



# *Commercially Available Broadly Tunable External Cavity Quantum Cascade Lasers*

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*IQCLSW*

*Monte Verita*

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*T. Day, M. Weida, D. Arnone, M. Pushkarsky, D. Caffey, S. Crivello, V. Cook*

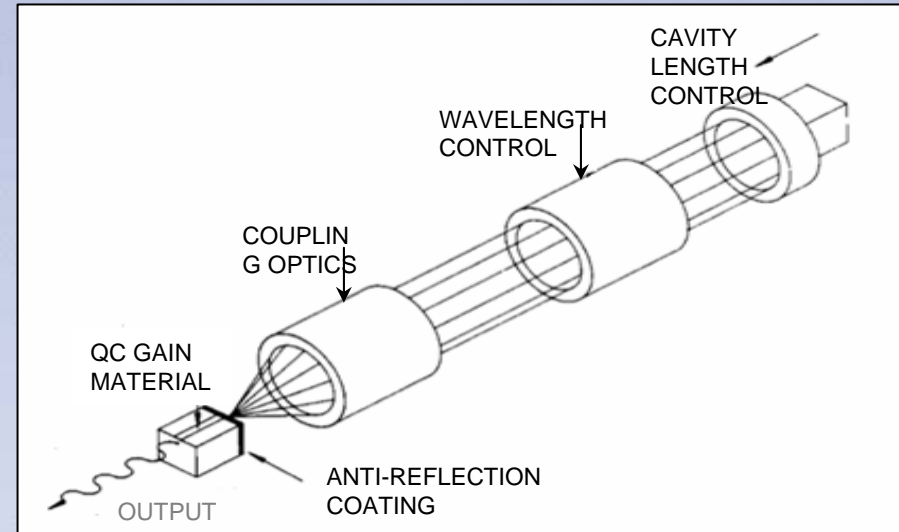
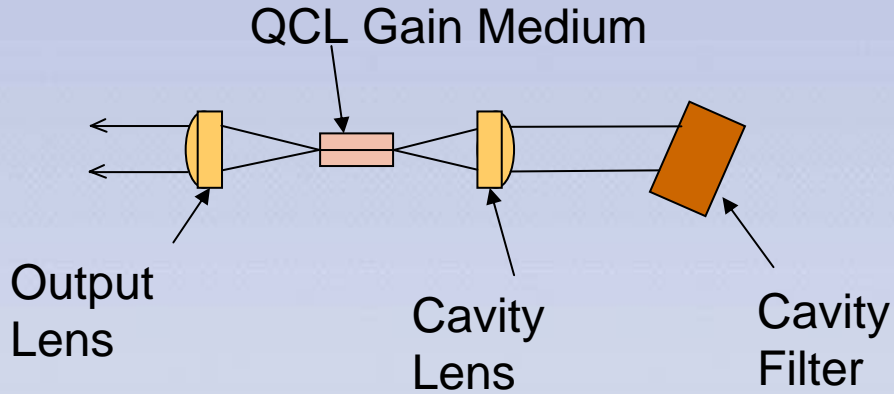
*Daylight Solutions Incorporated*



- ECQCL basics
- Key technologies and components
- Scientific instrument results
- Applications
- Next steps
- Summary



# ECQCL basics



P. Zorabedian, "Tunable External Cavity Semiconductor Lasers"

- Components need to be compatible with mid-IR radiation
- Micro-optic components required for compact lasers
- QC Gain Media needs to be AR coated and single mode
- QC attach needs to be robust and high thermal conductivity
- Filter tuning needs to be wavelength and phase controlled



## Key technology and components

QC gain media

AR coatings

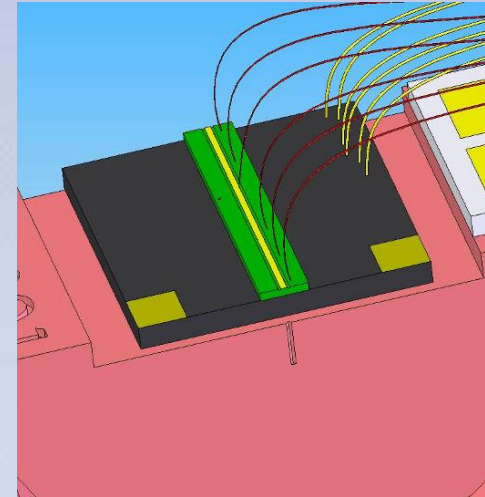
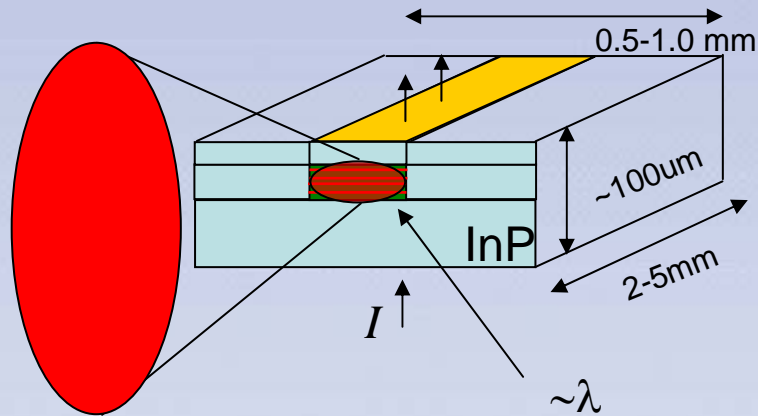
Micro-Optic lenses

Wavelength tuning and filtering

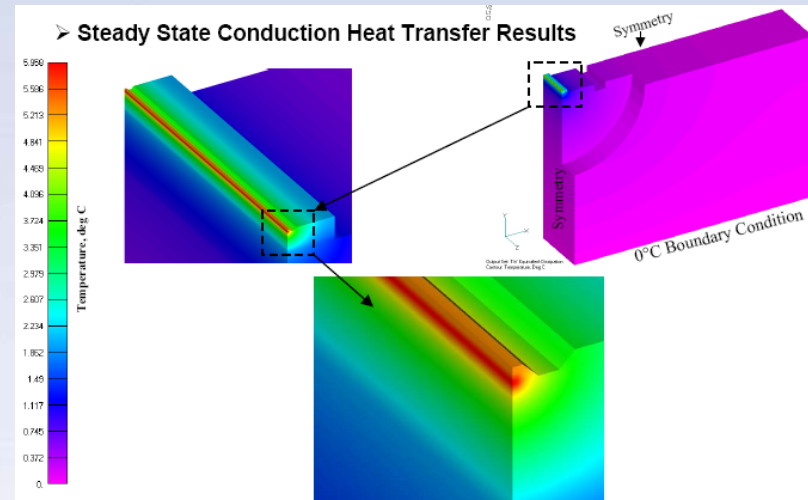
Instrument control

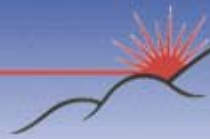


### QC Gain Media



- EPI up or down can be accommodated
  - Buried Heterostructures or Ridges
  - EPI down mounting for most efficient heat removal
  - Solder attach for high temperature operation
  
- Multiple commercial suppliers
  - Adtech
  - Hamamatsu
  - Alpes
  - Maxion
  - Laser Components
  - Nanoplus
  - III-V Labs

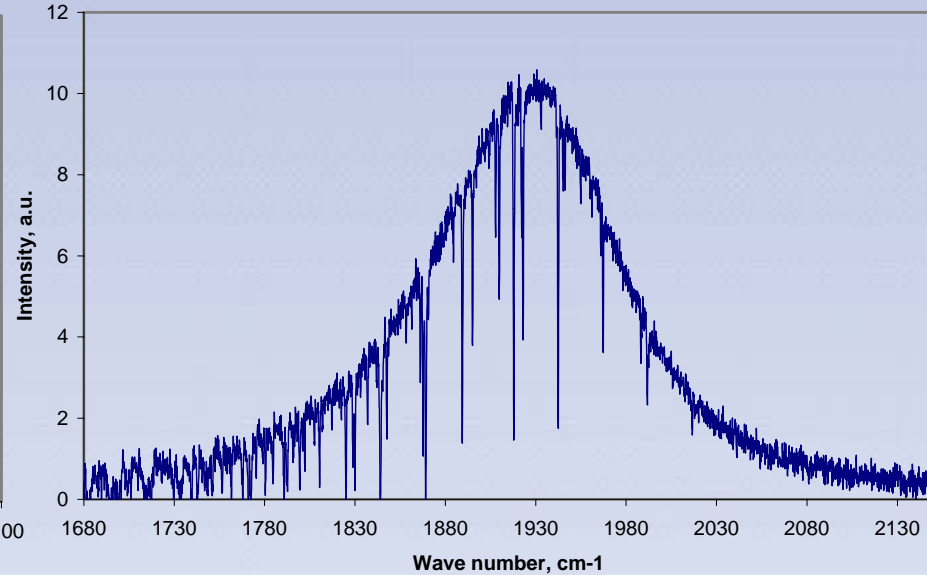
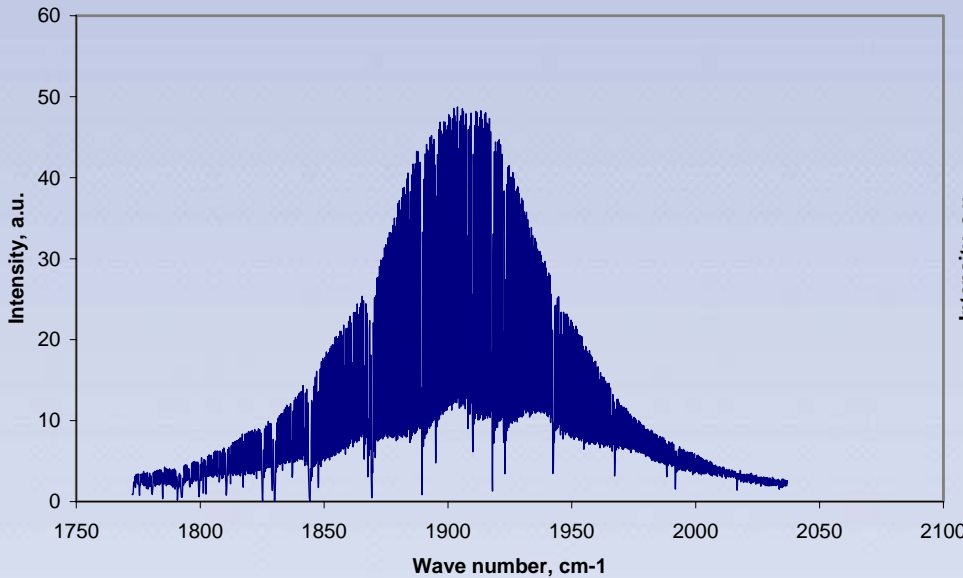




## AR Coatings

FTIR spectrum of uncoated 5.2 um

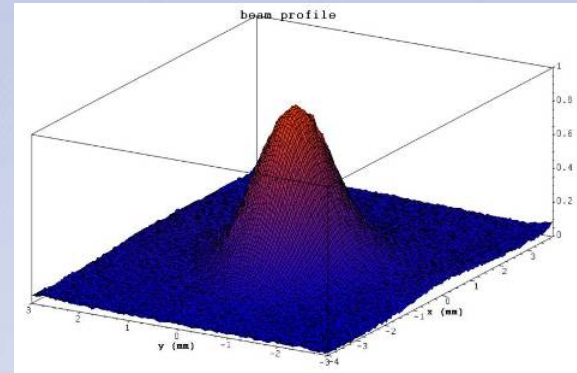
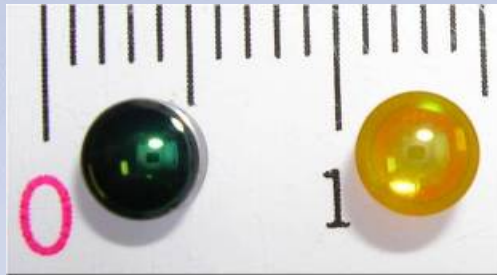
FTIR spectrum of 5.2 um after AR coating



- MID IR coating materials required
- Broad band performance required (thick coatings)
- Reflectivity's below 0.001 for optimum performance
- Long lifetime, high stress, high heat coatings

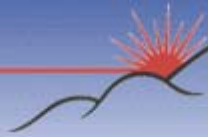


## Micro-Optic Lenses

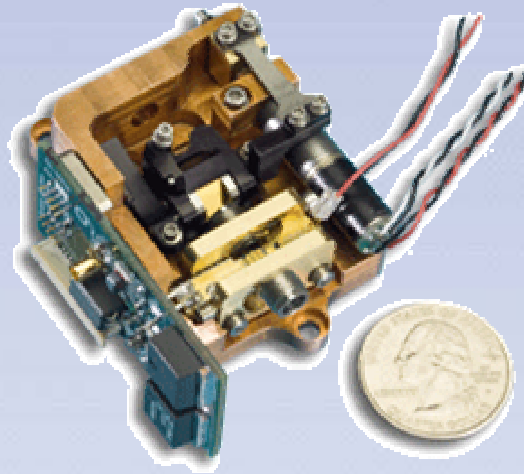


- Diffraction limited performance required
- High N.A. ( $>0.8$ )
- Low wave-front error manufacturing
- MID IR materials (ZnSe, Ge, Chalcogenide..)
- Aspheric surfaces required





## Wavelength filter and filter tuning



- Diffraction gratings provide high feedback (>80%)
- Disk drive or MEMS tuning are options
- Pulsed lasers do not need MHF (phase continuous) tuning
- High resolution tuning requires wavelength and phase control
- Digital encoders for wavelength readout



## Instrument control



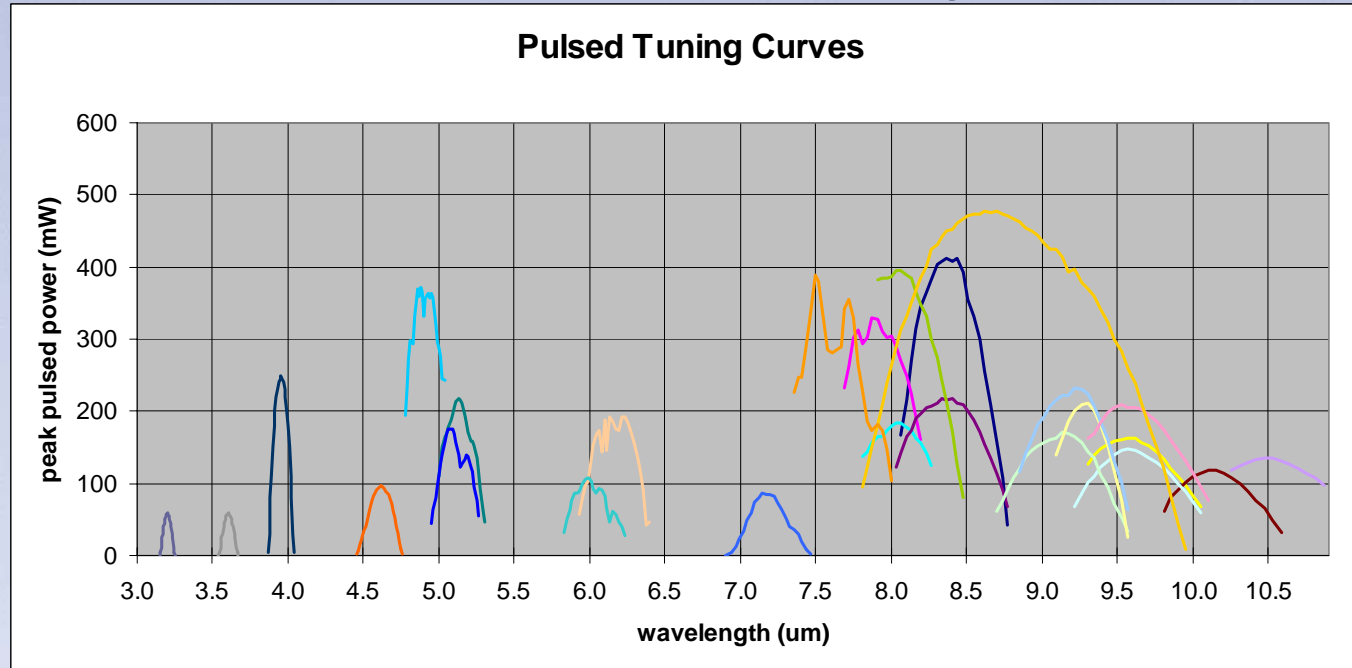
- Temperature control to 10mK
- Current control to ~2A
- High compliance voltages (up to 20V)
- Wavelength control to 1:10<sup>5</sup>
- Pulsed and CW operation
- Computer interface



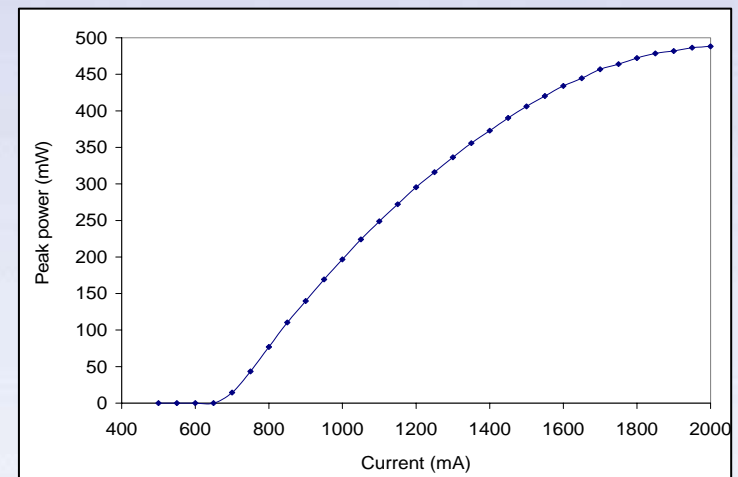
# Scientific instrument results



## Pulsed laser tuning



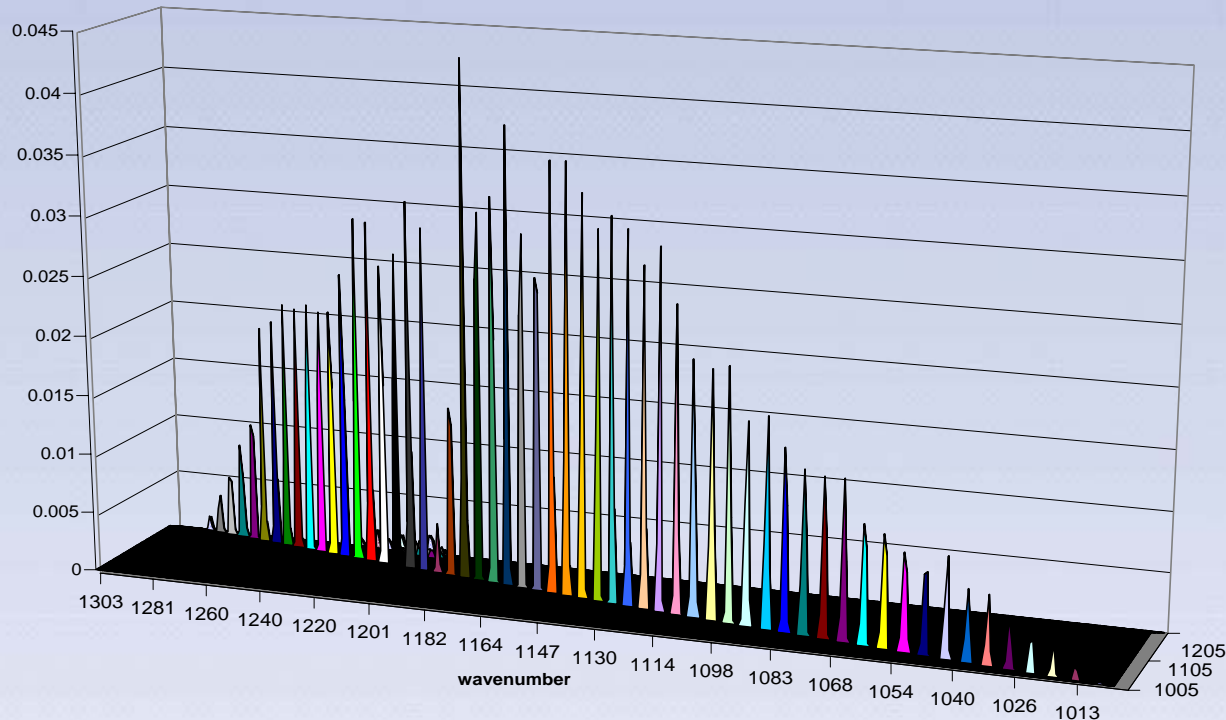
- Wavelengths from 4-11um
- Peak powers approaching 0.5W (duty cycle 1-40%)
- Pulsed laser line-widths  $<0.5\text{cm}^{-1}$
- Tuning ranges of 10% typical ....going to 25%





## Extremely broad tuning with pulsed lasers (gain media from Alpes)

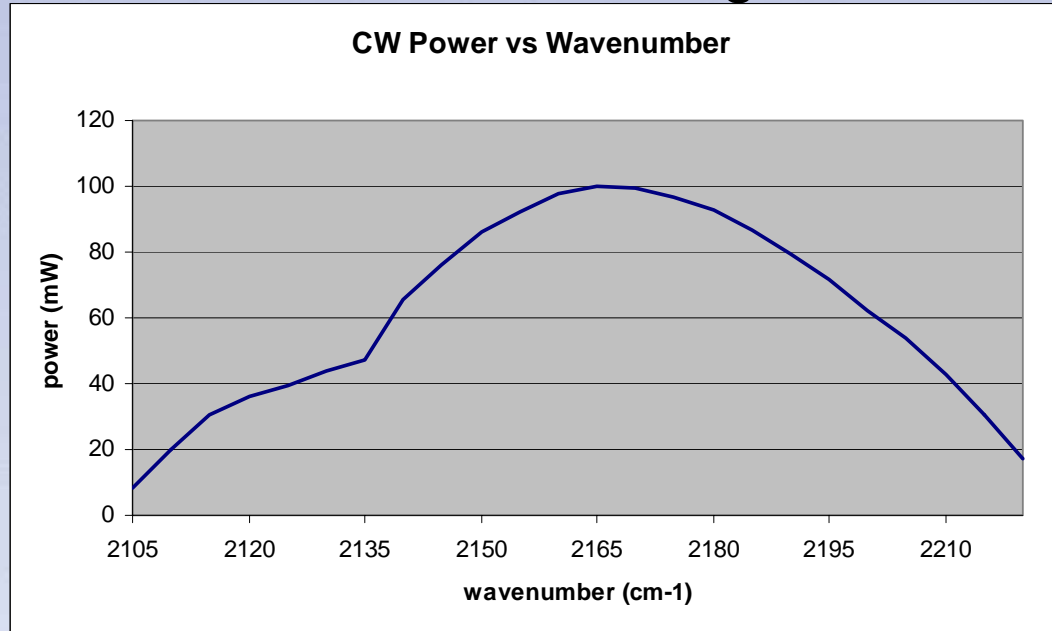
8.8um tuning data



- Single Mode tuning greater than  $275\text{cm}^{-1}$  (~25%)
- Peak powers of 100-500mW (1-10% DC)
- Operating temperatures of  $>20\text{C}$



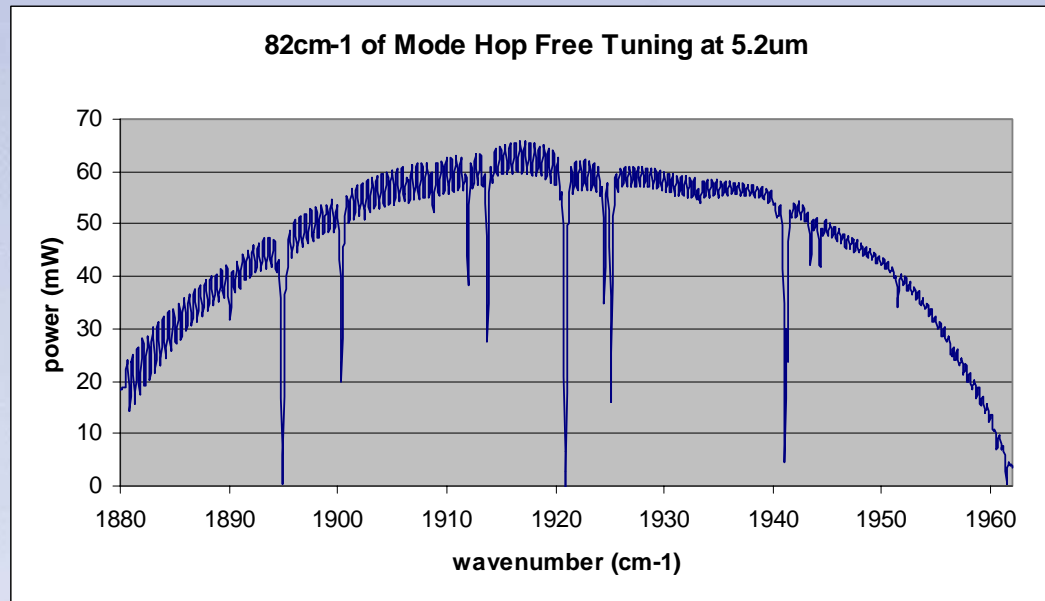
## CW laser tuning



- High powers (>100mW for latest devices)
- Low resolution (non phase continuous) tuning ranges to 10%
  - Tuning range >110cm<sup>-1</sup>
- Operating temperatures above 20C
- Center wavelengths from 4.5-10.5um



## CW laser tuning (high resolution / phase continuous)



- High powers (>100mW for latest devices)
- High resolution, continuous tuning ranges to 80cm-1
  - Linewidth < 0.001cm-1 long-term : short-term < 0.0001cm-1
- Operating temperatures at 20C
- Wavelengths from 4.5-10.5um

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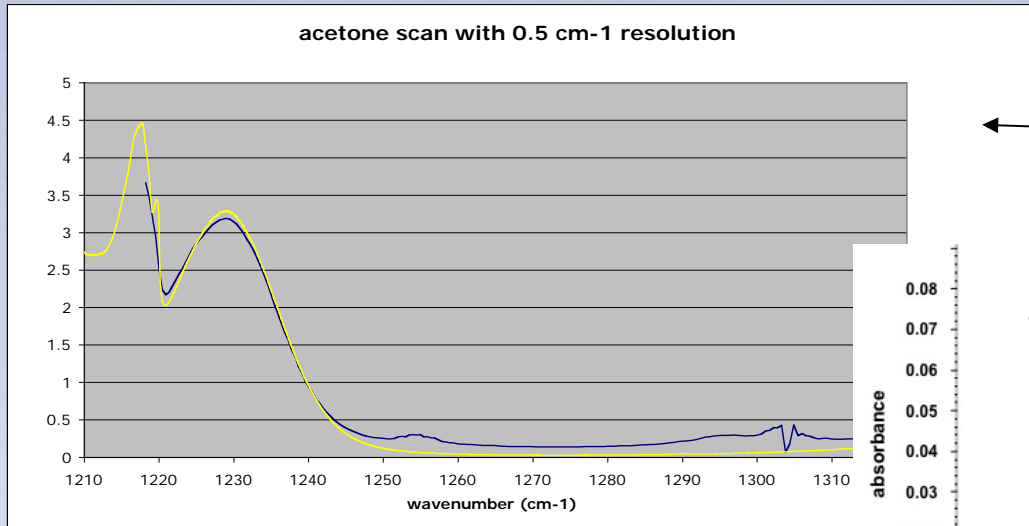
SOLUTIONS



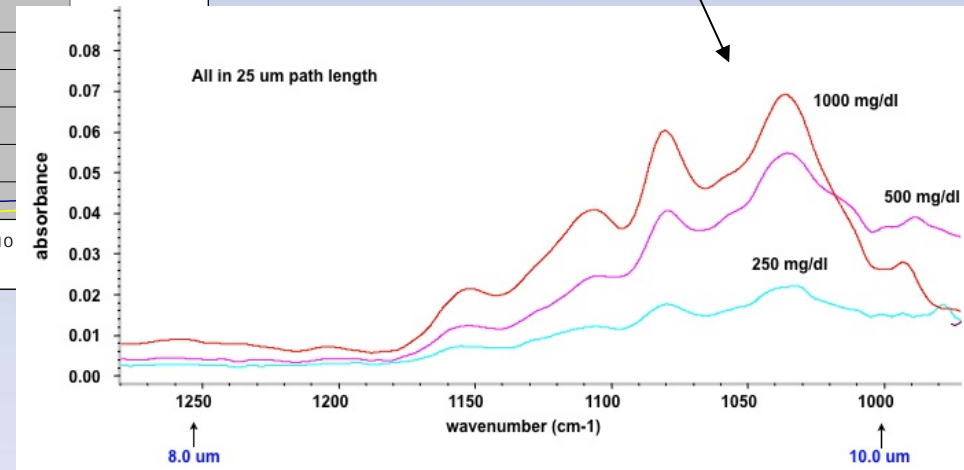
# Applications



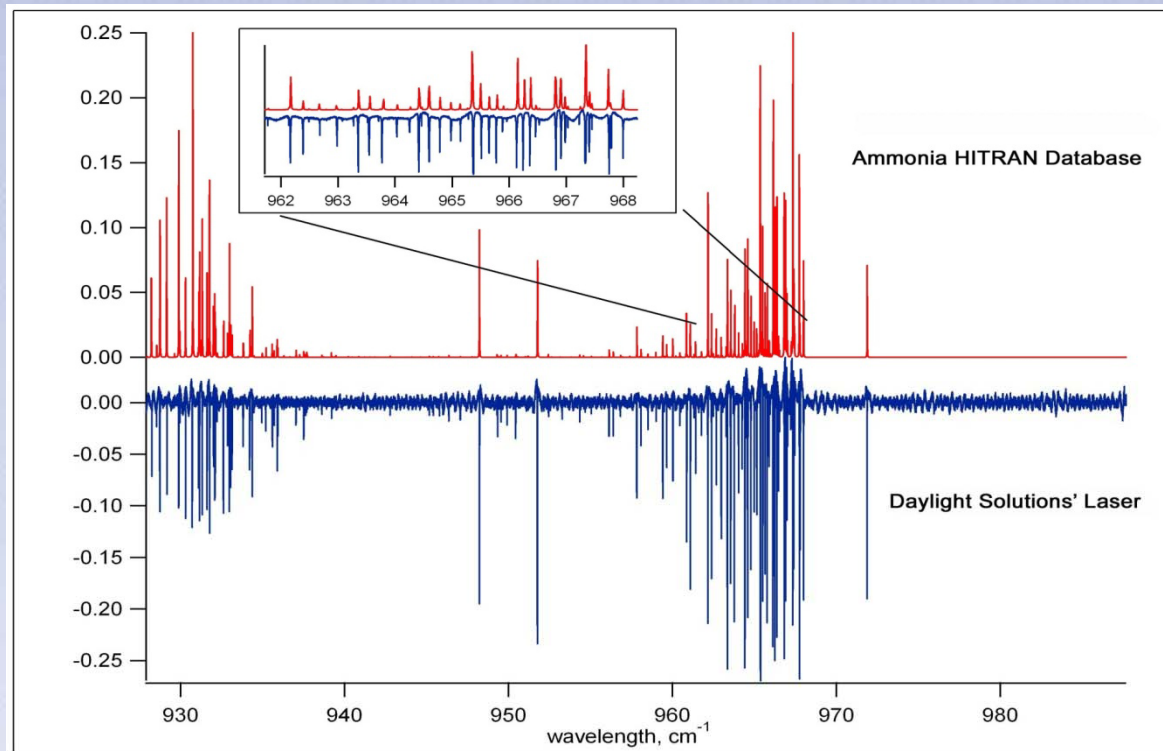
## Low Resolution Spectroscopy



Acetone and Glucose spectra

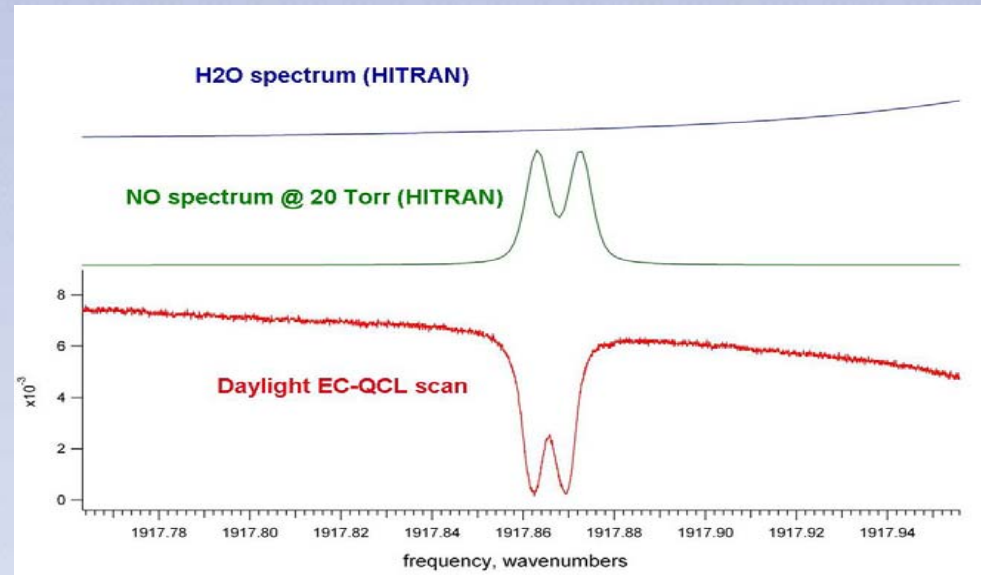
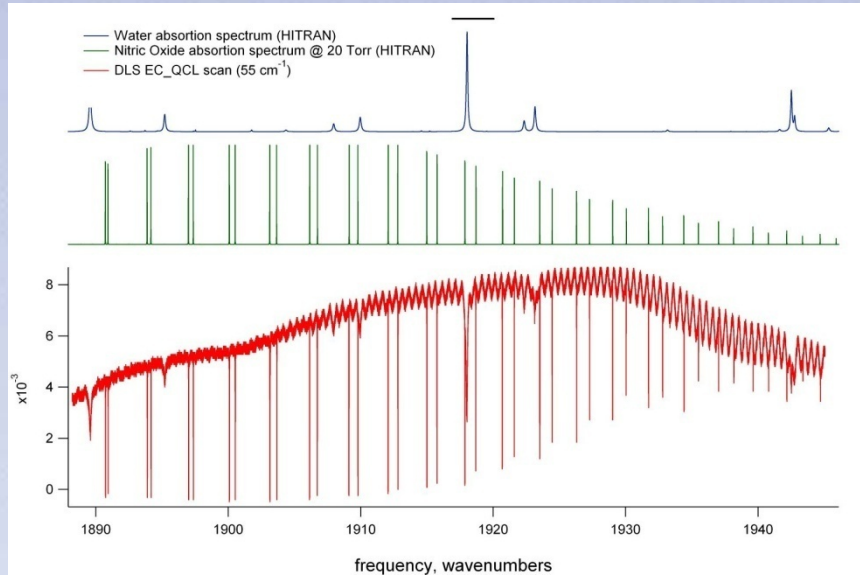


- Broad spectral features can be resolved with broad tuning lasers
- De-convolution algorithms exist using PCA
- Multi-species identification and quantification is possible

High Resolution Spectroscopy (NH<sub>3</sub>)

- Single scan with no reset or adjustment over 50cm<sup>-1</sup> in < 1s
- Laser line-widths (short term) < 10MHz
- Wavelengths at 4.6, 5.2, 6.0, 7.4, 9.6, 10.5  $\mu\text{m}$

## High Resolution Spectroscopy (NO)

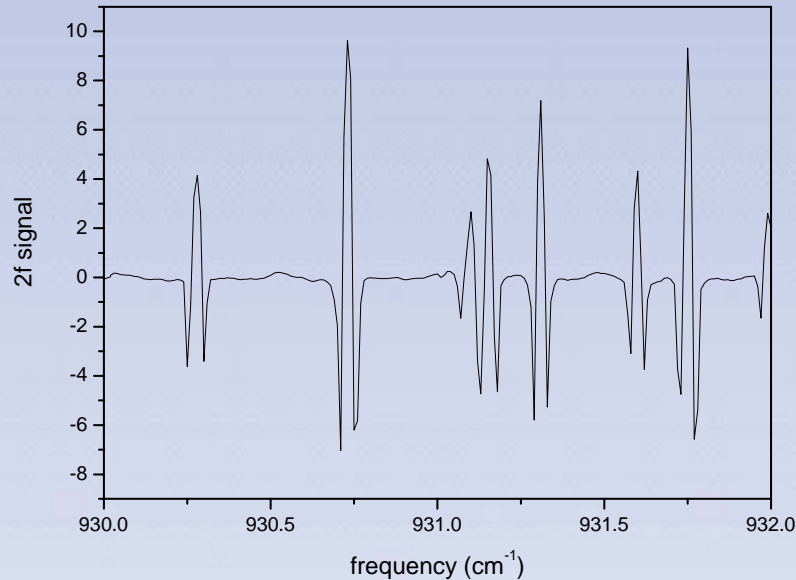


- Step control of center wavelength over full tuning range phase continuously
- Fine tuning with PZT to achieve inter-step continuous tuning
- Doublets can be easily resolved with laser linewidths below 10MHZ

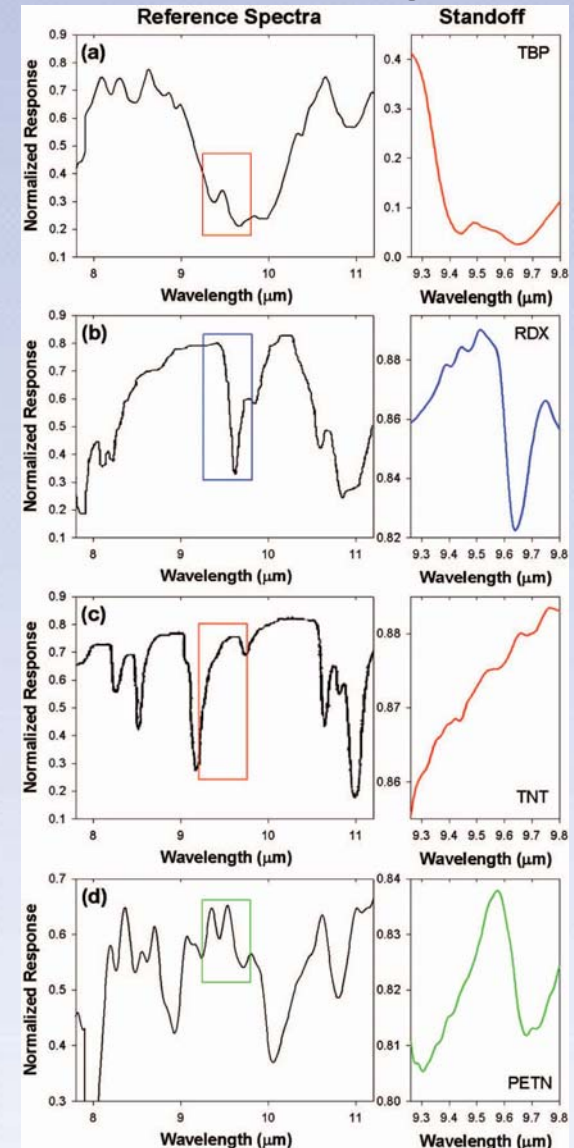


## SOLUTIONS

## Customer Applications (Courtesy Rice and Oakridge)

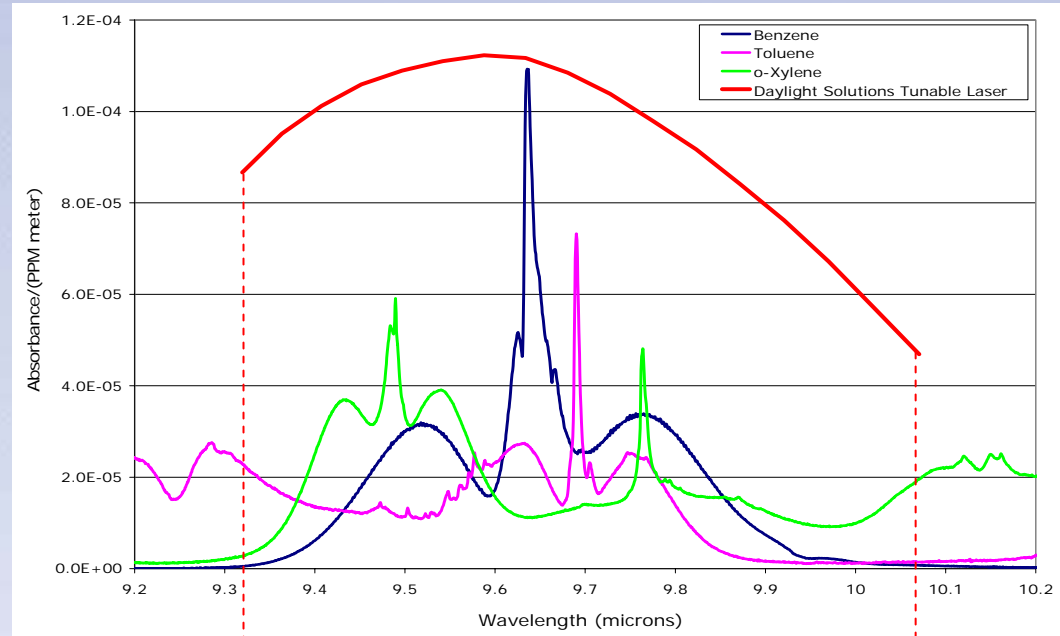
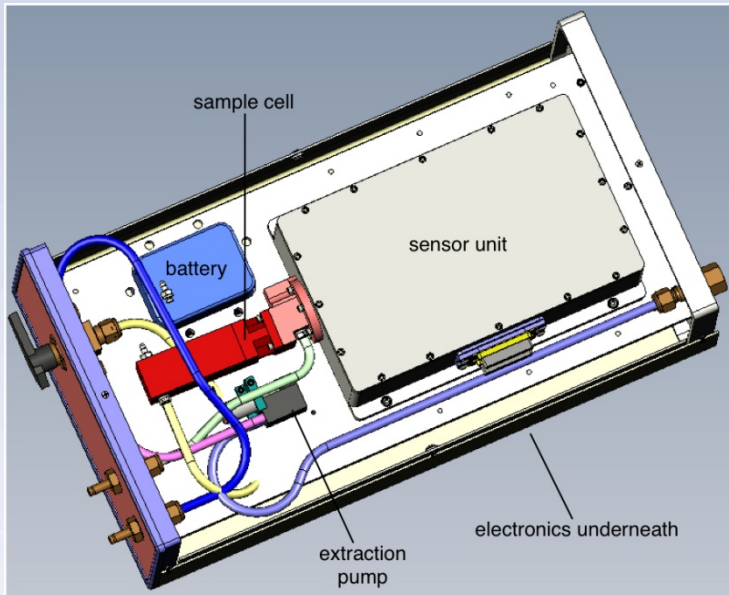


- High and low resolution
- 2f for NH<sub>3</sub> to survey scans of explosives
- Modulation for signal processing
- Coarse or fine tuning possible
- Applications from 4.2-10.6μm





### Integrated molecular detection subsystems



- Fully integrated microprocessor for spectral de-convolution
- Broad tuning ranges
- Multi-species identification





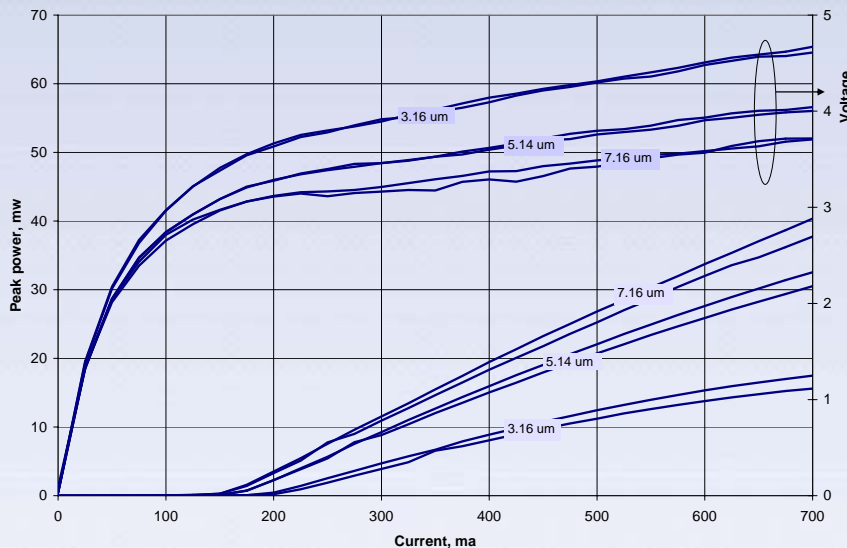
Next steps



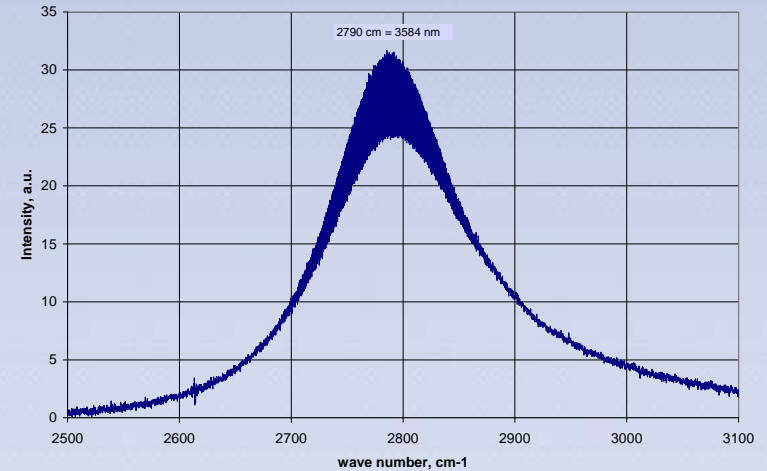
### Shorter Wavelengths (ICLs : collaboration J Meyer NRL)

- CW operating temperatures above 15C
- Powers above 10mW : Threshold powers less than 700mW
- Will make excellent ECICL

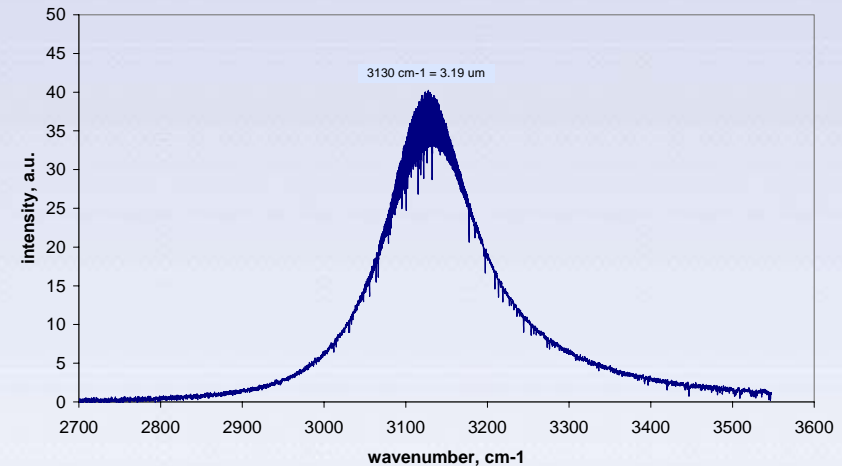
3.58 um ICL pulsed FP single facet power and voltage.  
500 nsec, 100 khz, 5%, mounted Epi up on copper.  
2 ICL samples ea. at 3.16, 5.14, and 7.16 um ridge width



FTIR spectra for a 5.14 um ridge ICL at 15C



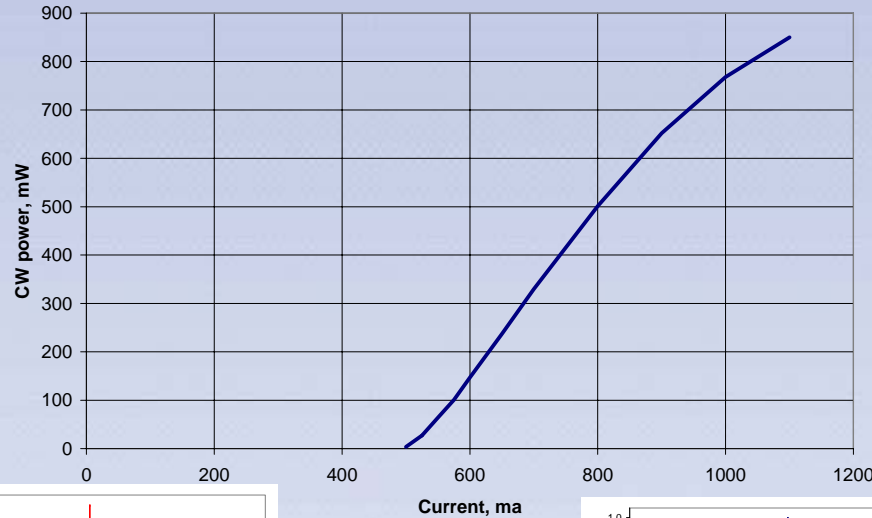
NRL 3.2 um ICL: Uncoated sub-threshold FITR spectrum  
3mm CL x 12 um mesa, 125 ma, 15 C



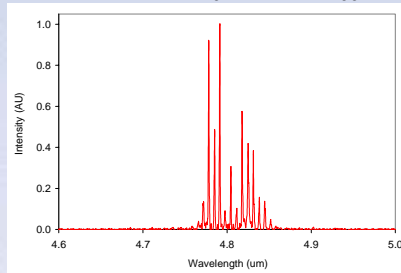


# Medium power : narrow linewidth : high volume packaging

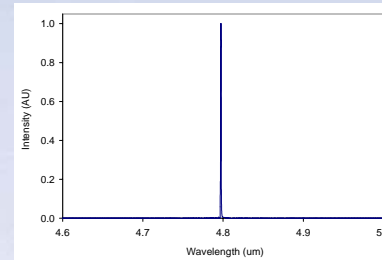
4mm CL x 12 um BH QCL ,15 C, CW



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Current, ma



EC-QCL

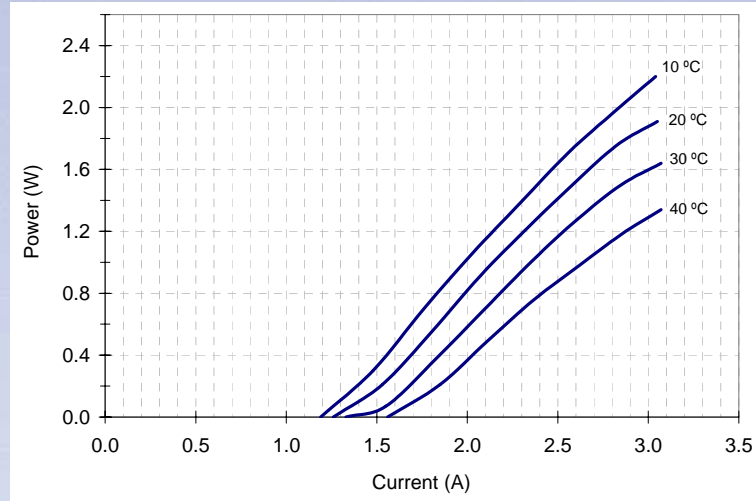
- Single ended output powers > 0.85W at wavelengths of 4.5-5.5um and T > 15C
- Long lifetime, high reliability, robust packaging with high wavelength stability
- Linewidths < 0.01cm<sup>-1</sup> using external cavity
- Manufacturable wavelength setting to 1:1000 Independent of temperature



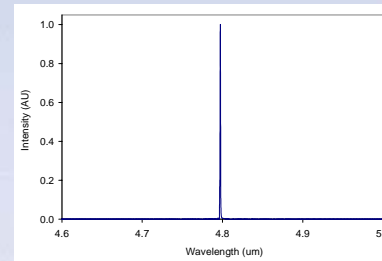
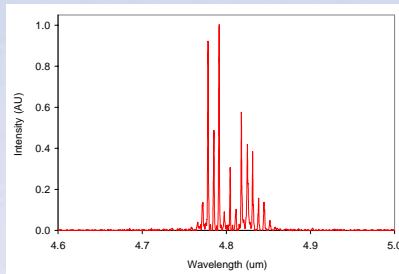


## SOLUTIONS

High Power : high reliability : high volume packaging



Fabry-Perot



EC-QCL

- Multiplexed powers > 2W at T > 10C (6-10% WPE)
- Long lifetime, high reliability, robust packaging
- Linewidths < 0.01cm<sup>-1</sup>
- Spatial or wavelength multiplexing

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SOLUTIONS



# Summary



- Commercial, robust ECQCLs are becoming mature
- All sub components and technologies continue to be refined and perfected
- Room temperature, full turn key systems available
  - Broad tuning ranges
  - Pulsed (low res) or CW (high res) achievable
- Next generation systems and subsystems are rapidly maturing
  - Fixed wavelength DFB replacements
  - High power integrated sub systems (10W minimum)
- Applications will continue to proliferate

*Continued evolution of miniature, tunable, ECQCL's into molecular detection, imaging and security applications will occur*



- The entire DLS team
- MIRTHE / Professor Claire Gmachl
- DOE
- DOD
- NRL
- Adtech : Alpes : Hamamatsu : Maxion
- Professor Frank Tittel
- Jerry Meyer and NRL