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Narrow-band quantum cascade detectors for infrared spectroscopic applications

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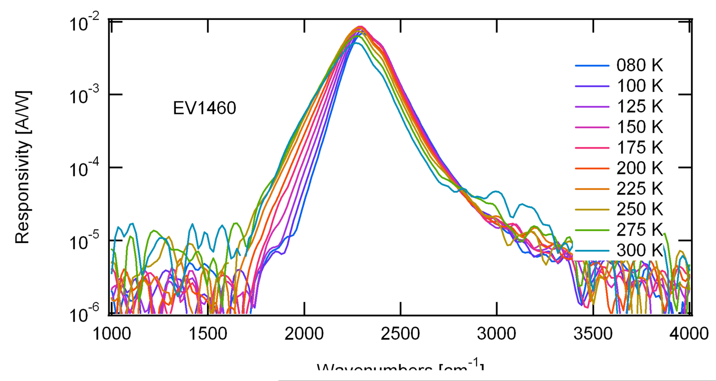
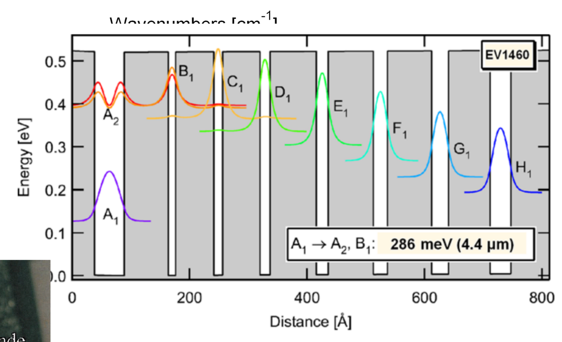
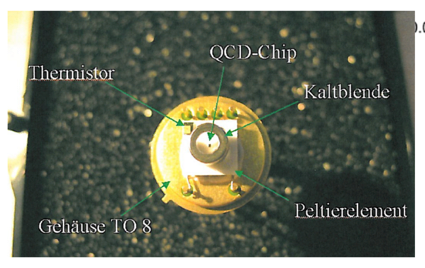
Quantum cascade detectors at λ=4.4µm (CO_2) and at λ=5.8µm (cocaine)

a) QCD at 4.4µm for CO_2 detection

- target wavelength 4.4µm (2260cm^{-1})
- InP substrate, GaAs/InAlAs AR
- 200µm x 200µm mesa
- top diffraction grating
- TO-8 package with TE cooler
- setup: amplifier 0.2µA/V
- 5mA/W (300K), 9mA/W (175K)

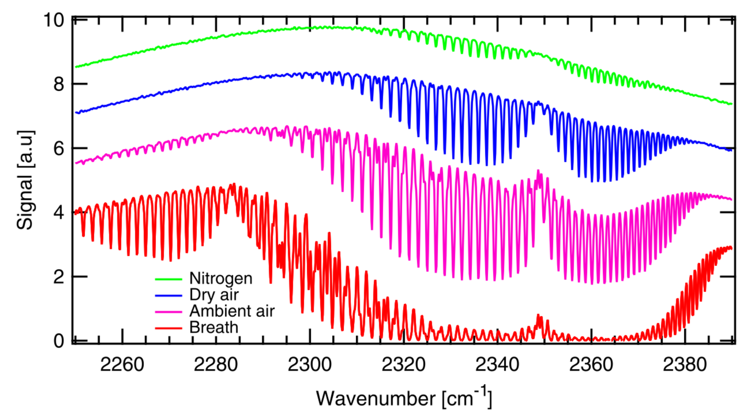






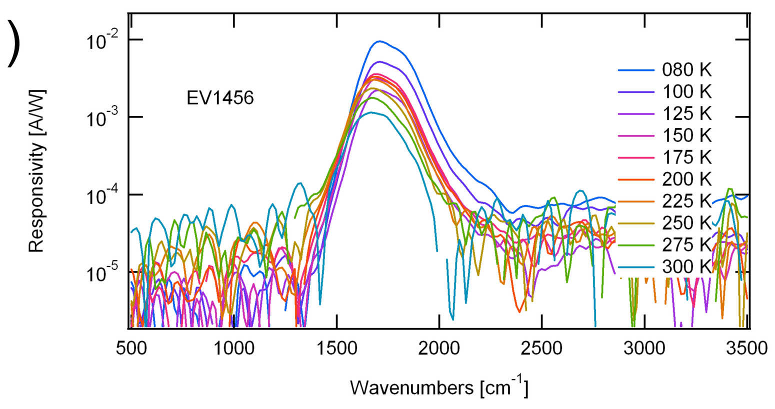
b) Employment in FTIR detection scheme

- goal: detect $^{13}C^{16}O_2$ vs. $^{12}C^{16}O_2$
- Glo-bar source, FTIR and QCD
- detection limit 500ppb



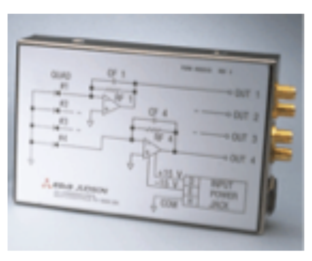
c) QCD at 5.8µm for cocaine detection

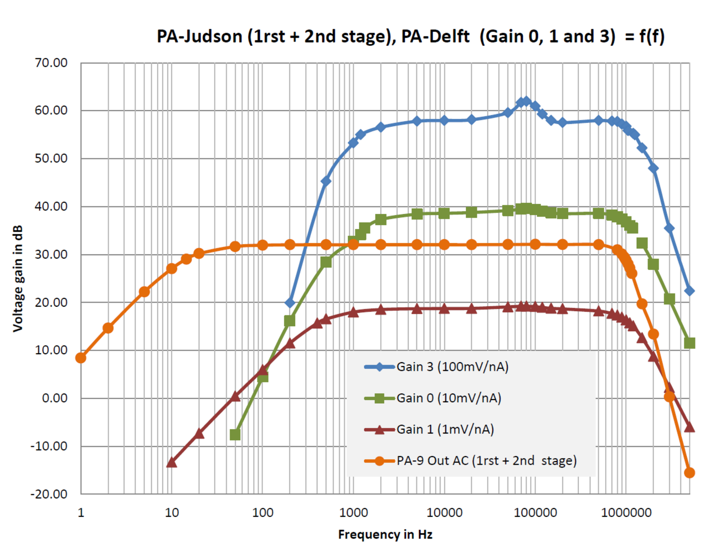
- target wavelength 5.8µm (2260cm^{-1})
- GaAs substrate, GaAs/AlGaAs AR
- 45° facet
- 3mA/W (250K)



Low-noise signal amplification

- QCD's are high-impedance
- Johnson noise dominant
- low-noise pre-amplifier design using AD8066ARZ
- compare vs. Judson PA-9-70
- gain (1MHz): 100mV/nA vs. 4mV/nA
- noise (10kHz): 45pArms vs. 35pArms
- LF cut-off: 1kHz vs. 14.5Hz





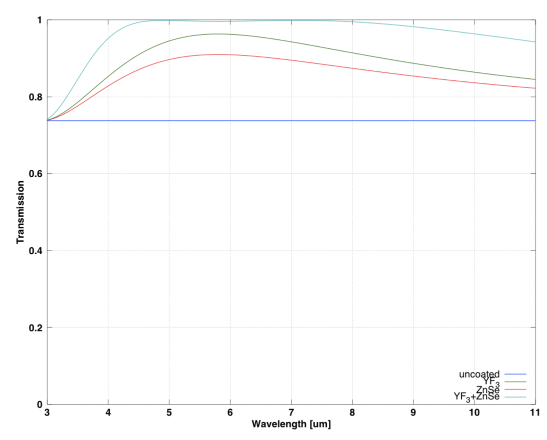
Reference

D. Hofstetter, J. Di Francesco, L. Hvozdara, H.-P. Herzig, M. Beck, CO_2 isotope sensor using a broadband infrared source, a spectrally narrow 4.4µm quantum cascade detector, and a Fourier spectrometer,
Applied Physics B, Vol. 103, No. 10.1007/s00340-011-4532-1, (2011)

Dielectric anti-reflection coatings, Bragg mirrors and gratings (simulation)

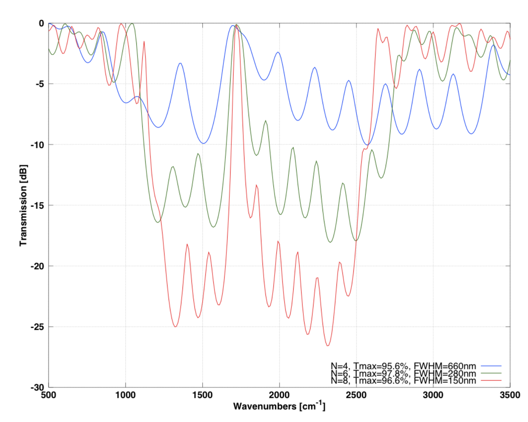
a) Single and bi-layer AR coatings for backside illumination

- backside illumination relevant for arrays
- use YF_3 (n=1.45) or ZnSe (n=2.40) λ/4 layers on GaAs (n=3.30), for λ=5.8µm
- improvement in transmission from 73.8% to 99.5%



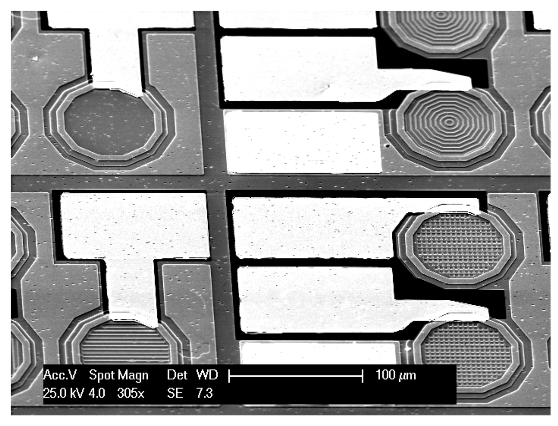
b) Double Bragg mirrors as AR coating and narrow bandpass

- two sequential YF_3/ZnSe Bragg mirrors
- transmission of 96.6% at λ=5.8µm
- 150nm linewidth (FWHM)
- > 15dB supression over wide wavelength range



c) Deep-etched dielectric gratings

- perpendicular incidence, scatter light into plane
- resonant or non-resonant
- polarization (in)sensitive



Integrated sensing scenario

- spectroscopic analysis of liquids (e.g. blood, saliva)
- fixed and multi-use sensing equipment: broadband source and TE-cooled linear QCD array module, bonded onto read-out electronics IC; easy-to-use web user interface thanks to embedded computer
- disposable one-time use Mid-IR silicon photonics liquid sensing chip
- entirely optical connection using diffraction gratings

Conclusion and outlook

- QCD's are promising for Mid-IR spectroscopic applications owing to the operation at temperatures achievable by TE cooling
- device performance based on existing quantum designs can be enhanced by consequently applying light capturing mechanisms (anti-reflective coatings and diffraction gratings)
- fabrication into linear arrays opens the possibility of high-resolution micro-spectrometers
- from the system integration point of view, sophisticated amplifier designs are required
- next up: (a) demonstration of grating structures for narrow-band operation, (b) compact detector + amplifier modules, (c) joint effort with EPFL for integrated microfluidic / QCD array cocaine detector