Quantum Cascade Laser Frequency Modulation for Trace Gas Detection

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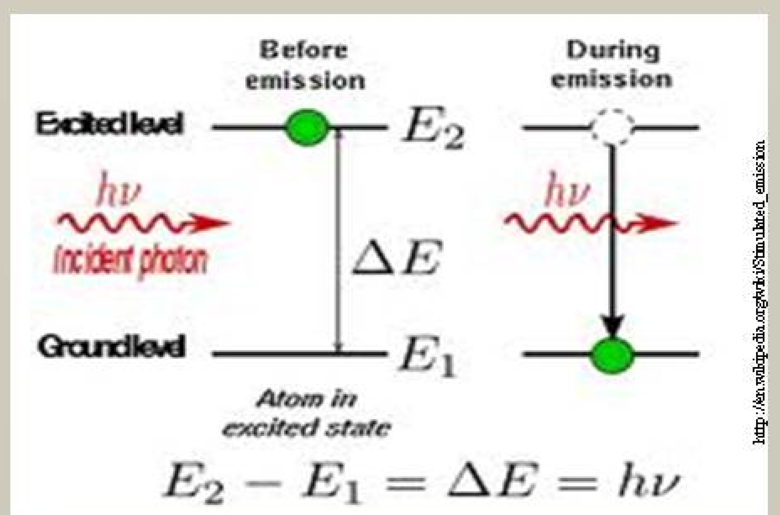
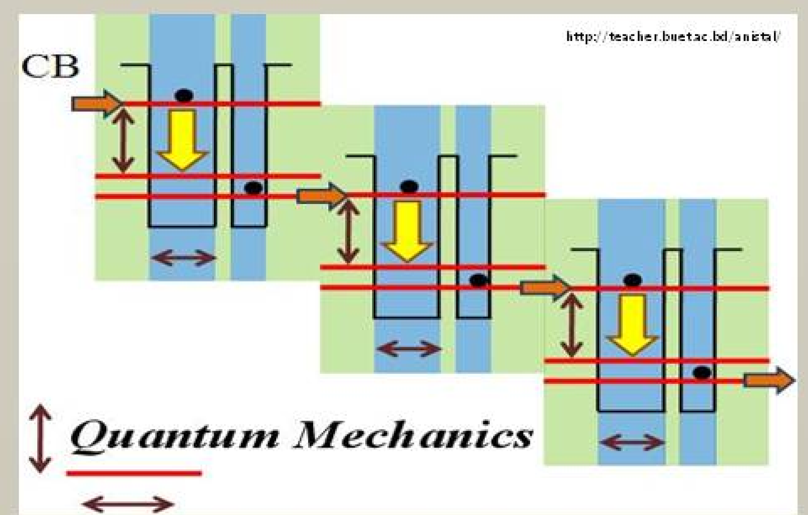
Quantum Cascade Lasers

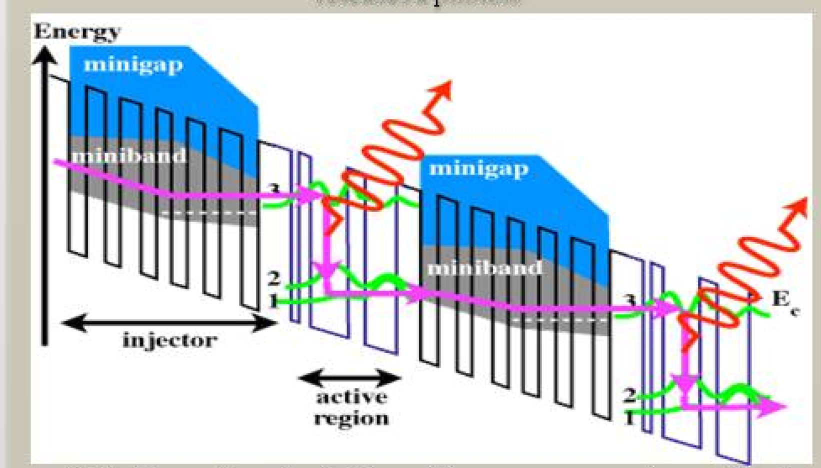
Quantum Cascade Lasers (QCL's) are a relatively new semiconductor laser with broad capabilities in the mid-to-far infrared frequencies due to their unique heterostructure that allows for high optical power within a very small medium.



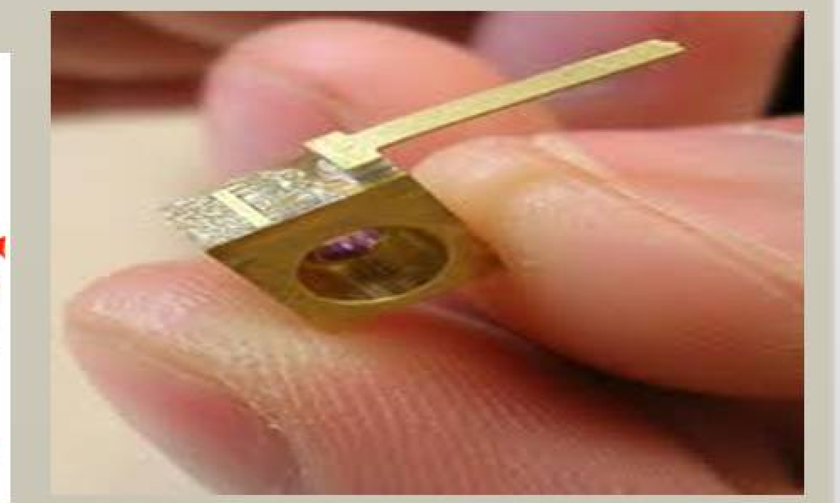
Electron is excited from the ground state to a higher state due to an energy source. When the electron returns to the ground state it releases a photon.



Electron transition between energy states within each quantum well.



QCL intersubbands, which contain numerous quantum wells. A single electron is capable of releasing several photons as it cascades down several energy gaps.

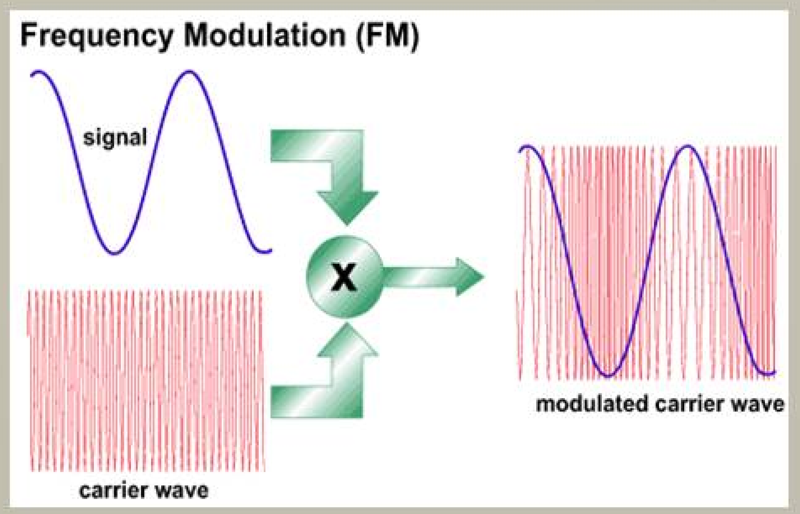


A Quantum Cascade Laser. The ability for multiple photons to be generated from fewer electrons frees this device from needing a electro-optic modulator or diode pump source.

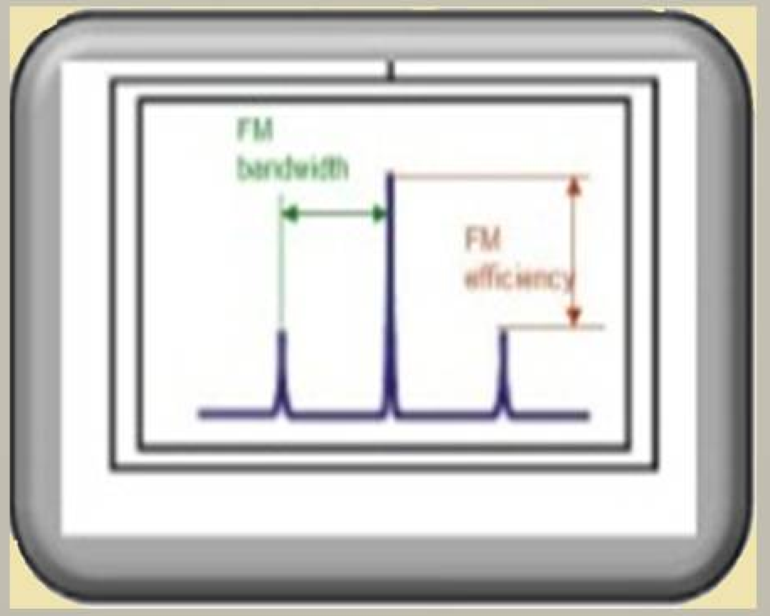
Currently, our team is attempting to calibrate our laser setup through frequency modulation so it may be used for numerous applications. Most notably, these applications include trace gas detection. This spectroscopy technique has many implications for possible NASA projects and missions in the long term.

Frequency Modulation

Frequency modulation is a signal processing technique in which information is sent via modification of a carrier frequency.



An example of frequency modulation in which information is placed on a carrier wave. The frequency of the carrier wave is adjusted to correspond to the information being sent. This type of modulation is usually found in radio transmissions.



FM modulation. When two modulated signals combine they create sidebands of various qualities.

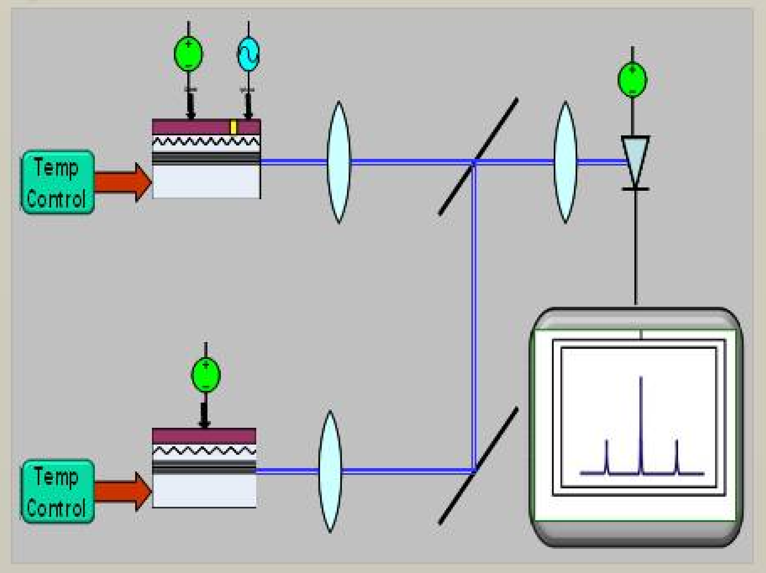
The optical field of the modulated signal can be presented as:

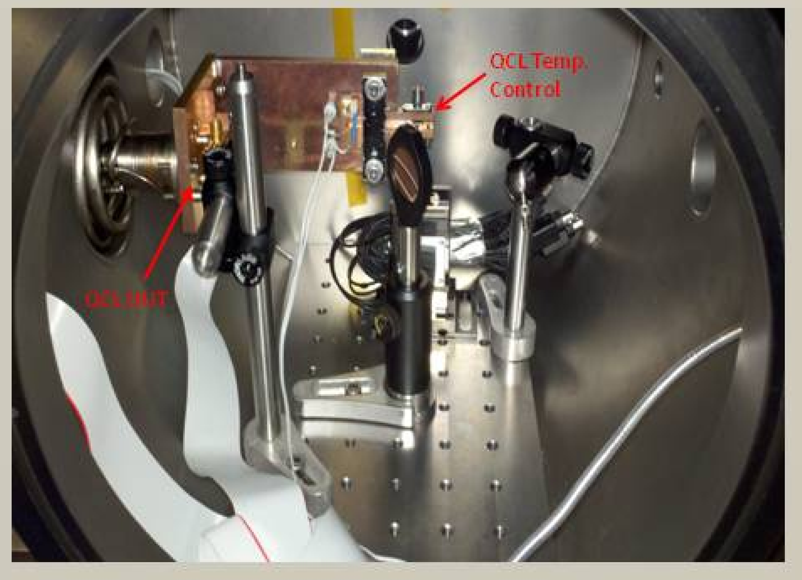
$$E \approx E_0 \exp(i\omega_0 t) \times \left[1 + \frac{\alpha}{2}\exp(i\Omega t) + \frac{\alpha}{2}\exp(-i\Omega t)\right] \times \left[1 + \frac{\beta}{2}\exp(i\Omega t) - \frac{\beta}{2}\exp(-i\Omega t)\right]$$

Where β is frequency modulation strength and Ω is modulation frequency, α is parasitic amplitude modulation which needs to be minimized in FM experiments

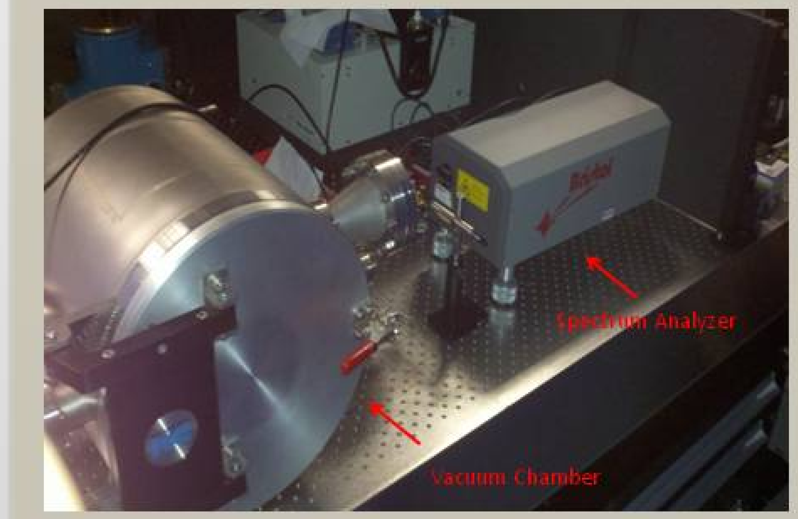
Optical System

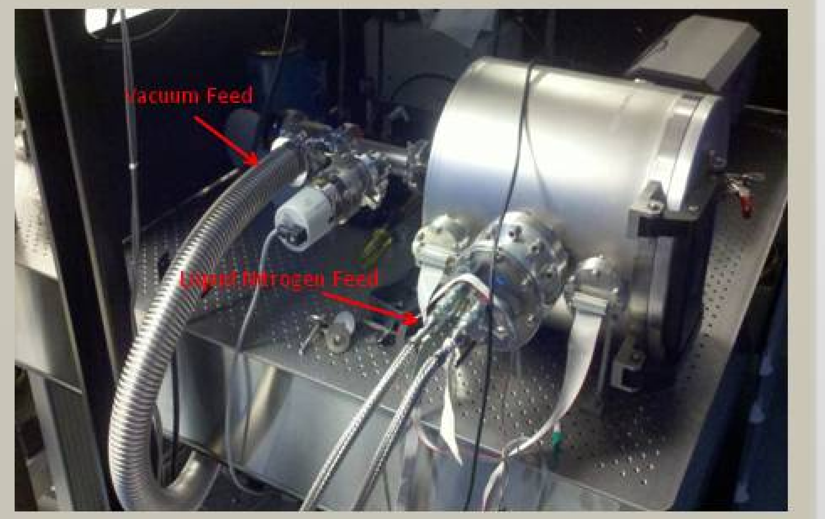
We construct an optical heterodyne setup where light from two identical QCL's combine on a photodetector and the IR frequency is extracted with an optical mixing process.





One QCL is a frequency modulated unit under test (UUT), while another serves as a reference that is temperature controlled to bring its carrier frequency close to that of the UUT. A photodetector is used for optical mixing and its output is connected to an RF Spectrum Analyzer for measurement.

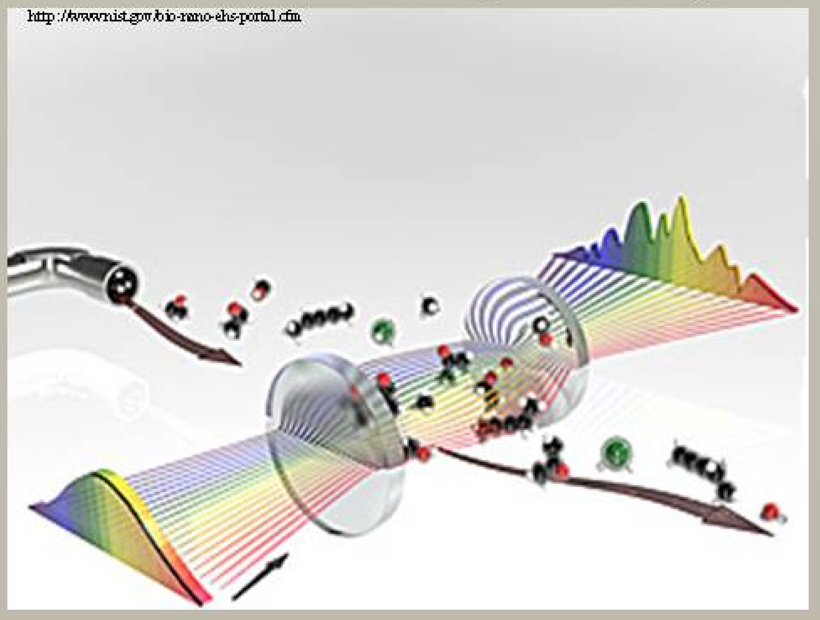


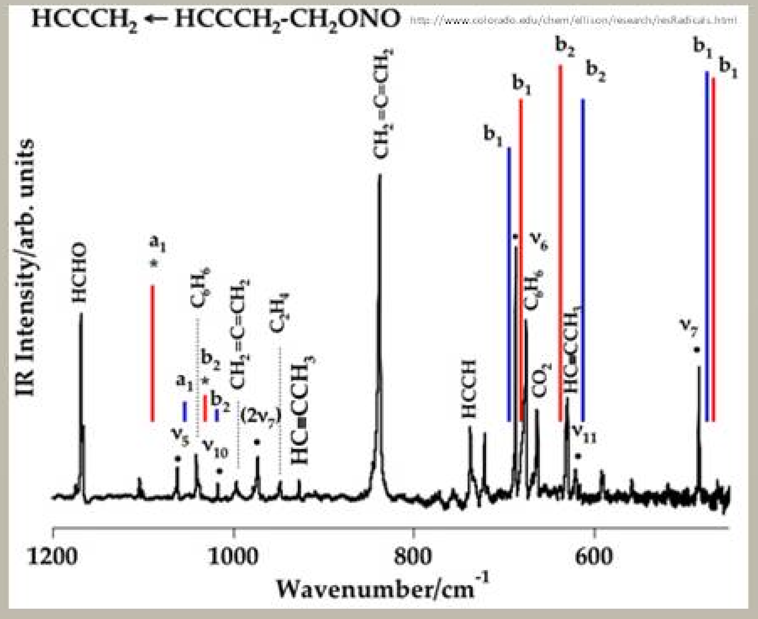


QCL's in our possession require cryogenic cooling for operation, so they are constructed inside the vacuum chamber and attached to a "cold finger" to cool the QCL's down to ~120K. A series of 4 lenses and a beamsplitter collimate the two beams and couple light to the photodetector.

Trace Gas Detection

Through frequency modulation, QCL's can be used in detecting gas molecules within the 3.5 – 12 μm spectral range. This range is suitable for detecting the emissions of various molecules such as methane, NO_3, fossil fuel byproducts, and even explosive material. These chemicals leave behind a "footprint," that can be detected within very narrow wavelengths. A QCL system would be able to lase a desired gas mixture and spectrally map out the various gas molecules inhabiting the air space.



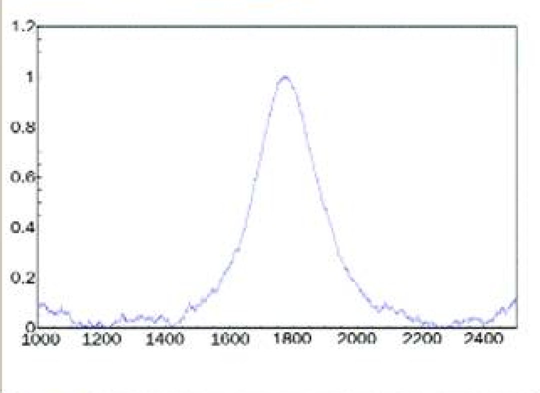


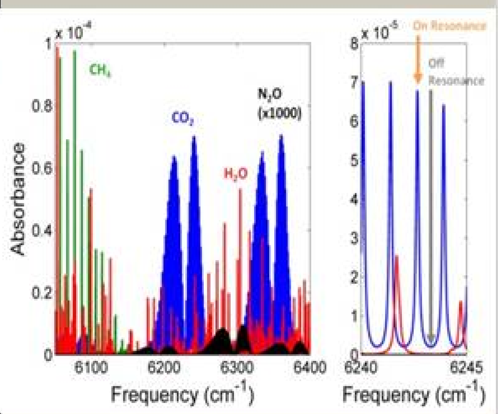
Possible Role in Future NASA Missions and Earth Science

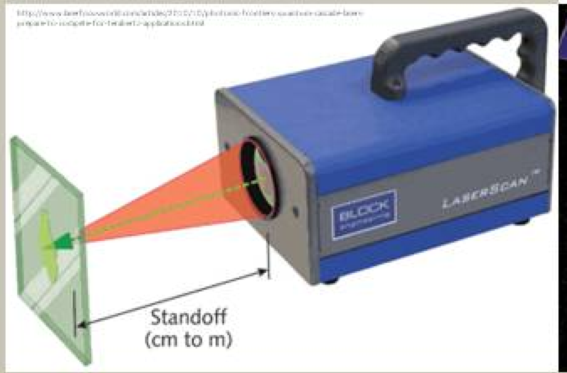
While current technological and manufacturing limitations have not made experimental usage of QCL's viable for short term NASA missions, it holds many future possibilities for Earth based studies.

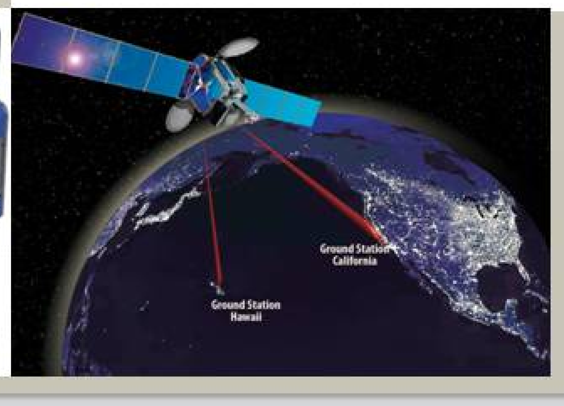
Their compact size and high optical power make them feasible for use in air flight and satellite missions for detecting changes in atmospheric conditions and greenhouse gas emissions.

QCL's provide many technological advantages due to their usability and ability to work within IR frequencies.









QCL portability also makes it a likely candidate for rapid data analysis of known hazardous areas or work areas prone with dangerous chemicals. QCL's are also a possible candidate for free-space communication.

Literature Citations

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