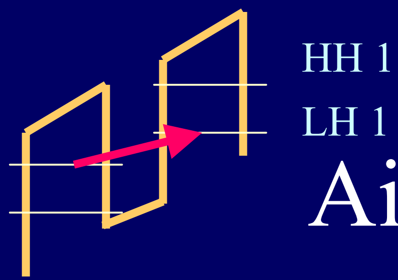
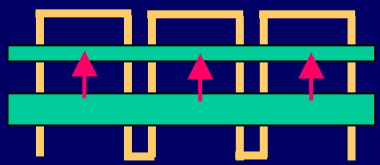
Terahertz Quantum-Staircase and Quantum-Parallel Laser Designs for GaAs/AlGaAs and SiGe/Si



Richard Soref

Air Force Research Laboratory



Quantum Staircase Laser

*Highly simplified cascade

*No injector sections

*Identical quantum wells

*Strain-balanced SiGe/Si

*PIP and NIN laser designs

Quantum Parallel Laser

*Simple flatband superlattice

*Low bias voltage

*"Super Superlattice" is the optimum design

*PIPIP and NININ designs

Report Documentation Page

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Principles and Limitations of Electrically-Injected Unipolar QSLs and QPLs

Quantum Staircase Injectorless Approaches:

1. Non-resonant-tunn. diagonal transition scheme: 1 QW
2. Phonon-depopulated resonant tunneling scheme: 3 QW per period, vertical transition
3. 1 QW per period resonant scheme: vertical transition

Limitations:

- At $\lambda < 20\ \mu m$, bias > 90 kV/cm
- 500 to 1000 periods are required.

Quantum Parallel Superlattice Approach:

- Inter-miniband lasing (4 levels in effect)
- Photon energy is less than LO phonon energy
- Appl bias bucks out built-in voltage from n/n^{+} contacts

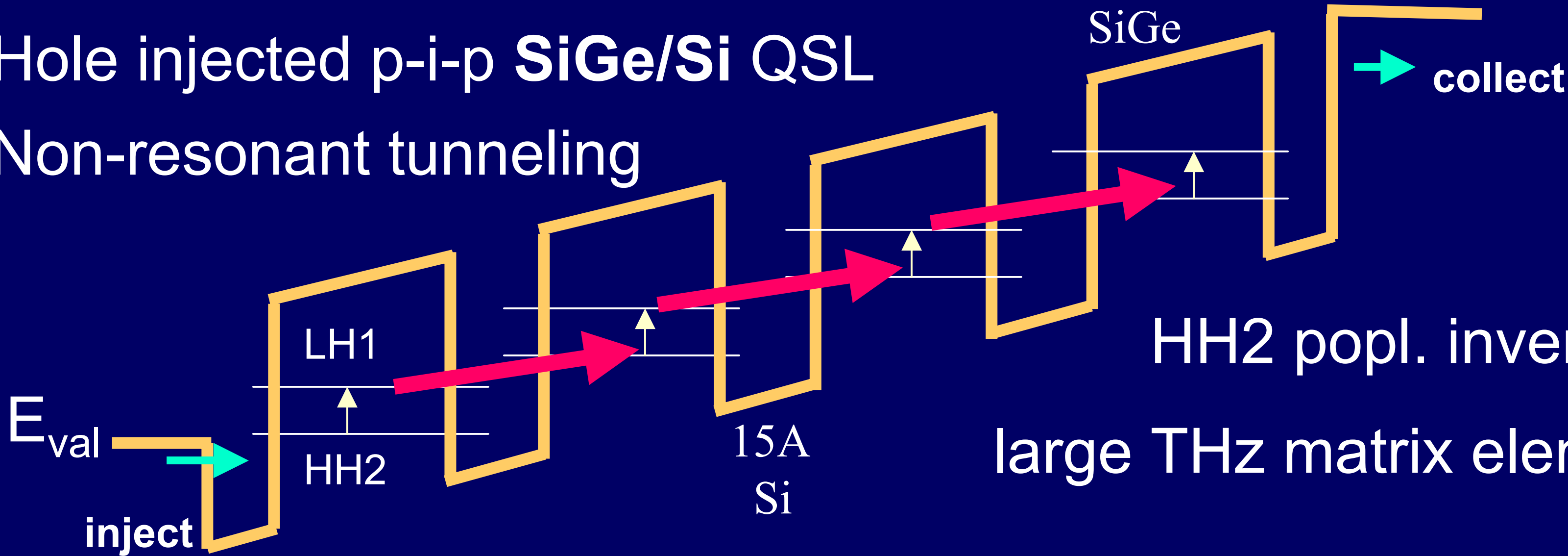
Limitations:

- Low gain at $\lambda < 12\ \mu m$, SiGe
- 500 to 1000 periods are required.
- Must use T < 25 K in GaAs

Hole Cascade via Inter-Well Diagonal Radiative Transition (designed in collaboration with University of Leeds team)

Hole injected p-i-p **SiGe/Si** QSL

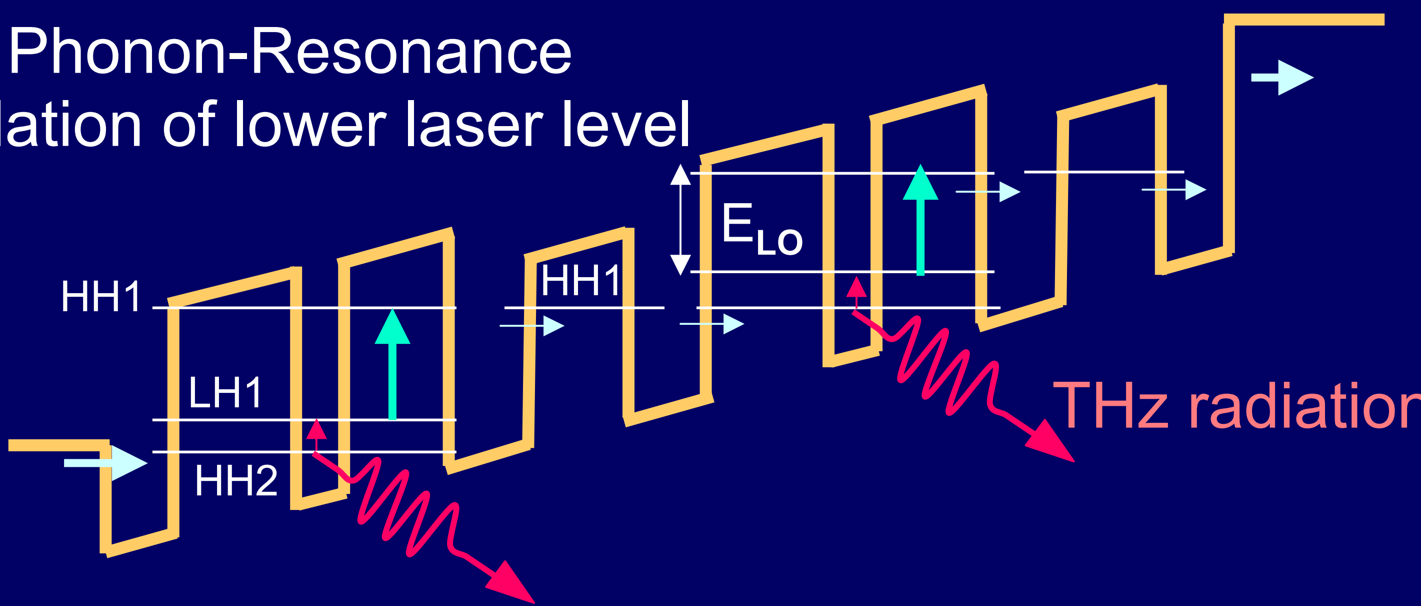
Non-resonant tunneling



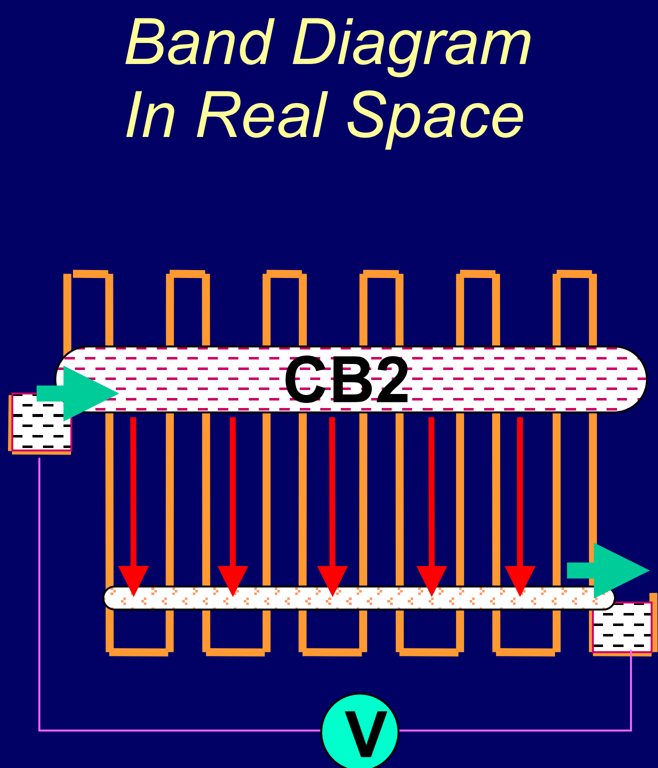
HH2 popl. inversion

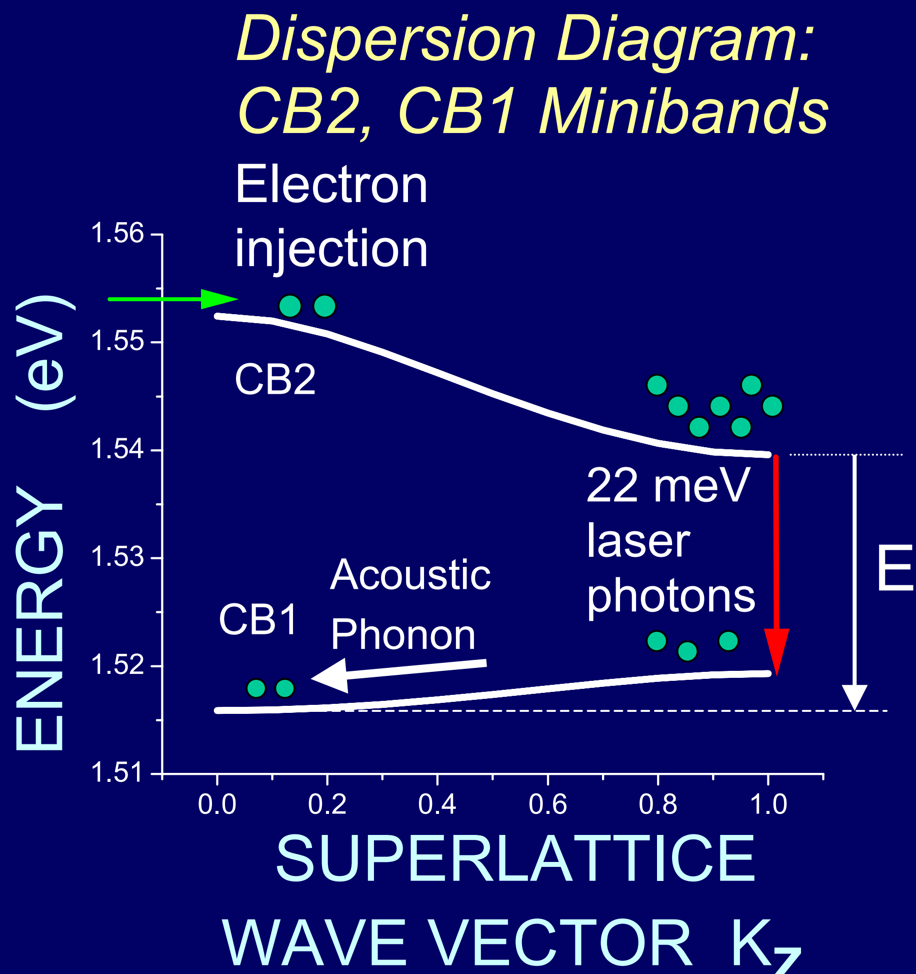
large THz matrix element

Phonon-Resonance depopulation of lower laser level



QPL: $GaAs/Al_{0.15}Ga_{0.85}As$ *200Å/24Å* Superlattice



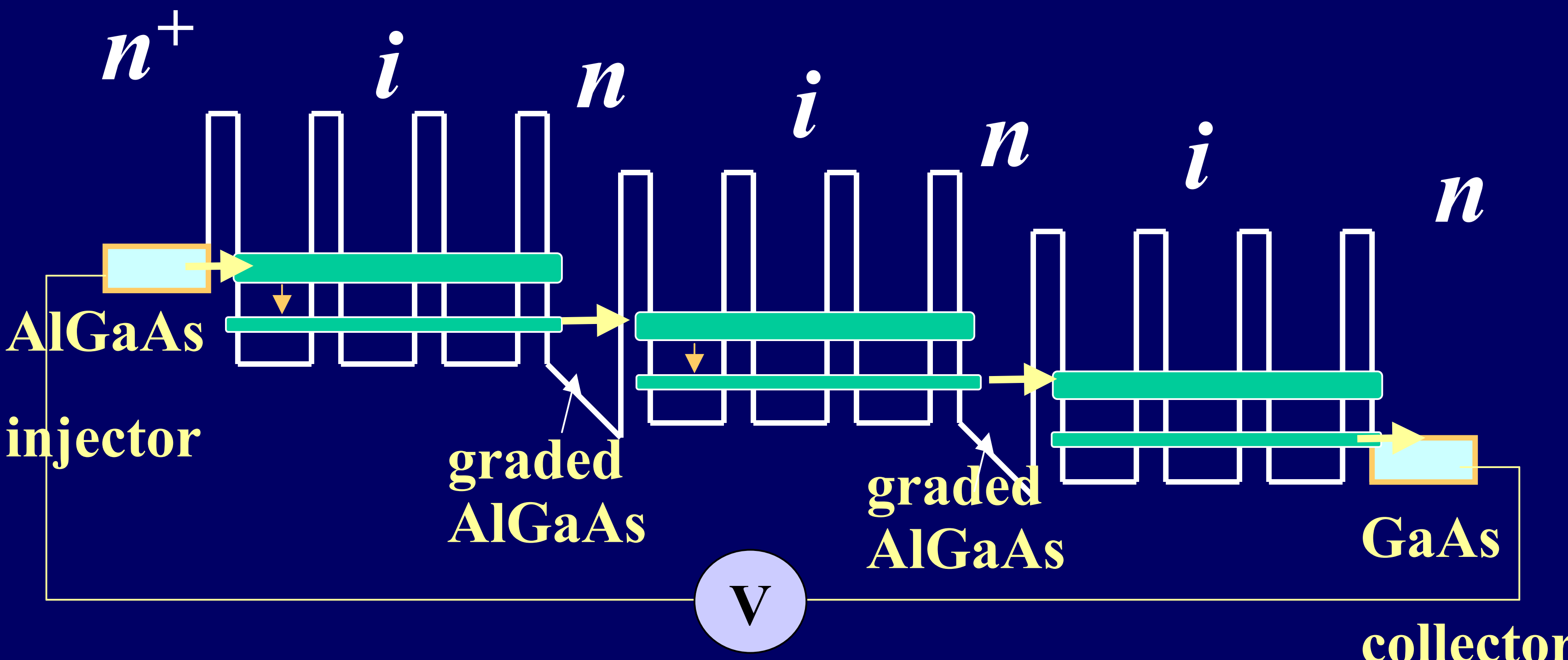


n-Ga(0.7)Al(0.3) elec. injector
n-GaAs collector
GaAs quantum wells
Ga(0.85)Al(0.15)As barriers

E < 36 meV, LO phonon emission is suppressed.

QPL constructed of “stiched” parallel regions; the “super super lattice”

Resonant tunneling of electrons between flatband SLs is obtained by the **composition-gradient** in the n-doped AlGaAs transfer barriers



Ballistic transport in each superlattice

Ways to Accelerate Future Developments– Possible Collaborations, Leverage, Improvement of Approach

- Try the new QPL in III-Vs and IV-IVs
- Try the phonon-depop QSL in SiGe (64 meV, 300K lasing?)
- Try the new GaN/AlGaN QSL (90 meV phonon-depop, CW at 300K?) G. Sun and R. Soref, APL manuscript

- New STTRs from AFOSR and ONR
- On-going STTRs
- European Union SiGe THz Project
- MURI from AFOSR and/or ONR
- Leeds EPSRC grant: n-type QCLs, and mid-IR QCLs

CONCLUSIONS…CHALLENGES…QUESTIONS

Conclusions:

* new SiGe and GaAs THz laser designs: simpler alternatives to the cascade, CVD

Challenges:

* several microns of epitaxy required
* non resonant staircase…as with Leeds
* tunneling via graded barriers in SSL

Questions:

* domain formation?   carrier cooling?
* good mode overlap in SSL?
* mode loss due to n-barriers in SSL?