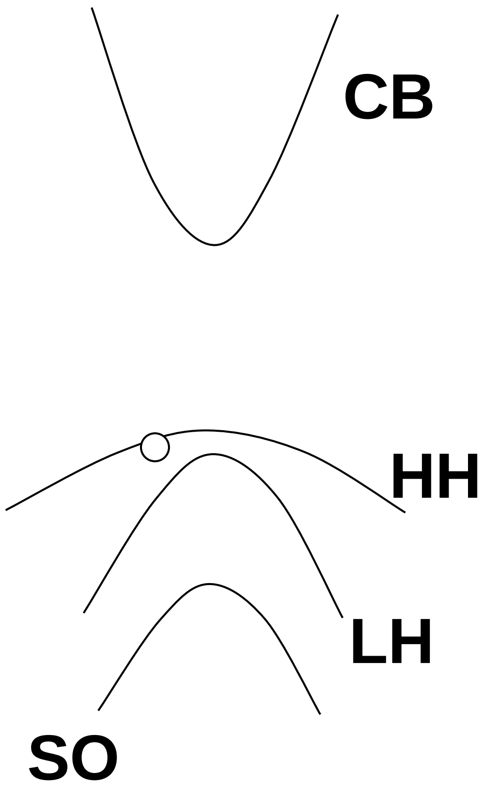
Radiative Current ($\sim E_g^2$)

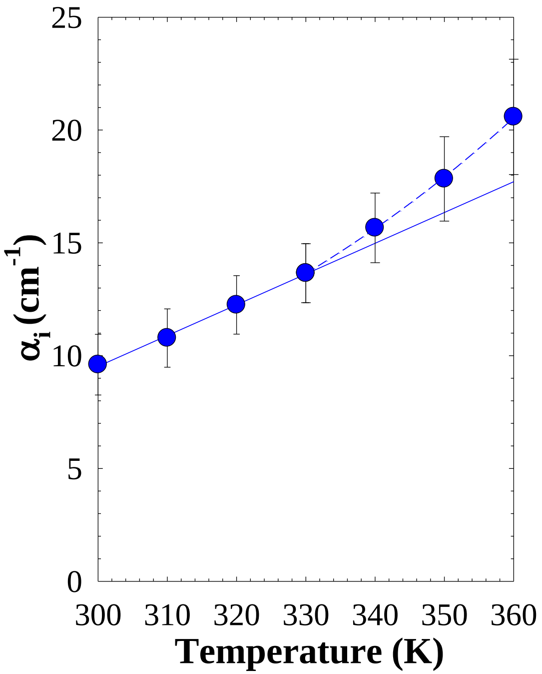
Calculated variation of CHCC Auger process

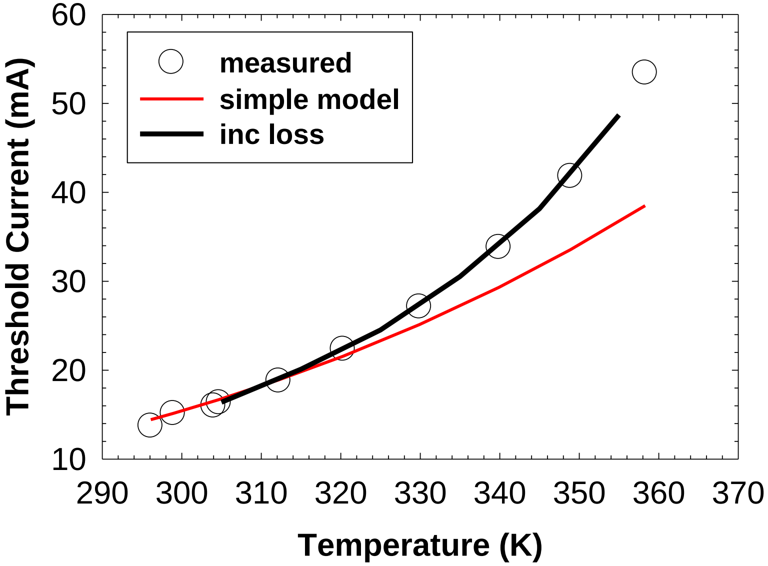
Calculated variation of CHSH Auger process

$$\propto p^2 n$$

Inter-Valence Band Absorption (IVBA)



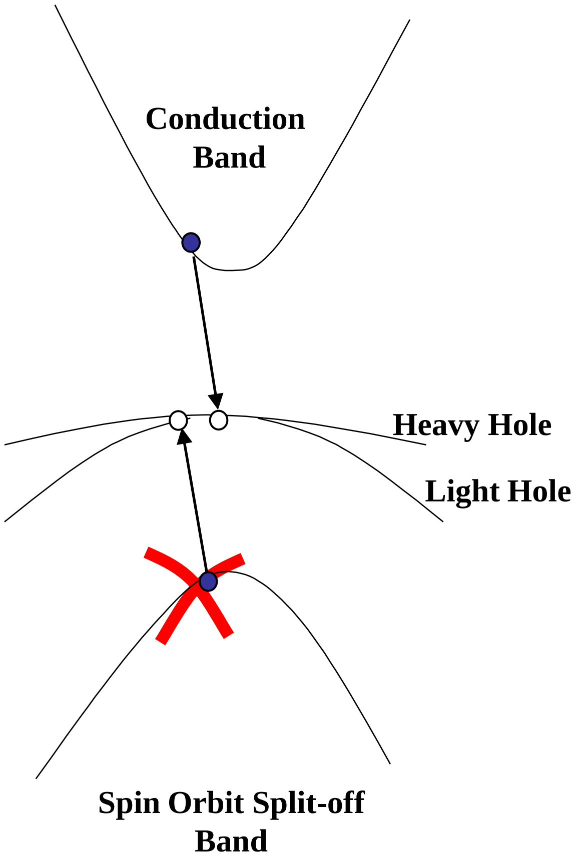




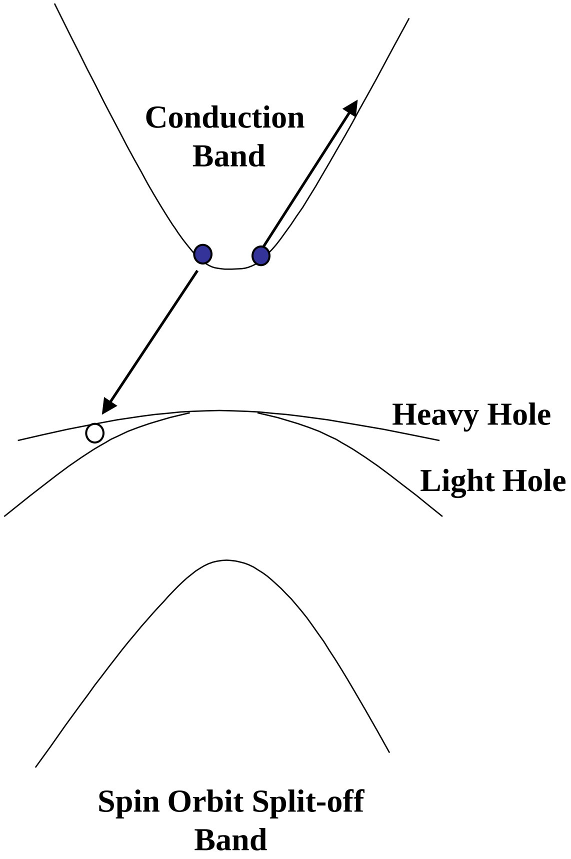
IVBA affects both threshold and slope efficiency and is also sensitive to the spin-orbit splitting, ΔSO

Auger suppression and persistence…

CHSH



CHCC

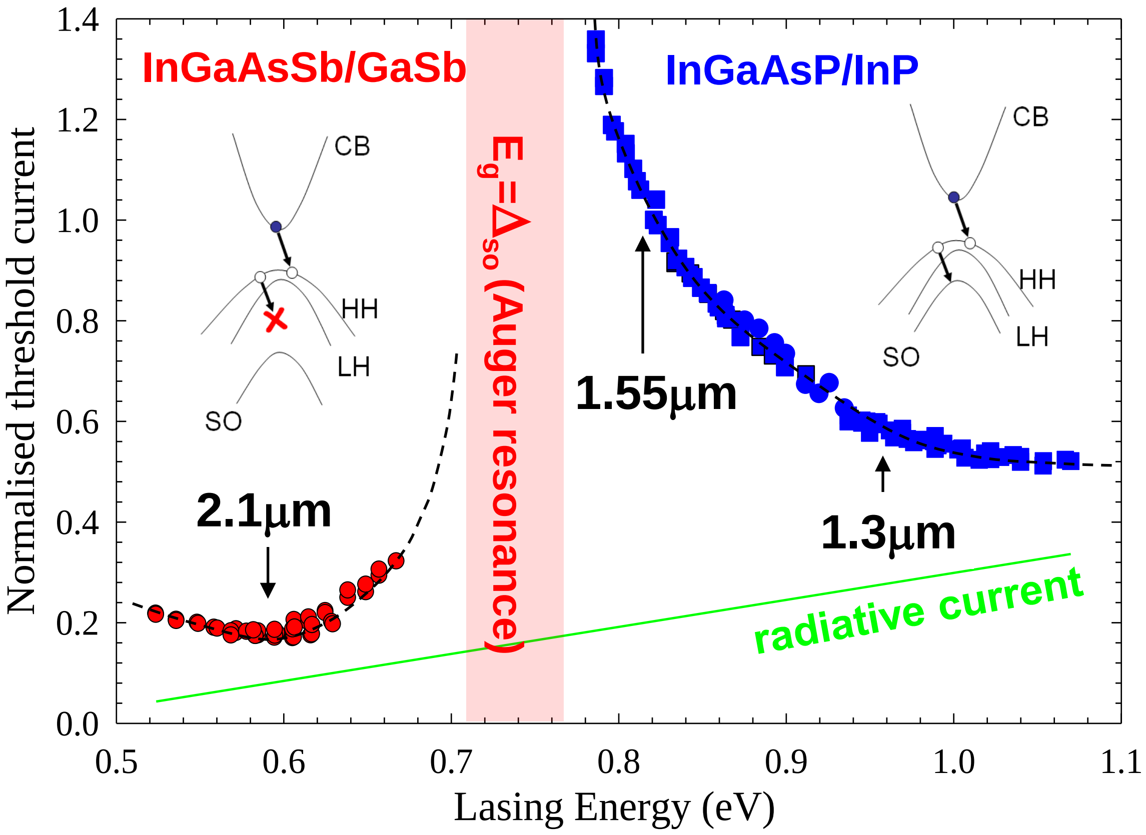


If $\Delta_{SO}>E_g$ CHSH is not allowed

CHCC process may still occur

Learning from the mid-IR…

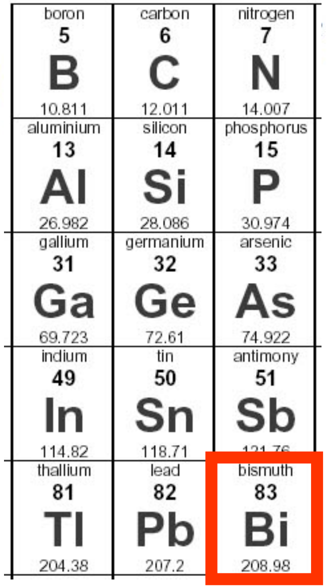
- InP devices: Laser performance gets worse with increasing wavelength (higher J_{th}, lower T_o etc.)
- Dominant path associated with hot-hole producing (CHSH) Auger process
- BUT, in GaSb based mid-IR lasers CHSH is suppressed since $E_g<\Delta_{so}$
- Antimonides won't help as much in the near IR…



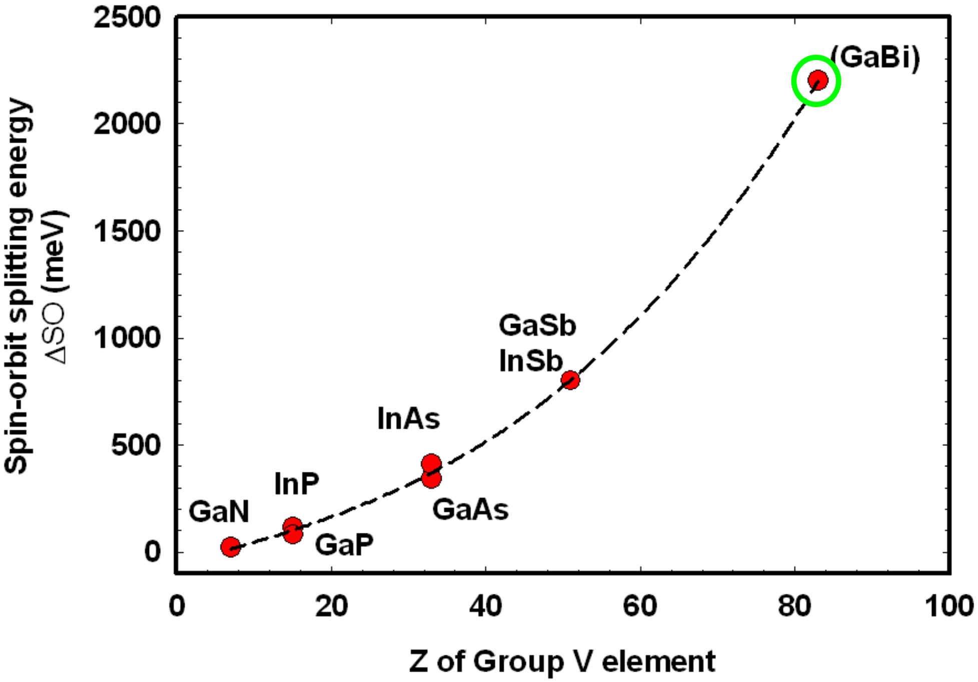
Can we achieve the same in the near-IR?

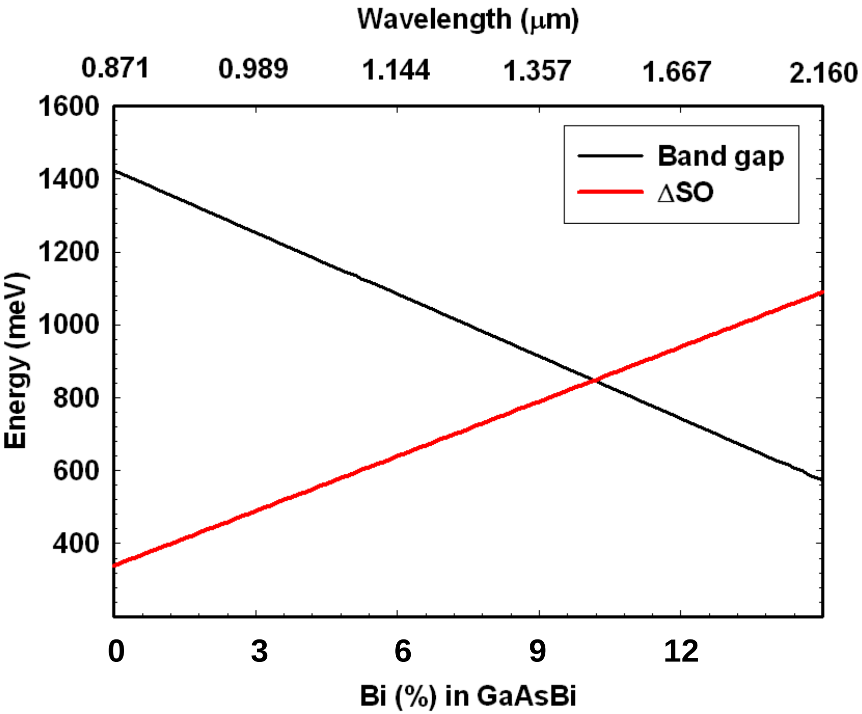
- The Spin-orbit splitting is a strong function of the group V element atomic number

- Bismuth is the largest stable group V element
    - ❑ Exhibits BAC effect in VB (cf. dilute nitrides)
    - ❑ Giant spin-orbit splitting bowing



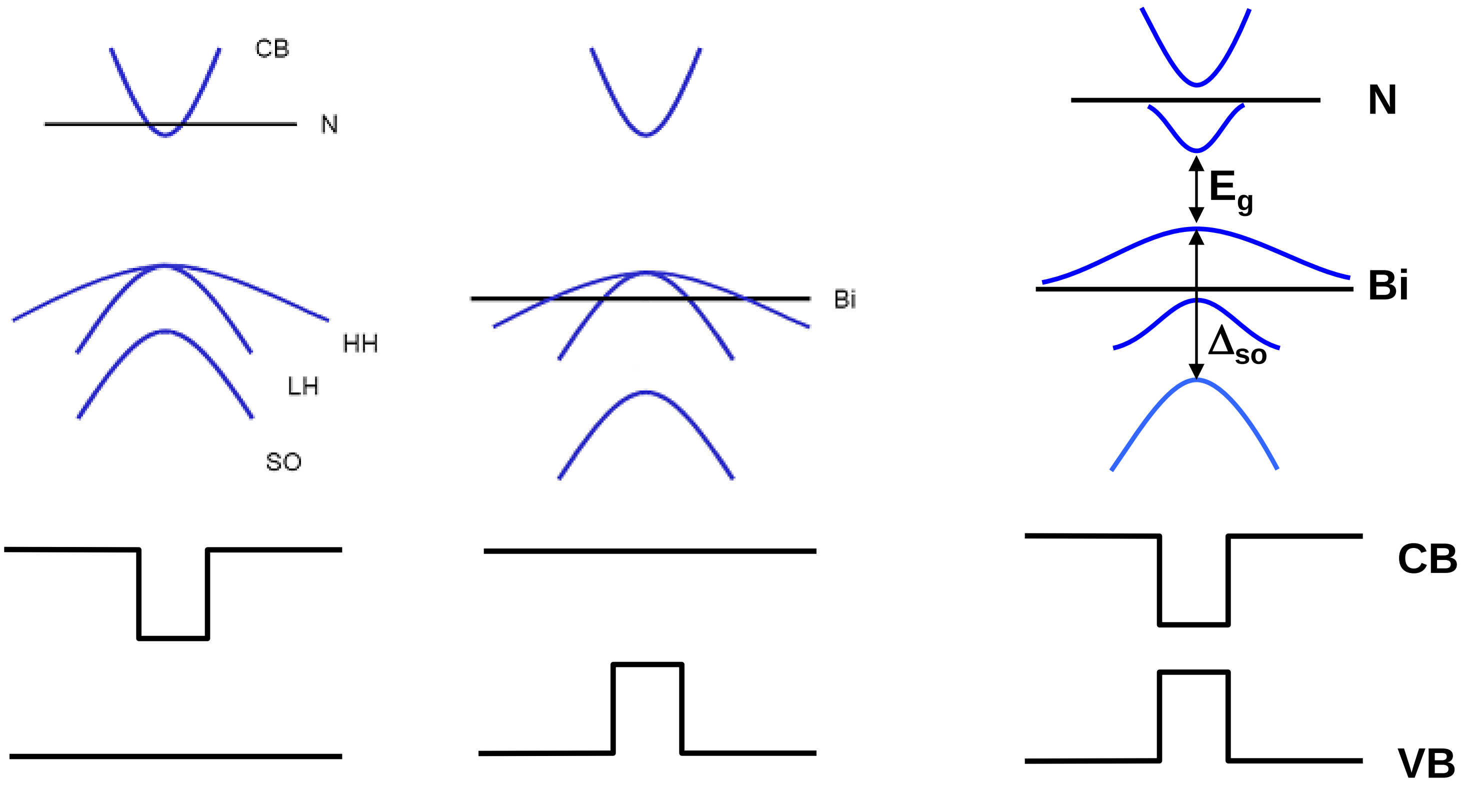
boron 5 **B** 10.811	carbon 6 **C** 12.011	nitrogen 7 **N** 14.007
aluminium 13 **Al** 26.982	silicon 14 **Si** 28.086	phosphorus 15 **P** 30.974
gallium 31 **Ga** 69.723	germanium 32 **Ge** 72.61	arsenic 33 **As** 74.922
indium 49 **In** 114.82	tin 50 **Sn** 118.71	antimony 51 **Sb** 121.76
thallium 81 **Tl** 204.38	lead 82 **Pb** 207.2	bismuth 83 **Bi** 208.98





Band engineering of GaAs(Bi,N)

GaAsN **GaAsBi** **GaAsBiN**



N atoms in GaAs:

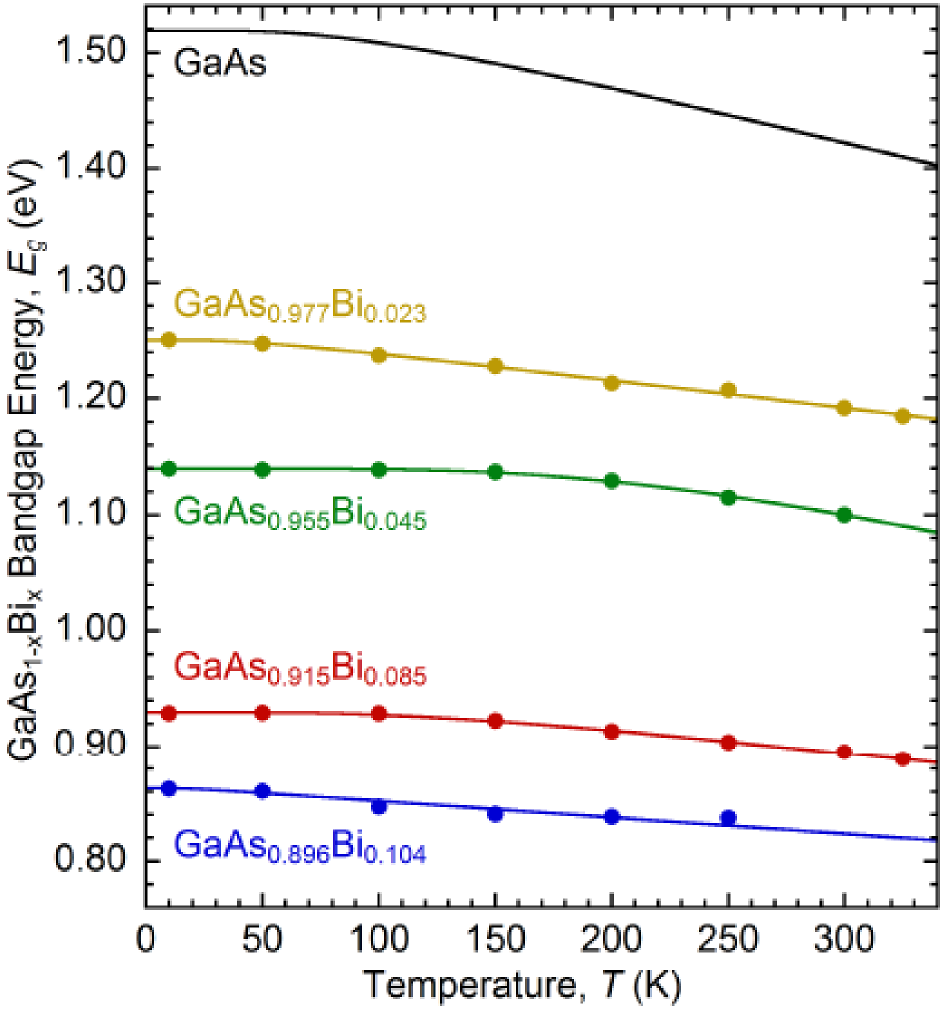
- **reduced E_g arising from the N-CB anticrossing**

Bi atoms in GaAs:

- **reduced E_g originating (mainly) from the Bi-VB anticrossing**
- **large increase in Δ_{so}**

Wide scope for optoelectronic device designs

GaAsBi alloys – PL

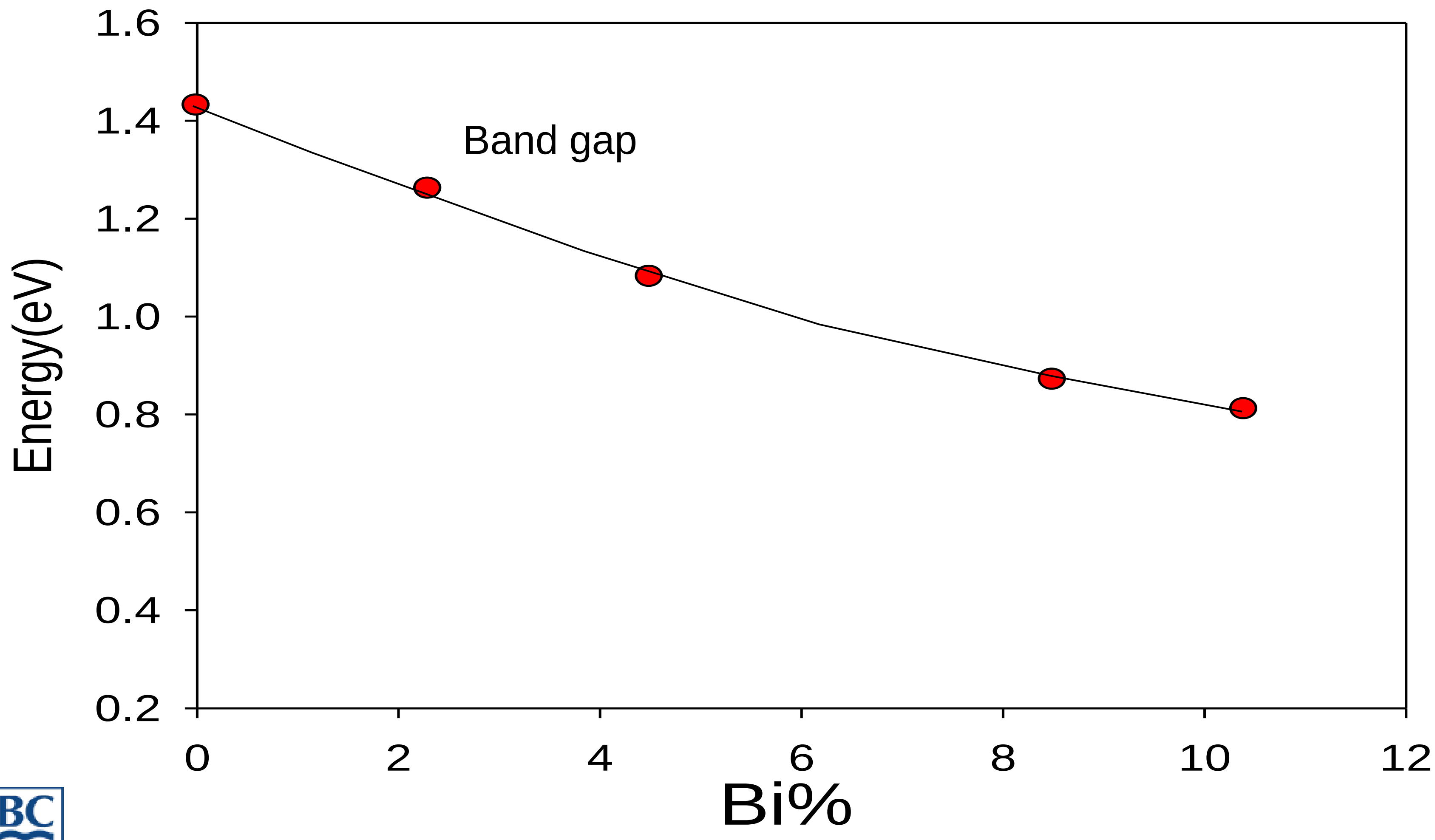


← **1.55μm**

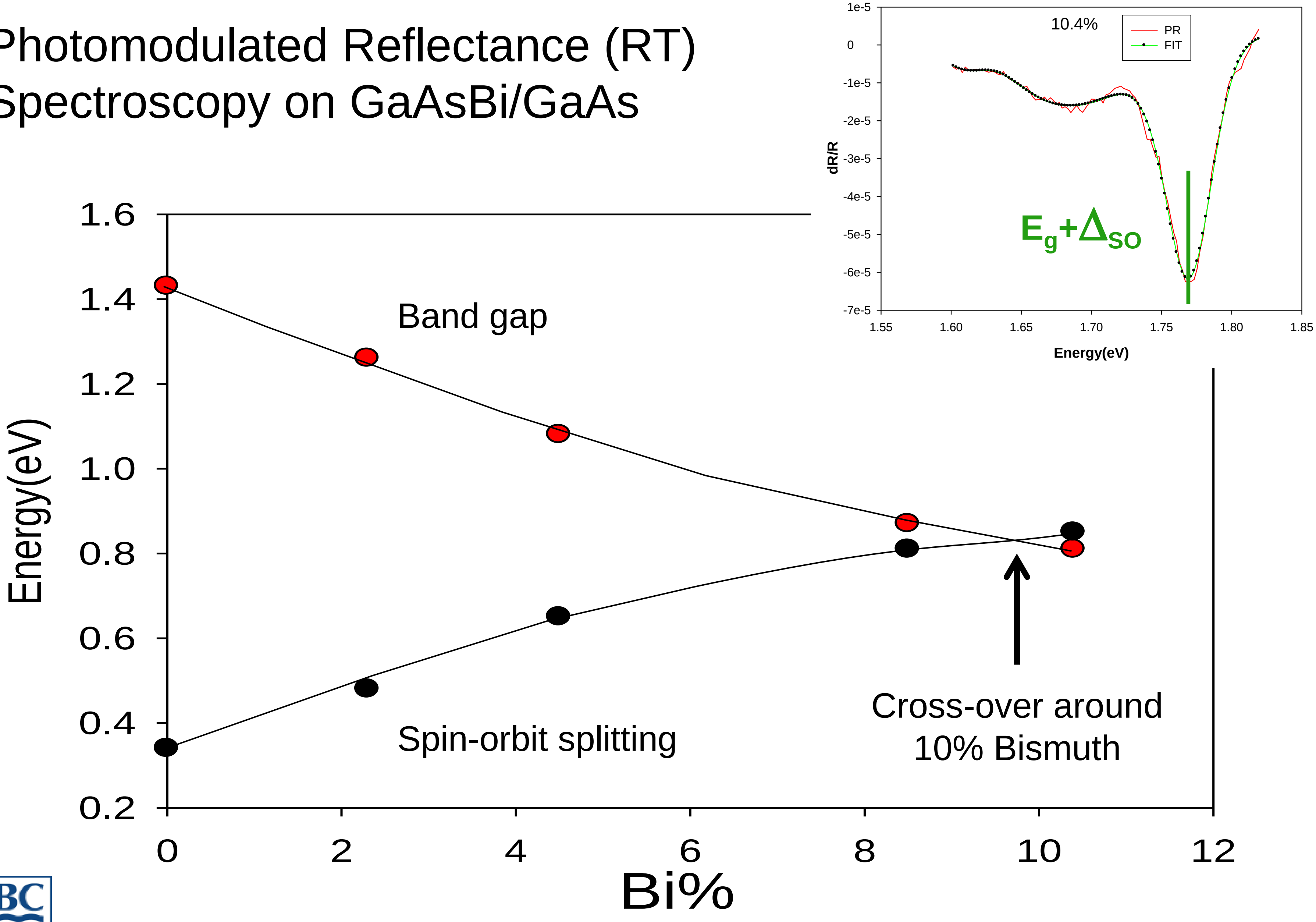
- MBE-grown samples up to ~10% Bi
- Weak temperature dependence of band gap due to valence band anti-crossing effect
  - Potentially very beneficial for devices (eg. smaller de-tuning relative to grating in DFB laser)

Samples grown at UBC, from Tom Tiedje (now UVic) & Xianfeng Lu (now ASU), PL with Shane Johnson & Ding Ding (ASU)

Photomodulated Reflectance (RT) Spectroscopy on GaAsBi/GaAs



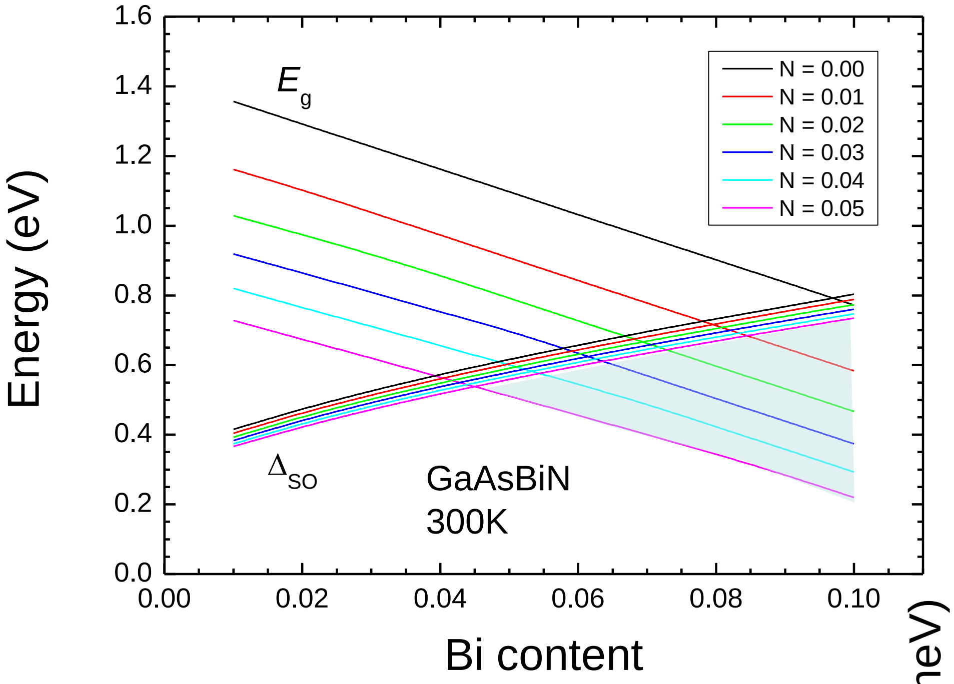
Photomodulated Reflectance (RT) Spectroscopy on GaAsBi/GaAs



Cross-over around
10% Bismuth

www.surrey.ac.uk

Quaternary GaAsNBi/GaAs for MidIR

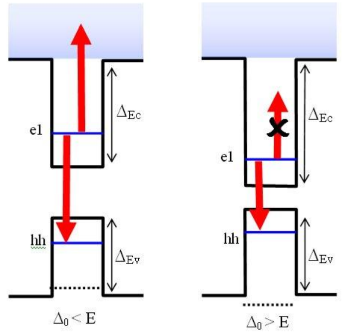


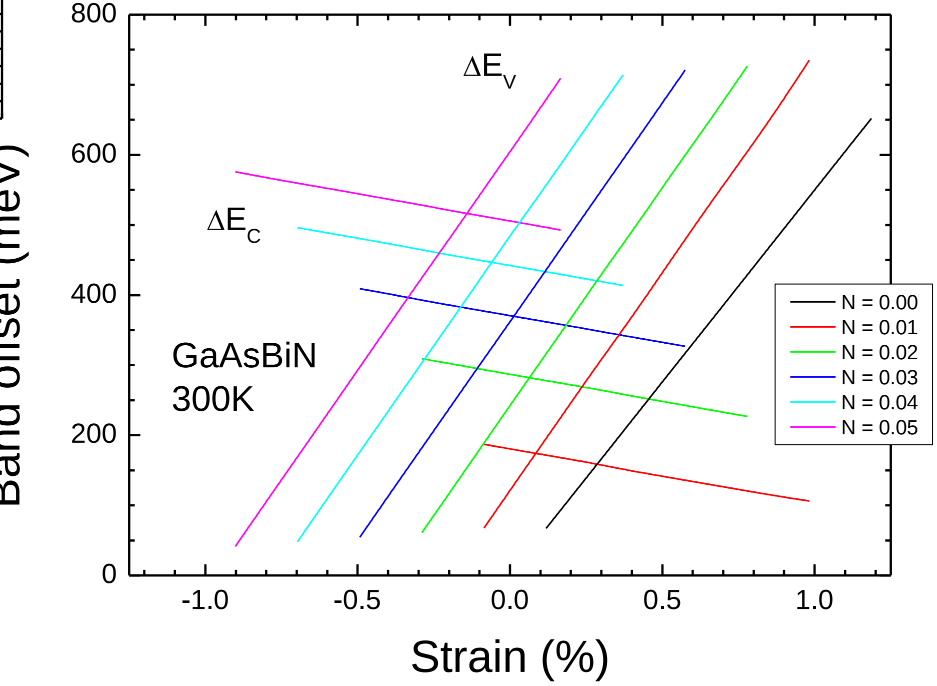
Δ_{SO}, E_g, strain and band offsets well controlled with this alloy

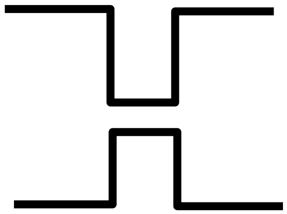
Potential to make

$\Delta_{SO}>E_g$ and $\Delta_C>E_g$ +kT

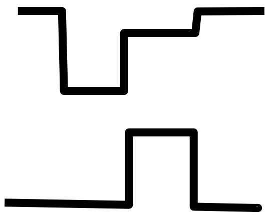
(also suppress CHCC?)







GaAsNBi/GaAs (Type I)



GaAsN/GaAsBi (Type II)

Summary

- Near-IR InP based lasers suffer from Auger recombination (and IVBA). This lead to high thresholds, low efficiency and temperature sensitivity
- If $E_g<\Delta_{so}$ the hot-hole generating CHSH Auger process (and IVBA) may be minimised/eliminated. This may be possible with Bismides.
- Bismides alloys offer flexible control of E_g , Δ_{so} , band offsets, band alignment and strain
- Candidate materials include GaAsBi for the near-IR and GaNAsBi for mid-IR applications