

Parasitic Thermal Wavelength Modulation In TDLAS

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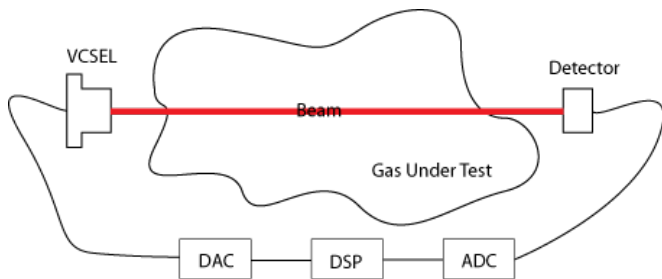
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Outline

- 1 Motivation
 - Tunable Diode Laser Absorption Spectroscopy (TDLAS)
 - Wavelength Modulation
- 2 Resolving the Discrepancy
 - Physical Model
 - Thermal Model
 - Solutions

Absorption Spectroscopy

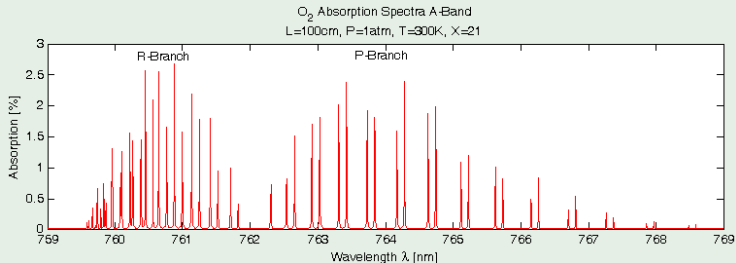


- Allows for non-contact probing of gas parameters such as temperature (T), pressure (P), and concentration (χ_m).
- Based on Beer's Law $\frac{I_o(\lambda)}{I(\lambda)} = e^{S(T)f(\lambda)P\chi_m\ell}$.

Absorption Spectra

- Integrated area proportionate to density
- Individual line strength based on state occupancy
- State occupancy proportionate to temperature

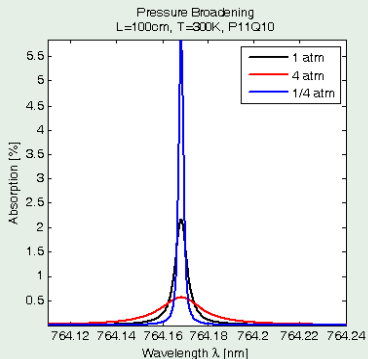
Oxygen's A-Band 759-769nm



Absorption Line Shape

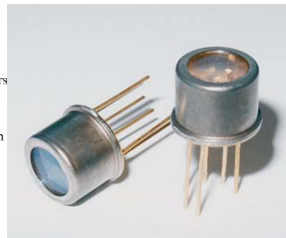
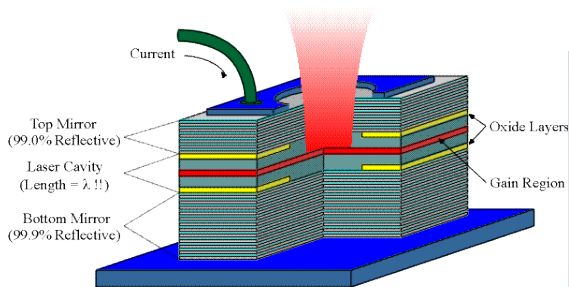
- Line shape $f(\lambda)$ strongly dependant on pressure
- Weakly dependent on temperature

Pressure Broadening



Tunable Diode Laser Absorption Spectroscopy (TDLAS)

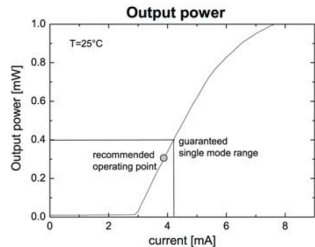
- Fiber optic communications industry has driven IR diode prices down
- Diode lasers wavelength can be current modulated
- Small size and robustness compared to gas lasers allows for new applications



VCSEL Modulation Parameters

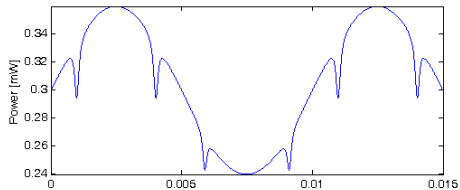
- AM Modulation
 $k_p = 0.3 \text{ mW/mA}$
- λ Modulation
 $k_i = 0.3 \text{ nm/mA}$
- $\lambda_o = 764 \text{ nm}$
- $V_{op} = 2.4 \text{ V}$
- $i_{th} = 3 \text{ mA}$
- Single mode and polarization stable below 5mA

VCSEL PI Curve

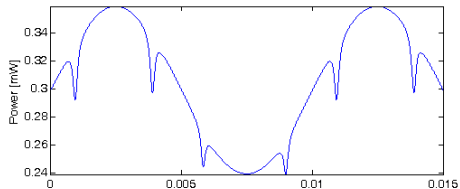


Theory and Practice

Theory



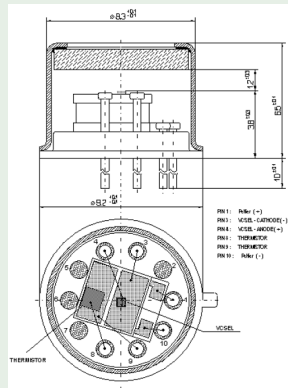
Practice



Die and Package Geometry

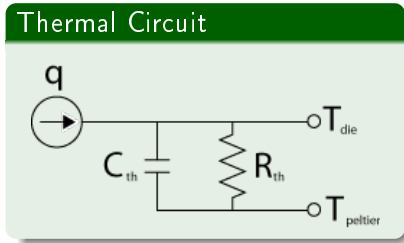
- Small die 0.5x0.5x0.3mm
- Large peltier cooler
- Evacuated hermetic package
- VCSEL active cavity on the die top
- GaAs substrate
- Wavelength is a function of die temperature and current density!
- $\lambda(\tau) = k_{ij}(\tau) + k_t T(\tau)$

VCSEL Package



Circuit Equivalent Cauer/Foster Model

- $q_{rad} = (i - i_{th}) k_p$
- $q_{heat} = iV_{op} - q_{rad}$
- $R_{th} = \frac{L}{kA}$
- $C_{th} = \frac{kV}{\alpha}$
- For GaAs: $\alpha = 0.31 \text{ cm}^2/\text{s}$
 $k = 0.55 \text{ W/cmK}$
- This die: $L = 0.2 \text{ mm}$
 $A = \pi 0.25^2 \text{ mm}^2$ $V = LA$



$$q(\tau) = C_{th} \frac{dT}{d\tau} + \frac{T(\tau)}{R_{th}}$$

Sinusoidal Drive

- $\frac{dT}{d\tau} + \frac{1}{RC} T = i(\tau) A + B$
- $A = \frac{(V_o - k_p) i_{ma}}{C}$, $B = \frac{k_p i_{th}}{C} + i_o$, $i(\tau) = \cos(\omega\tau)$
- $T = e^{-\tau/RC} \left[\int e^{\tau/RC} (A \cos(\omega\tau) + B) d\tau + D \right]$
- $T = \frac{A}{\sqrt{\zeta}} \cos(\omega\tau - \varphi) + BRC + D e^{-\tau/RC}$
- $\zeta = \frac{1}{(RC)^2} + \omega^2$, $\varphi = \arctan\left(\frac{1}{RC\omega}\right)$
- $1/RC = 344 \text{ Hz}$
- $\varphi = 29^\circ$
- $\frac{A}{\sqrt{\zeta}} k_t = 0.0039 \text{ K}$

1D FDTD Caur Model

- Finite Difference Time Domain
- Explicit R-C Formulation
- Oscillating Heat Input at Node 1
- Fixed 300K at Node 21

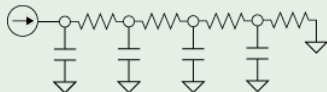
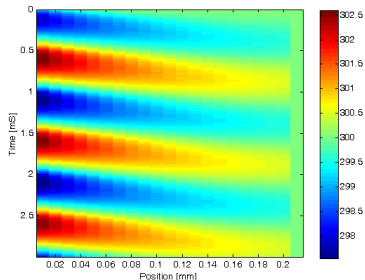
- Update $T_i^{p+1} =$

$$\frac{\Delta\tau}{C_i} \left[q_i + \sum_j \frac{T_j^p - T_i^p}{R_{ij}} \right] + T_i^p$$

- Stability

$$\Delta\tau \leq \left[\frac{C_i}{\sum_j (1/R_{ij})} \right]_{\min}$$

20 Node Simulation



For Further Reading I



J. P. Holman

Heat Transfer.

McGraw Hill, 1990.



E. Kreyszig

Advanced Engineering Mathematics.

Wiley, 1993.



R. Hanson, et al.

Mass Flux Sensor for Aircraft Jet Engines.

<http://hanson.stanford.edu/research/diode/massfluxsensor.htm>.



Avalon Photonics.

760nm VCSEL Data Sheet.

<http://www.avap.ch/pdfs/AVAP760TO510.pdf>.