

Wavelength Conversion and All-Optical Switching in QCL's.

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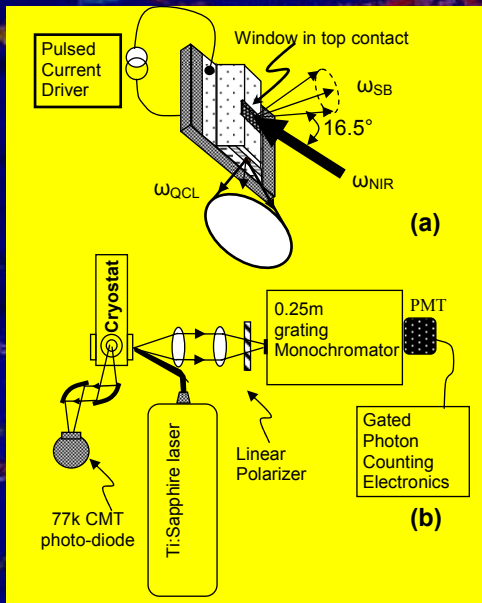
And

***Dymtro Kundys, Luke Wilson John Cockburn and Maurice
Skolnick, Sheffield University.***

Outline

- *Device Design.
- *Materials Considerations.
- *Frequency mixing experiments.
- * THz laser results.
- *All-optical switching.
- *Concluding Remarks.

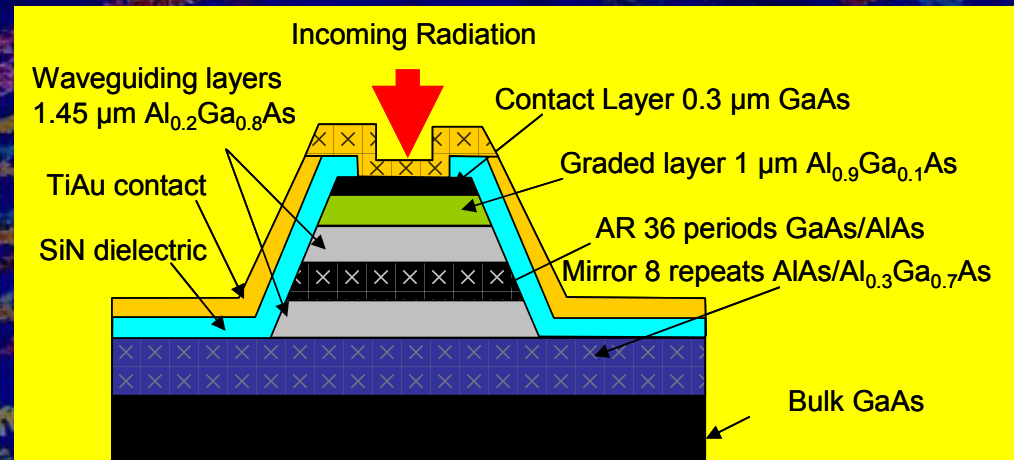
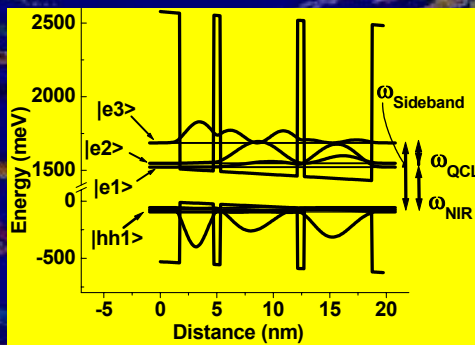
Device Design



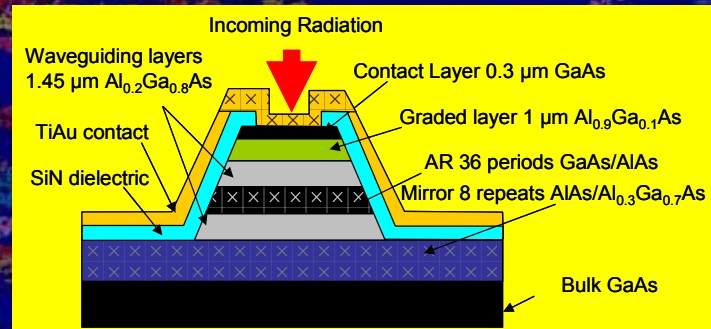
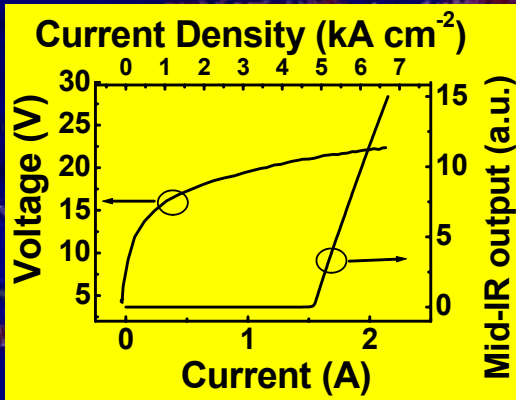
*Standard (-ish) QCL with window in top contact

* Needs cladding layers transparent to bandgap radiation

* Needs DBR for reflective mode experiments.



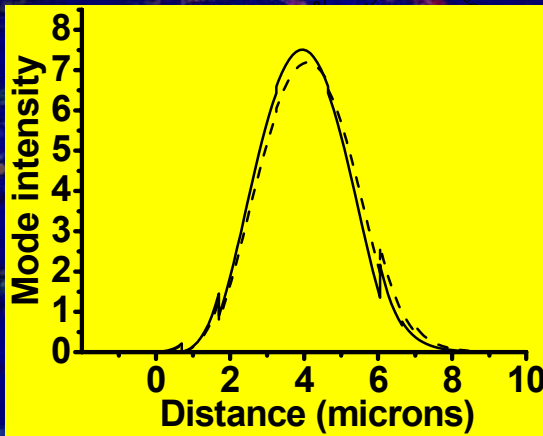
Materials Issues



* Lots of Al, but electrically stable.

* J_{Th} indistinguishable from devices without holes or DBR's

* DBR looks much like cladding to the QCL mode.

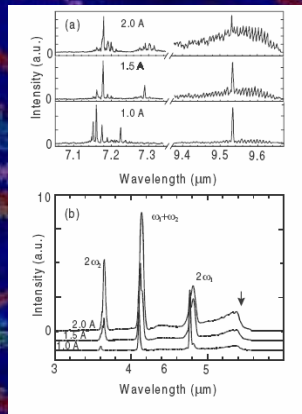
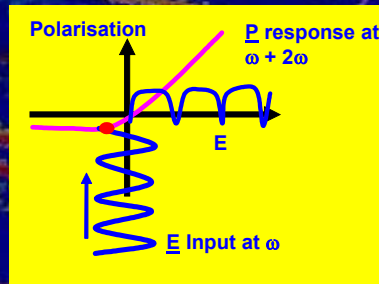
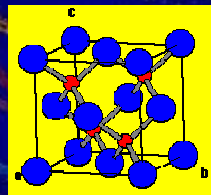


Non-linear optics for new wavelengths

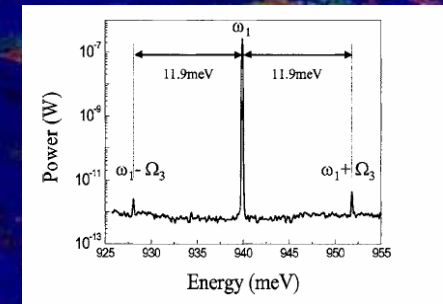
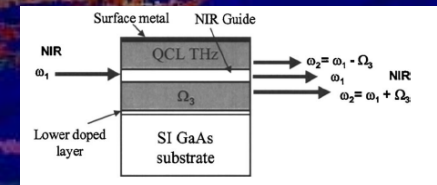
*QCL cavities have high radiation density and the intrinsic $\chi(2)$ of III-V's.

*Artificial resonances can be designed-in.

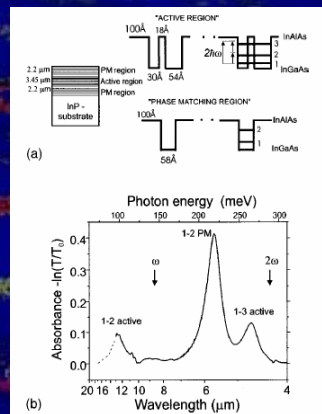
*Designable dispersion for phase matching.



N Owschinikow et al. PRL, 90 (4), 043902-1 (2003).



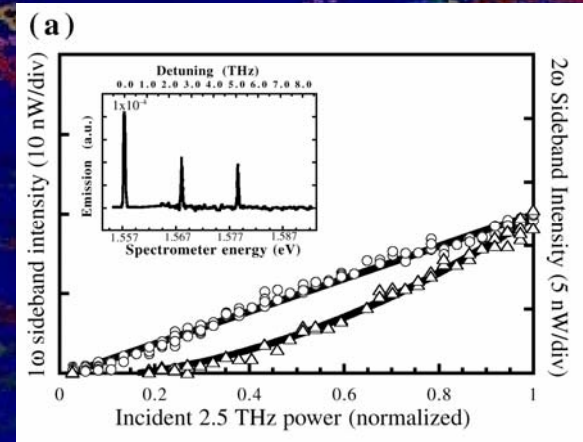
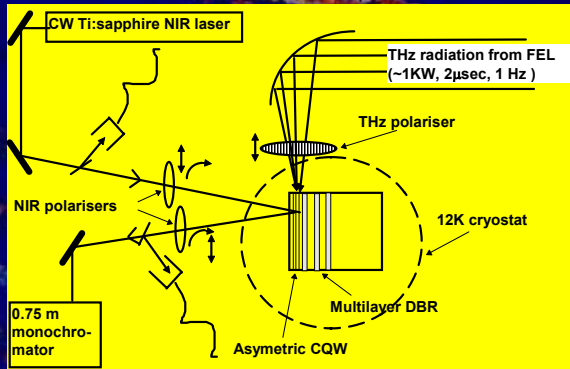
S S Dhillon et al. APL 87, 071101 (2005).



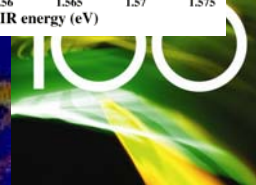
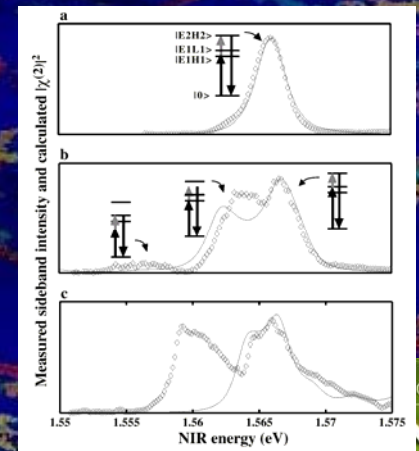
K L Vodopyanov et al. APL 72(21), 2654 (1998).

ITQW Ambleside Sept 2007.

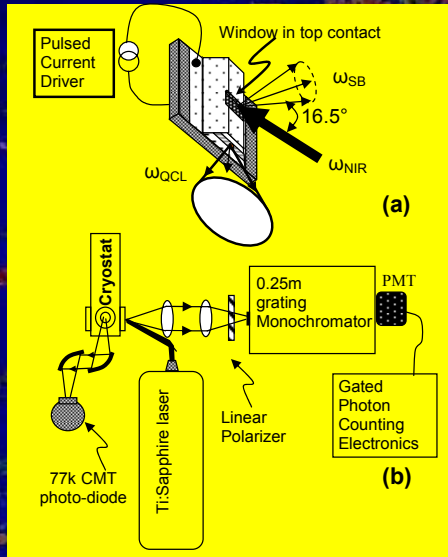
Earlier FEL Experiments.



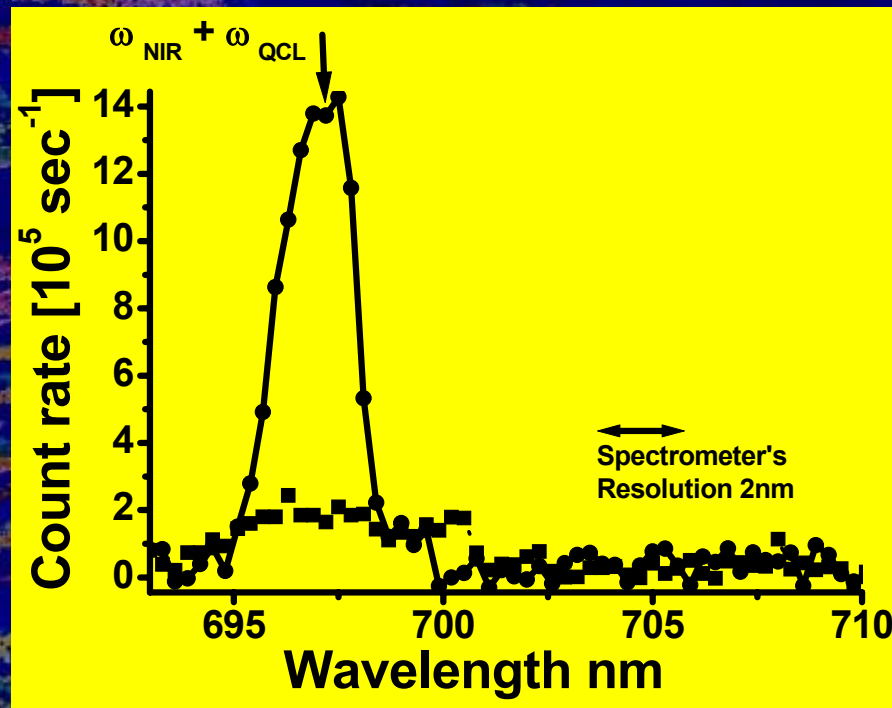
- *Easy phase-matching.
- *Polarisation insensitive.
- *Broad bandwidth.
- *telecomms λ 's



Sideband spectra.



*Gated measurement.



THz lasers

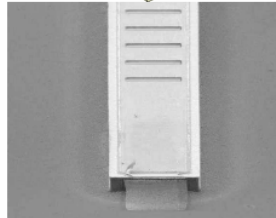
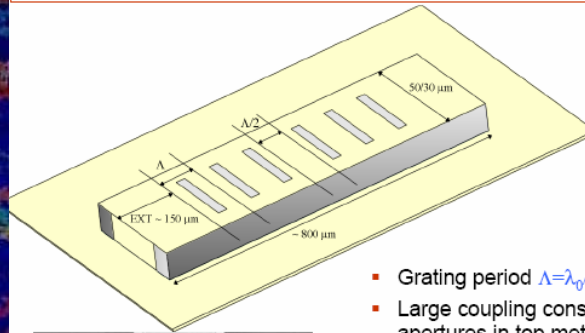
* $\Delta\lambda/\lambda \sim 1\%$

*Closer to DWFM applications.

*Tunes over wide frequency range.

*Polarisation insensitive.

Surface emitting second order DFB lasers



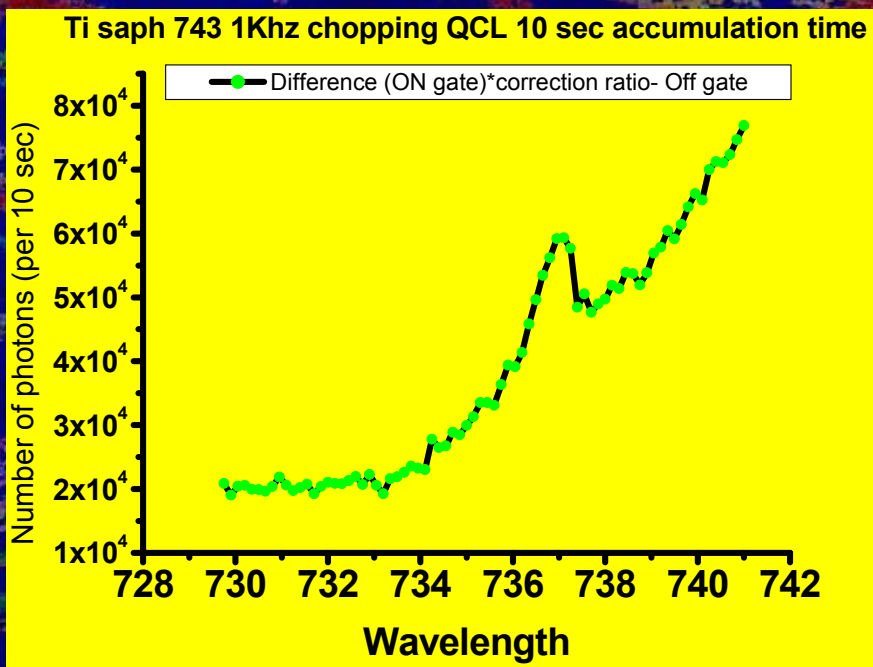
- Grating period $\Lambda = \lambda_0 / n_{\text{eff}}$ ($\sim 30 \mu\text{m}$ for $\sim 3 \text{ THz}$)
- Large coupling constant κ obtained by having apertures in top metal
- Lithographically defined dry- etched facets to control phase of reflection at the facets
- Challenging fabrication
- Challenging design – higher order lateral modes need to be avoided

Sideband generation in THz lasers

* $\Delta\lambda/\lambda \sim 1\%$

*Sideband has right polarisation dependence

*Tunes over wide frequency range.

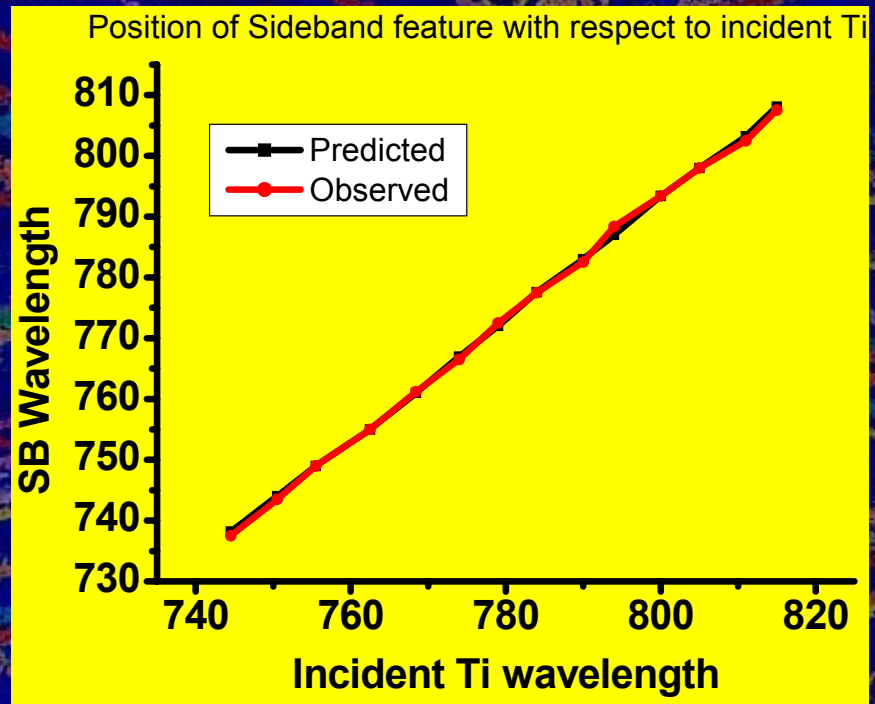


Sideband tracks with incident wavelength.

* $\Delta\lambda/\lambda \sim 1\%$

*Sideband has right energy dependence

*Tunes over wide frequency range.

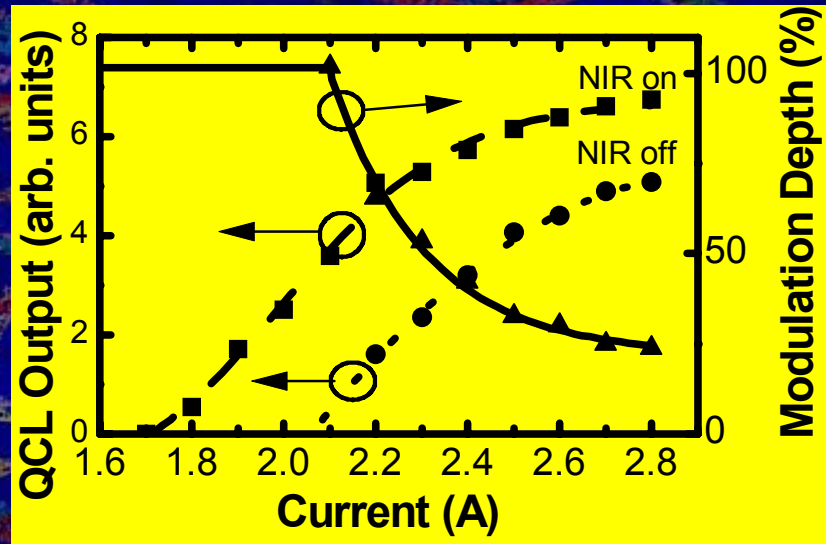


All-optical switching.

*Seen only in 25% Al samples.

*QCL J_{th} lowers when Bandgap radiation is applied.

*100% modulation depth possible @ ~ 50% of Max QCL o/p power.

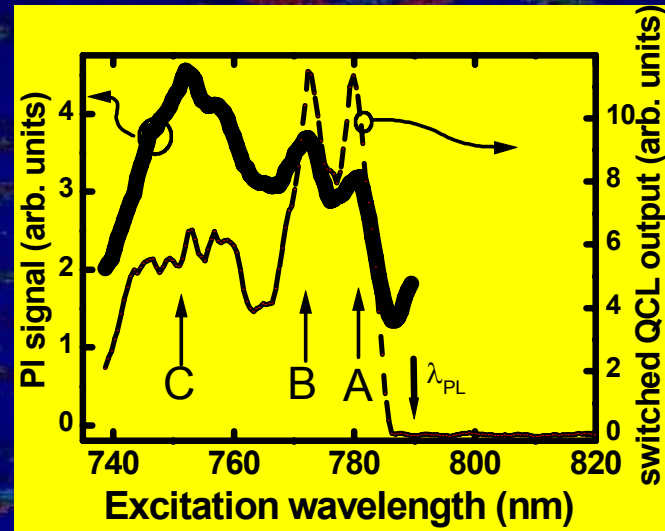


Spectral Dependence.

*Follows same spectral sensitivity as Active region PLE

*QCL J_{th} lowers when Bandgap radiation is applied.

*Implies switching effect originates with photoexcitation in AR.



Switching dynamics.

- *Even with PRF down to 200Hz, switching intensity is independent of pulse timings (!)
- * Applying 10 nsec / 120 mW asynchronous pulses, need 13 to switch device for PRF's 10Hz-> 10kHz (!)
- *Current pulse "resets" memory of NIR illumination.
- *Re-timing function for telecomms.



Switching Mechanism?

- *Switching fluence 6×10^{10} photons, i.e $\sim 2 \times$ electrons flowing in the 100 nsec J pulse.
- * Could be J enhancement, but how come the long memory?
- *Of 0, 10, 20, 25% Al clad devices , only 25% ones switched.
- *Everything was below $\sim 120\text{K}$ anyway

Two possibilities

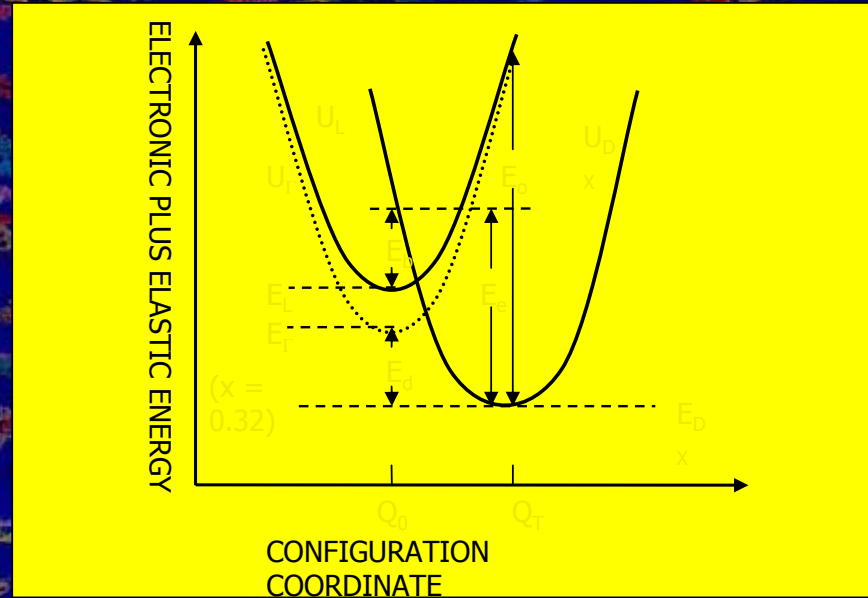
DX centres in AlGaAs

* $\sim 10^9$ donors under window

* Could hold $\sim 1/2\%$ of switching charge

* Would be field ionised by J pulse, with long recapture time?

* Known to appear only at low T and $x > 22\%$



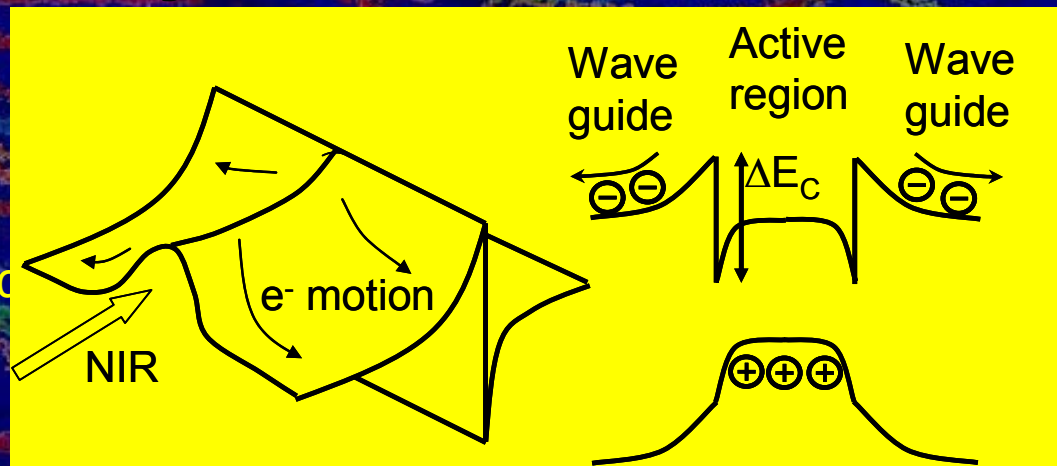
Charge separation at heterojunction

* Barrier only present for $X \sim 20\%$ in clad

* Needs "giant ambipolar" diffusion mechanism* to spread charge.

* Would work at high T and in InGaAs.

* Watch this space....



* See K H Gulden et al. PRL 66, 373 (1991).

Concluding remarks

- * NL frequency mixing demonstrated
- * Electronically modulatable two-terminal device for a variety of telecoms functions. (add-drop, packet switching, high bandwidth, data transparent conversion etc.)
- * Principles transferable to telecomms wavelengths.
- * That elusive “killer application” for QCL’s?