Navigating the MIR Market: Applications, Products, and Developments

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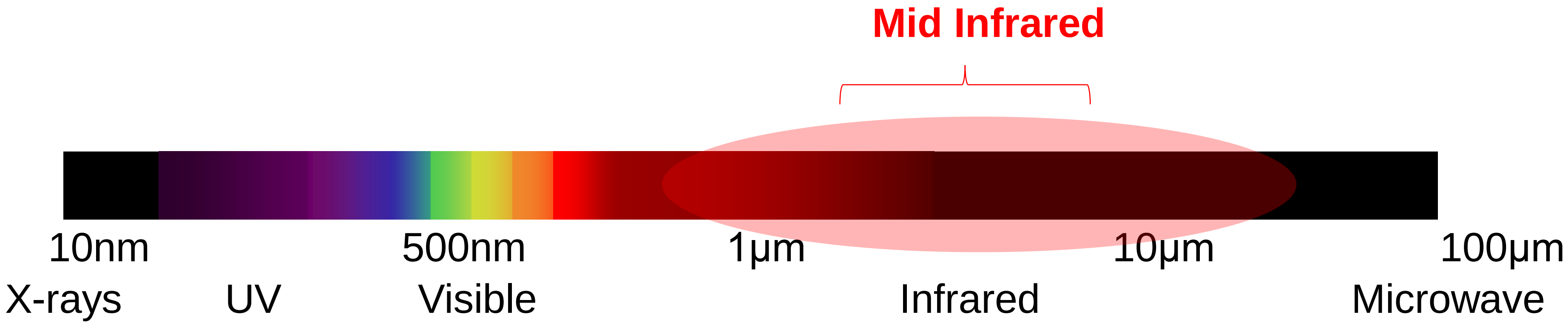
Index

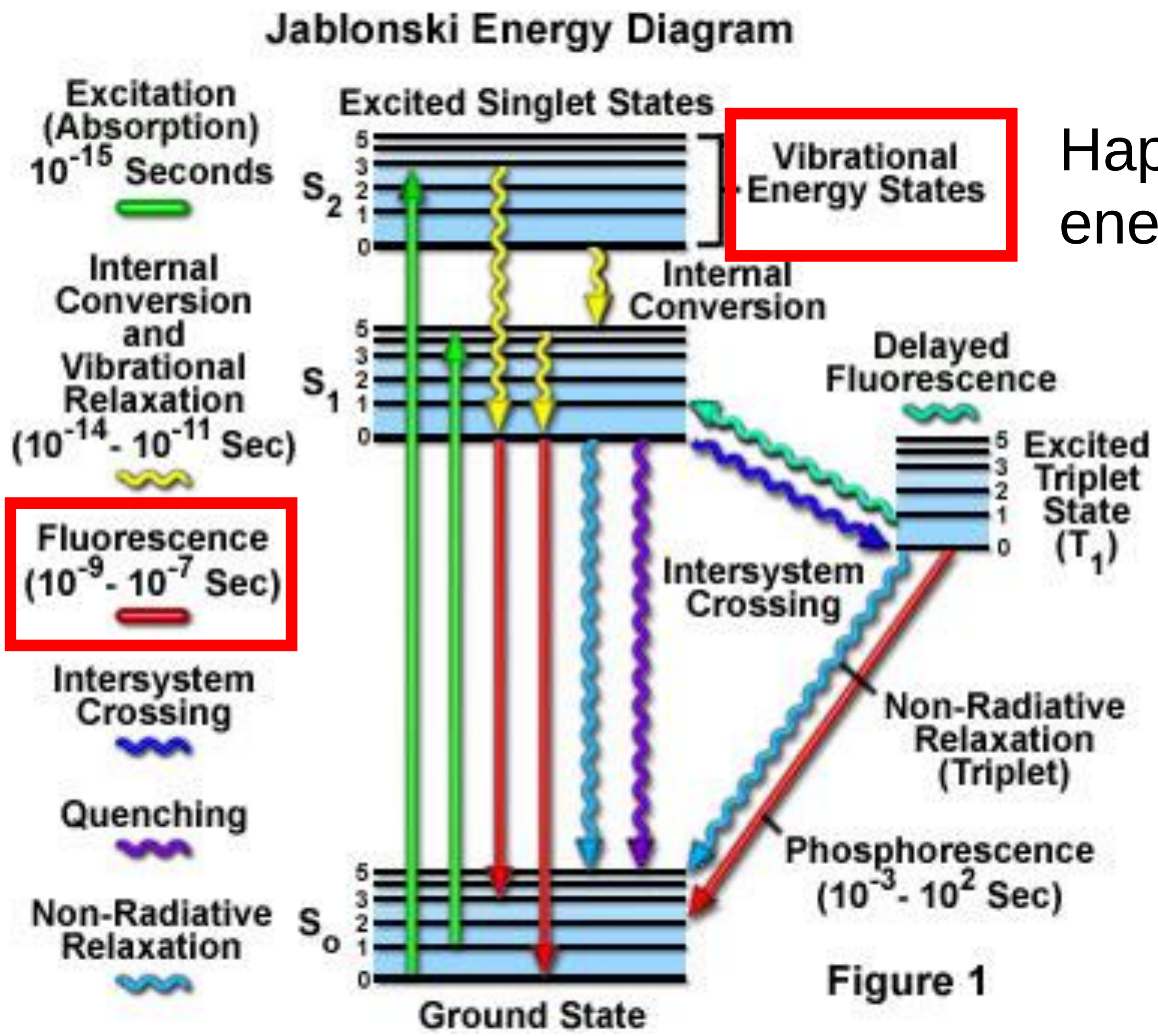
- Why are infrared measurements important? (pt. 2)
- Common applications
- Detector technologies
- Light sources
- Developments from Hamamatsu

What is the MIR region?

~3 µm to 20 µm for the purposes of this presentation



Molecular Energy States

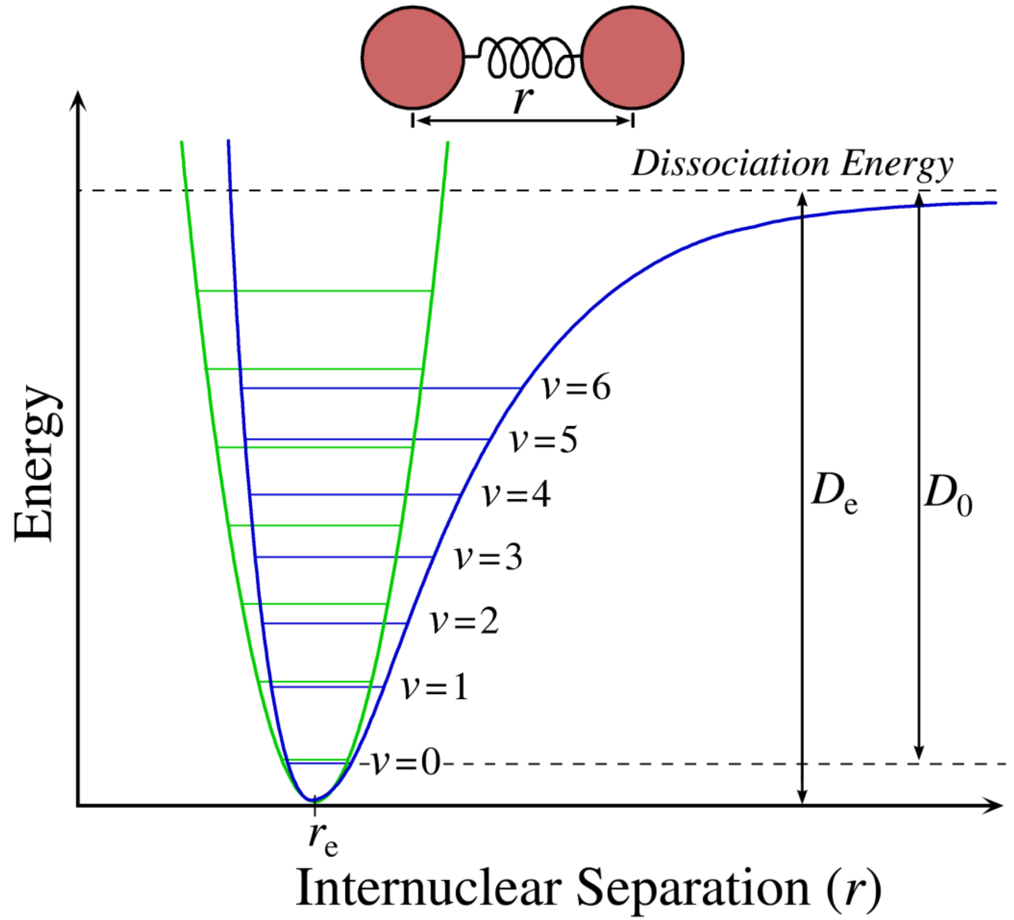


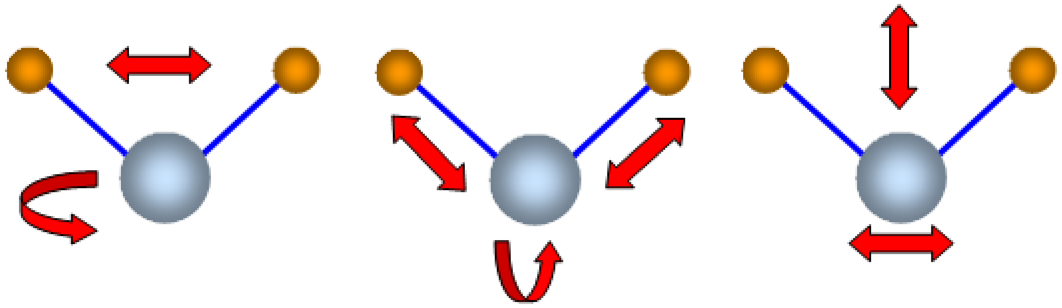
Happens with less energy (IR)

Happens with more energy (UV/Vis)

https://micro.magnet.fsu.edu/primer/java/jablonski/jabintro/index.html

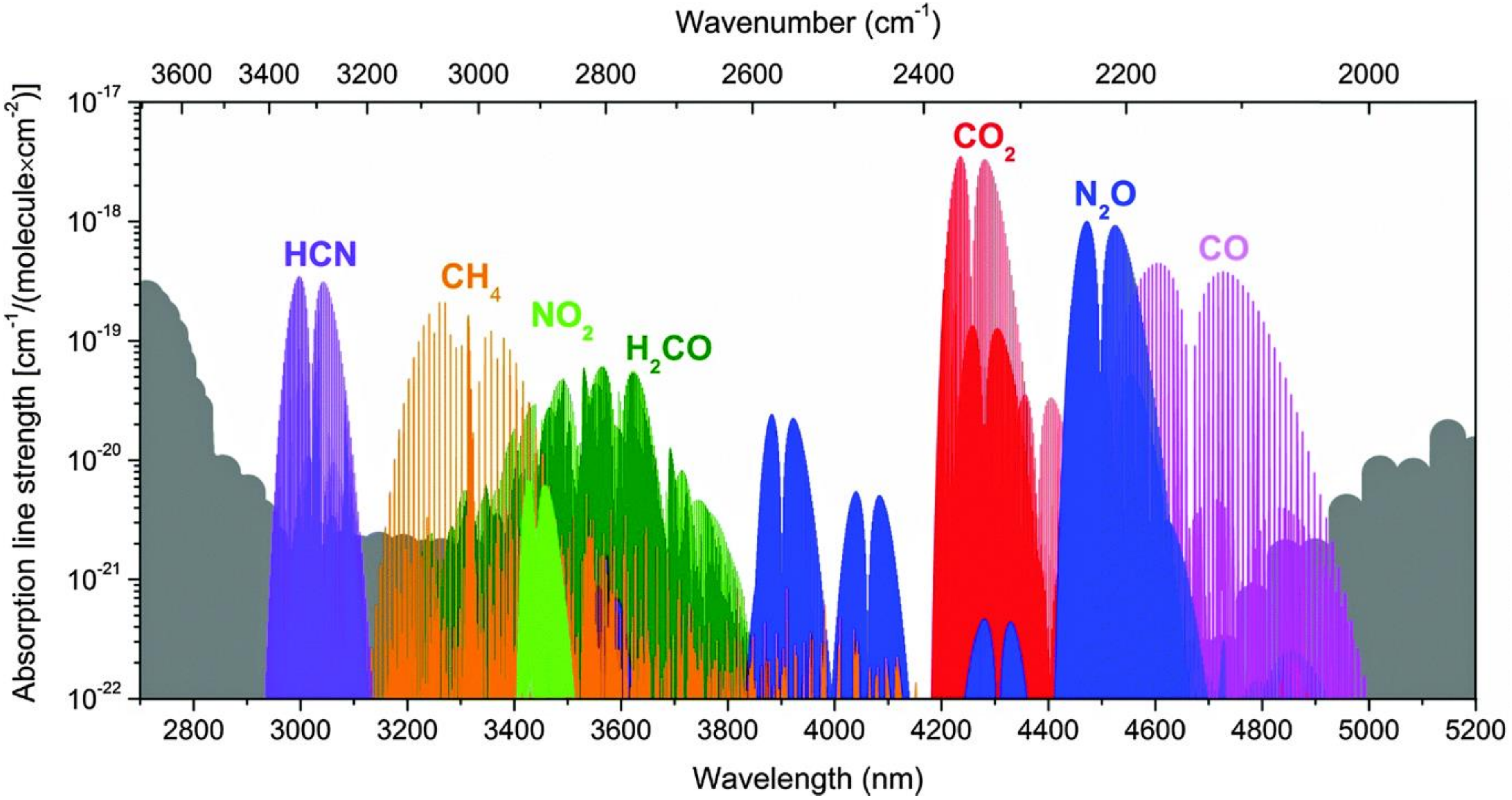
Molecular Vibration

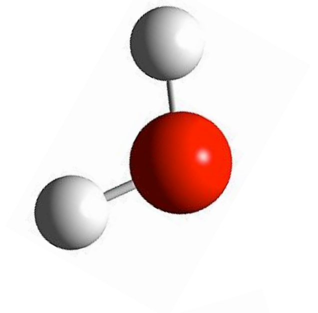


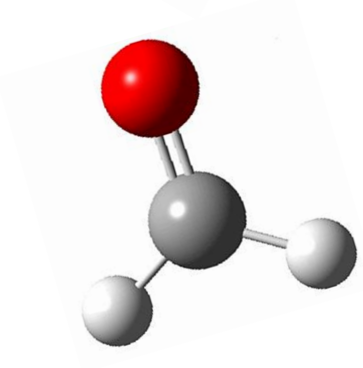


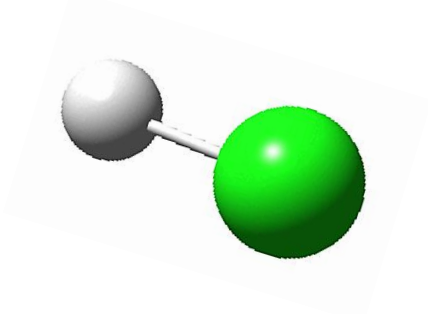
https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Map%3A_Physical_Chemistry_(McQuarrie_and_Simon)/13%3A_Molecular_Spectroscopy/13.05%3A_Vibrational_Overtones

Absorption Bands



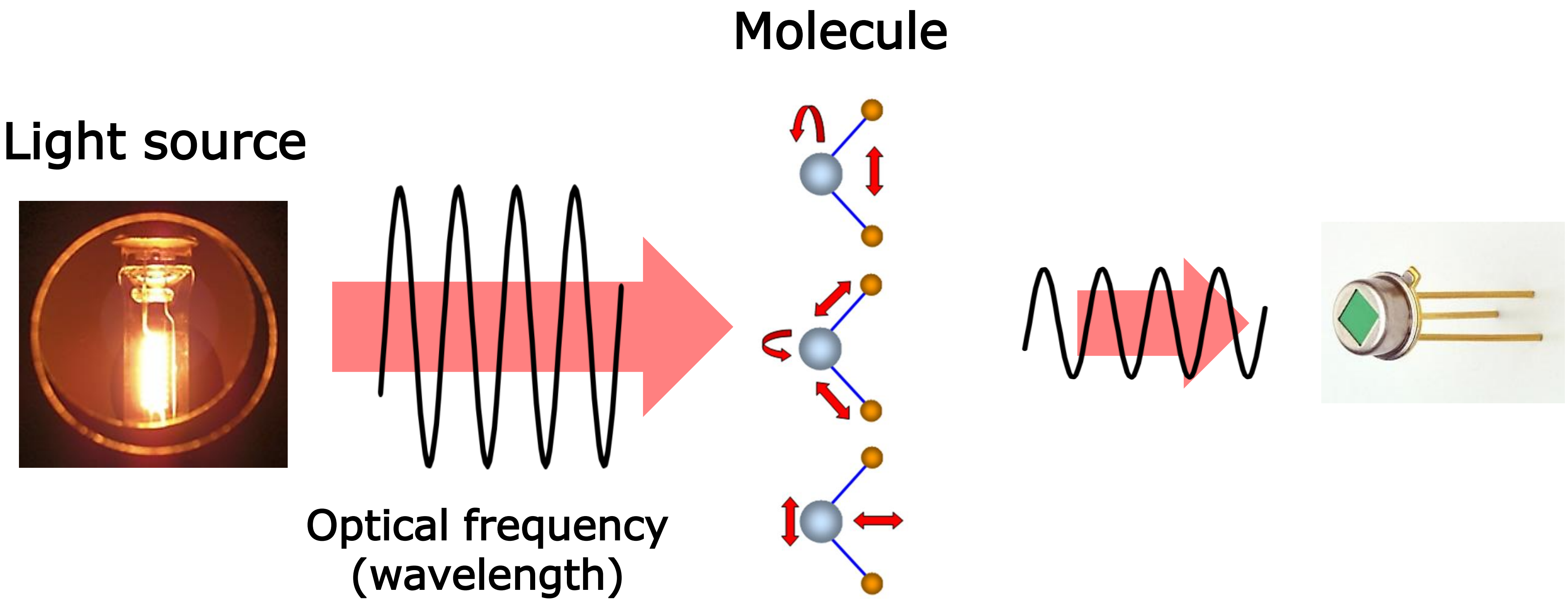




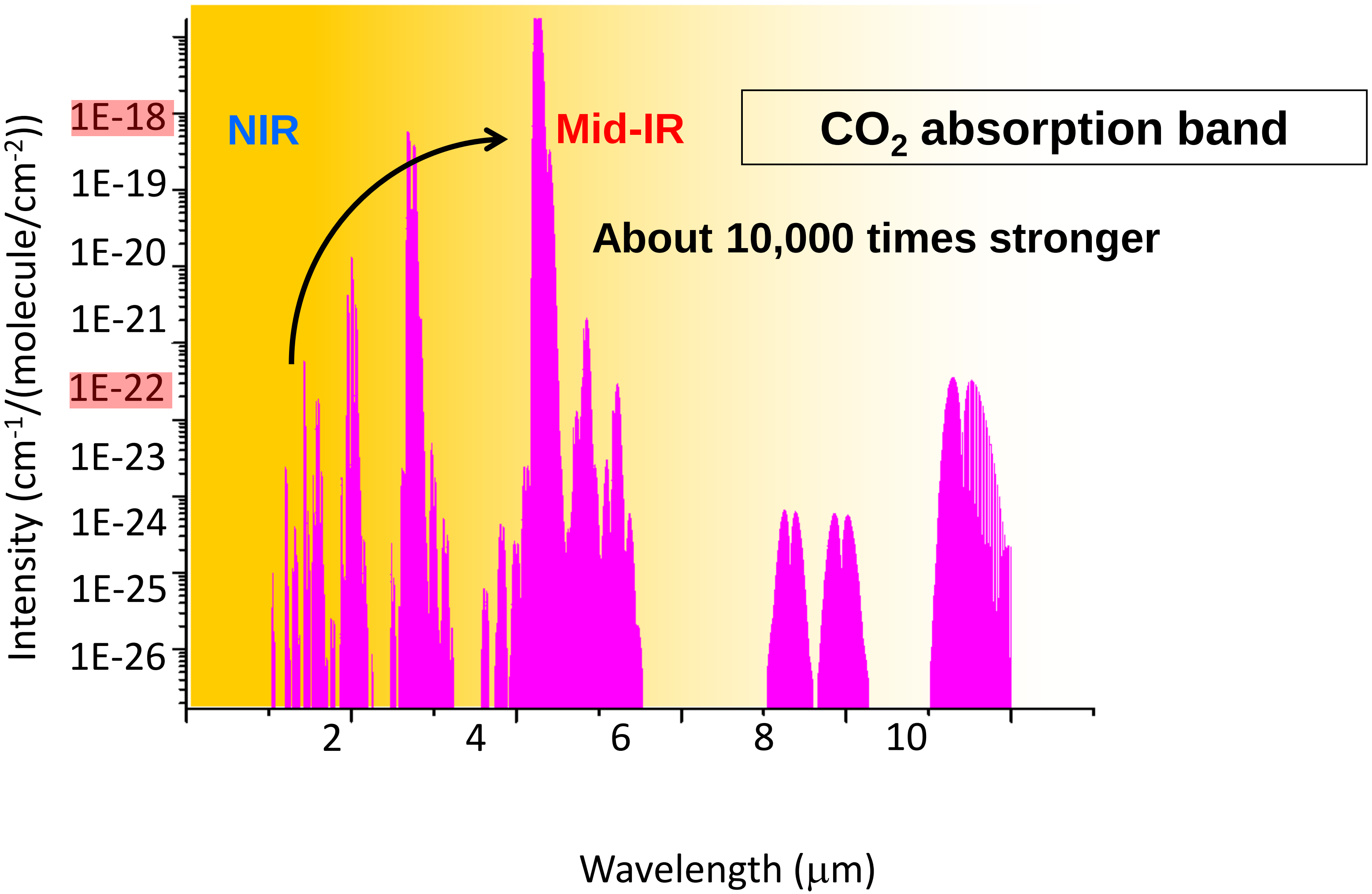


Source: HITRAN database

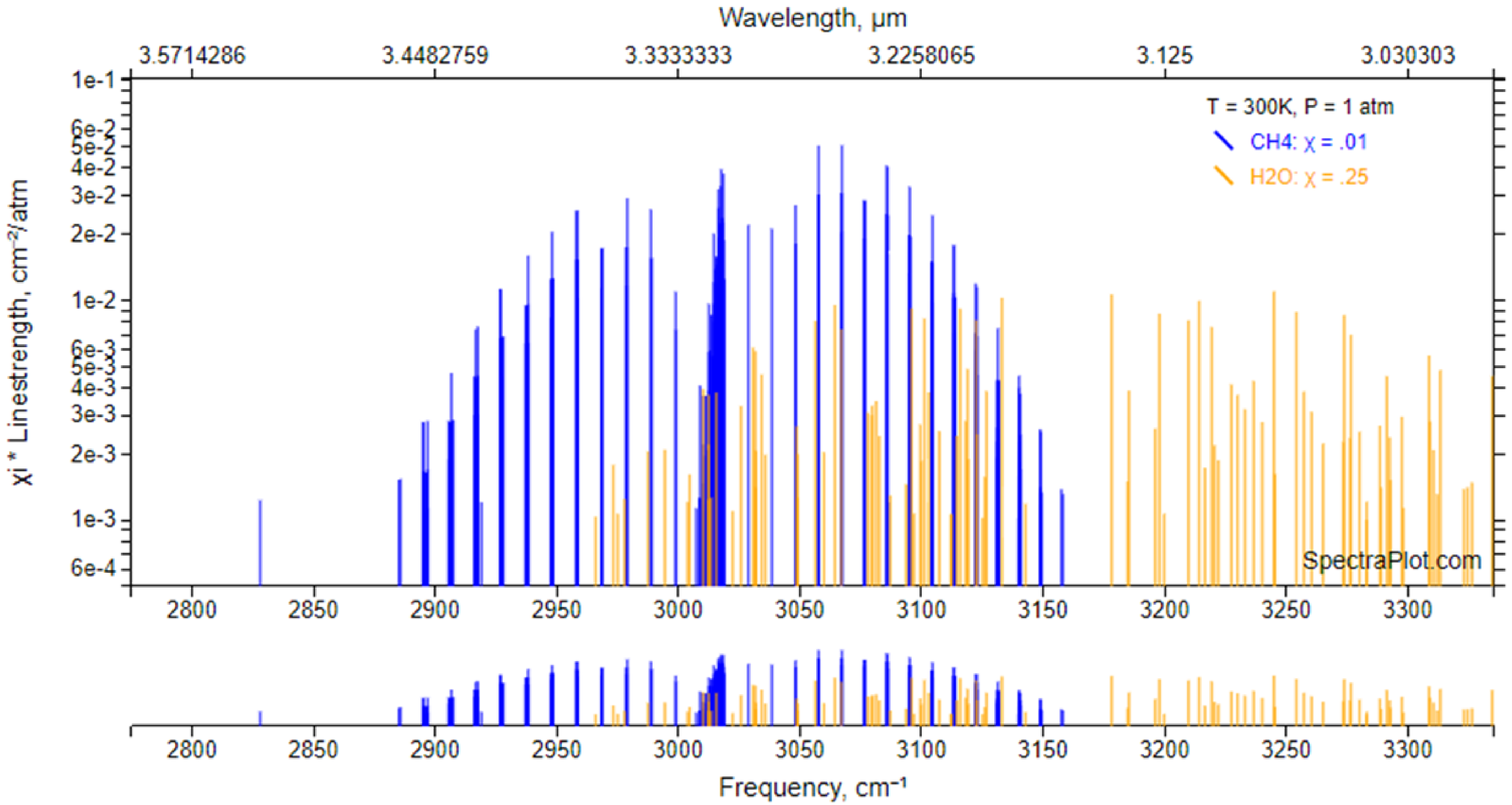
■ Optical absorption in action



Carbon Dioxide Example



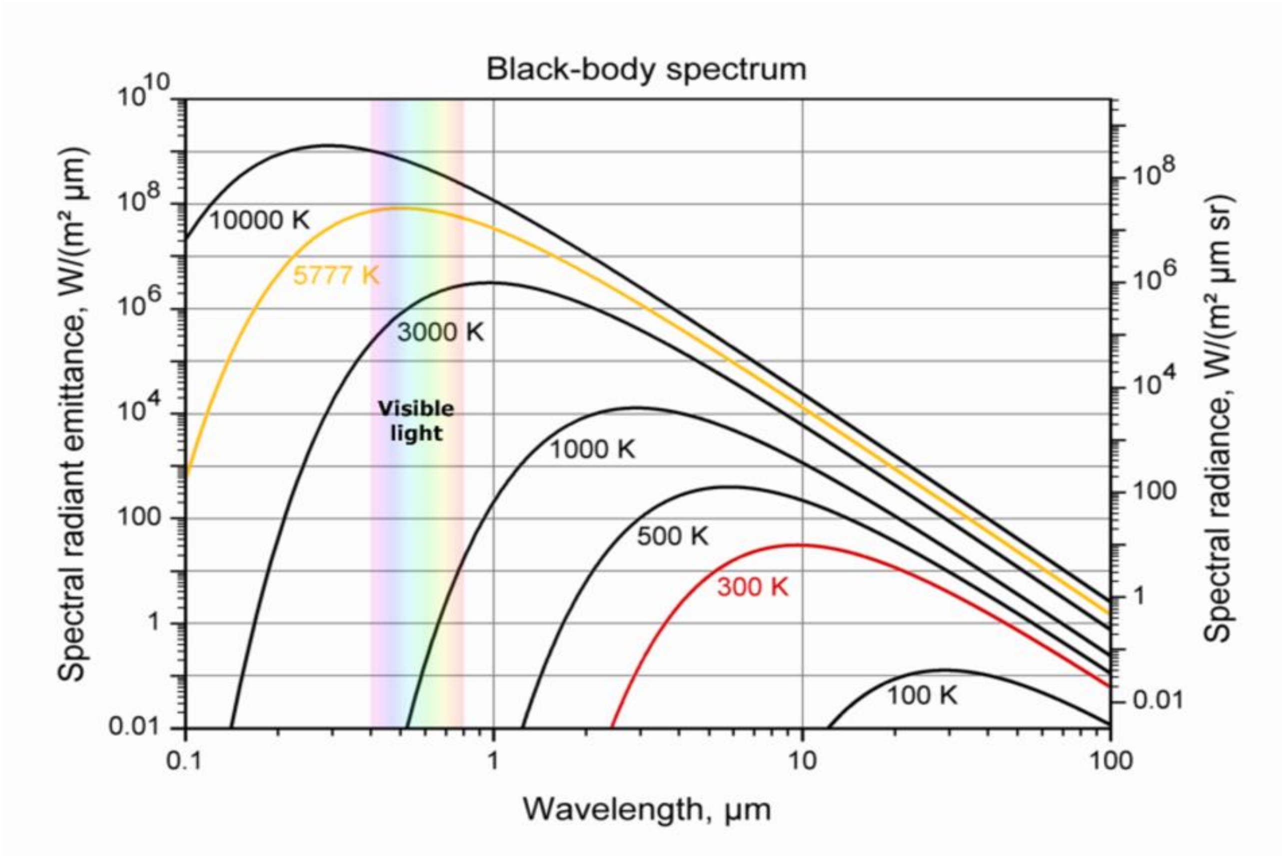
Methane Example



Source: spectraplot.com

Blackbody Radiation

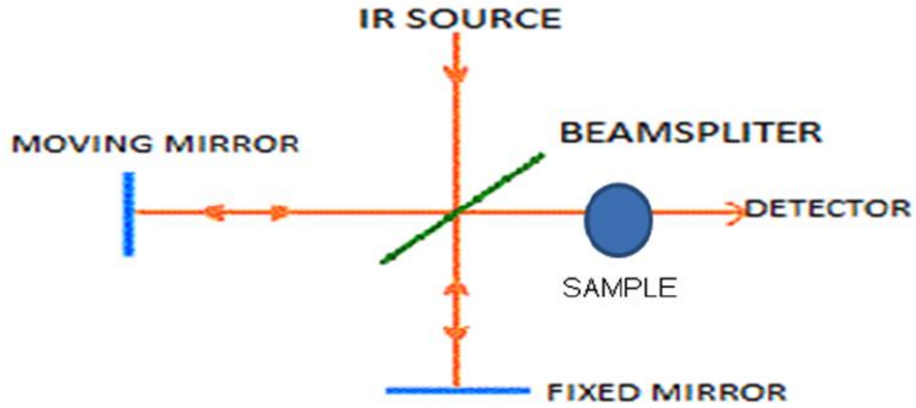
- When there is heat there is radiation
- Medical, industrial, and semiconductor spaces have critical dependence on process monitoring
- IR readings are a good choice for "cooler" substrates



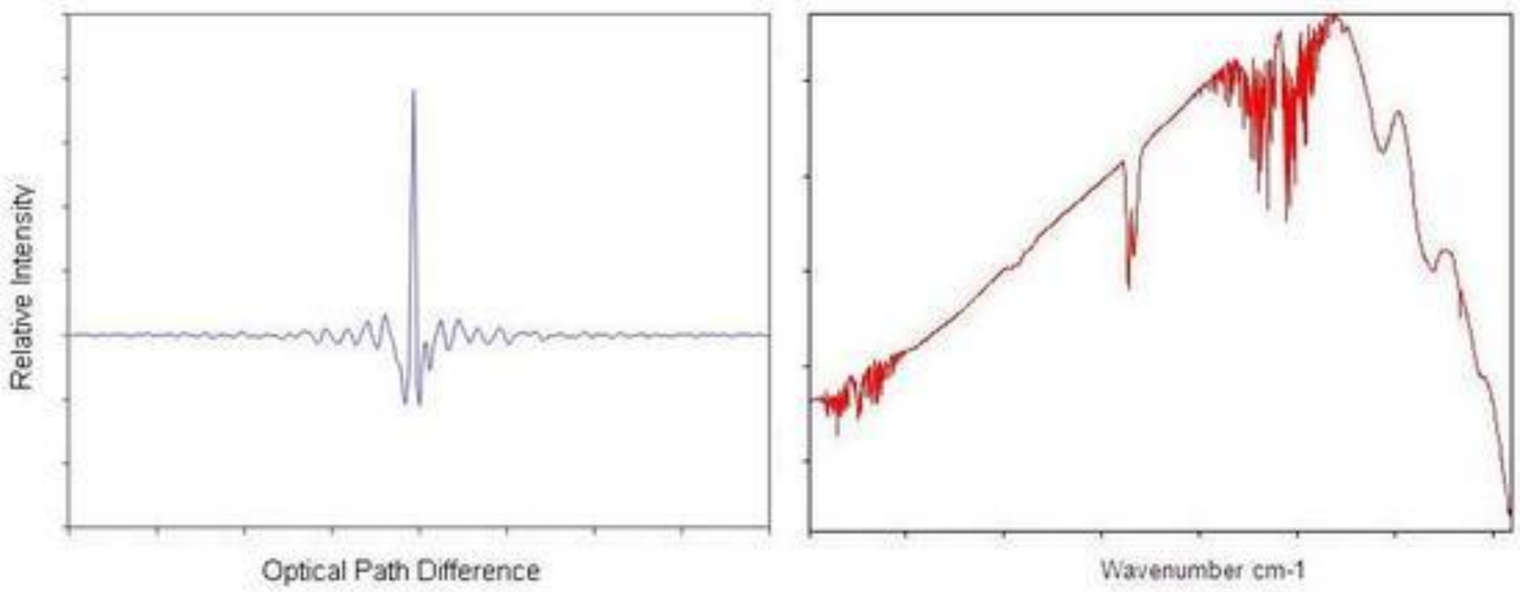
http://www.sun.org/encyclopedia/black-body-radiation

Applications

Fourier Transform Infrared (FTIR)

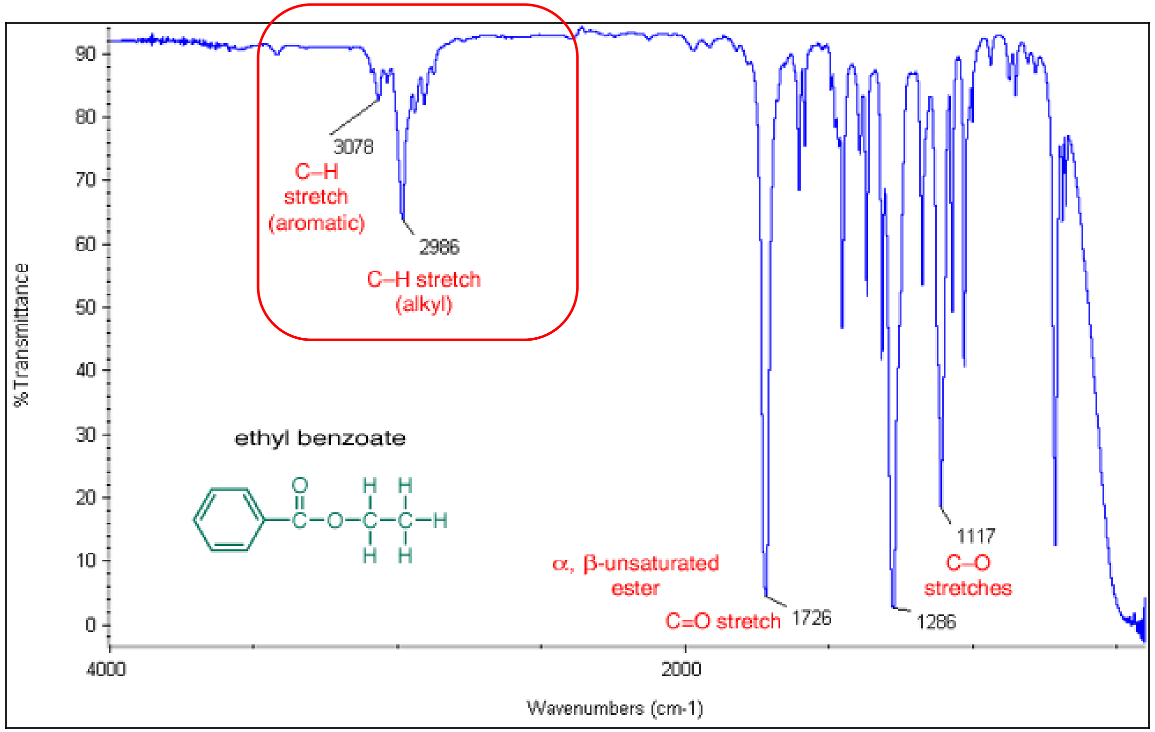


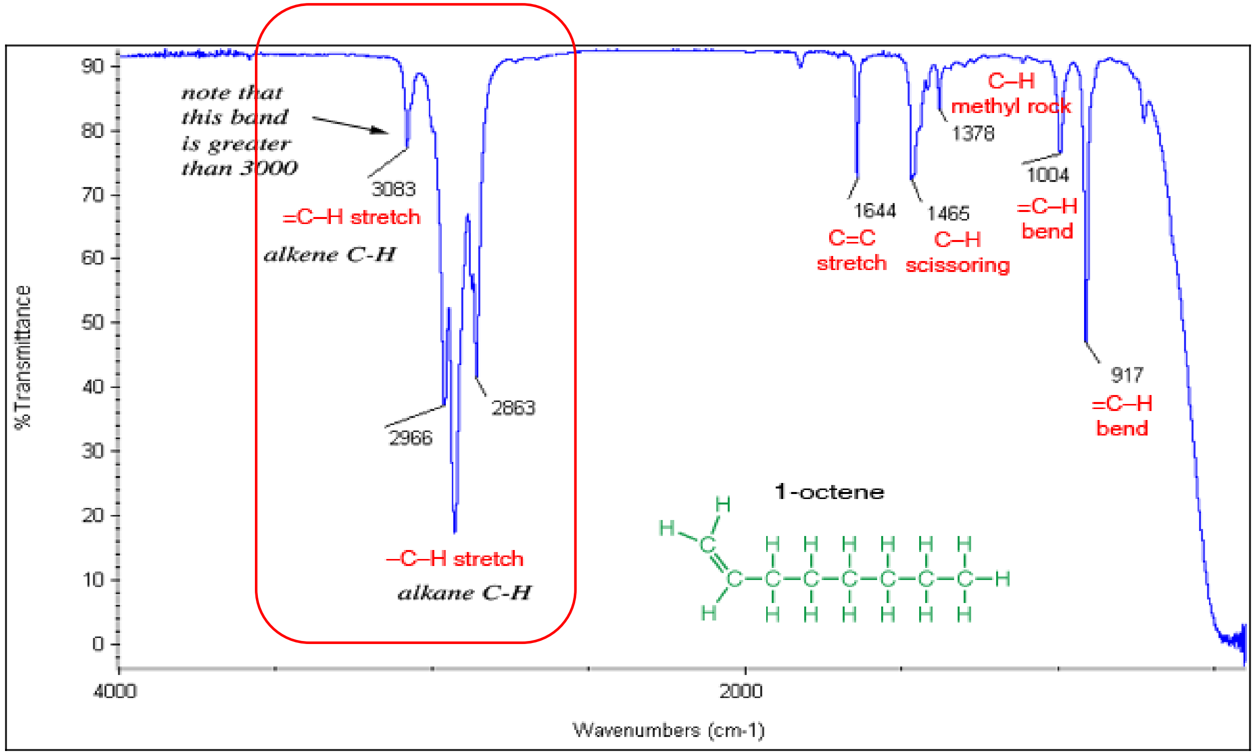
$$F(\omega)=\int_{-\infty}^{\infty} f(t)e^{j\omega t}\partial t$$



- https://www.researchgate.net/figure/Schematic-diagram-of-FTIR_fig4_292788248

Fourier Transform Infrared (FTIR)



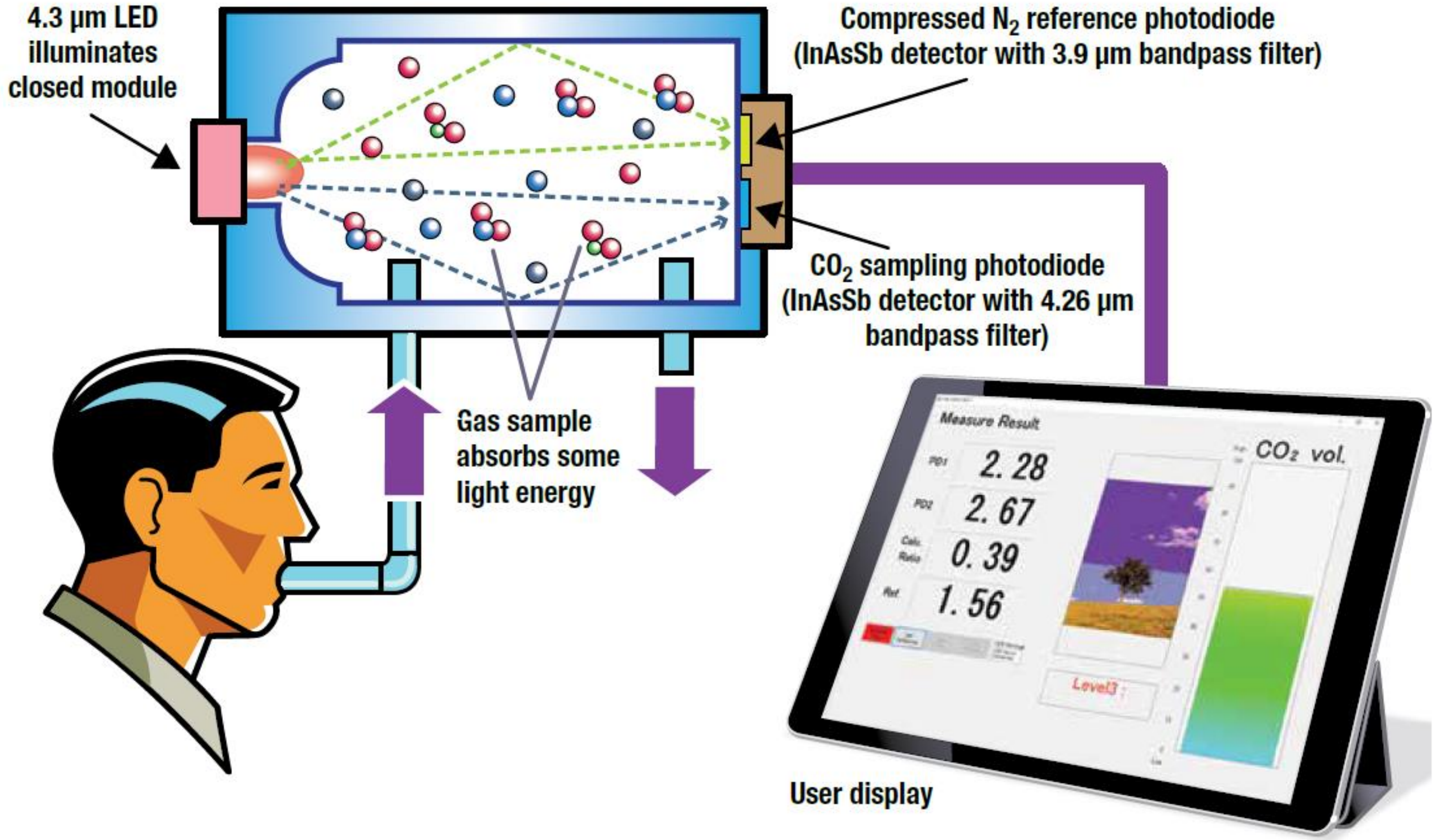


- Different chemical structures yields different absorption characteristics

https://orgchemboulder.com/Spectroscopy/irtutor/alkenesir.shtml

Non-Dispersive Infrared (NDIR)

- No spectral data, but focuses on the concentration of one gas
- If you have a reference channel, ratio of voltages correlates to concentration
- PPM sensitivity possible

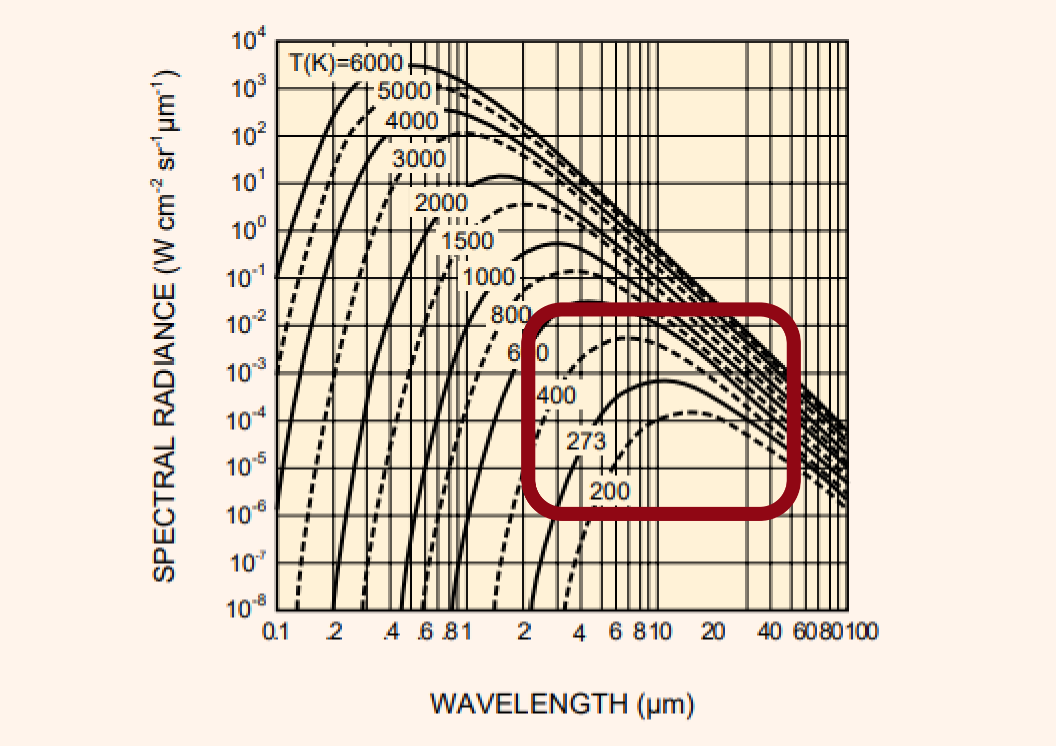


Temperature Sensing

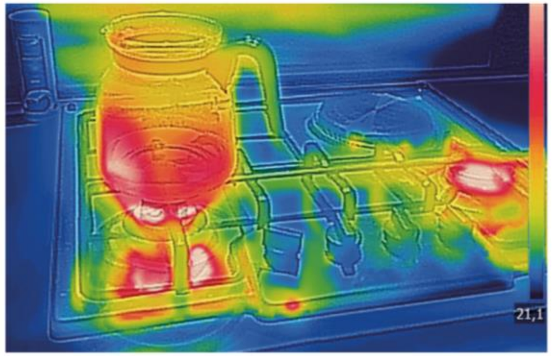
- Detectors sensitive in the MIR can be integrated for temperature measurements

- Emissivity of materials, differing characteristics for emitting thermal energy

- If someone has a fever, peak radiance is in the MIR



273 K = 32 F   311 K = 100 F



Pyrometer

- Monitor temperatures at a distance, monitor a process

- Process monitoring stops problems before they happen, overheating materials = defects.

- Proper optics and calibration involved

Summary – Why MIR?

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Strengths

- Molecules have vibrational interactions with IR light, which are unique and have a spectral “fingerprint”
- Tight absorption bands allow high sensitivity measurements
- NDIR and FTIR can identify and quantify certain species
- Avoid potential sources of interference
- High accuracy temperature readings for “cooler” temperatures, critical for certain processes

Challenges

- Complex space to navigate for detectors
- Developing market for light sources
- High demand for technical skills – electronics, physics, and optics
- Associated with higher cost

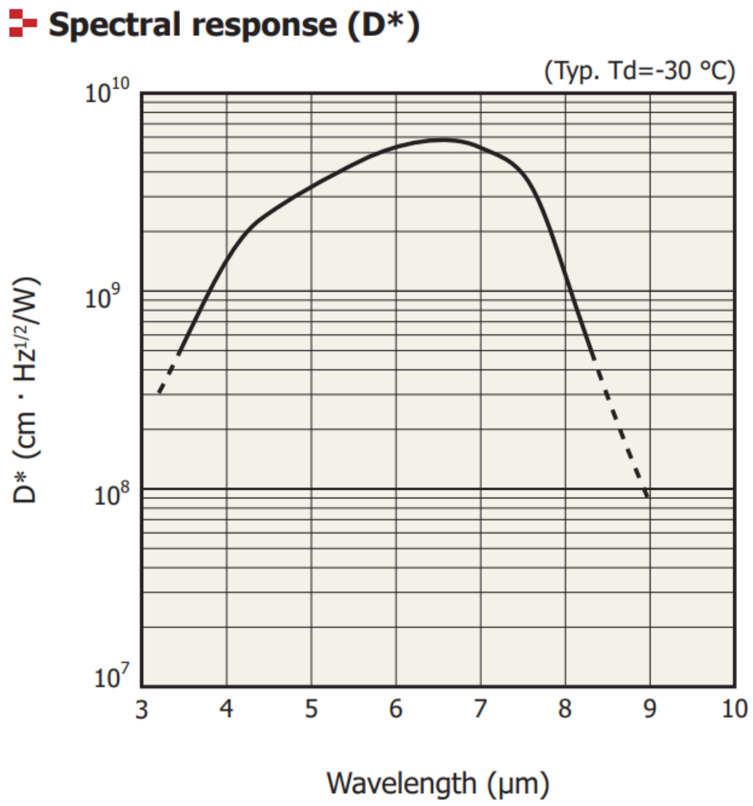
Detector Technologies

Consequences of Choice

- Using a room temperature detector at 10X the cost of a drop in replacement
- Using too much cooling when plenty of power is available, higher cost paid
- Difficulties with noise, hindering sensitivity
- Improper readout design
- Unable to run at desired speeds/frequencies

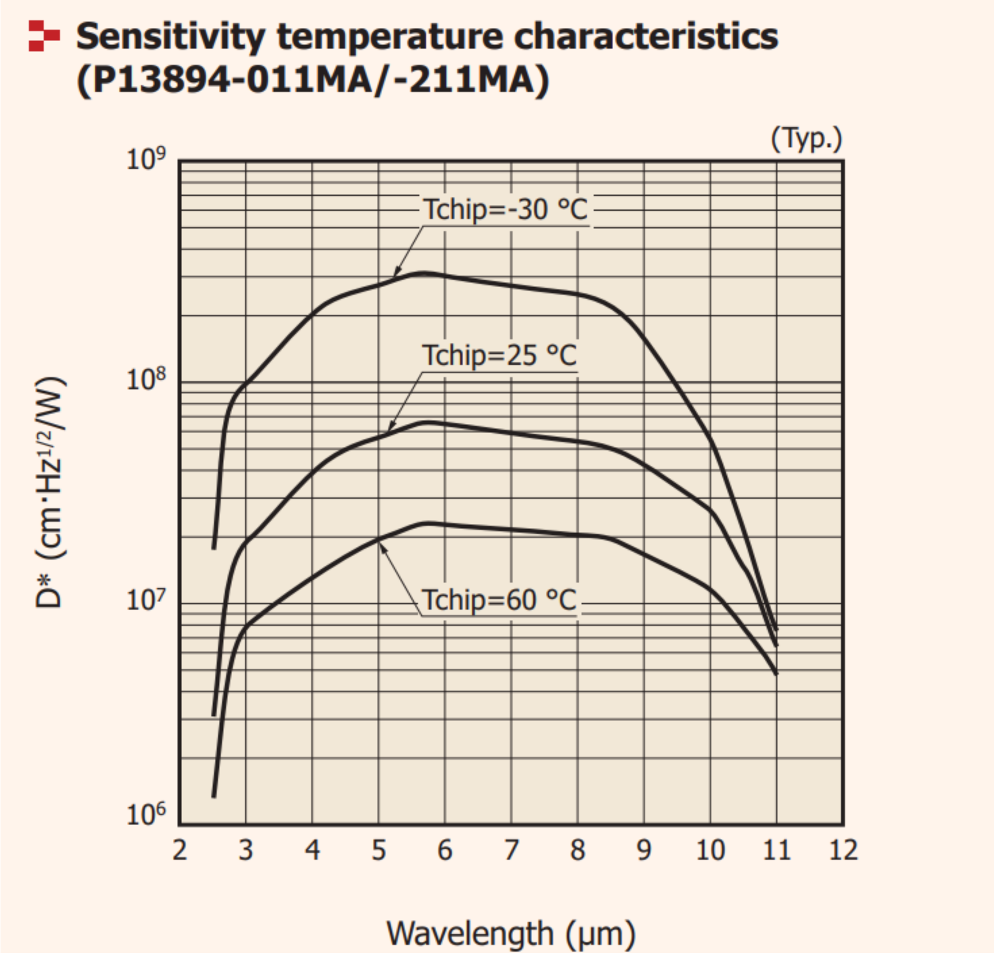
Important Specifications

- D* (Specific Detectivity) – sometimes also called sensitivity
  - $\frac{\sqrt{Area*Bandwidth(f)}}{NEP}$, $cm*\sqrt{Hz}/W$
  - Compare detectors with different areas
  - Differs with wavelength
- Speed, rise time
- Temperature dependence, Thermoelectric (TEC) cooling
- Linearity



Effects of Cooling

- Like most compound semiconductor detectors, cooling can yield more desirable performance
- Usually TEC element in can package but sometimes LN2 dewar
- Lower noise (higher D*) and increase in shunt resistance
- TEC is a fixed cost that can add hundreds per stage of cooling
- Price and complexity vs. performance



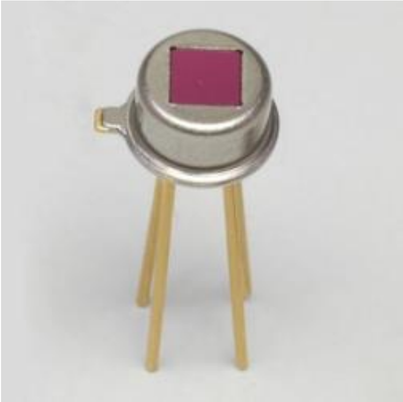
Thermal Detector - Thermopile

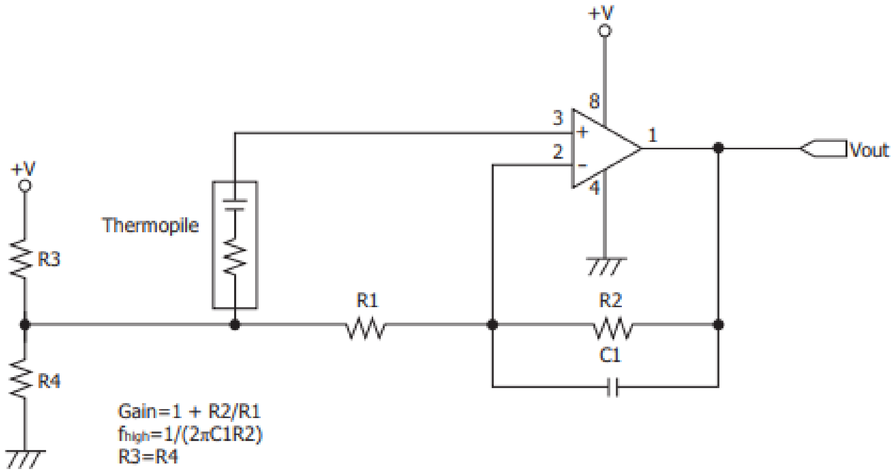
Strengths

- Low cost
- Consistent sensitivity curve, independent of wavelength
- Versatile

Challenges

- Although curve is consistent, D* is relatively low
- Cannot perform high frequency, rise time on the order of milliseconds

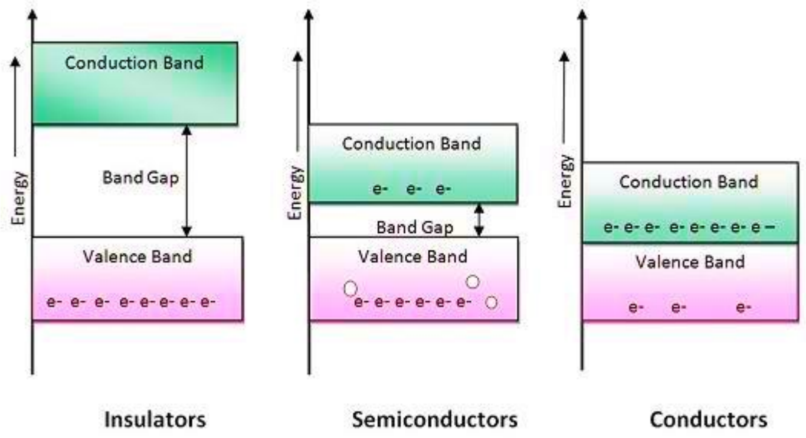




Principle of solid state solution

- Different materials yield different band gaps
- Design also has impact and may be proprietary

$$E = h\nu = \frac{hc}{\lambda}$$



Semiconductor materials of focus

- Lead Selenium/Sulfide (PbS/PbSe)
- Mercury Cadmium Telluride (MCT)
- Indium Arsenide Antimonide (InAsSb)
- All with multiple possible vendors

https://electricalvoice.com/material-classification-based-energy-band-diagram/

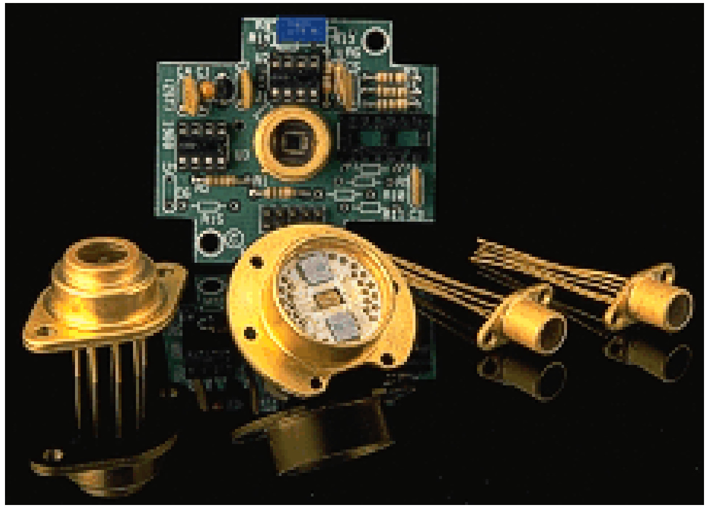
Lead Detectors (PbS/PbSe)

Strengths

- Low cost
- Good D* to about ~6 micron

Challenges

- Not RoHS compliant
- Sensitive to temperature changes
- Extra noise makes high accuracy measurements difficult
- Limited response in the longer wavelengths



Source: Teledyne Judson

Mercury Cadmium Telluride (MCT)

Strengths
- High D* with immersion lens
- Industry standard for high accuracy FTIR
- High speed
- Detection out to 20+ micron with multi-TEC cooling

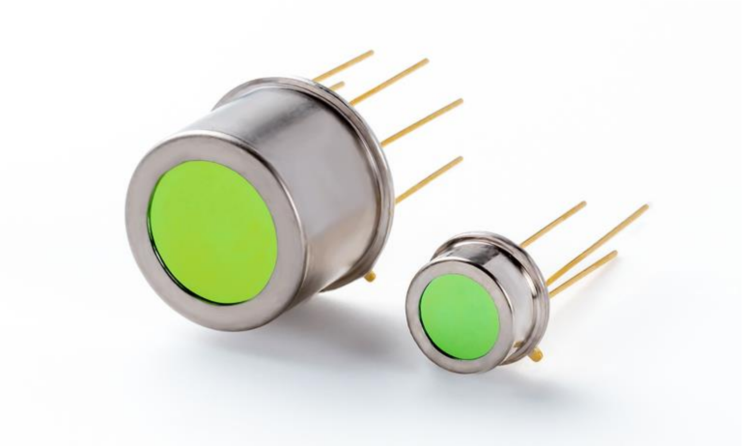
Challenges
- Not RoHS compliant – but exceptions due to lack of long wavelength options
- Unit to unit variability, variable spatial uniformity
- Managed by limiting operation in linearity curve, limiting dynamic range
- Uncooled detectors are expensive

Source: Vigo

Indium Arsenide Antimonide (InAsSb)

Strengths

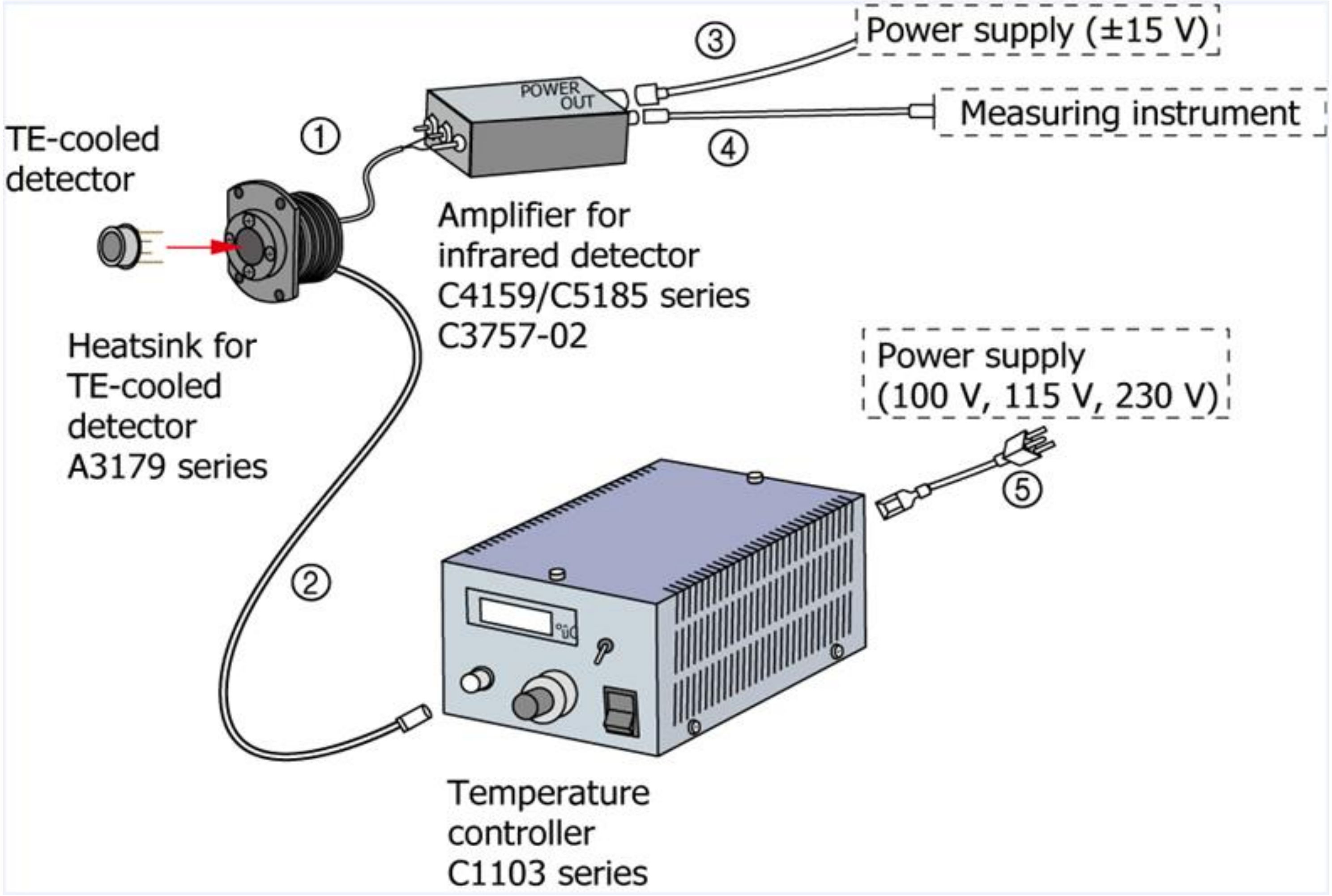
- RoHS compliant
- High speed
- Low-cost uncooled detectors – New option for temperature readings!
- Much more consistent manufacturing



Challenges

- Marginally less sensitive, lower D*
- Cannot reach longer wavelengths – 14 micron is the current limit

Setup Example



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Photovoltaic (No bias)

- Typically used for higher accuracy measurements
- Doesn’t require bias on detector but requires amplifier for voltage output
- Sensitivity/shunt resistance and unit to unit consistency are significant

Photoconductive (Bias)

- Typically used for higher speed, high light power at impact
- Bias on detector
- Leakage current leads to higher noise ratio

Summary for Comparison

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Thermopile	InAsSb
• Cheap and versatile, mostly used for temperature measurements • Flat sensitivity curve but relatively low performance versus solid state • Slow by comparison (millisecond rise times)	• RoHS compliant • Uncooled detectors now available at lower cost • Dual-channel is a great choice for NDIR gas analysis • May have lower D* and currently capped at 14 micron response
MCT	**PbS/PbSe**
• High D* and main choice for applications that require 20+ micron detection • Unit to unit variability, can cause issues in certain applications • Uncooled detectors are expensive	• High D* at lower cost versus other solid state detectors • Sensitivity changes with ambient temperature, can be contribute noise • Limited response for longer wavelengths

Light Sources

Light Sources – Thermal Sources

- **Incandescent and full IR lamps, utilizing blackbody light principle**

Strengths

- Low cost
- Can withstand high current inputs, achieving higher output
- Broad output, can utilize filters

Challenges

- High power requirements
- Shorter lifetimes
- Extreme heat can create design difficulties

Source: Newport

Light Sources - LED

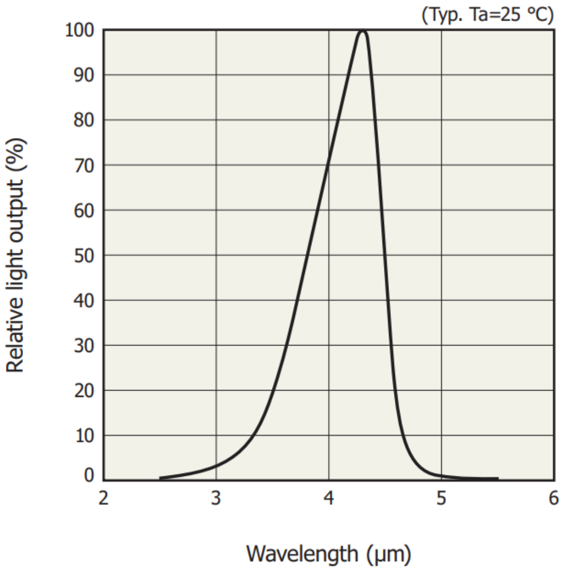
- **Solid state material for light generation instead of detection**

Strengths

- Low cost (though it's more than comparable thermal)
- Long lifetime
- Low power requirements, great for portable NDIR
- Peak emission wavelength (example 4.3 micron)

Challenges

- Not suitable for multiple gases
- Low output power
- Typically suited for high frequency modulation and low duty cycle

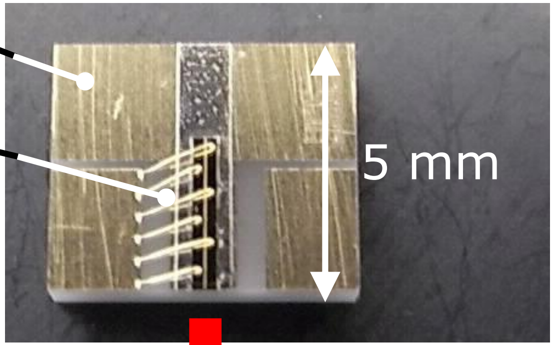


Quantum cascade lasers

■ Mid-infrared semiconductor laser

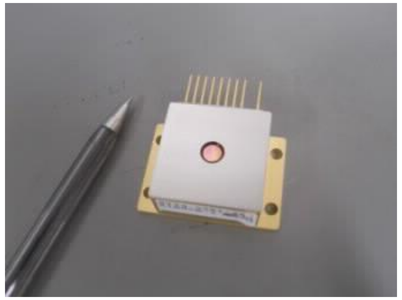
Sub-mount

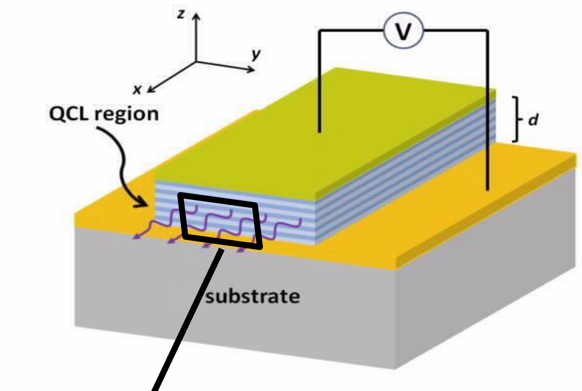
QCL-chip

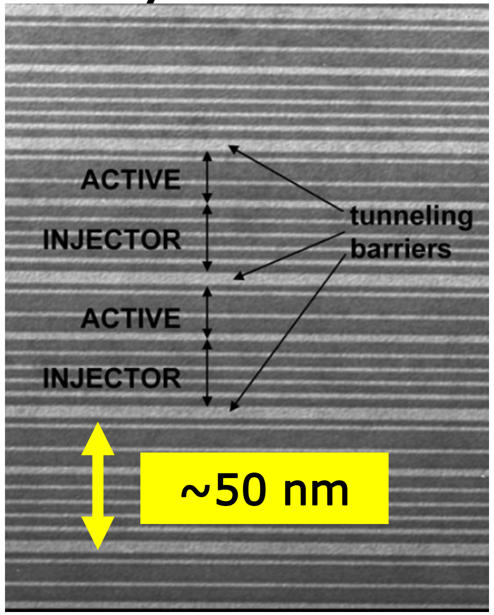


Laser radiation

packaged product

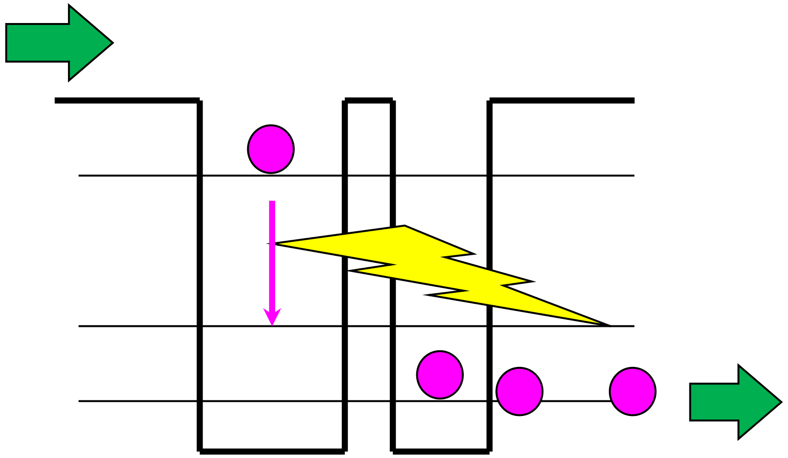




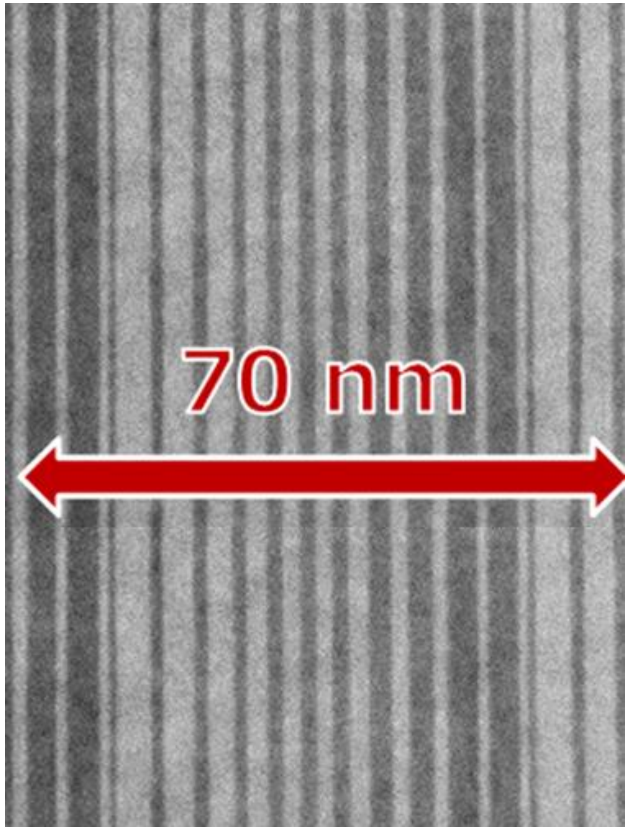


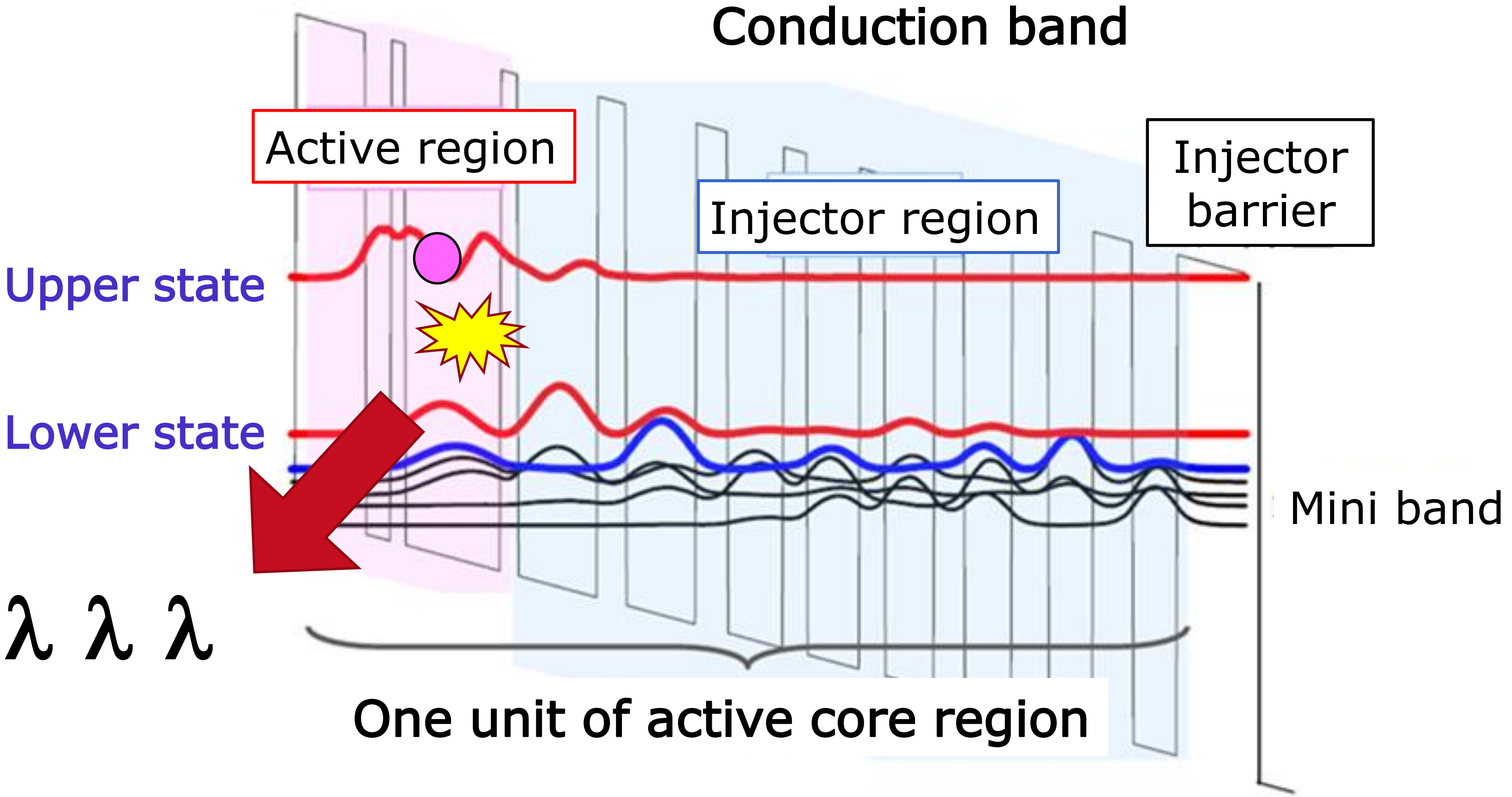
■ Multiple Quantum wells

- ✓ InGaAs/InAlAs
- ✓ Ultra thin layers (10 Å)
- ✓ Sub-band transition
- ✓ Quantum effect
- ✓ Cascading process



- What is going on in the active core region?
  - Multiple Quantum wells (MQWs)





Quantum Cascade Laser (QCL)

Strengths

- Much higher output power
- A laser, not a dispersive source
- DFB structure (single wavelength grating) provides tight linewidth that can achieve parts per trillion in gas analysis
- Also useful for observing isotopes and vibrational states

Challenges

- Cost is very high versus alternatives, this is specialized technology
- Requires expertise and accessories to perform measurements
- 500+ mA injection current required

Quantum Cascade Laser (QCL)

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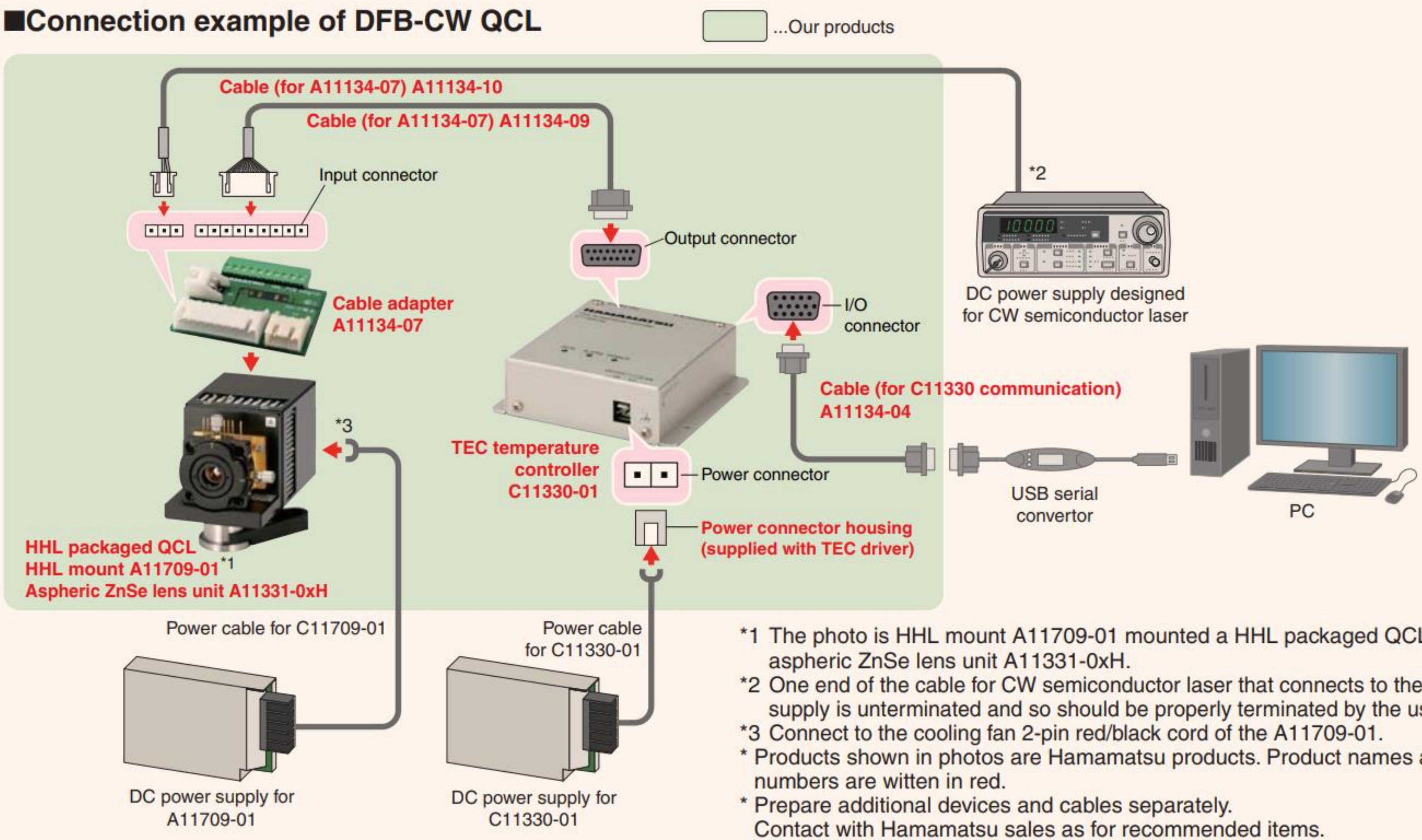

*1 The photo is HHL mount A11709-01 mounted a HHL packaged QCL and a aspheric ZnSe lens unit A11331-0xH.
*2 One end of the cable for CW semiconductor laser that connects to the DC power supply is unterminated and so should be properly terminated by the user.
*3 Connect to the cooling fan 2-pin red/black cord of the A11709-01.
* Products shown in photos are Hamamatsu products. Product names and part numbers are witten in red.
* Prepare additional devices and cables separately. Contact with Hamamatsu sales as for recommended items.

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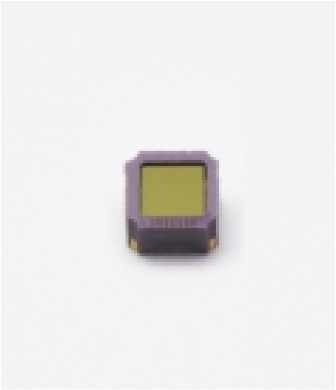
Developments from Hamamatsu

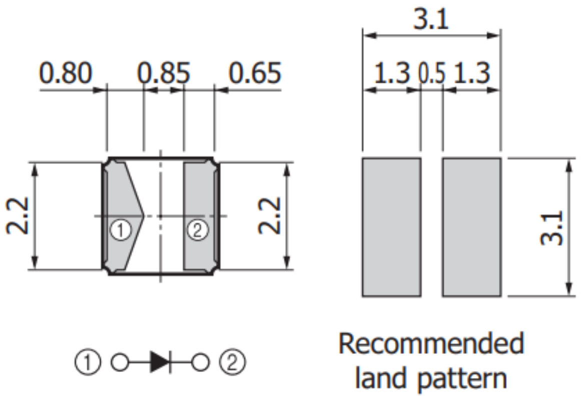
Addressing Market Demands

- Cost has always been a problem for optical technology, price is commonly a barrier to larger markets
- MIR LEDs are not quite efficient although they are have low power consumption, higher output is typically needed
- InAsSb has a short cutoff, limiting applications especially involving organic molecules
- Using optical components requires high proficiency in electronics, user friendly modules can mitigate this problem

New Low Cost Option

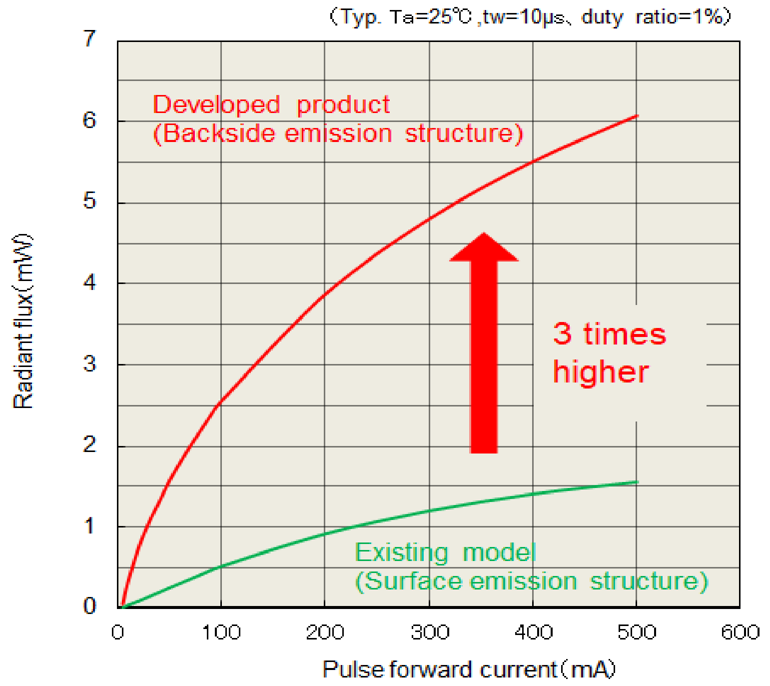
- Proprietary design yields high performance at room temperature!
- Ceramic package (surface mount) and filters, less than half the cost of TO can!
- Units ready for CO2 and CH4/light hydrocarbons
- Ceramic package for LED also drives down cost
- Dual channel for reference method (1000x the speed and 10x the sensitivity)





High Flux LED

- Low output power has been a challenge in the past
  - Originally ~0.3 mW with QCW 50% duty cycle
  - Improved to 1 mW!
- Material structure innovations have led to a massive increase in output
- Still lower power consumption and long lifetimes if modulated
- Same form factor
- More power = more sensitivity and less stress on optics, calibration, electronics noise etc.

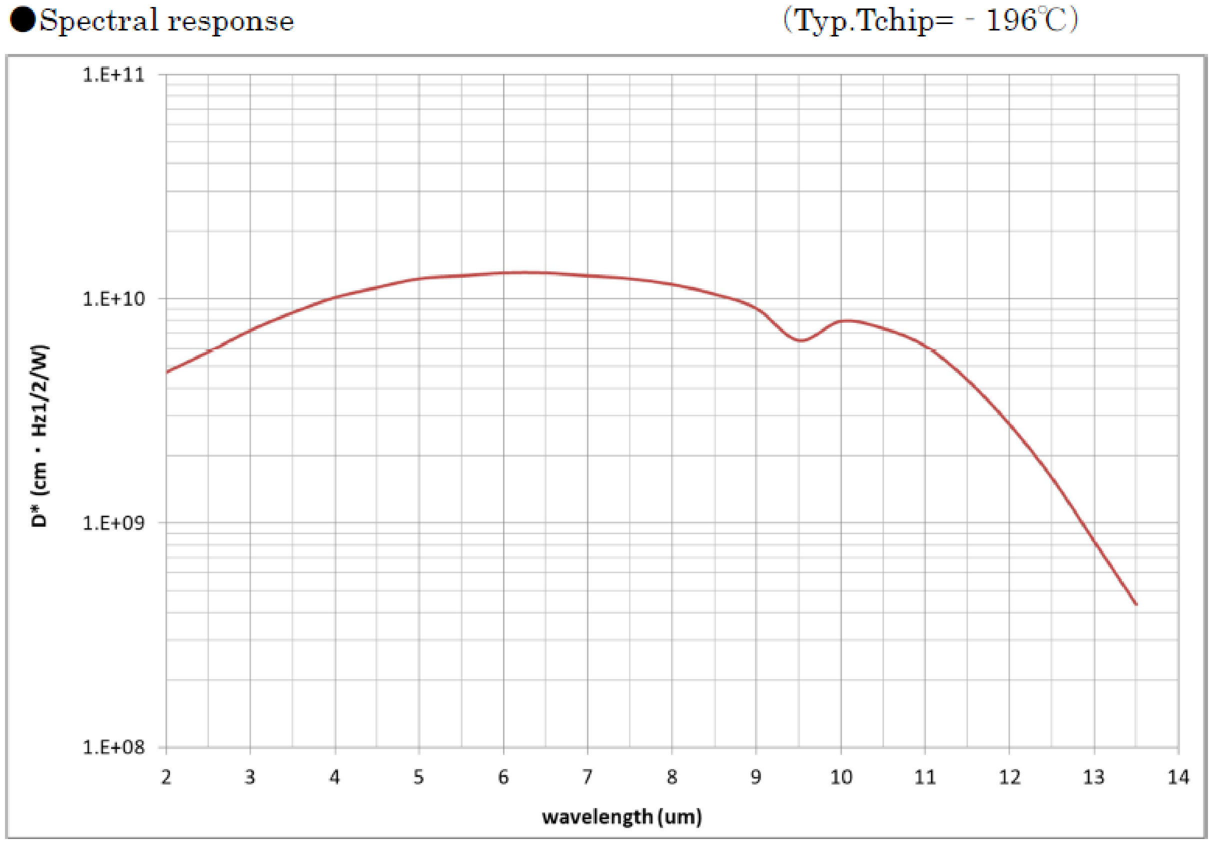


Type no.	Peak emission wavelength λp*4			Radiant flux ϕe*4	
	Min. (μm)	Typ. (μm)	Max. (μm)	Min. (mW)	Typ. (mW)
L15893-0330M	3.1	3.3	3.4	1.1	1.9
L15894-0390M	3.8	3.9	4.1	1.0	1.7
L15895-0430M	4.1	4.3	4.4	0.6	1.0

*4: IF=80 mA, QCW mode

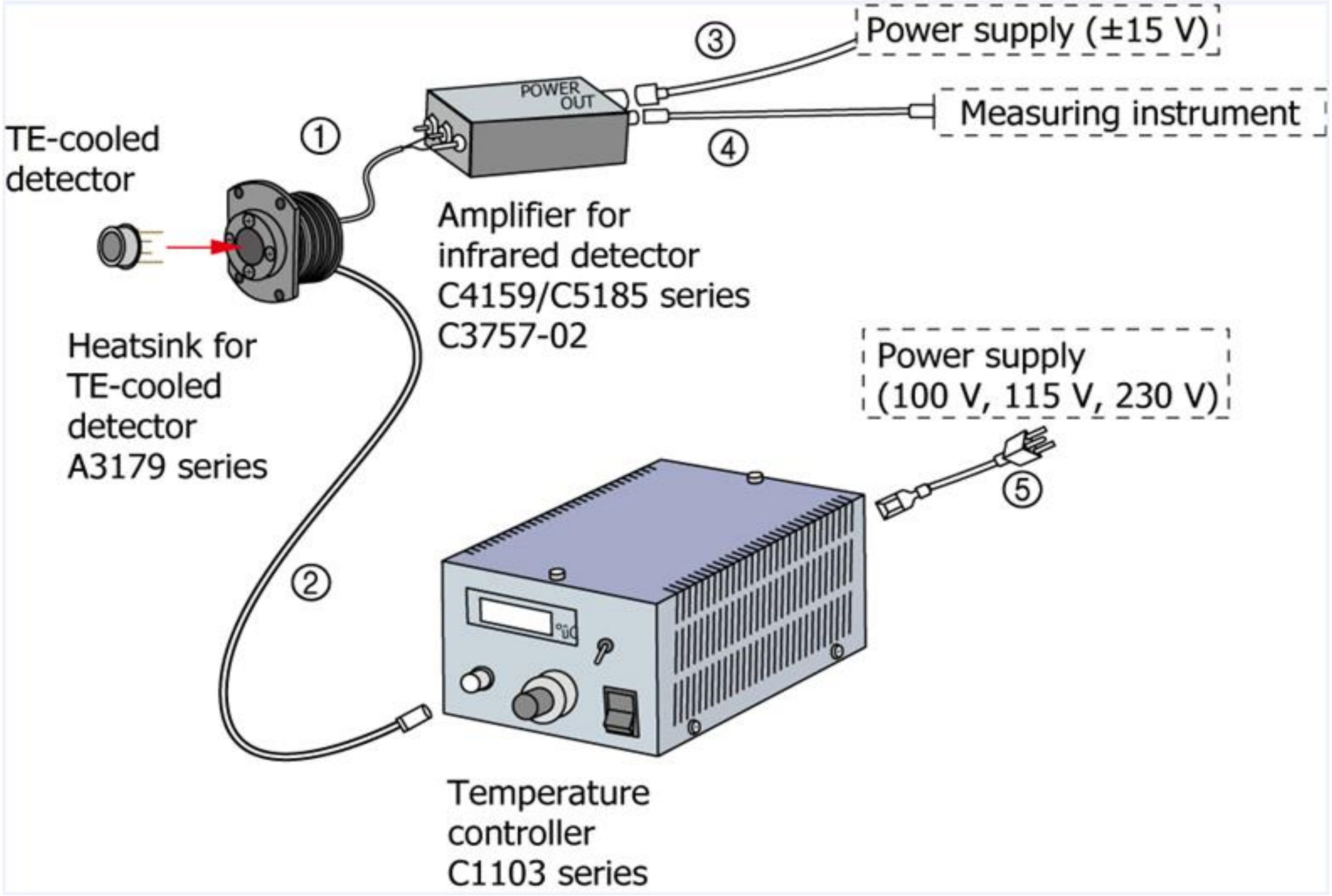
Type II Superlattice InAsSb

- Proprietary layering scheme yields new characteristics
- High D* and sensitive out to 14 micron
- Currently available in LN2 dewar but TEC cooling coming soon
- Finally an alternative to MCT



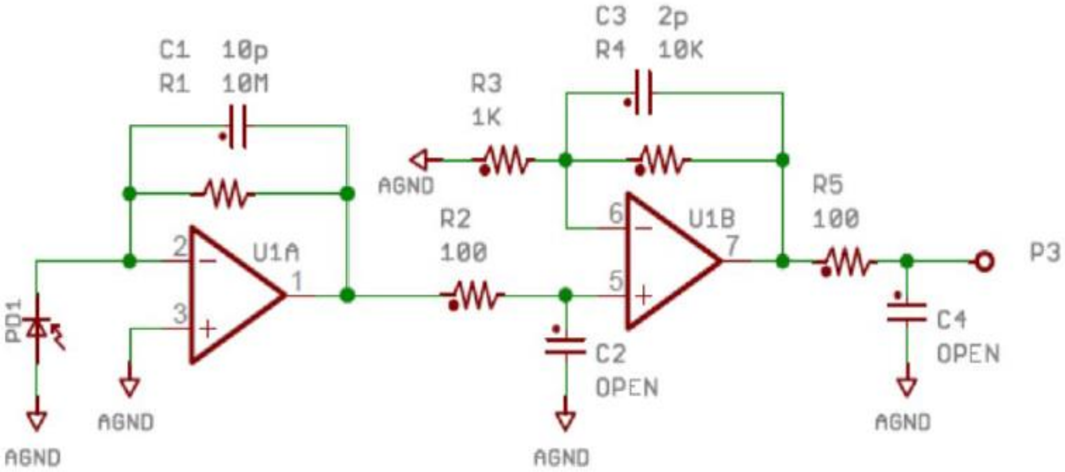
Doc.No. K02-19016

Setup Example



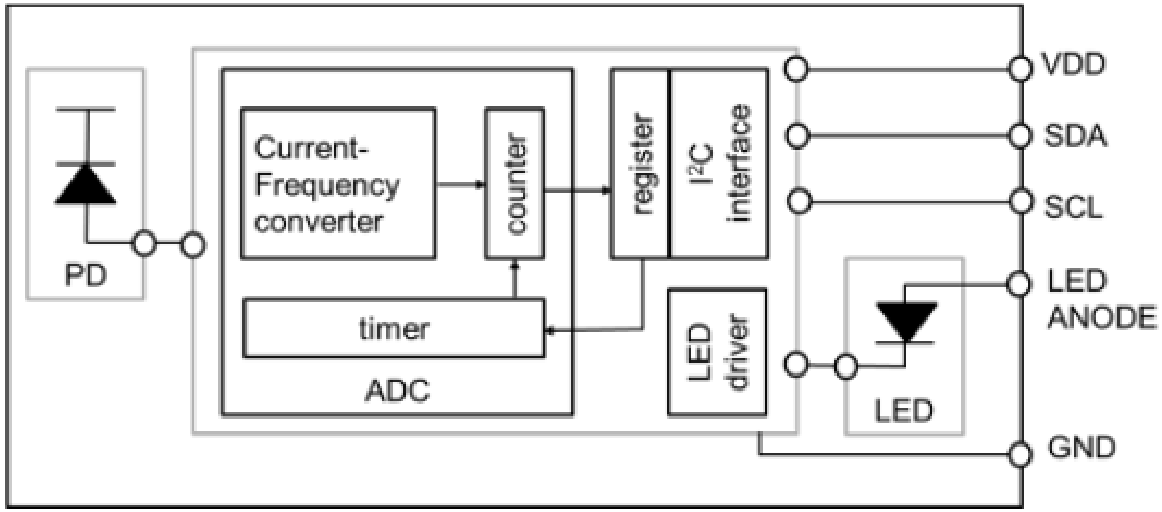
Customization, Module, and ASIC Capabilities

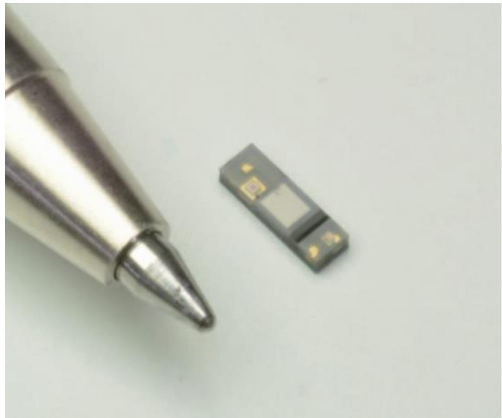
- A large share of our business is custom engineering
- Some modules already standardized
- ASIC to match your specific design
- Integration of light source, electronics and detector in a single package
- Changes such as:
  - Additional TEC stages
  - Window material
  - Amplifier specifications

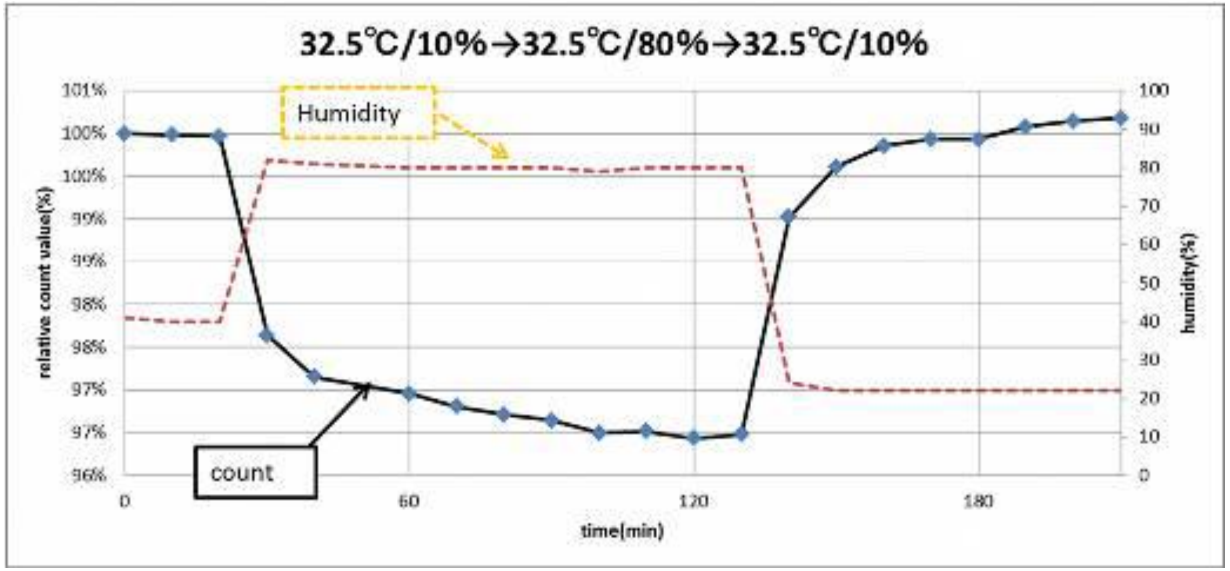


InGaAs Humidity Sensor

2 Block diagram







Module Integration

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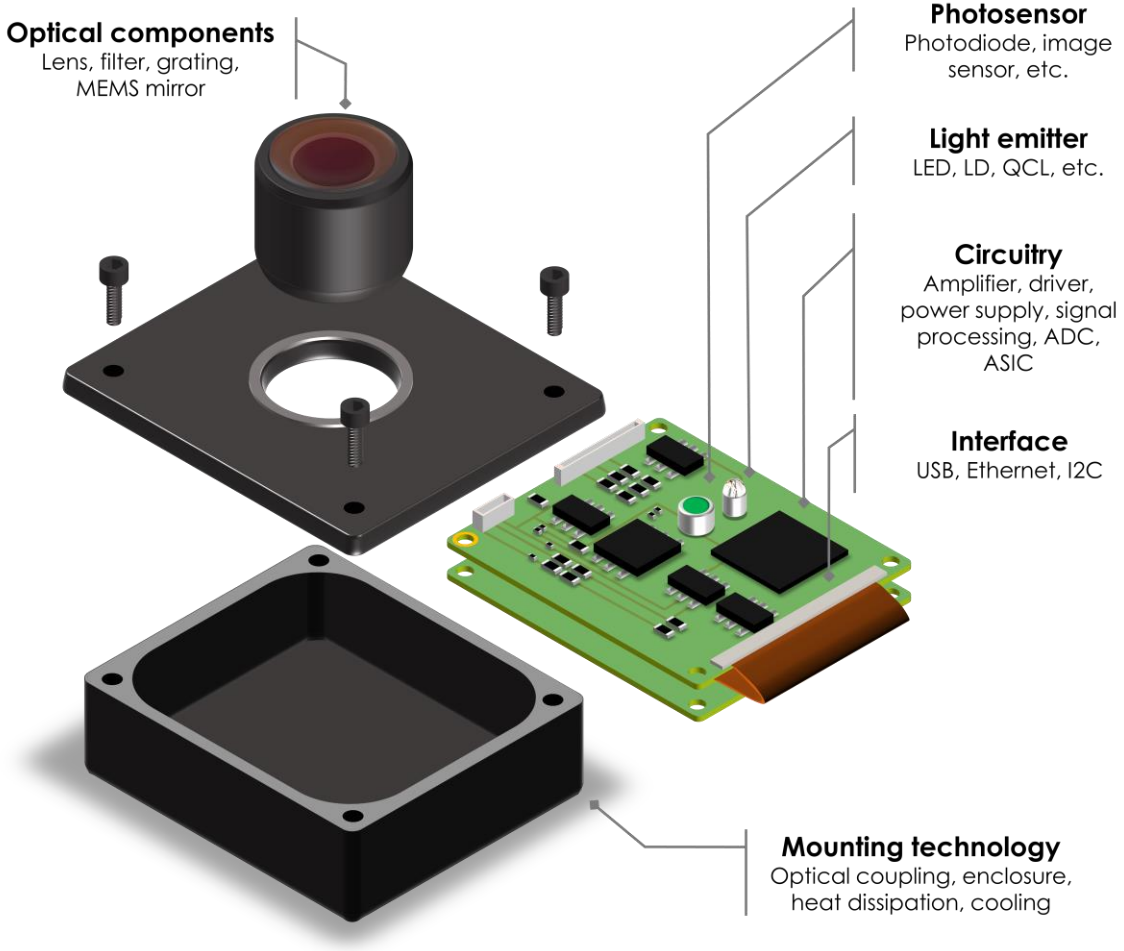
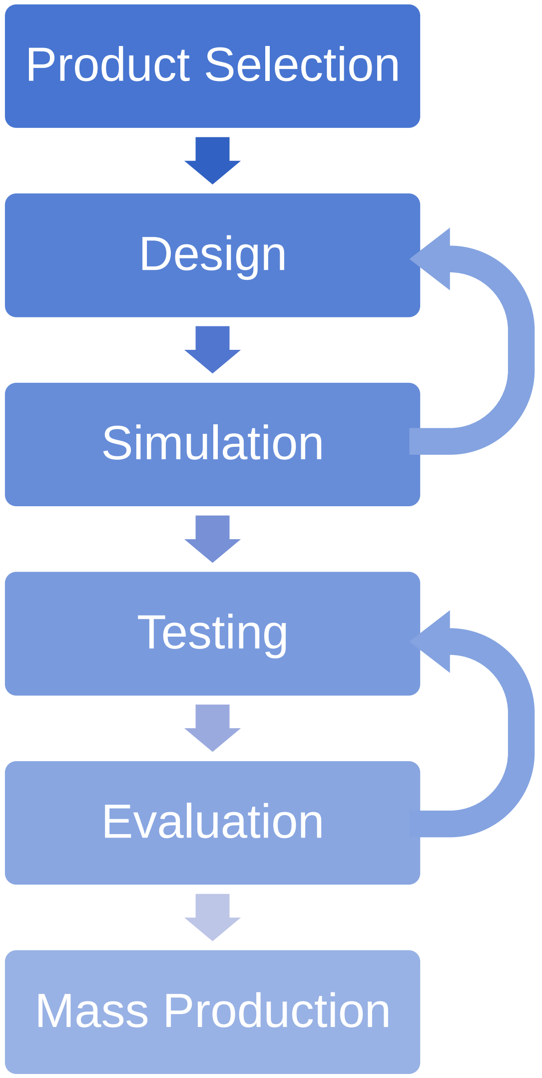
Hamamatsu Custom Module Capability



- ✓ Full product range of detectors & light sources
- ✓ Over 60 years in-house design design & manufacturing experience
- ✓ SNR, optical, and signal simulation
- ✓ One vendor responsible for product quality, focus on high-reliability
- ✓ Global company with local sales and applications support
- ✓ ISO certified, high-mix, low-volume production, optimized for custom-products



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Week #	Weekly Topics	# of Talks	Talk #1 Date	Talk #2 Date
1	Introduction to Photodetectors	2	26-May-20	28-May-20
2	Emerging Applications - LiDAR & Flow Cytometry	2	2-Jun-20	4-Jun-20
3	Understanding Spectrometer	2	9-Jun-20	11-Jun-20
1 Weeks Break				
4	Specialty Products – Introduction to Light Sources & X-Ray	2	23-Jun-20	25-Jun-20
5	Introduction to Image Sensors	2	30-Jun-20	02-Jul-20
1 Weeks Break				
6	Specialty Products – Laser Driven Light Sources	2	14-Jul-20	16-Jul-20
7	Image Sensor Circuits and Scientific Camera	2	21-Jul-20	23-Jul-20
8	Mid-Infrared (MIR) Technologies & Applications	2	28-Jul-20	30-Jul-20
1 Weeks Break				
9	Photon Counting Detectors – SiPM and SPAD	1	11-Aug-20	
10	Using SNR Simulation to Select a Photodetector	1	18-Aug-20	

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