Characterization of Quantum Cascade Laser Wafers

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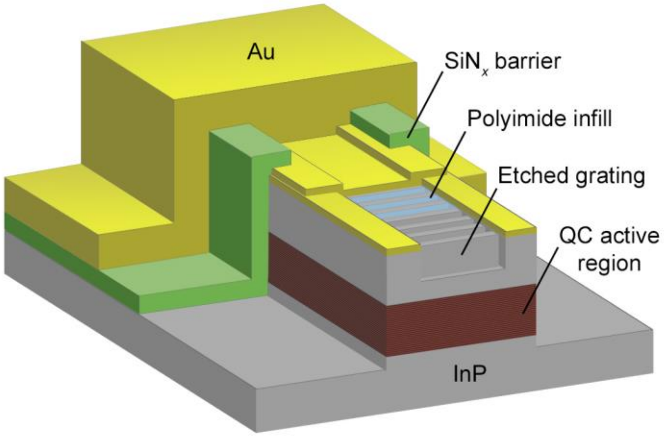
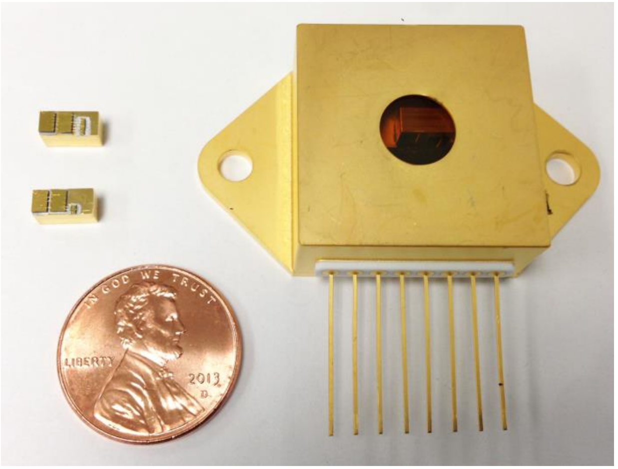


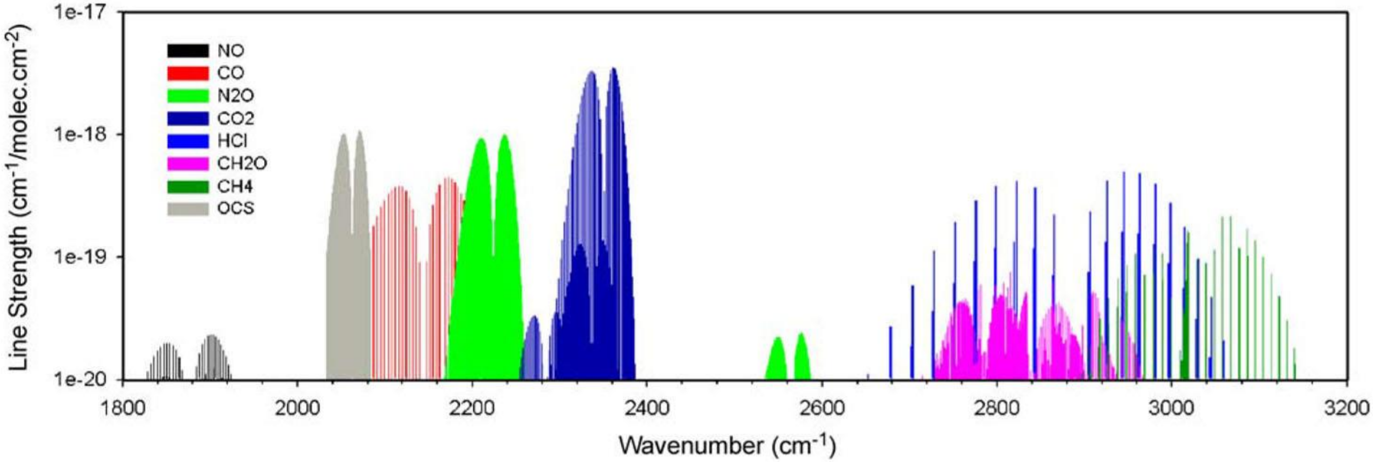


Jet Propulsion Laboratory

California Institute of Technology

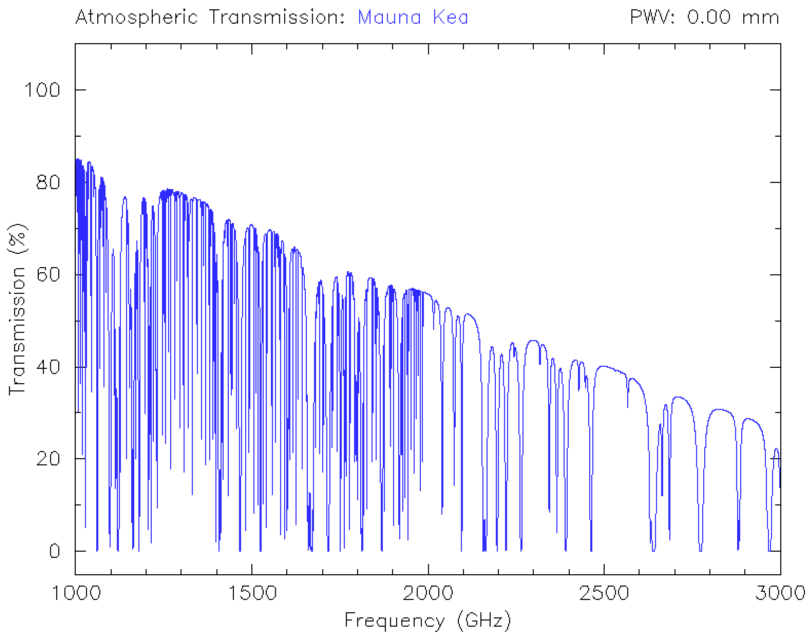
Absorption Spectroscopy

- Measure absorption as a function of frequency
- Atoms and Molecules absorb specific frequencies
  - Strength of absorption corresponds to concentration
- Many molecules have strong absorption in the IR



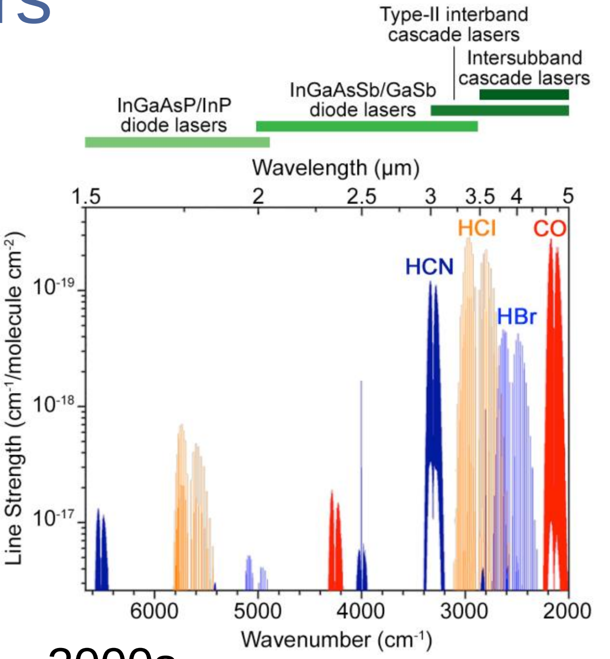
Why Lasers for Absorption Spectroscopy

- Broadband incoherent source can identify absorption to infer concentration but is limited in resolution
- Lasers can be tuned to emit at a specific frequency
    - High spectral brightness
    - Controllable tunability
    - Resolving absorption frequency with increased resolution using the source and not the apparatus



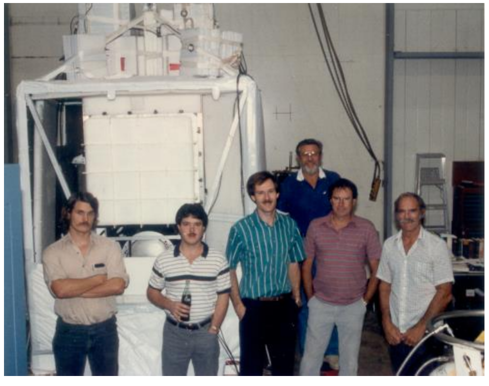
Consumer Applications of Lasers

- Lasers have many consumer applications
- Optical lasers used for laser pointers, disc drives, etc.
- Near IR lasers for telecommunications
- No consumer applications of IR lasers



1980s

Liquid helium-cooled lasers

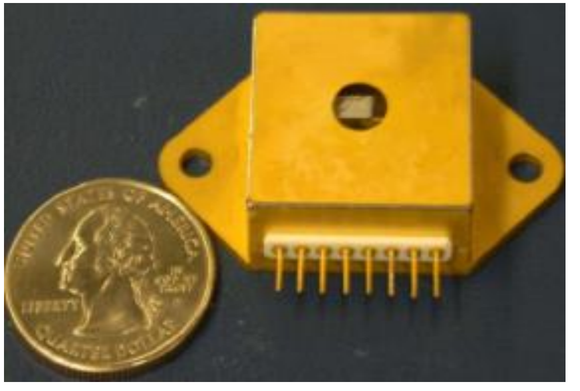


1990s

Liquid nitrogen-cooled lasers

2000s

Thermoelectrically cooled lasers



Gas monitoring for manned spacecraft safety and fire detection

- CO is a particularly useful early warning indicator of common combustion hazards
- NASA requires improved accuracy, response time, and maintainability compared with existing electrochemical sensors

International Space Station, March 2011

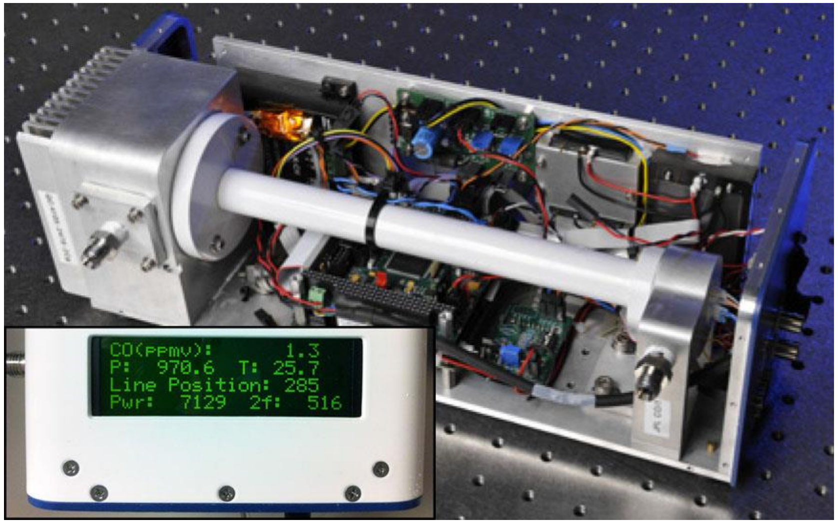
Low-gravity combustion tests of common spacecraft plastics

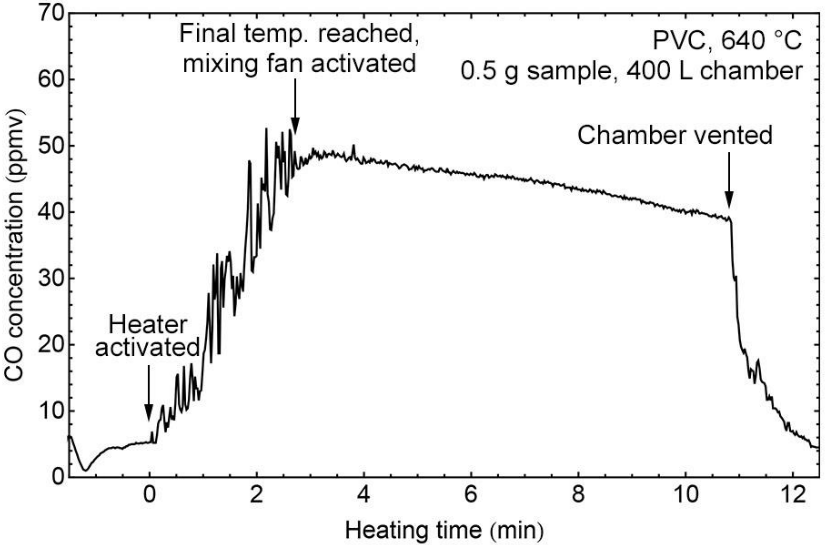
Mylar | Ultem 1000 | Nomex

Credit: NASA Glenn Research Center

JPL prototype CO monitoring instrument

- Robust 25 cm single-pass absorption cell
- QC laser module with integrated TE cooler and room-temperature HgCdTe detector
- Tune laser wavelength across a single absorption line



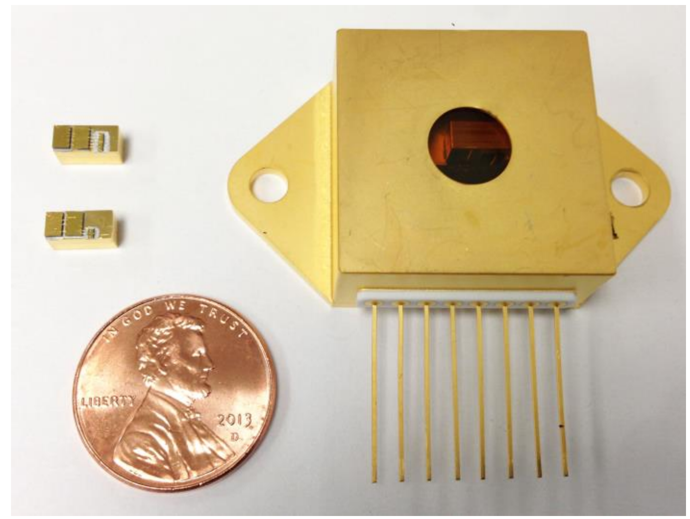


Comparison with commercial QC laser source

Hamamatsu commercial QC laser source

- CW operation: >0.8 A, 10-12 V
- Emission wavelength: 4.57 µm
- TEC power: 40 W typical
- Module power: 50 W typical

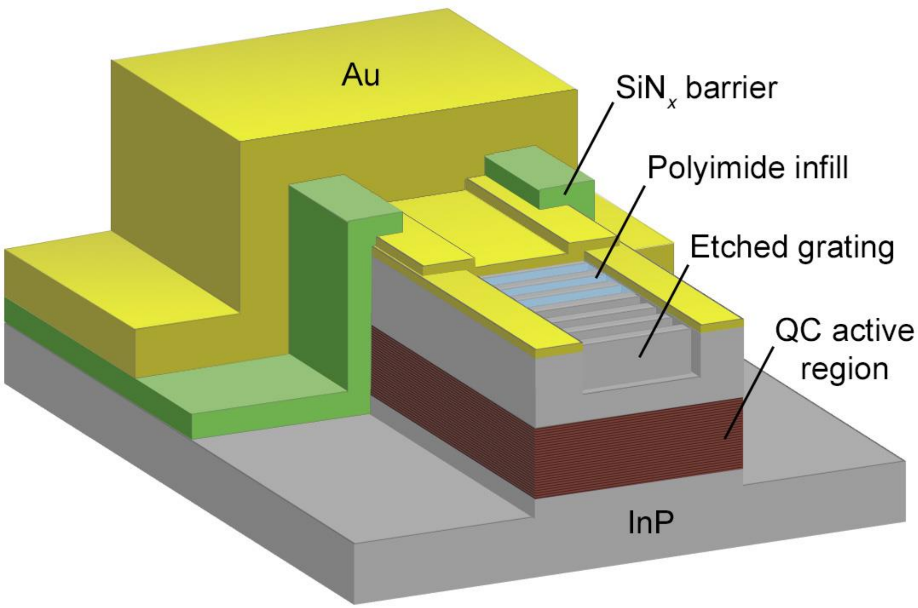
Fully packaged JPL QC laser, shown with 1- and 2-mm lasers on submounts

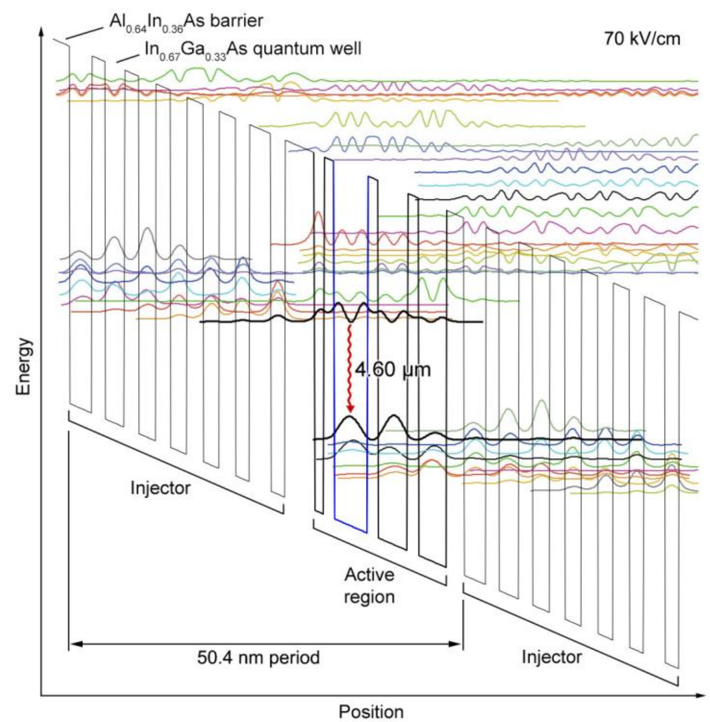


- CW operation: <0.25 A, 10-12 V
- Emission wavelength: 4.75 µm
- TEC power: up to 4 W
- Module power: <7W

Index-coupled DFB QC lasers fabricated without regrowth

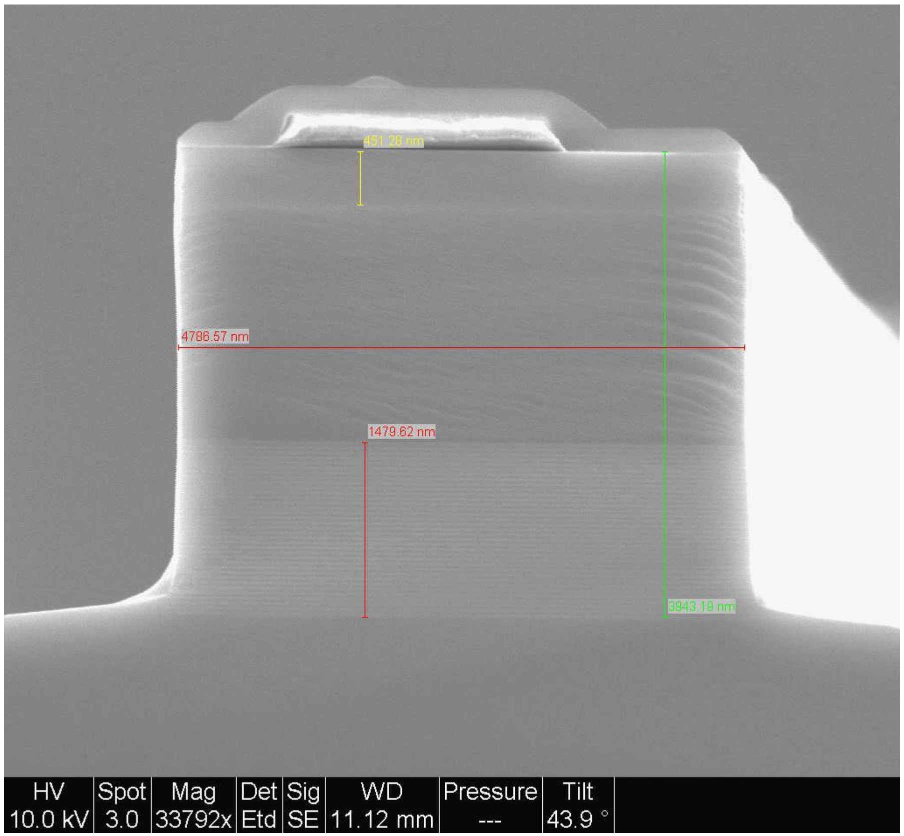
- Alternating layers of two different semiconductors create discrete electron energy levels within conduction band
  - Control energy of radiative transitions
- Top-side heat extraction facilitated by thin (~500 nm) SiN_x barrier and thick electroplated Au



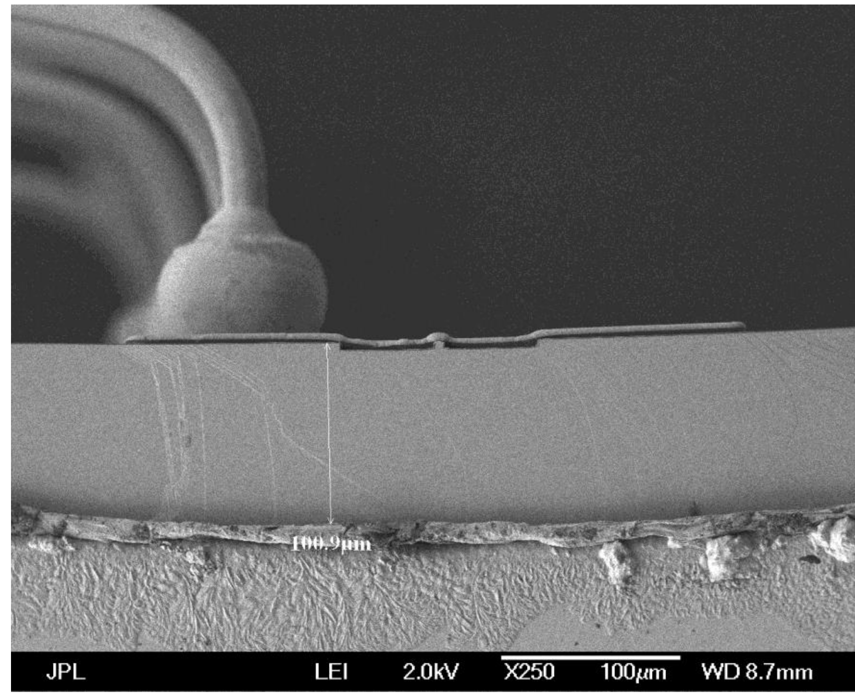


Laser fabrication

Etched laser ridge



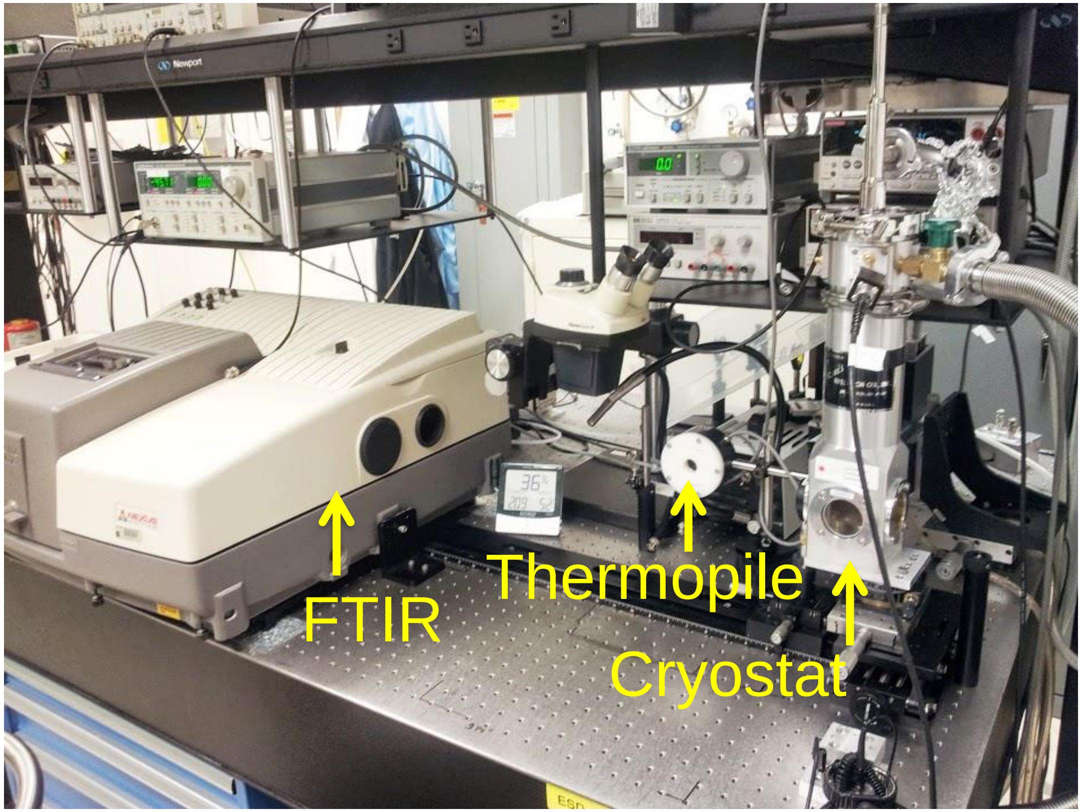
Mounted laser chip

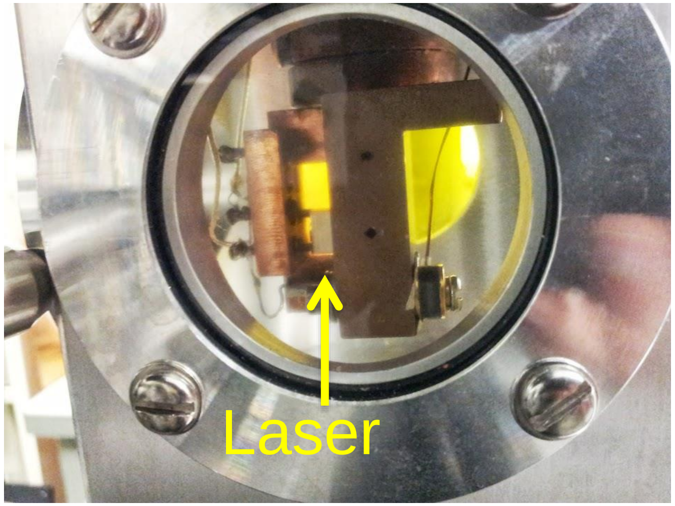


Why Cryostat Measurements

- Some of the lasers we fabricate do not lase at room temp.
- Losses
  - Facet Loss
  - Free Carrier Absorption
  - Resonant Intersubband Transitions
  - Waveguide Loss
    - Metal Contact Absorption
    - Surface Scattering
- The Gain of the laser increases with decreasing temperature
  - The presence of phonons creates additional energy pathways for electrons that do not result in photon emission

Setup

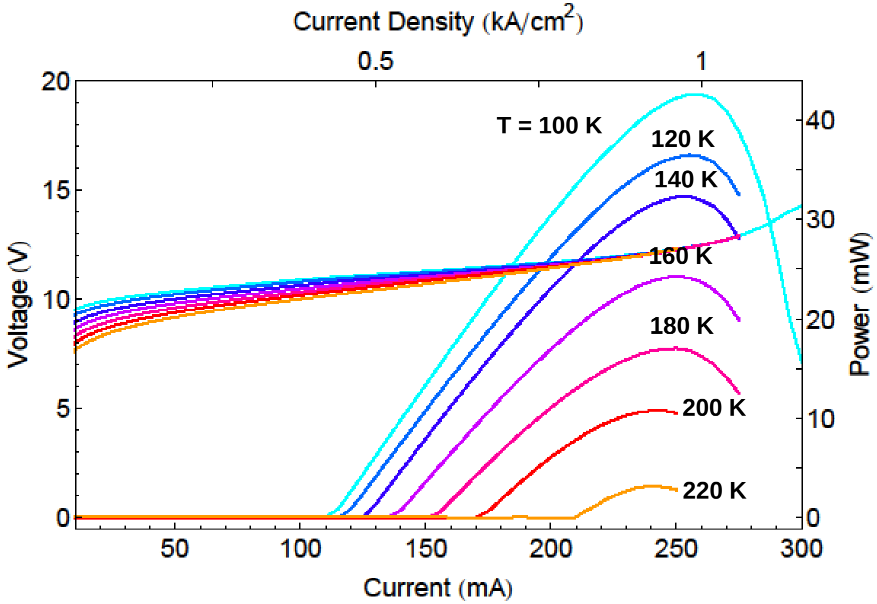




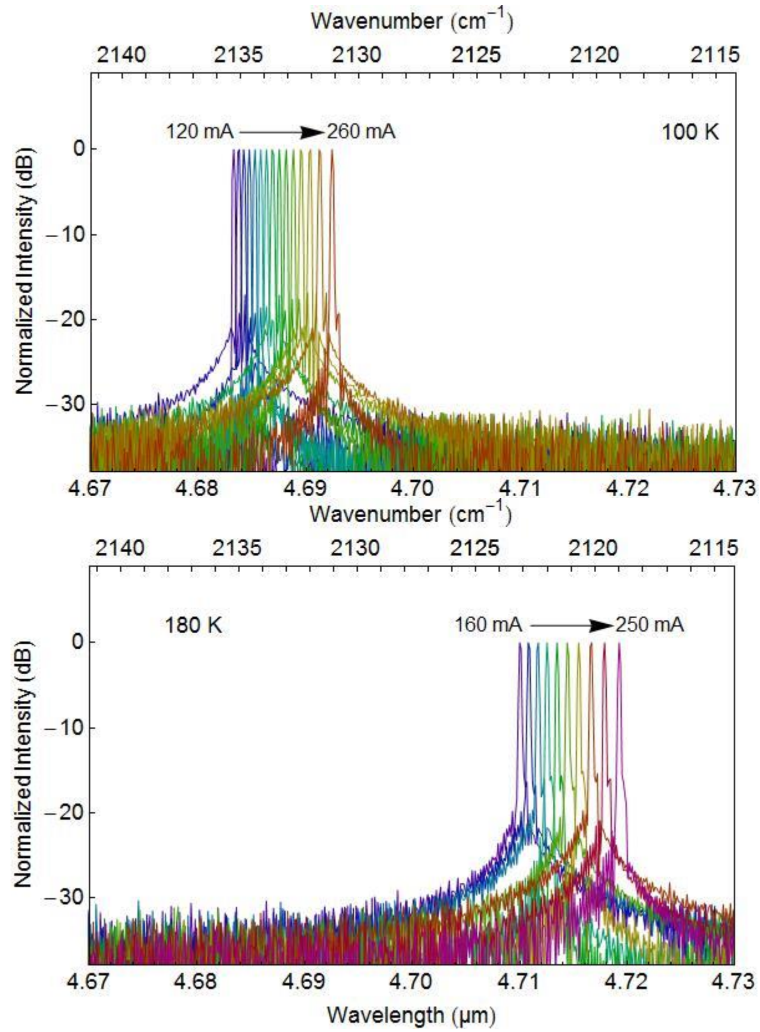
DFB QC laser performance: 5 µm ridge, 1-mm cavity length

- Uncoated facets; electroplated Au top contact
- Mounted on Cu submounts epitaxy side up with AuSn eutectic solder
- Emission at 4.75 µm with grating pitch of 760 nm

CW light-current-voltage performance



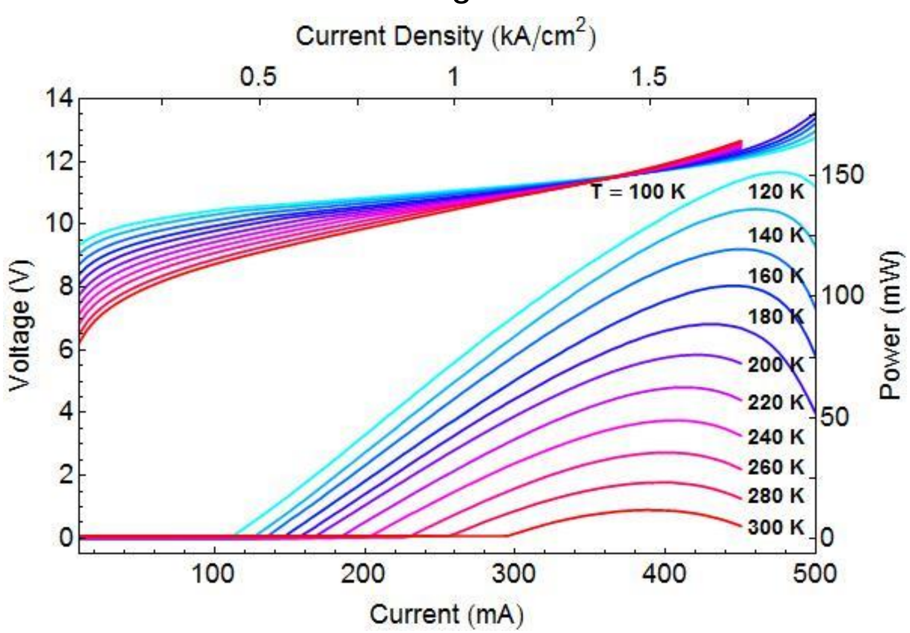
Emission spectra



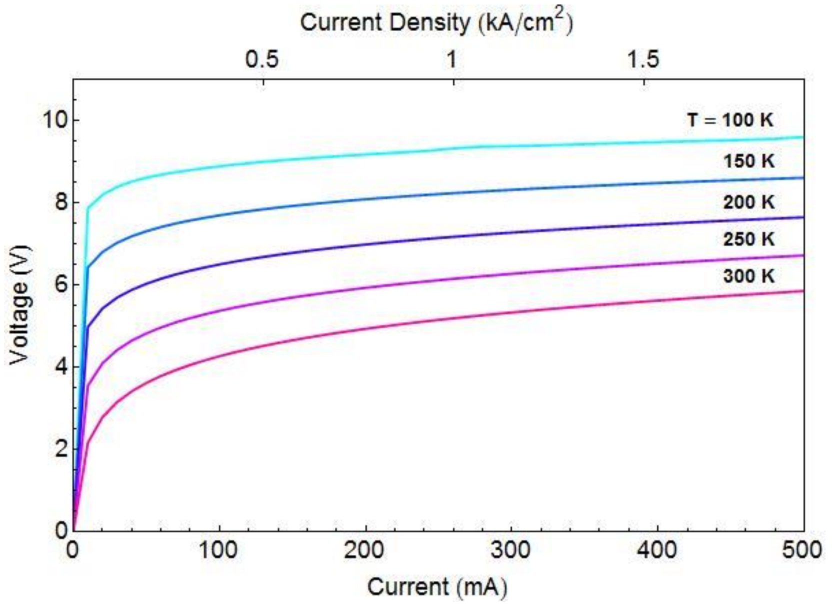
Processing Issues

- No CW laser emission down to 100 K for some lasers
- Voltage is strongly temperature dependent and unexpectedly low near room temperature
- Could this be related to surface defects created during etching?
- Tried fabricating lasers with wet-etched ridges

Working Laser

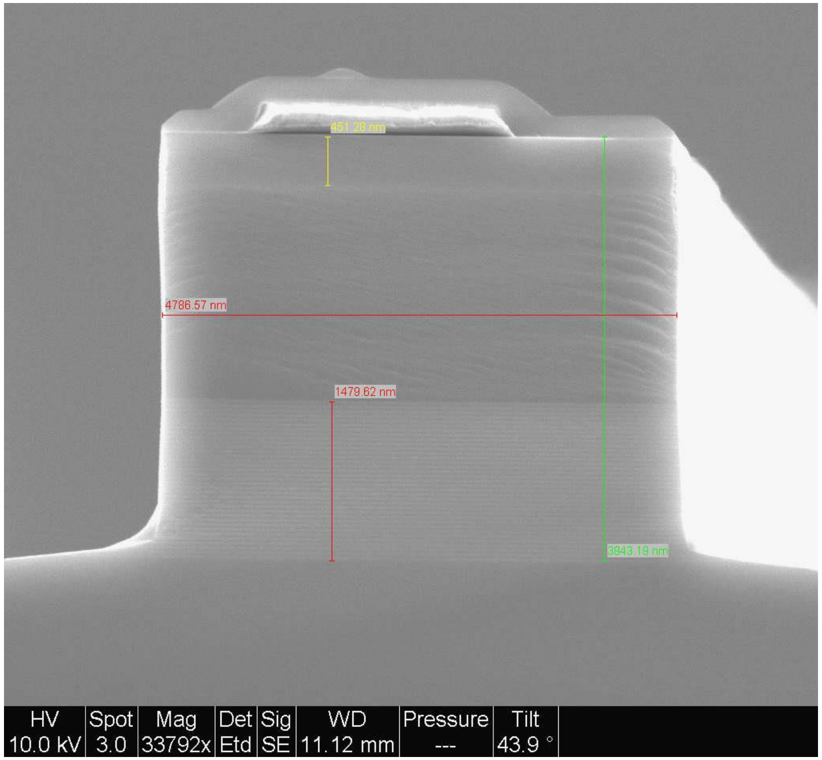


Non-Working Laser

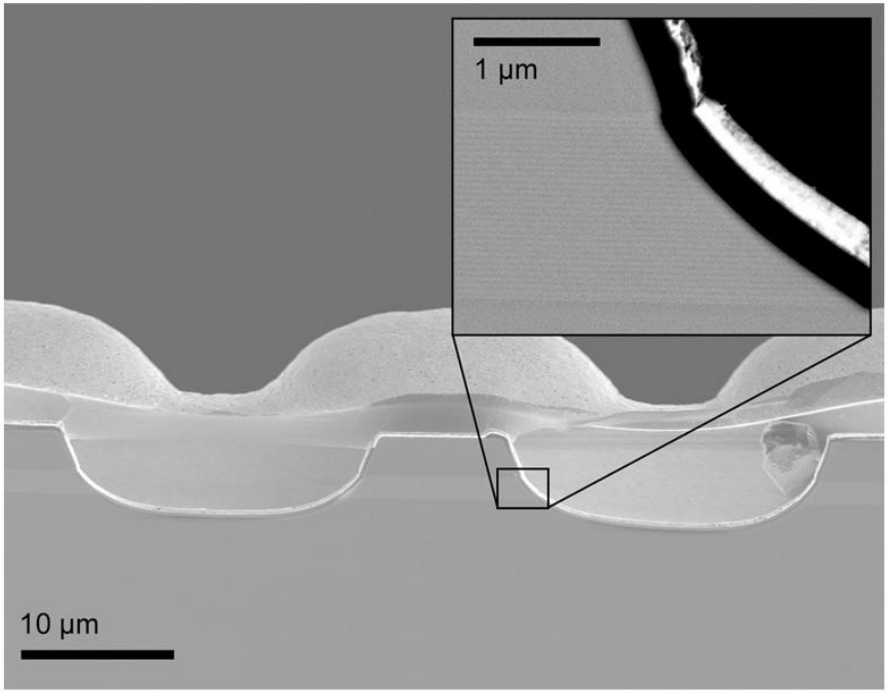


Different Etching Methods

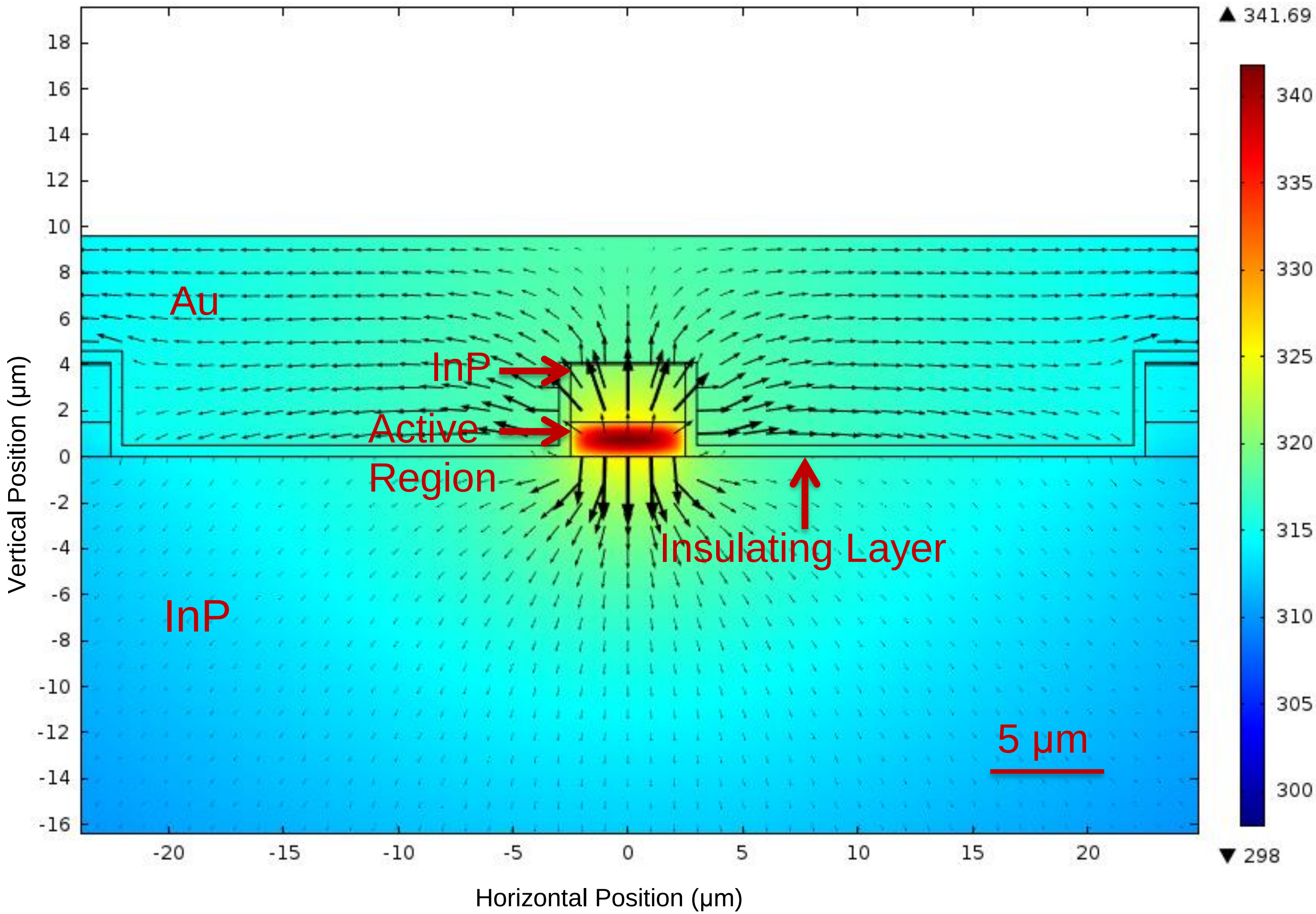
Dry Etched



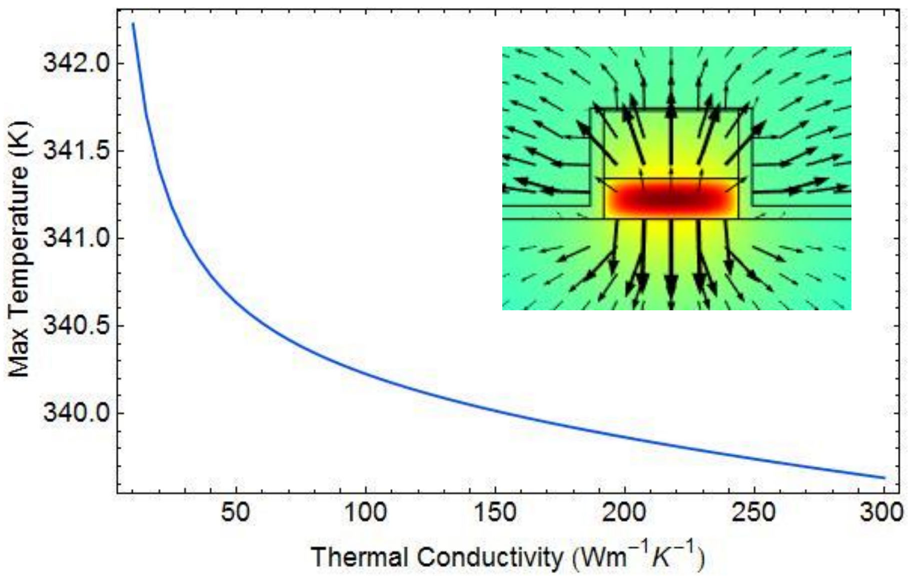
Wet Etched

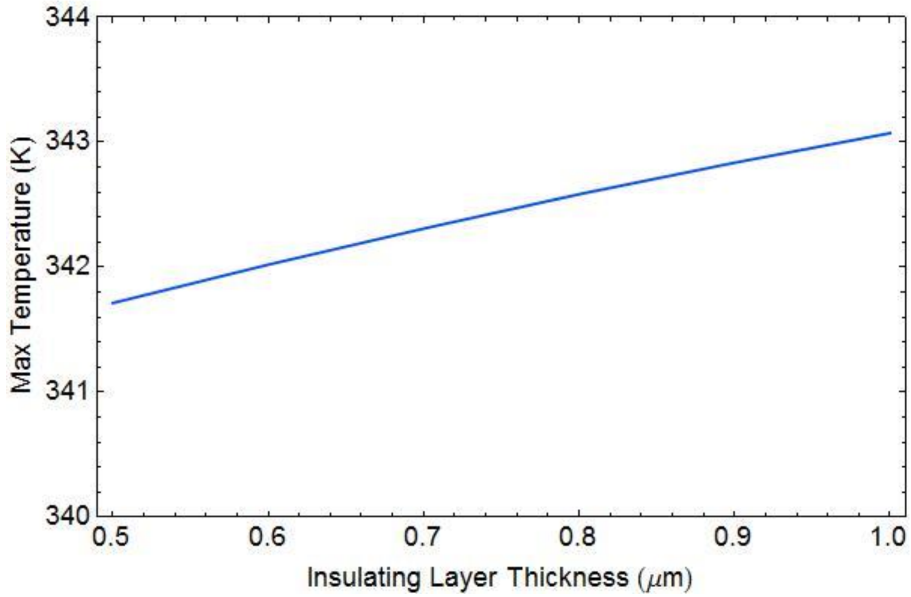


Thermal Modeling Of Laser



Max Temp in Laser Vs. Insulating Layer Thickness
(For Laser Operating at 2 W/mm with Thermal Conductivity of 15 W/(m K))





Summary

- Processing can cause current pathways that cause low voltages at high temperatures and current leakage
  - Improvements need to be made to fabrication process
- Thermal modeling show only small variation in temperature with thermal conductivity and thickness of insulating layer
- Challenge for QC lasers is power consumption, but improvements are both possible and practical

Acknowledgments

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