# Laser Spectroscopy and Potential Modeling

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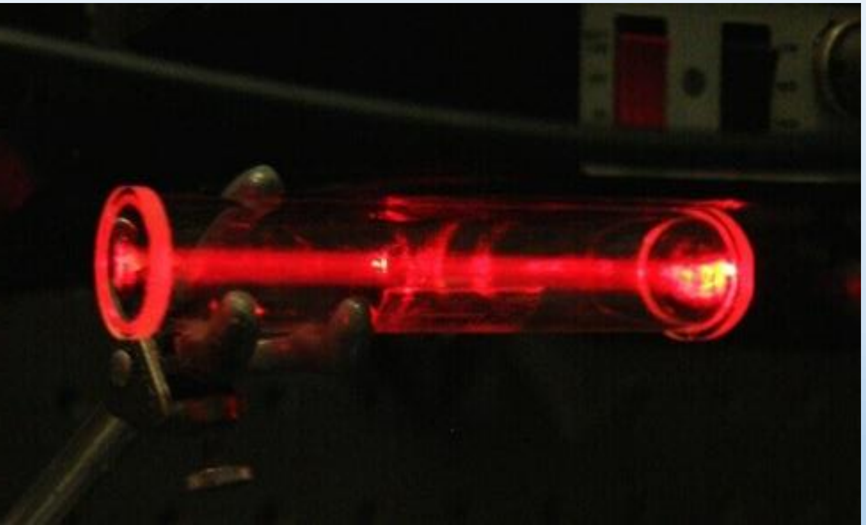
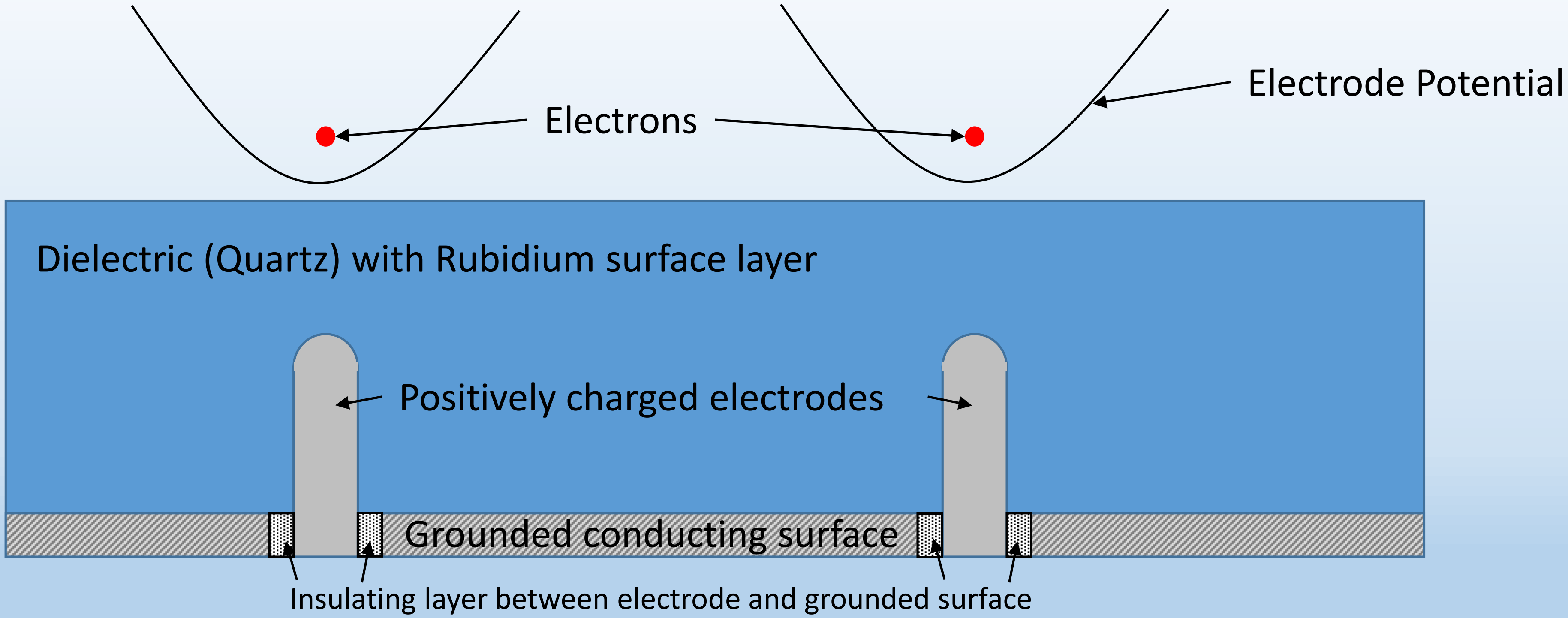


# Main Experiment

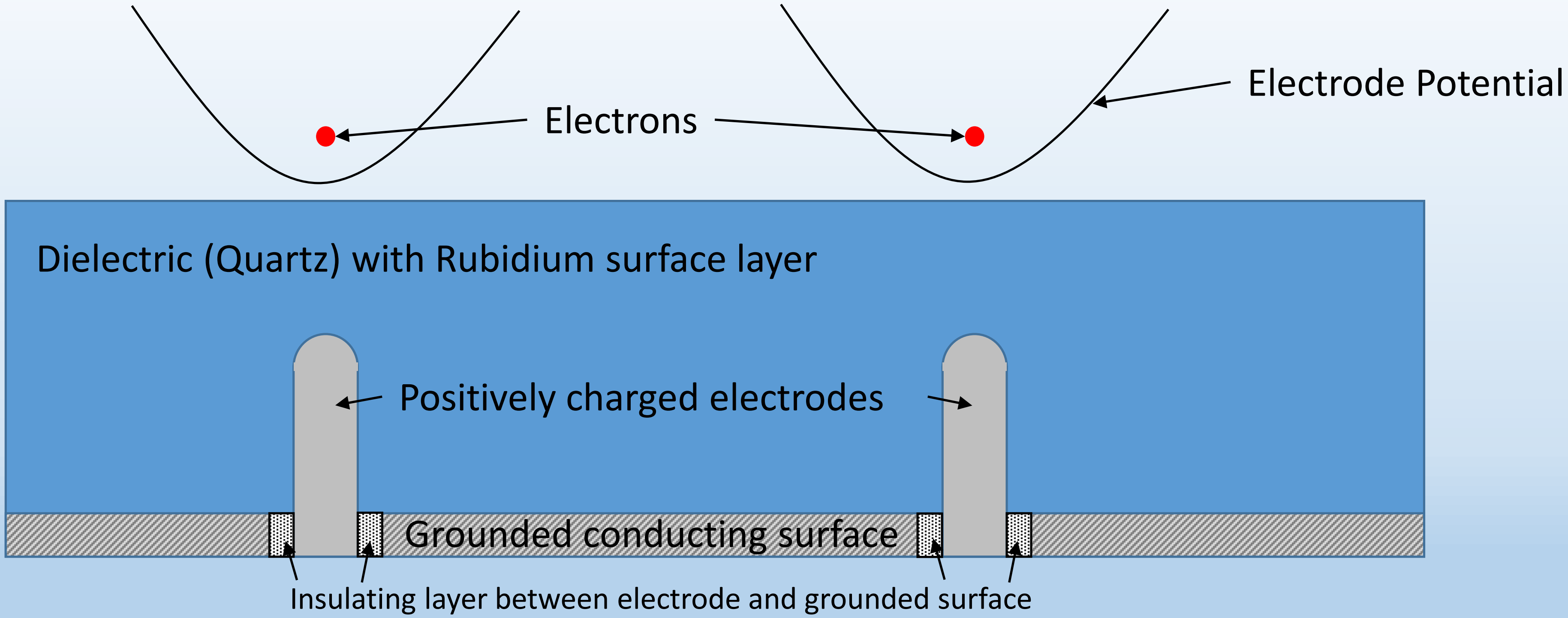
-Electrons held in free space above a dielectric surface
-Motion normal to surface quantized by Coulomb potential
-In-plane motion controlled by electrodes, quantized by harmonic oscillator potential
-Individual electrons can be excited using an infrared laser

-Goal: Create entangled states that can be used to store quantum information



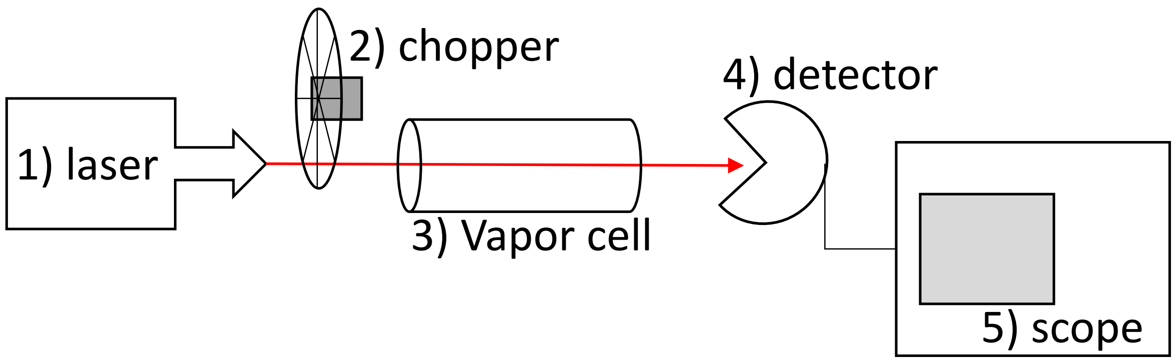
# My Projects

- Laser Spectroscopy
  - Tune the laser to excitation frequencies of electrons
  - Precise enough to excite energies normal to surface, avoid in-plane excitation
- Potential Modeling
  - Find parameters for electrodes that produce desired potential shape
    - Energy level spacing/Number of bound states
  - Check accuracy of harmonic oscillator approximation



# Spectroscopy Setup

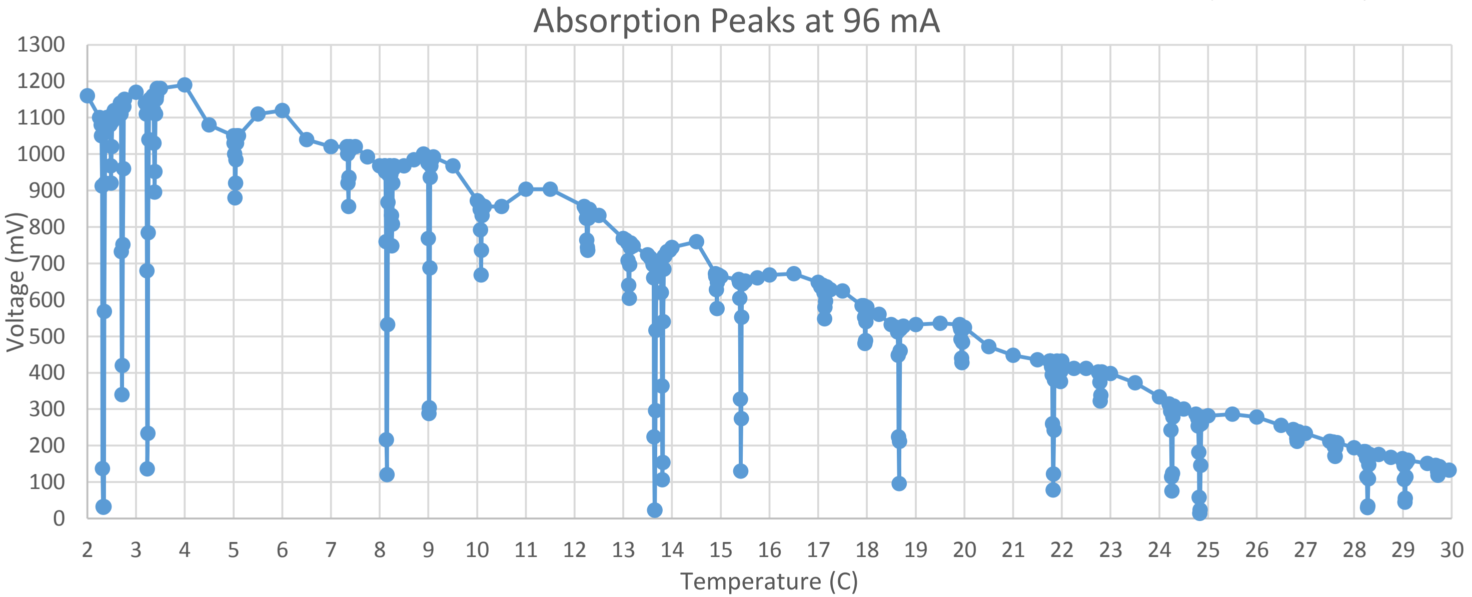
- Measure absorption frequencies of $CO_2$ using a tunable laser
- Hold current at 96mA, change temperature to adjust frequency
- Drops in output power indicate absorption by $CO_2$




Experimental Setup

1) Quantum Cascade Laser*, Wavelength 4300-4350 nm
2) Optical chopper- “chops” laser signal into pulses
3) $CO_2$ vapor cell
4) Photodetector- measures incoming laser power, outputs voltage
5) Oscilloscope- displays signal from photodetector

*Current and Temperature Adjustable

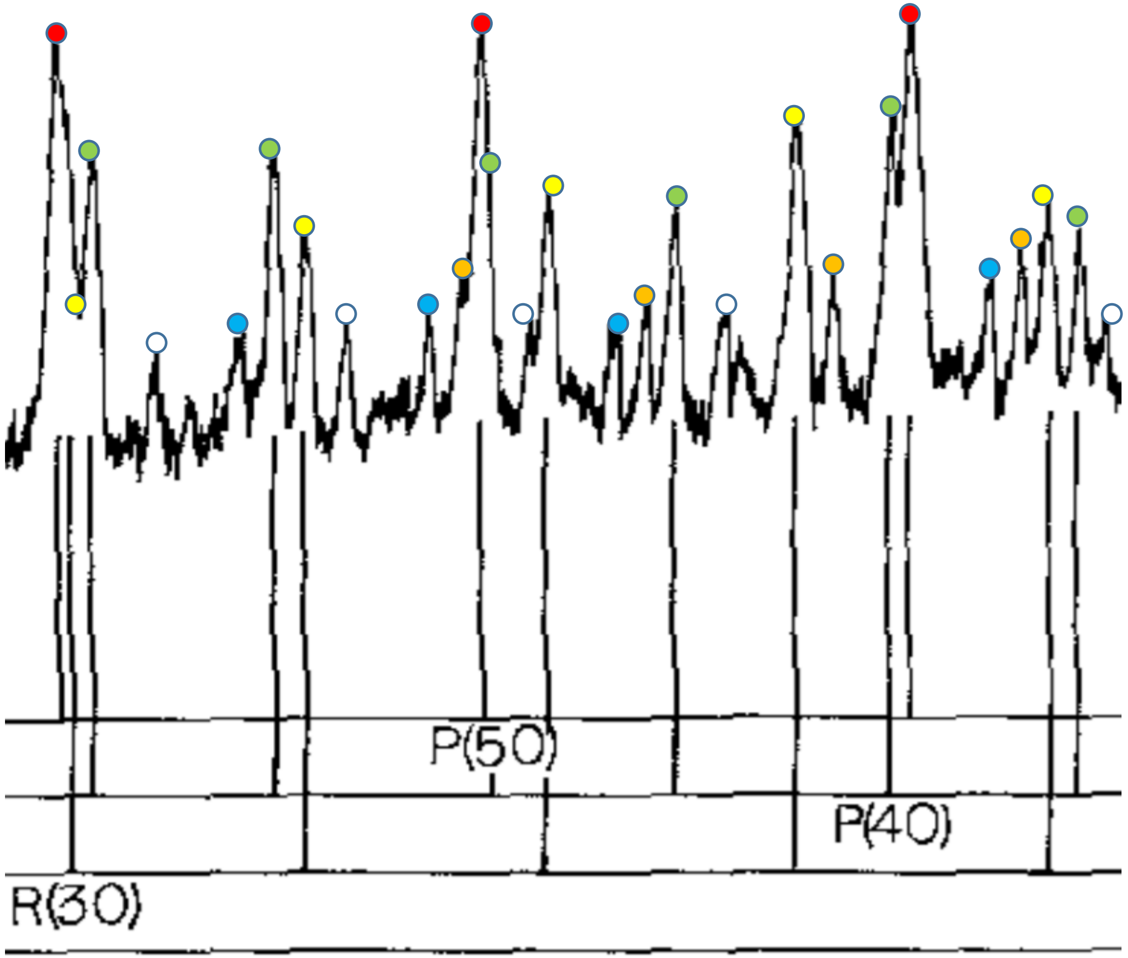


# Spectroscopy Objectives

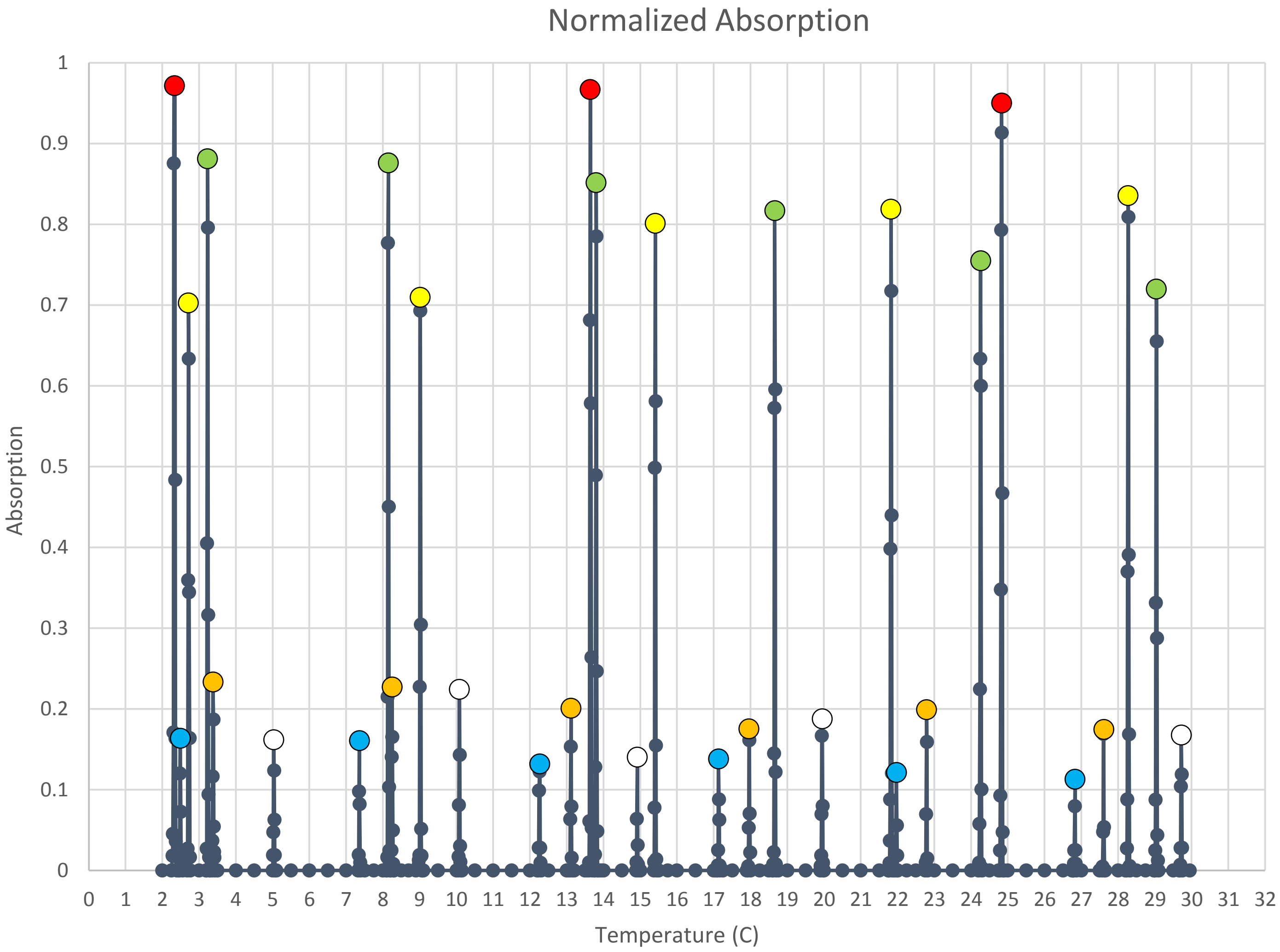
- Match observed absorption pattern to known spectrum of $CO_2$
  - Frequencies of absorption peaks are well known
- Observe linearity of laser response
  - Linear frequency response needed to match results
  - Linear power response less important, observe general behavior

# Results: Absorption Spectrum

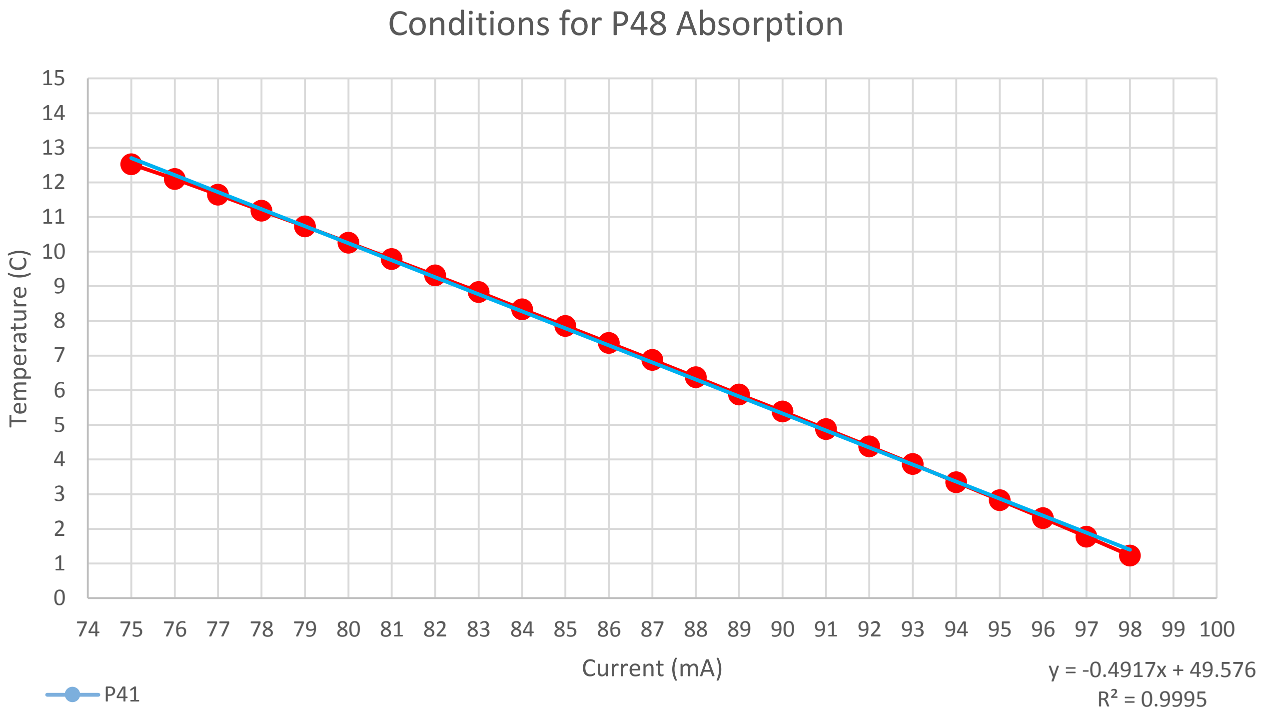
Comparison: 1968 Spectroscopy study using spectrographs

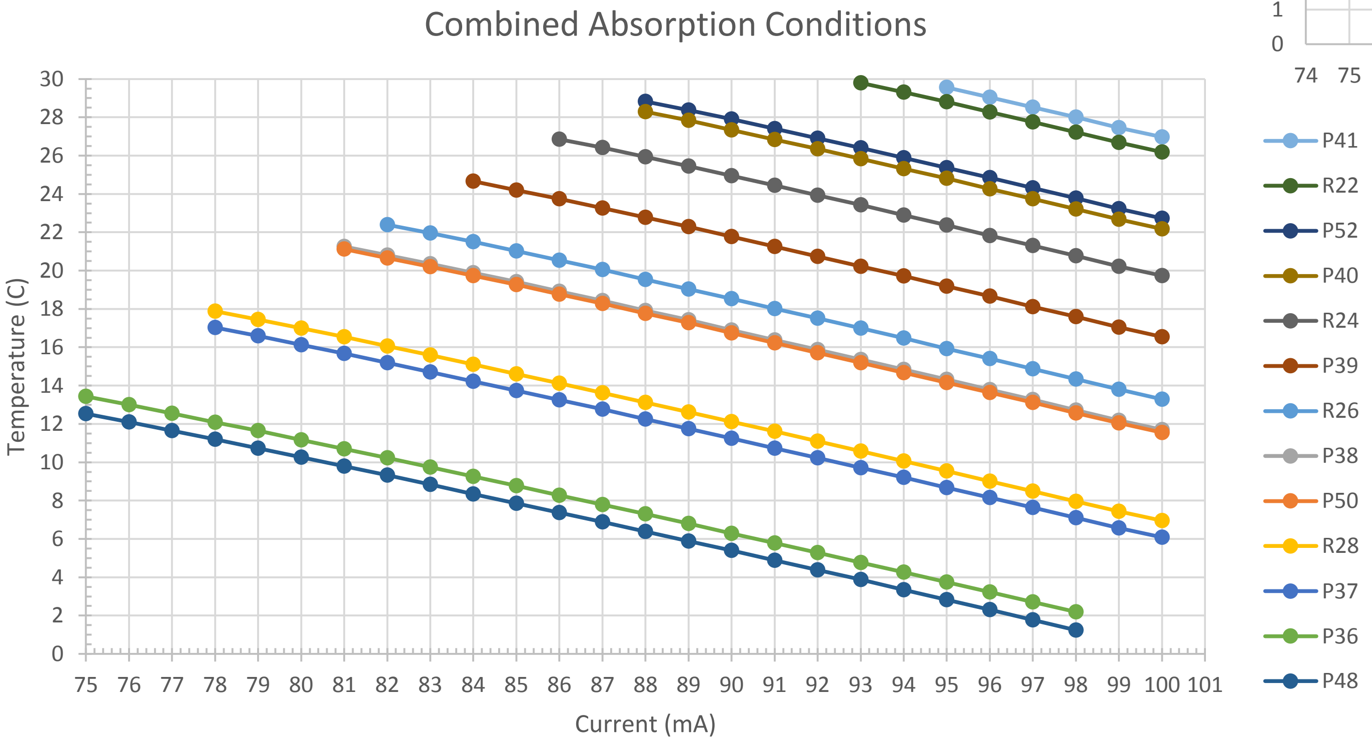


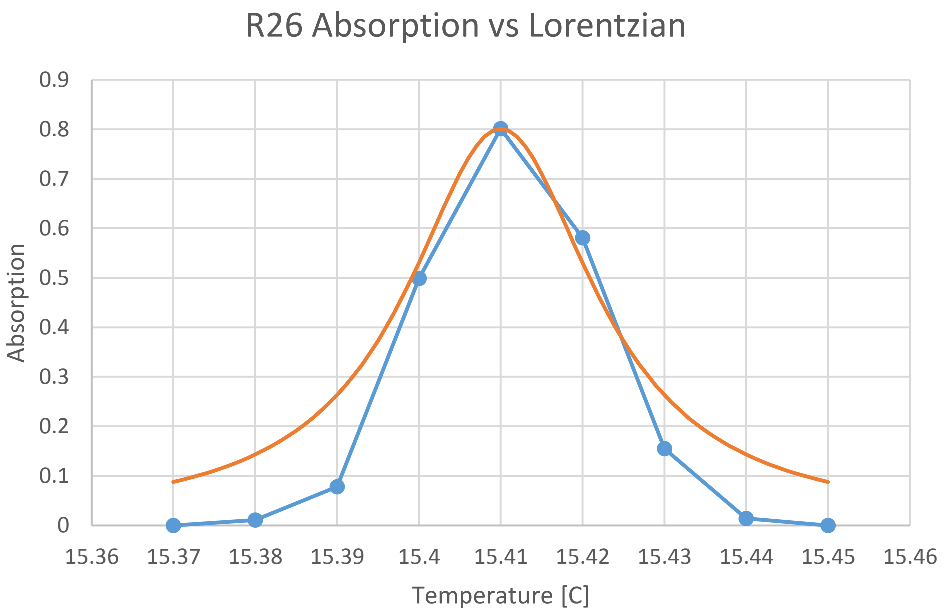

Results obtained through laser spectroscopy



# Results: Laser Behavior



# Conclusions: Laser Spectroscopy

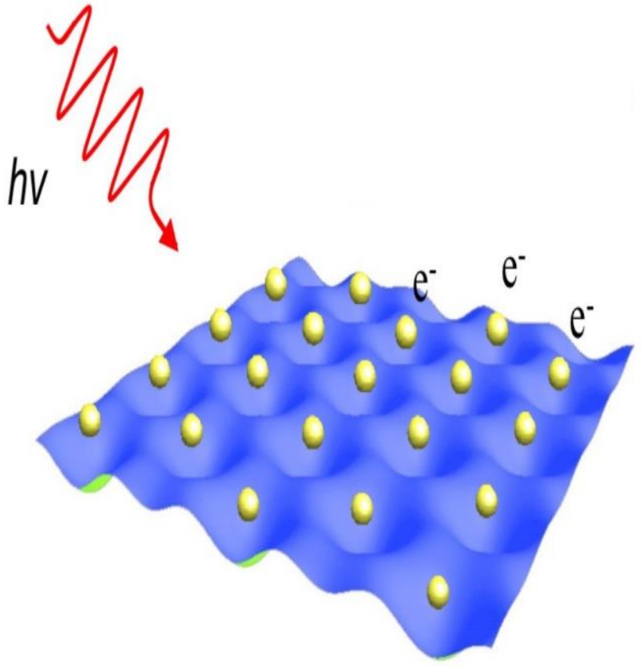
- Laser frequency varies linearly and can be accurately determined for given input conditions
- Laser power varies approximately linearly with some fluctuation
- Some broadening of absorption peaks is present, effects are minimal
  - Broadening independent of power
- Laser can be tuned precisely to excite normal-to-surface electron energies while avoiding excitation of in-plane energies

# Potential Modeling

Examine how in-plane motion of electrons is quantized

Find best parameter values for electrodes

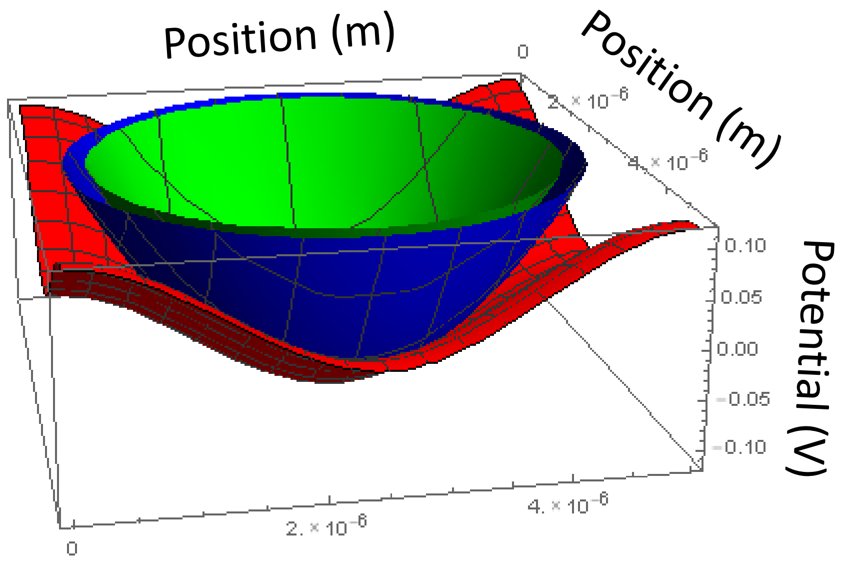
- Similar experiments use a liquid Helium surface to vertically confine electrons
  - Electron spacing ~0.5 µm, Laser wavelength ~1 cm
- Our experiment uses a dielectric surface
  - Electron spacing ~5 µm, Laser wavelength ~4.3 µm



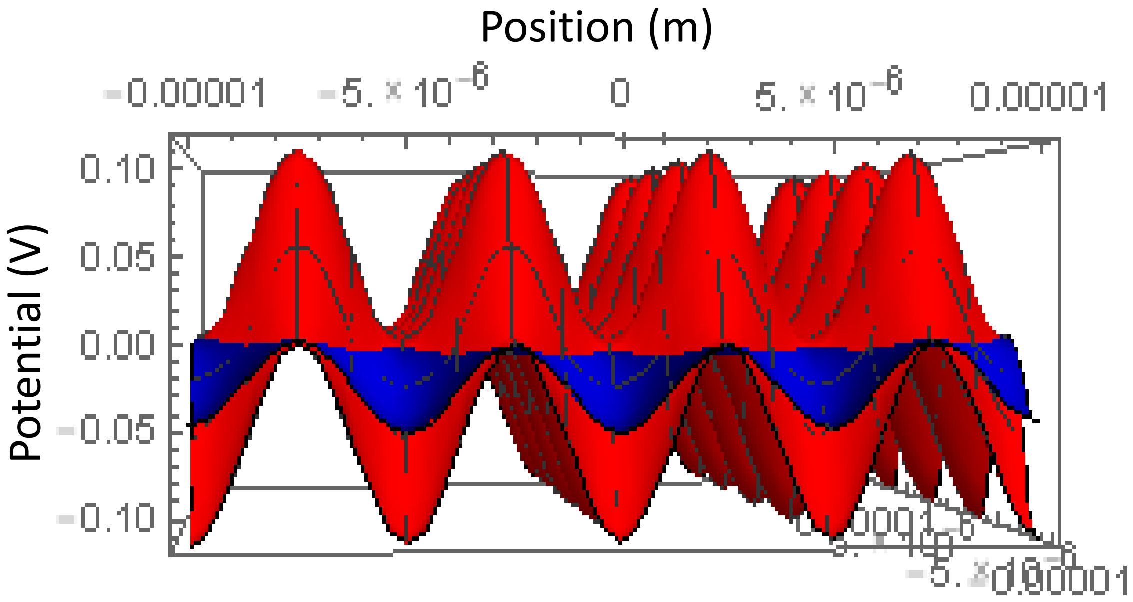

Can electrode geometries from liquid He experiments also be used in our experiment?

How can the electrode potential function be simplified by approximations?

# Results



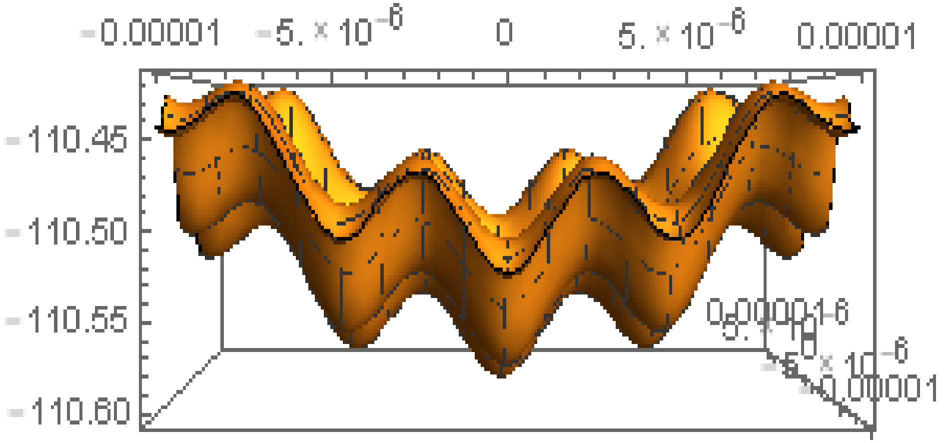

Green: Actual potential (single electrode)
Blue: Harmonic oscillator potential
Red: Sinusoidal multielectrode approximation



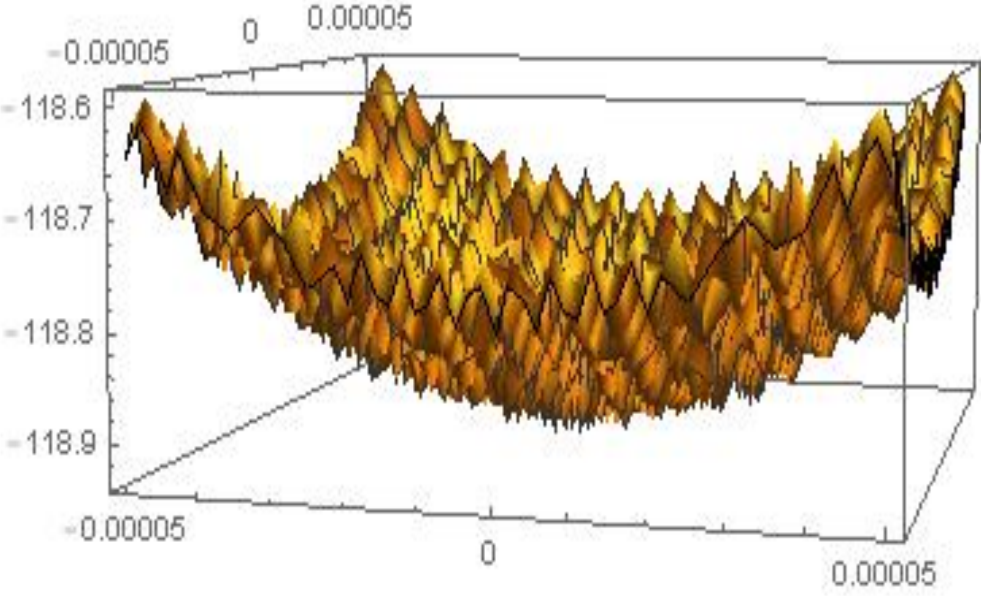

Red: Sinusoidal multielectrode approximation
Blue: Actual potential (1000 electrode array)

+Harmonic Oscillator approximation is valid
+Electrons can be localized by electrode potentials with many (100+) bound states
+Bound states are spaced by 20 GHz
+Sinusoidal approximation* holds when multiplied by a constant
*comes from a different electrode geometry

# Limitations




Potential of a 40x40 array of electrodes. Curvature effects are sharper, well depth is unchanged.




Zoomed-out view of the actual electrode potential for a 100x100 array. Note that wells have constant depth despite overall curvature.

-Sinusoidal approximation not valid over large arrays

+actual potential can be flattened out

-Large arrays are needed to see agreement between sinusoidal model and actual potential

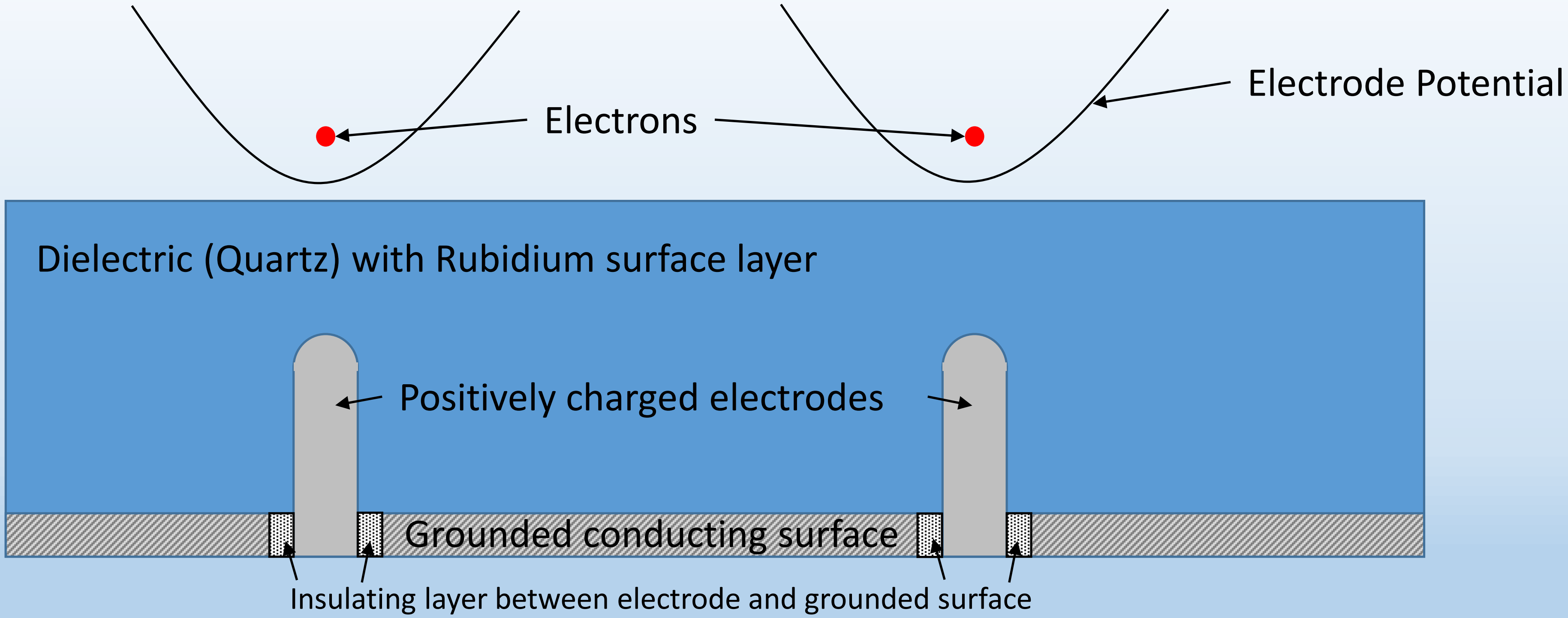
-Adjusting parameters has a limited effect on improving fit

# Conclusions: Potential Modeling

- In-plane position of electrons can be localized using electrodes
- Electrode potential can be approximated by a harmonic oscillator potential
  - Energy gap between in-plane excited states is ~20 GHz as desired
- Large electrode arrays are needed to reduce curvature effects
- Altering electrode dimensions has a limited effect on the shape of the resulting potential

# Summary

- Laser is capable of precisely exciting individual electrons
- Electrons can be confined by an electrode array with reasonable dimensions
- Energy gap between in-plane excited states is large enough to avoid unwanted excitations by the laser
- System could potentially be used for quantum information and quantum computing!



# Acknowledgements

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