Terahertz Quantum Cascade Lasers:
What is the Effect of Doping Locations on Lasing Frequency?

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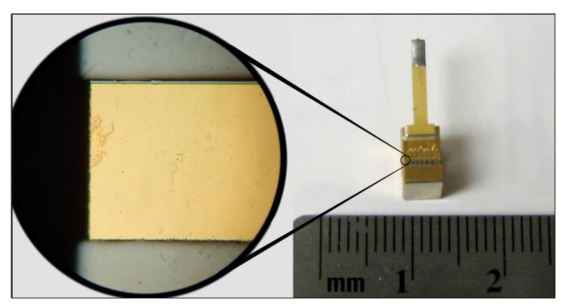
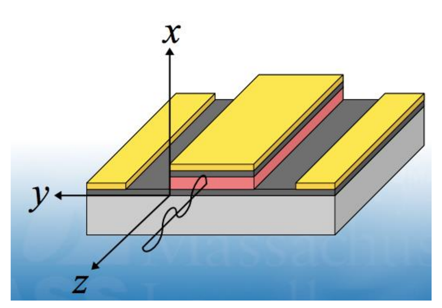
Texas Tech Undergraduate Research Conference 2020

What is a Quantum Cascade Laser (QCL)?





A QCL uses electron transitions between man-made quantum well levels, which are built by stacking up alternating layers of semiconducting material with thicknesses of only a few atoms.

Why Terahertz QCL's?

Terahertz QCL's are compact and produce coherent waves that can detect subsurface cracks in wind turbine blades, non-invasively detect cancer, detect concealed weapons and chemicals, etc.

(Redo-Sanchez, A. et al., Jour. of Infra., Mm, and THz Waves 34 (9), p. 500 (2013))

Method

A computational algorithm was built and validated that determines the electron wavefunctions and energy levels in a QCL when space charge effects are included. This algorithm was used to determine the lasing frequency *f* of the 2.9 THz Barbieri QCL structure for all possible doping locations; two adjacent quantum wells as well as two separated quantum wells.

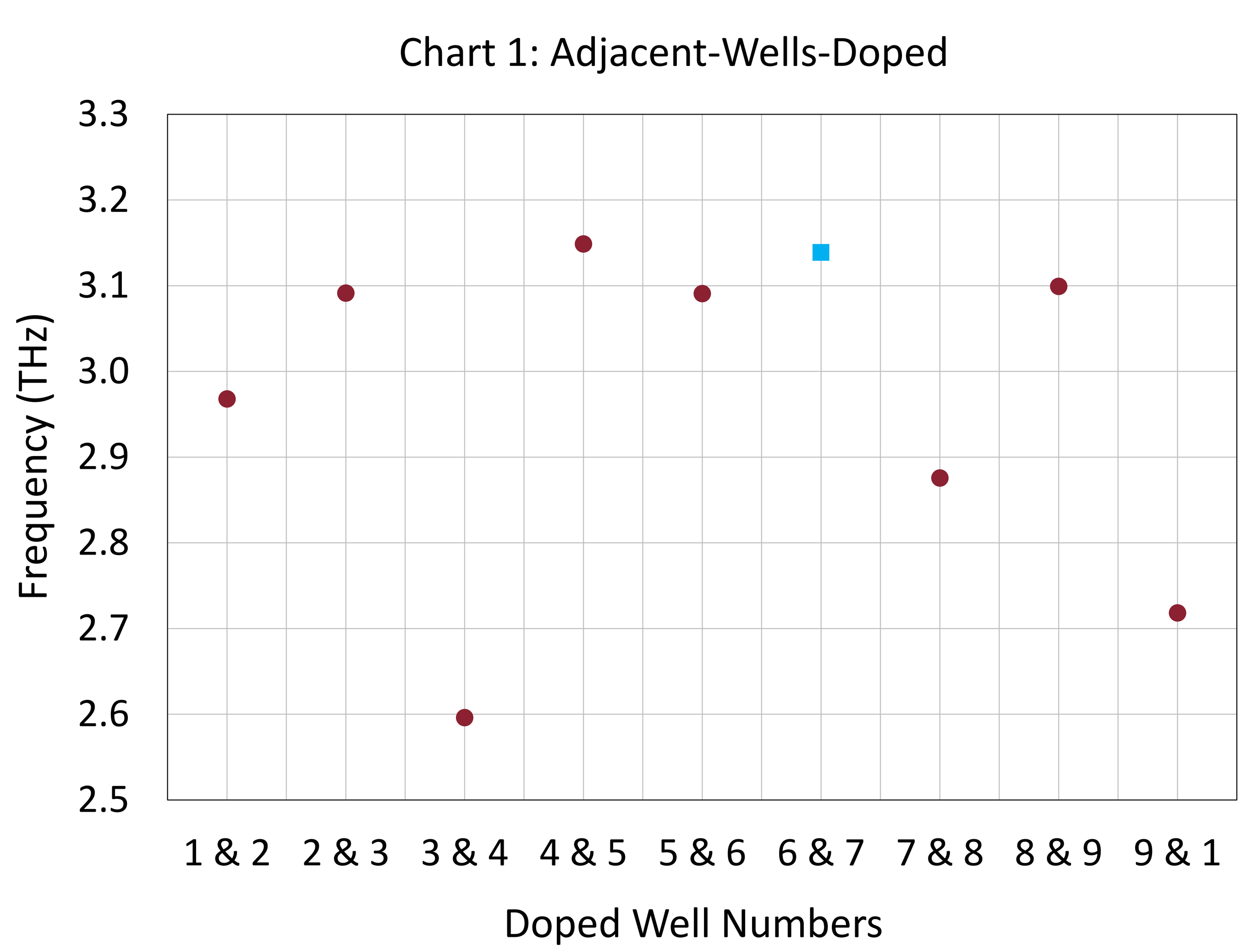
(Barbieri, S. et al., Appl. Phys. Lett., 85 (10) p. 1674 (2004))

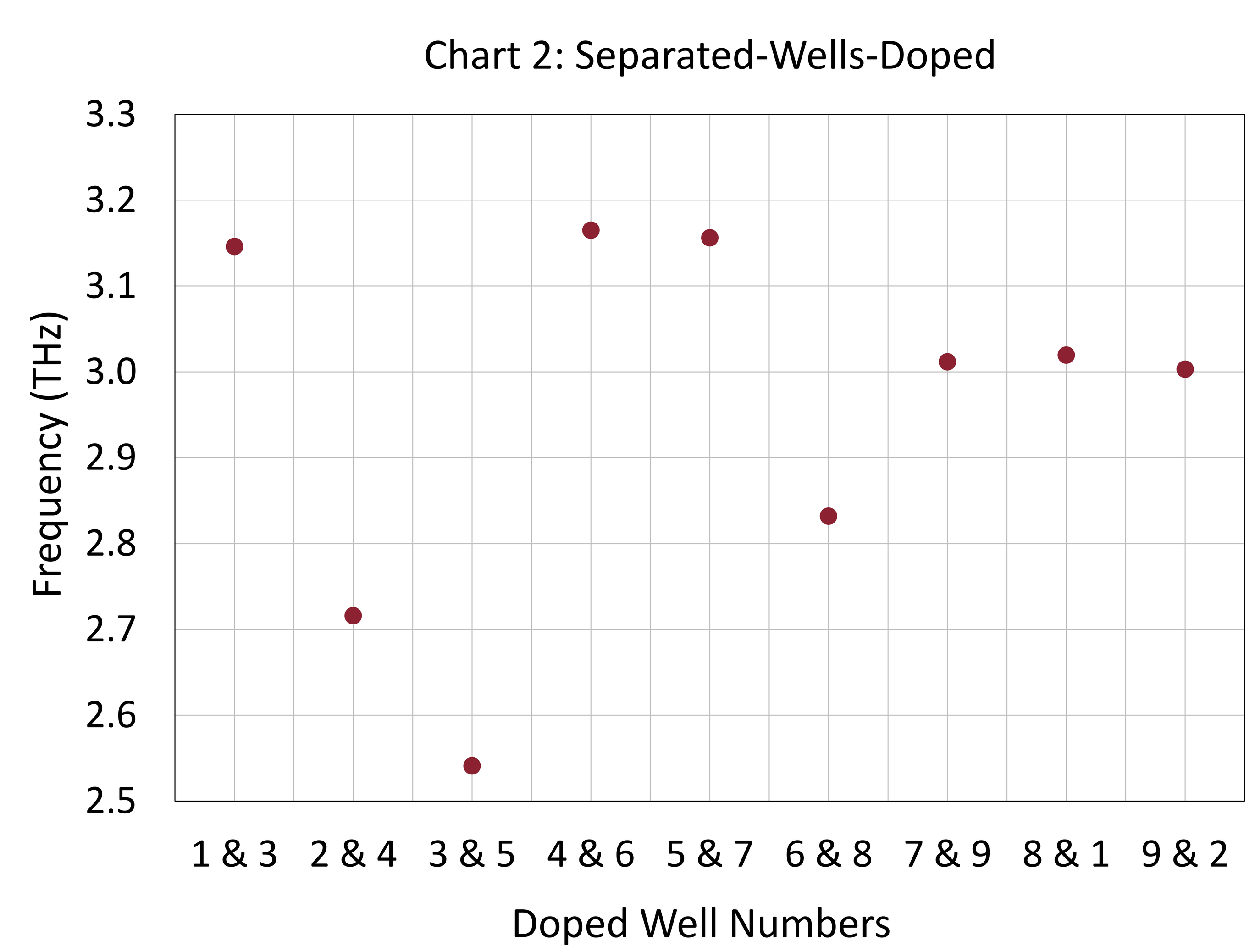
Abstract

A terahertz quantum cascade laser (QCL) uses electron transitions between man-made quantum well levels to emit terahertz electromagnetic waves that can detect manufacturing defects, cancerous tissue, etc. These wells are built by stacking up alternating layers of semiconducting material with thicknesses of only a few atoms. We built and validated numerical code that calculates the electron wavefunctions and energy levels when space change effects are included, by self-consistently solving the Schroedinger and Poisson equations. This code is able to accomplish this for any QCL structure. The structure used in this study, known as the 2.9 THz Barbieri structure, consists of a particular sequence of materials, thicknesses, and doping for each layer. The purpose of this study was to determine the lasing frequency in THz when altering which of two wells were doped. The resulting lasing frequencies ranged between 2.5 and 3.5 THz. Therefore, the frequency was found to be significantly affected by the choice of which quantum wells were doped.

Results

As can be seen in the lasing frequency plots below, the choice of doping location was found to significantly change the lasing frequency. Chart 1 shows the lasing frequency for all possible adjacent-wells-doped cases and Chart 2 shows the lasing frequency for all possible separated-wells-doped cases. As can be seen in the wavefunction images at the bottom, the choice of doping location was found to significantly change the wavefunctions. Figure A shows the original Barbieri structure. Figures B and C show each case that had *f* closest to that of the original structure; adjacent-wells-doped and separated-wells-doped, respectively. Figures D and E show each case that had *f* the most different from that of the original structure; adjacent-wells-doped and separated-wells-doped, respectively. The *f* of the original structure is shown as a blue square.





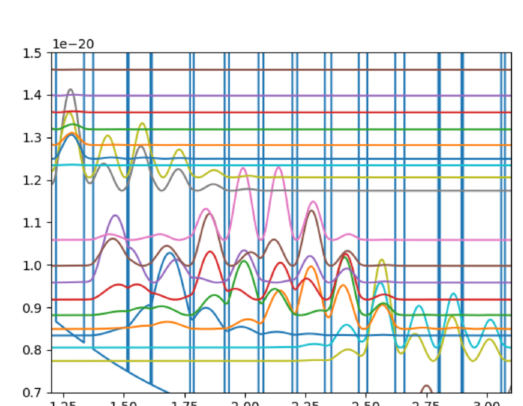


Figure A (original)

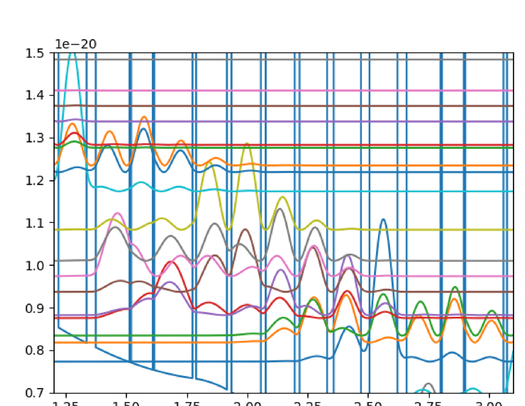


Figure B (wells 4 & 5)

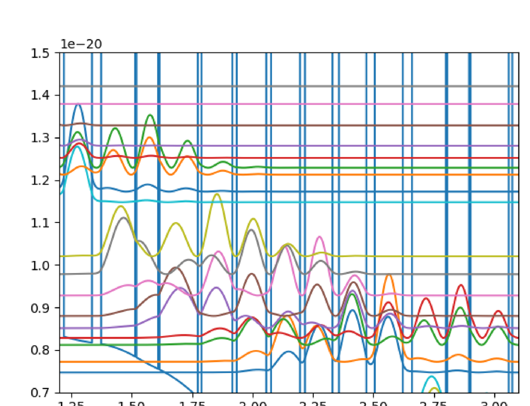


Figure C (wells 1 & 3)

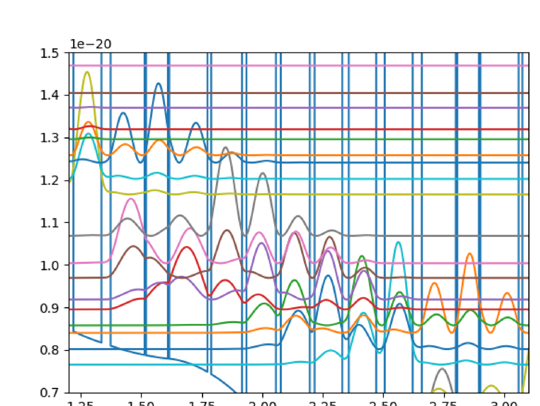


Figure D (wells 3 & 4)

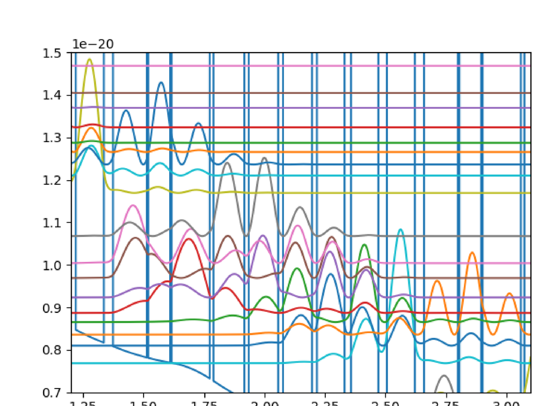
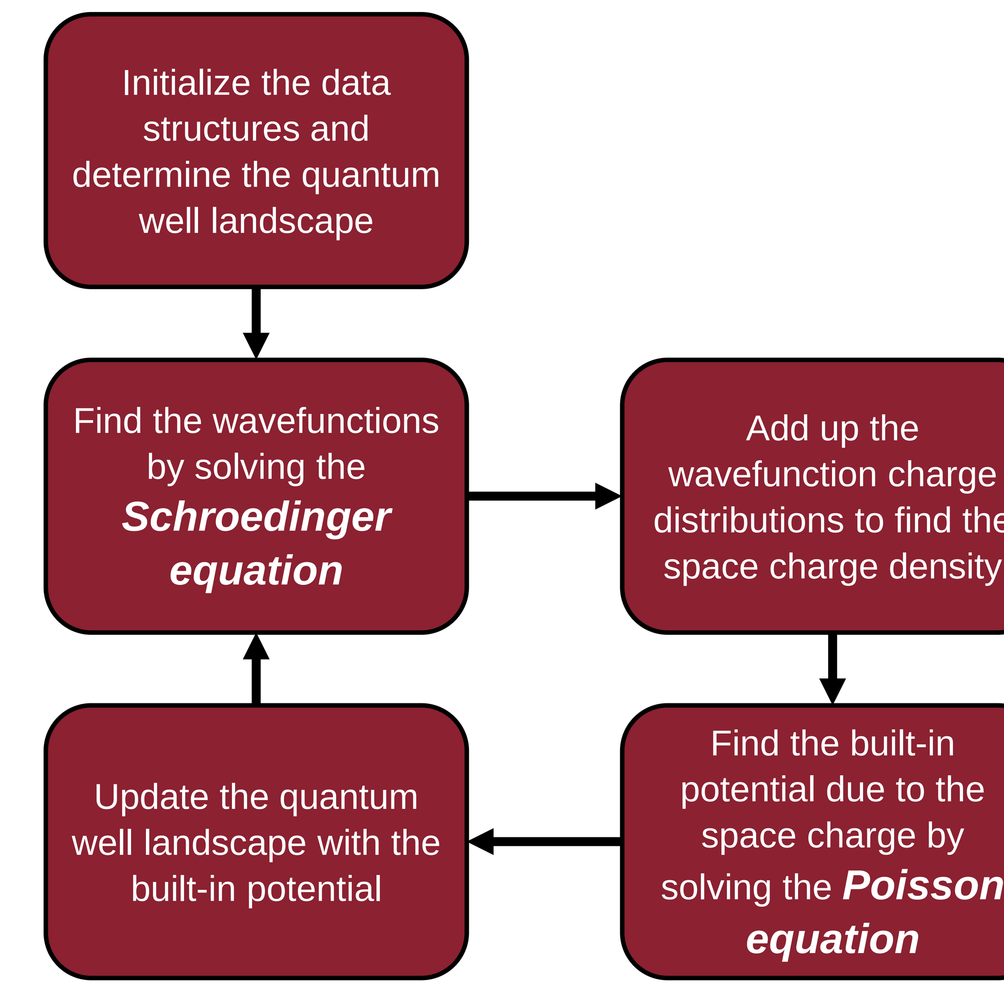


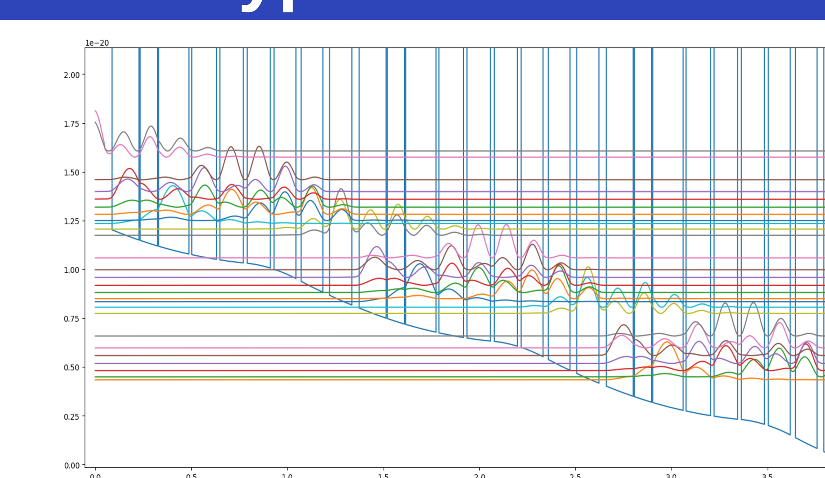
Figure E (wells 3 & 5)

How Does the Algorithm Work?



The algorithm self-consistently solves the Schrodinger and Poisson equations using an iterative approach. The iterations continue until the built-in potential has converged to a stable value.

Typical Results



This image shows the full results for the original 2.9 THz Barbieri structure. The algorithm carries out calculations over grid points spanning three periods of the core QCL structure.

Conclusion

The choice of doping location was found to significantly alter the wavefunctions and lasing frequency. For the 2.9 THz Barbieri structure, changing the doping location was found to change the lasing frequency within the range of 2.5 THz to 3.2 THz.