# Design and Characterization of an Extended Cavity Diode Laser for $NV^-$ Center Excitation

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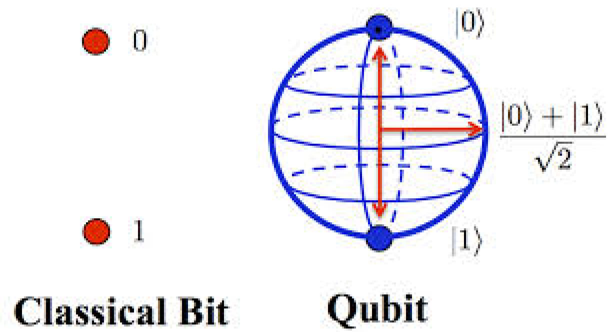
# Overview

- Quantum Computing and Nitrogen Vacancy (NV) Centers
- Extended Cavity Diode Laser (ECDL) Design and Construction
- Laser Characterization
- Conclusions and Future Work

# Quantum Computing

- A classical bit takes on one of two states. A quantum bit (qubit) can be in any superposition of two basis states.



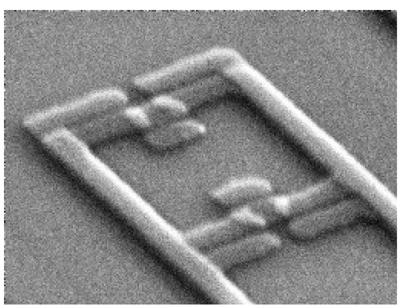

- QC algorithms with faster runtimes than classical algorithms
  - Shor's algorithm: integer factorization in polynomial time
- Secure communication using quantum key distribution
- Quantum simulation

http://blogs.testclue.com/wp-content/uploads/2014/08/images.jpg

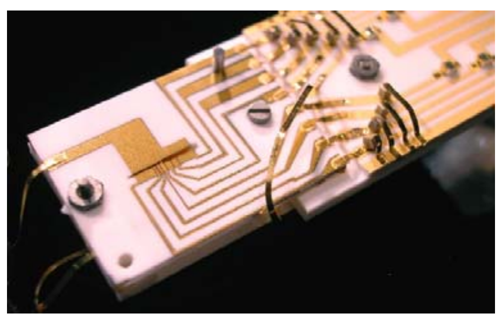
# Types of Qubits

| Physical support | Name | Information support | $\|0\rangle$ | $\|1\rangle$ |
|---|---|---|---|---|
| Photon | Polarization encoding | Polarization of light | Horizontal | Vertical |
| | Number of photons | Fock state | Vacuum | Single photon state |
| | Time-bin encoding | Time of arrival | Early | Late |
| Coherent state of light | Squeezed light | Quadrature | Amplitude-squeezed state | Phase-squeezed state |
| Electrons | Electronic spin | Spin | Up | Down |
| | Electron number | Charge | No electron | One electron |
| Nucleus | Nuclear spin addressed through NMR | Spin | Up | Down |
| Optical lattices | Atomic spin | Spin | Up | Down |
| Josephson junction | Superconducting charge qubit | Charge | Uncharged superconducting island (Q=0) | Charged superconducting island (Q=2e, one extra Cooper pair) |
| | Superconducting flux qubit | Current | Clockwise current | Counterclockwise current |
| | Superconducting phase qubit | Energy | Ground state | First excited state |
| Singly charged quantum dot pair | Electron localization | Charge | Electron on left dot | Electron on right dot |
| Quantum dot | Dot spin | Spin | Down | Up |

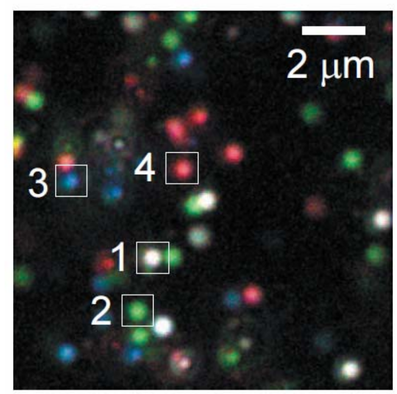
http://en.wikipedia.org/wiki/Qubit



Flux qubit, Royal Holloway University (Wikipedia)

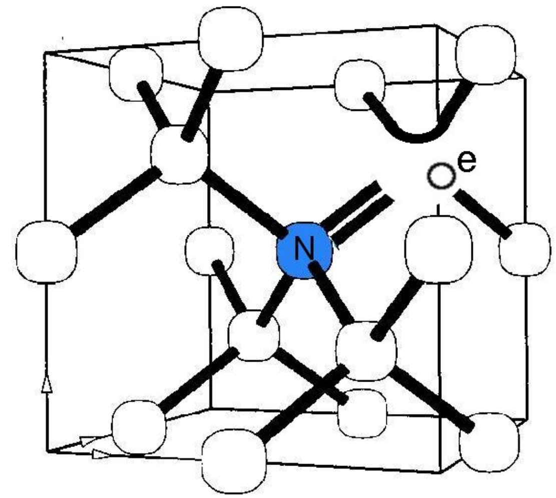


Trapped ions, NIST (physicsworld.com)

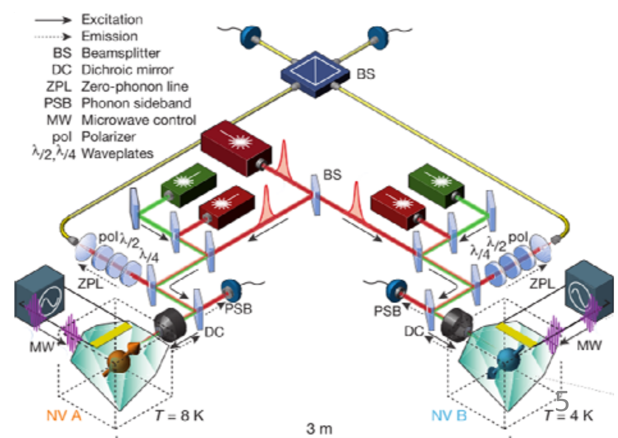



NV Centers [1]

# NV Centers




- Point defect in diamond
- $NV^-$ charge state: two unpaired electrons form spin S=1 system
- Useful as spin qubits
  - Long electron spin coherence times
  - Electron spins can be manipulated and read out optically




http://en.wikipedia.org/wiki/Nitrogen-vacancy_center

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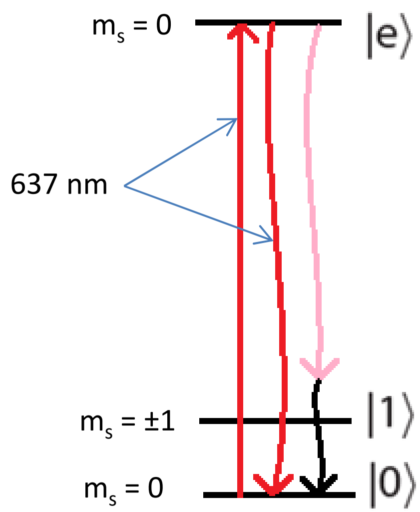
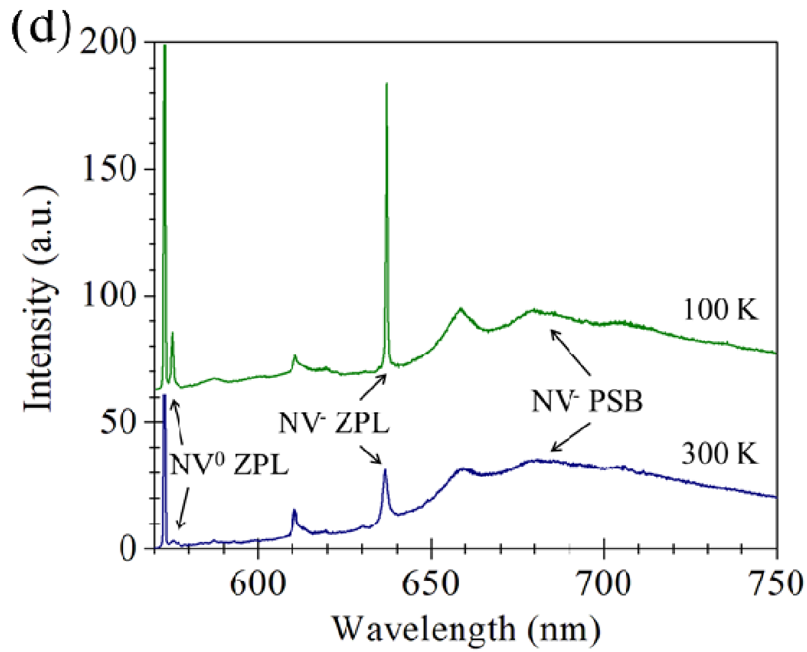
# NV- Optical Excitation and Photoluminescence

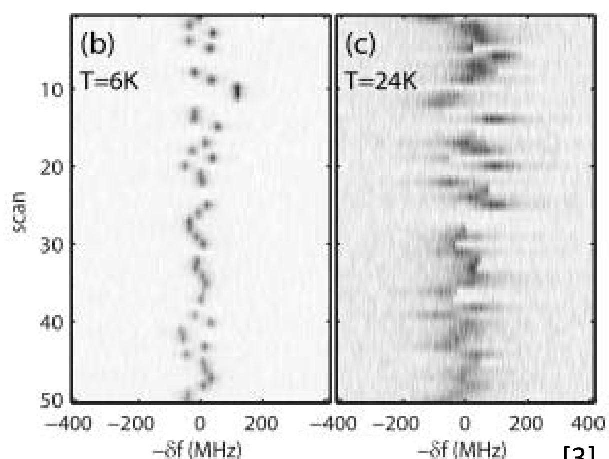



- Can optically excite $NV^-$ on resonance with zero phonon line (ZPL) in order to read out state or manipulate electron spins
- ZPL emission important for entanglement of NV centers

# Spectral Diffusion and ZPL Broadening

- Frequency at which any given NV- center emits wanders over time
  - Spectral diffusion caused by sensitivity to changes in local electric field
  - Broadening of ZPL as temperature increases

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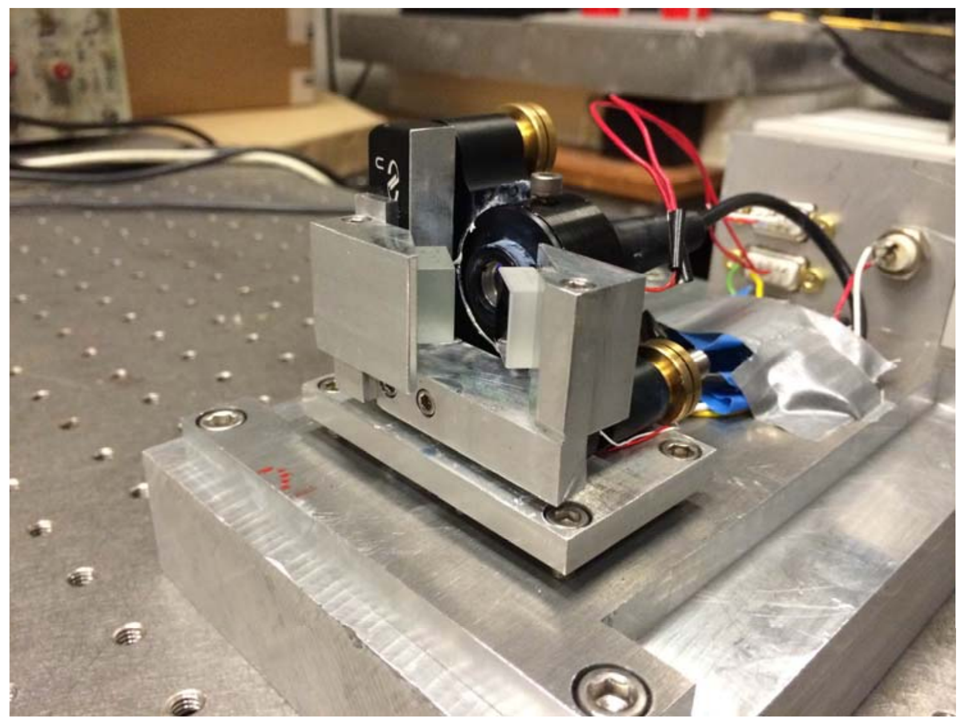
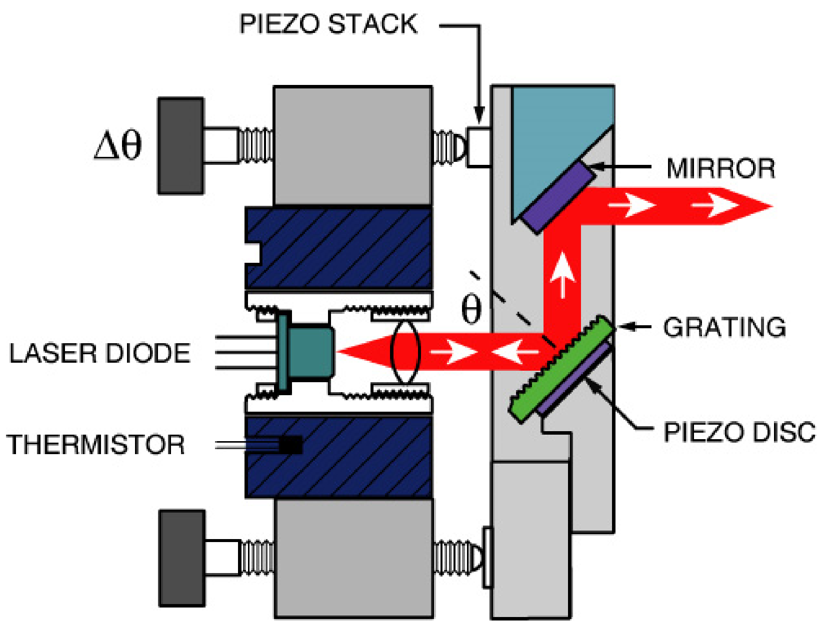
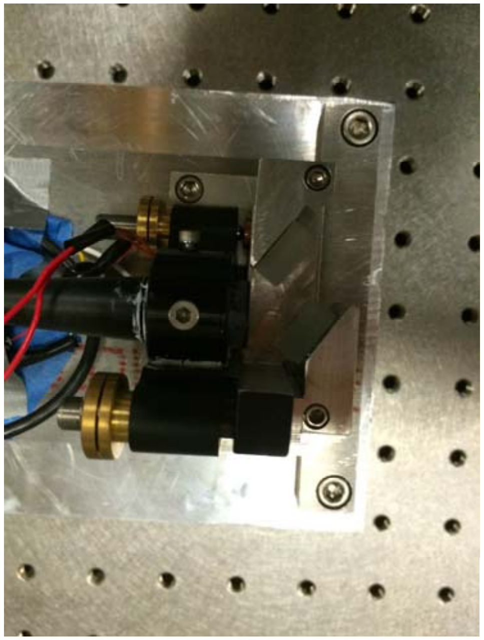
# Extended Cavity Diode Laser

- Tunable narrow linewidth laser
- Will be used to characterize photoluminescence of $NV^-$ center samples
- Tunable range must be wider than worst-case frequency range of $NV^-$ ZPL



# ECDL Design

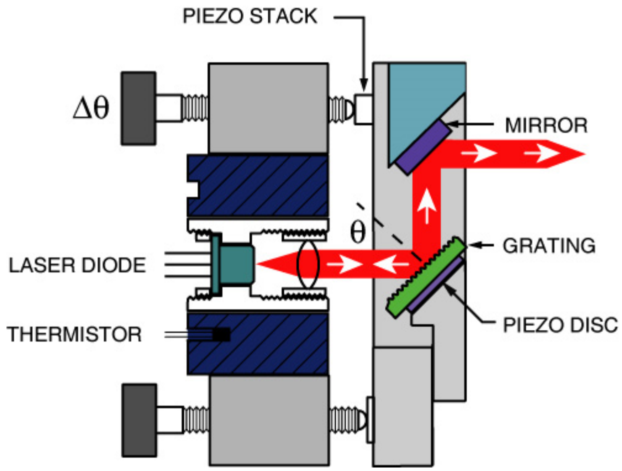


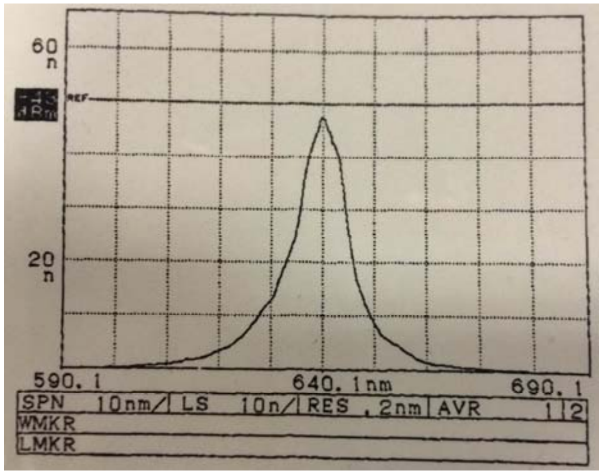



- Lasing frequency of broadband laser diode tuned using diffraction grating
- First order diffraction from grating coupled back to diode
- Direct reflection coupled out of cavity as beam

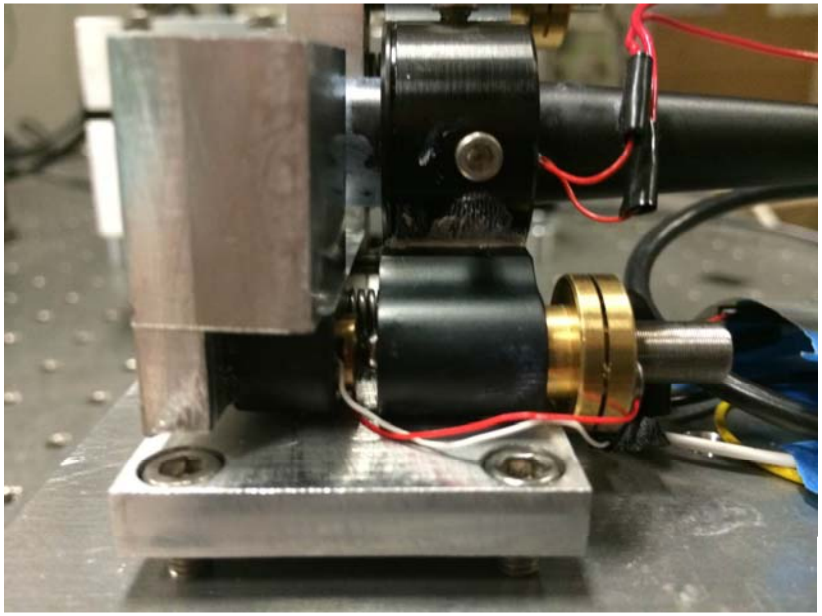
http://optics.ph.unimelb.edu.au/atomopt/diodes.html

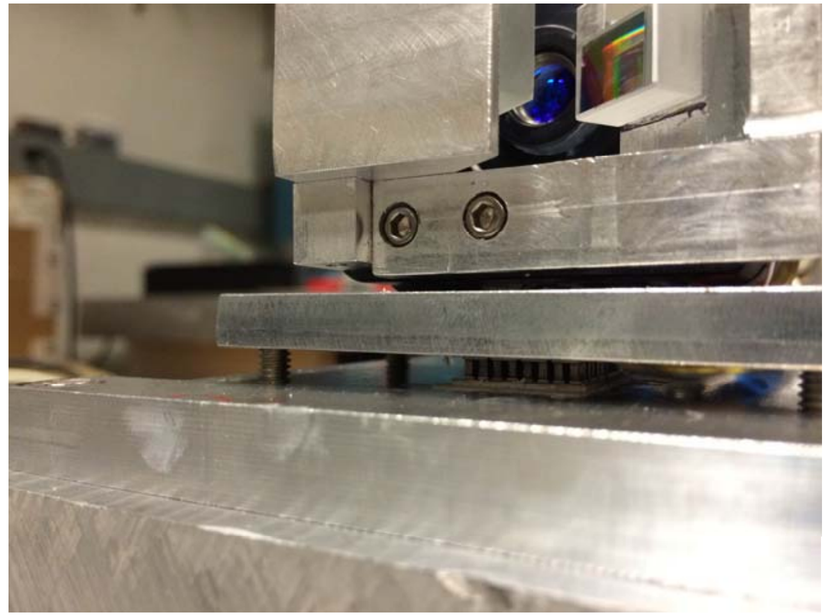
# ECDL Design

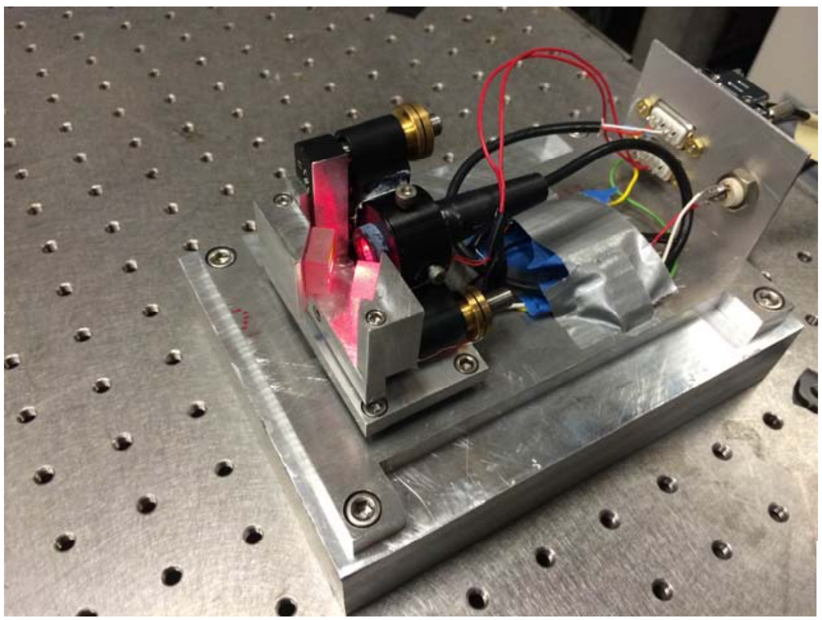


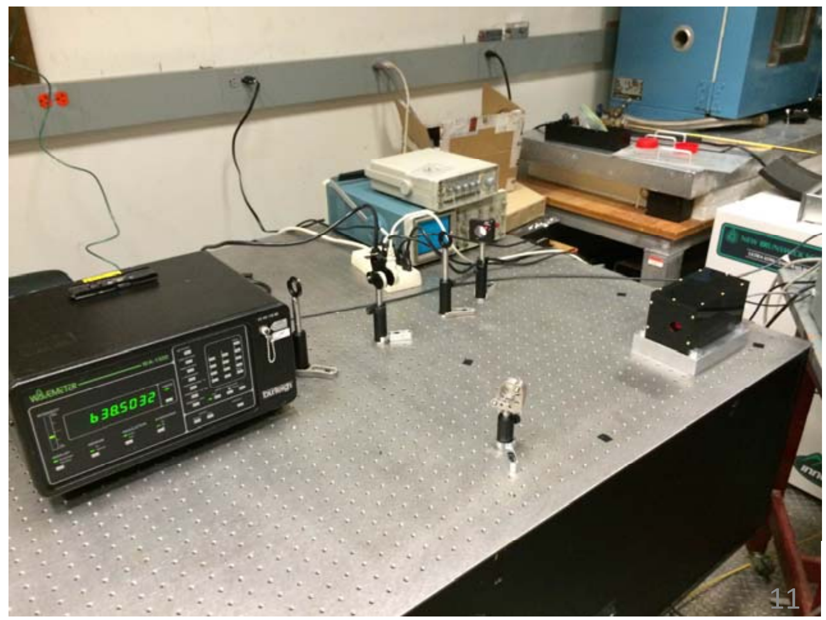




- Littrow configuration: $\theta = arcsin(\frac{\lambda}{2d})$
- $\lambda = 637nm$ and $d = (1800\frac{lines}{mm})^{-1} \Rightarrow \theta \approx 35°$
- Thorlabs piezostack responds to 100V signal with 3.0um displacement
- $\Delta x = 3.0\mu m \Rightarrow \Delta\theta = 0.0046° \Rightarrow \Delta\nu = 50GHz$
- Need at least 5GHz continuous scanning range





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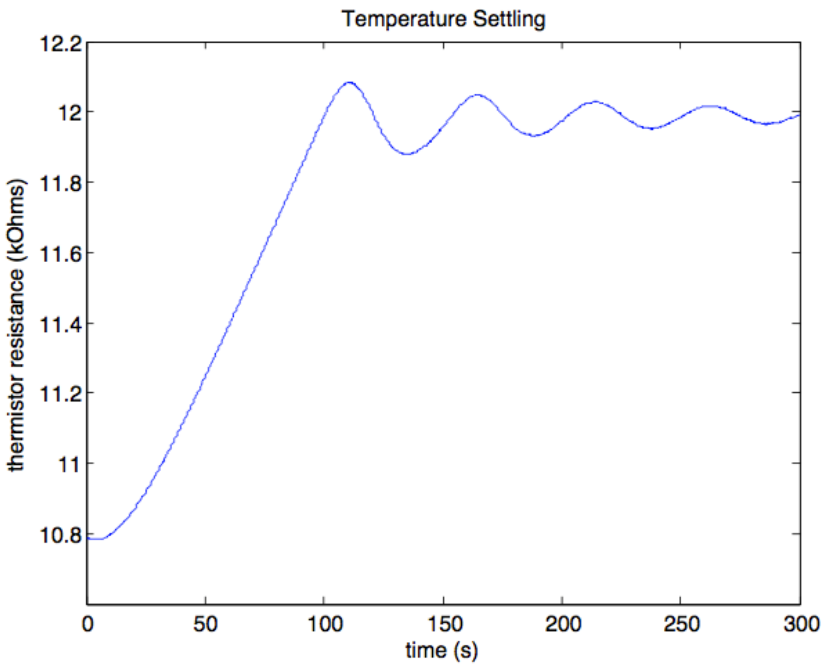
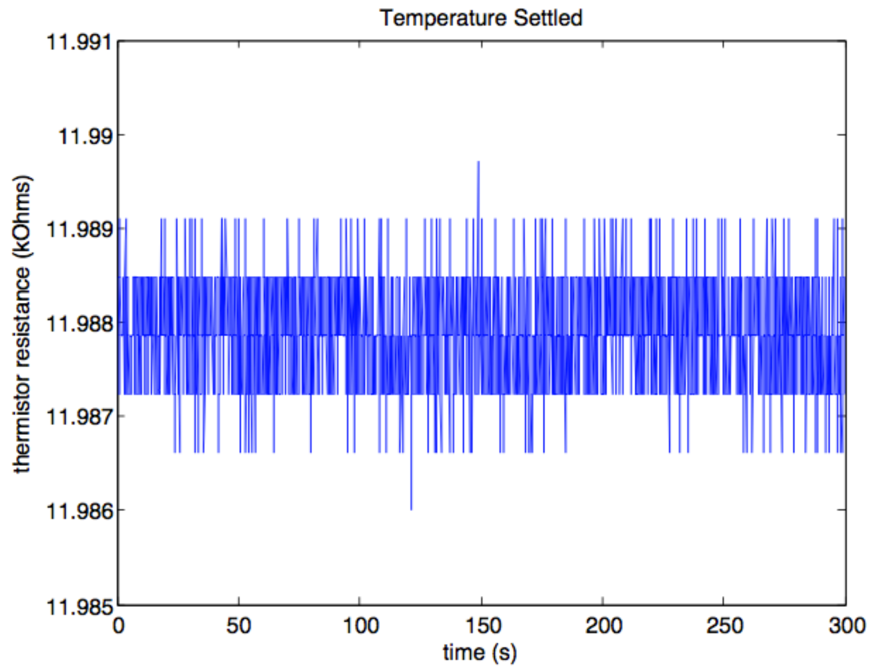
# Laser Characterization

- Aiming for frequency noise on the order of 1MHz or less
- Laser stabilized with Thorlabs LDC240C Diode Current Controller, TED200C Temperature Controller
- Frequency characterization performed using Burleigh Wavemeter, Fabry-Perot etalon
  - Lab spectrometer has 14GHz resolution

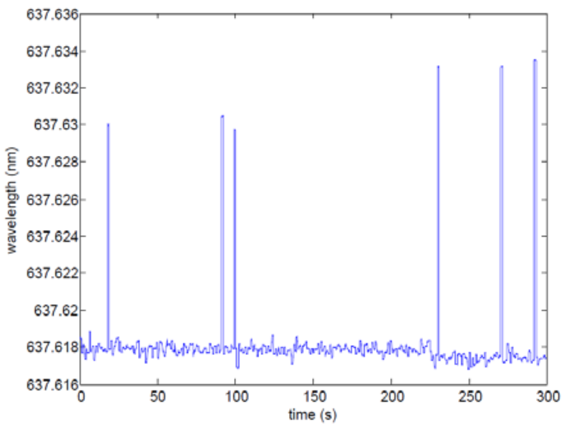
# Temperature Stability

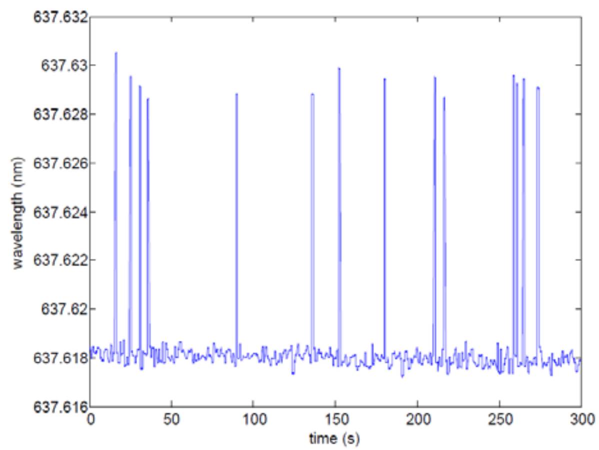


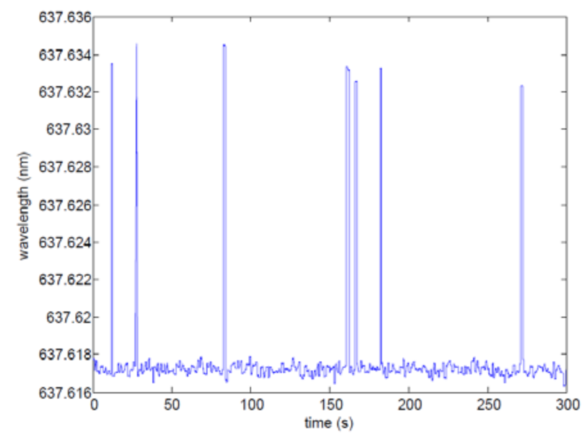



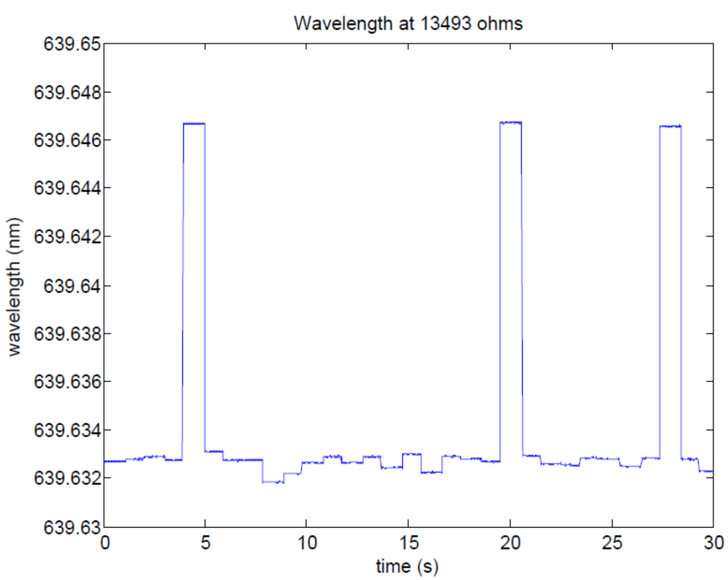

- Laser diode has strong frequency response to changes in temperature
- Temperature controlled using 2.5A thermoelectric cooler, 10kOhm thermistor, and Thorlabs TED200C temperature control box
- Stable to within ±1 ohm, corresponding to ±0.002 degrees C
- Preferred temperature for frequency stability remains undetermined

# Frequency Stability



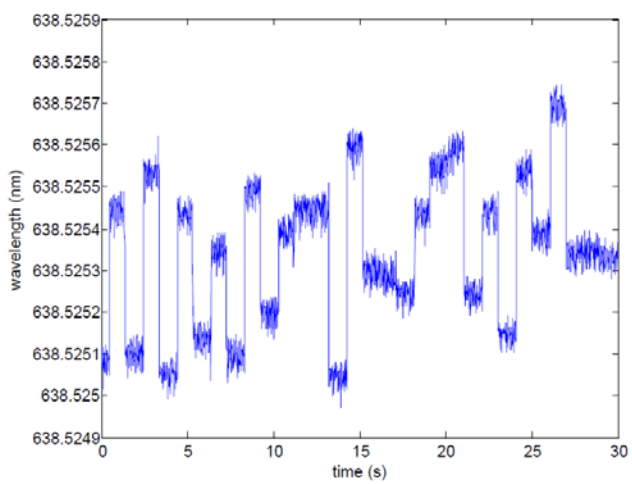



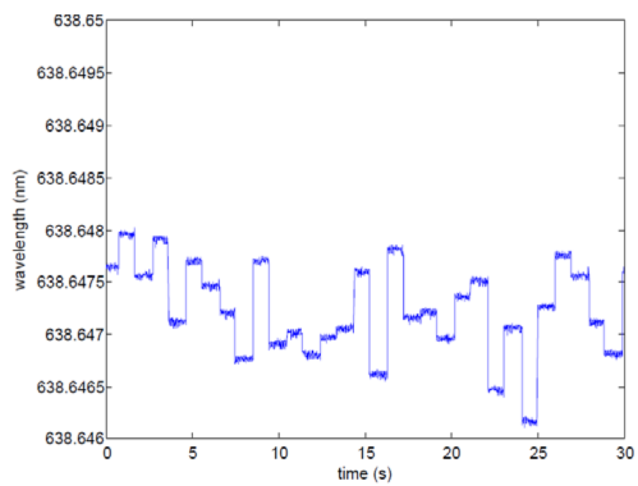



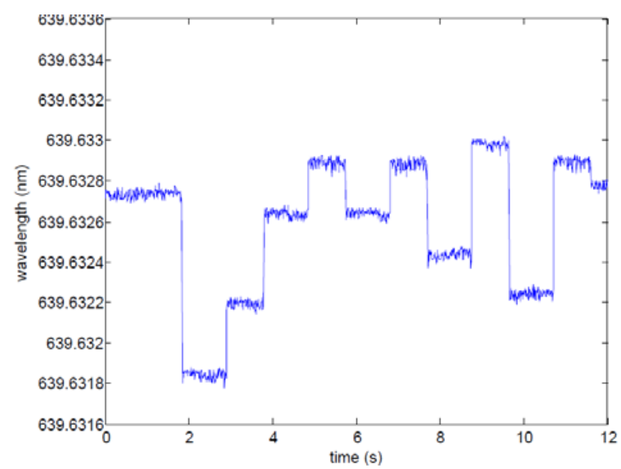

- Frequency hops in 8-12GHz range
- Close to expected size of mode hops due to mode spacing of laser cavity

# Frequency Noise Close-Up

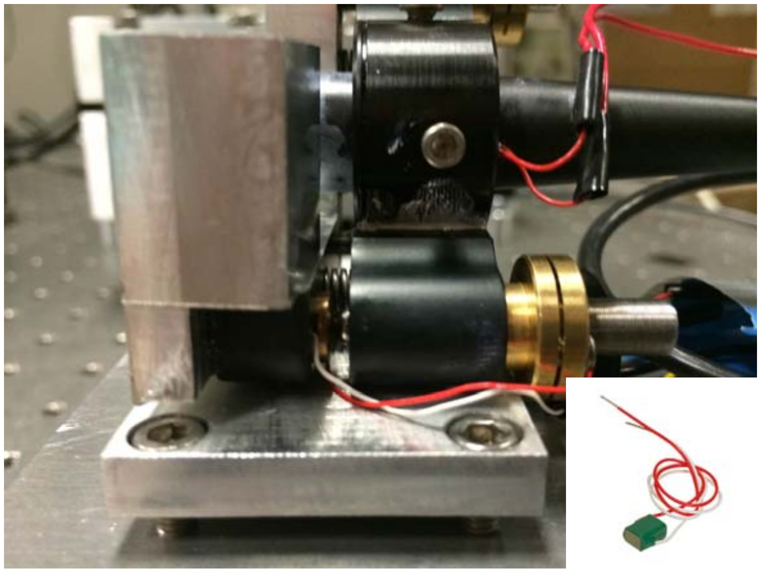
- Smaller hops occur roughly once per second
  - Due to resolution of Wavemeter or DAQ device?
- 0.0001nm = 75MHz

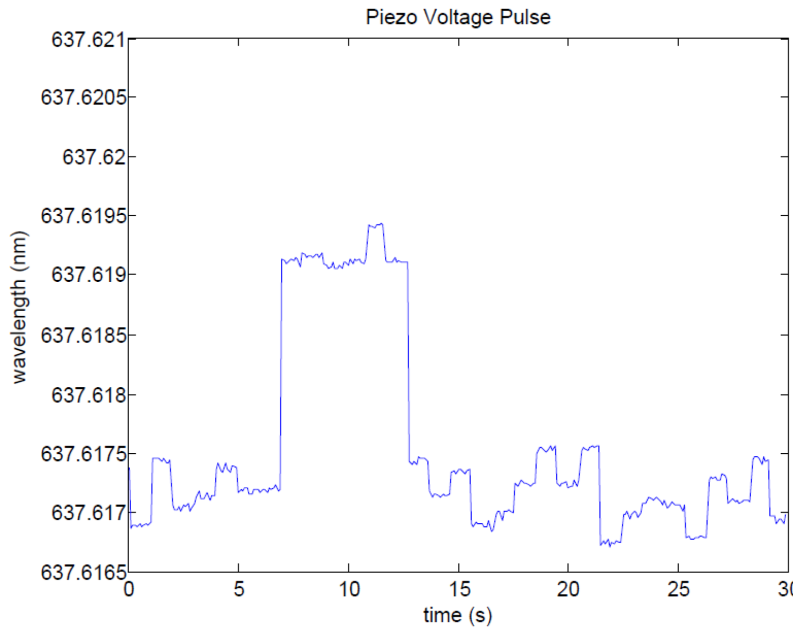


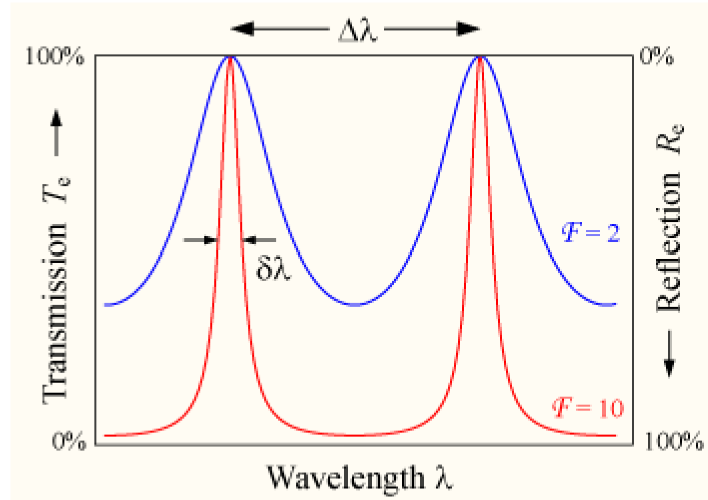
# Piezostack Functionality






- Change in frequency due to piezo voltage of 26V is 1.5GHz, an order of magnitude smaller than expected

# Fabry-Perot Etalon




- Optical cavity between two high precision mirrors
- Transmission peaks occur when laser frequency scans through resonant mode of cavity
- FWHM of transmission peaks a function of mirror reflectivity (assuming narrow laser linewidth)
- For our etalon, transmission peak FWHM is 27MHz and FSR is 1.5GHz

http://upload.wikimedia.org/wikipedia/commons/7/7e/Etalon-2.png

# Conclusions and Future Work

- I have constructed an ECDL with frequency noise on the order of 100MHz
- Further work should be done to determine optimal temperature and current for frequency stability
- Laser should be characterized using Fabry-Perot etalon
- Additional insight into sources of frequency noise could be achieved by transformation into the frequency domain
- Tunability of ECDL not as good as expected; need to make measurements with a higher voltage source

# Acknowledgements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- Ron Musgrave
- Stephen Dilorio
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# Questions?