Mid-IR distributed feedback interband cascade lasers and their application for detection of CH_4

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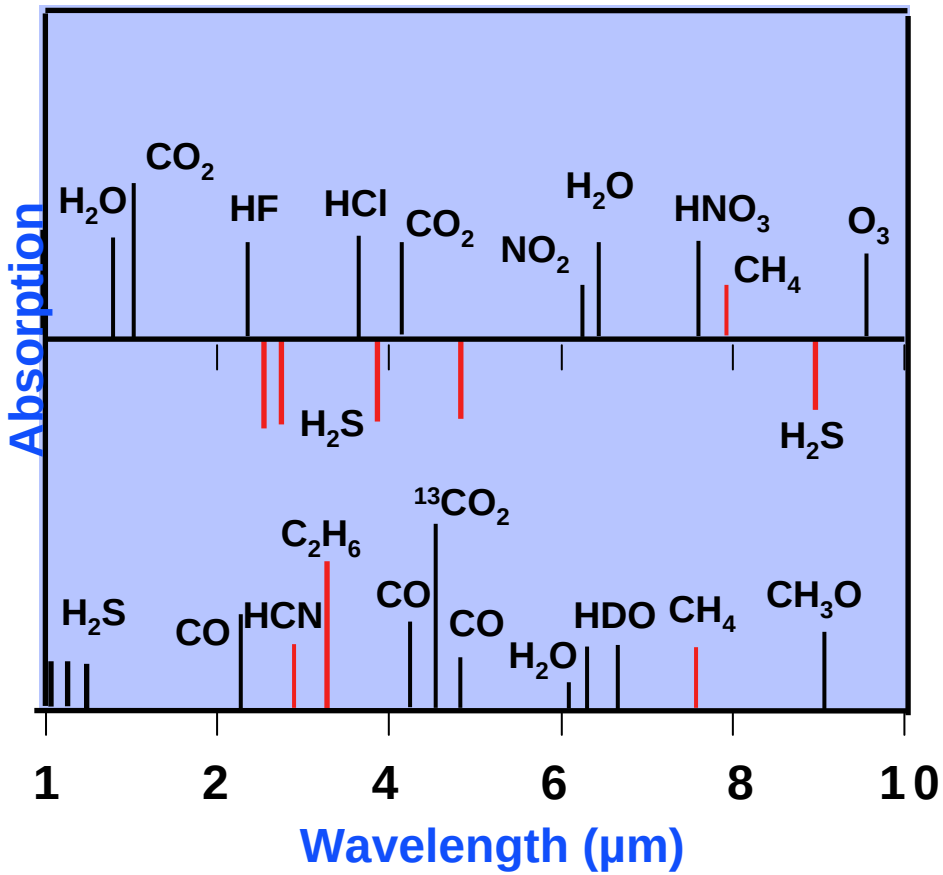
Why Mid-IR Lasers?



- Molecules possess strong fundamental vibration-rotation lines in the mid-IR
- Mid-IR improves sensitivity by orders of magnitude over near-IR spectroscopy
- There is less spectral interference in the mid-IR

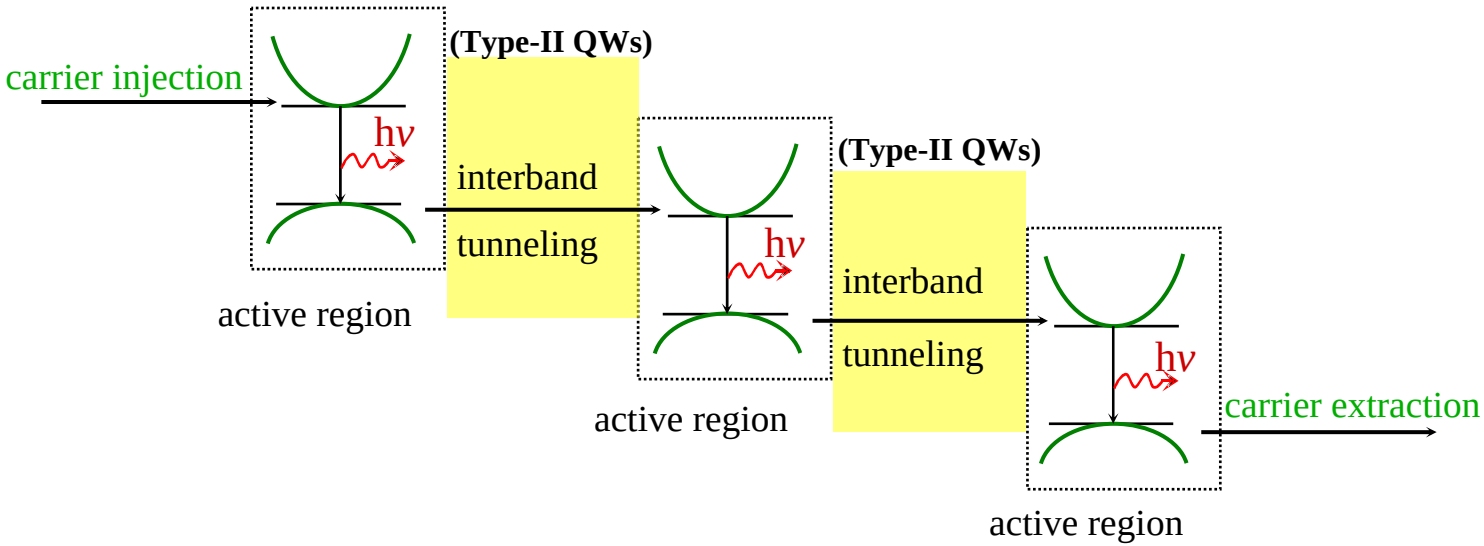
Planetary science payoff is very high—

- Atmospheric chemistry
- Hydrocarbon signatures at 3–4 μm & biogenic gases throughout the mid-IR important for life detection
- Possible precursors to molecules of biological relevance important for prebiotic chemistry (e.g. ethane, C_2H_4, HCN, HC_3N)
- Isotopic ratios can be obtained

For JPL and NASA, the interest is mainly in planetary and Earth science.

What is Interband Cascade (IC) Laser?

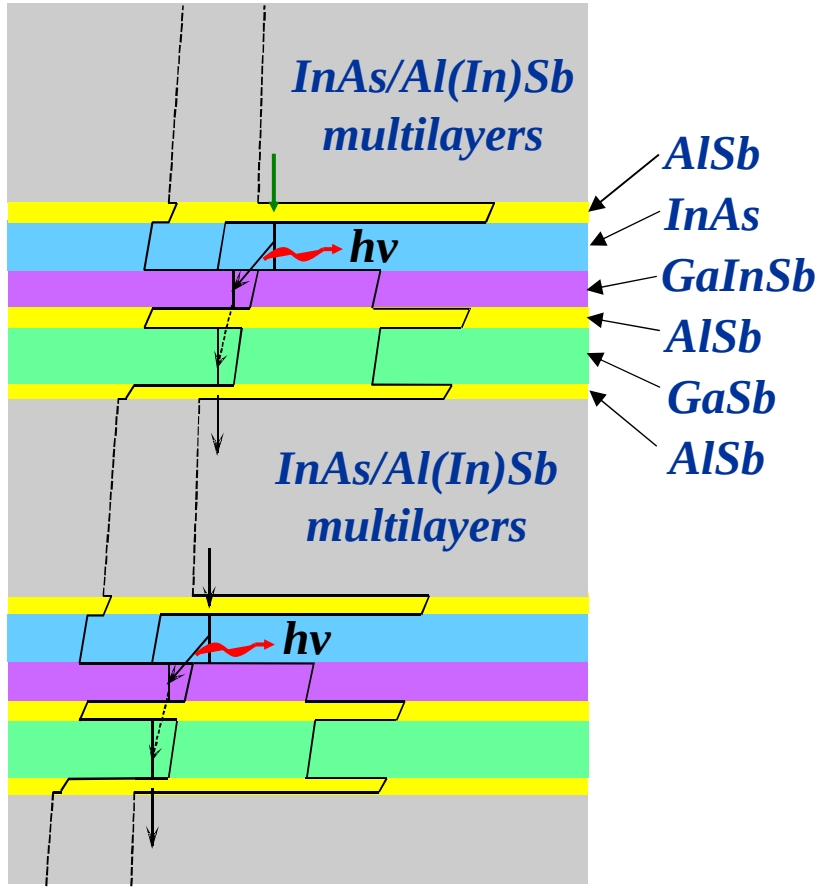
[original concept, R. Q. Yang, Superlattices and Microstructures, **17**, 77 (1995)]



- **cascade process —**
  - » high efficiency, high output power
  - » uniform injection of carriers over every stage
  - » lower carrier concentration required for threshold, thus lower loss
- **interband transition —**
  - » circumvents fast phonon scattering, but faces non-radiative Auger recombination
- **type-II quantum wells (QWs) —**
  - » facilitates interband tunneling for cascade process
  - » excellent carrier confinement because of band-gap blocking

Material system, MBE growth, fabrication

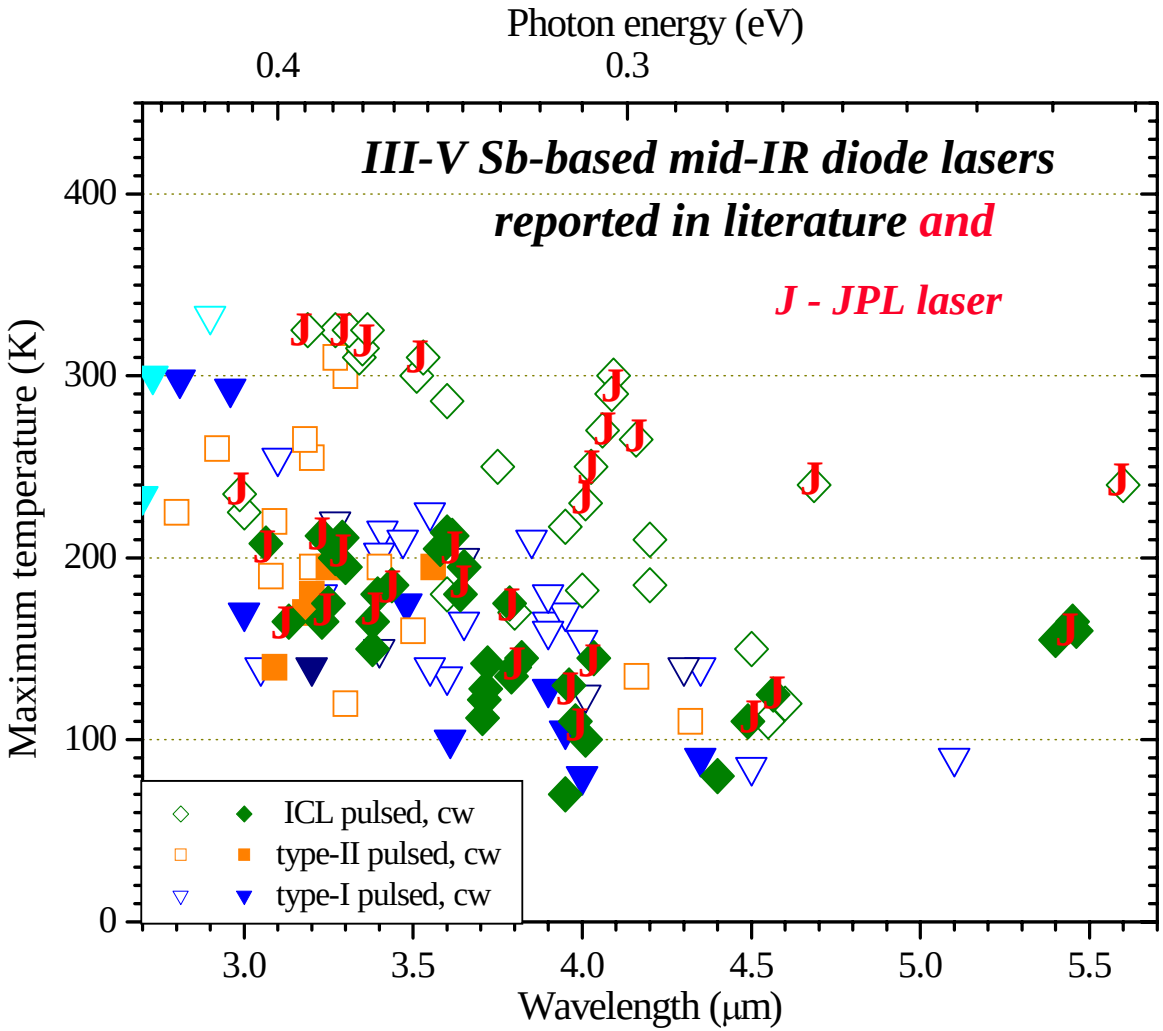
- **Sb-based III-V QW structures —**
  - » lattice constant near 6.1 Å grown on GaSb
  - » quality of GaSb substrate is not yet as good as GaAs and InP
- **interband transition in type-II QWs —**
  - » allows for wide wavelength tailoring range
  - » alleviates problem of Auger recombination with reduced wave-function overlap between transition states
  - » possibility of suppressing Auger losses through quantum engineering, challenging with inaccuracies of material parameters
  - » can have benefits from strain effect in QWs
- **MBE growth —**
  - » Very complicated structure with more than 2000 layers and >15 hour growth time
  - » Some uncertainty and roughness in interfaces
  - » Requiring precise control of layer thickness and composition; changes of ±1 Å can shift the lasing wavelength out of a molecular resonance

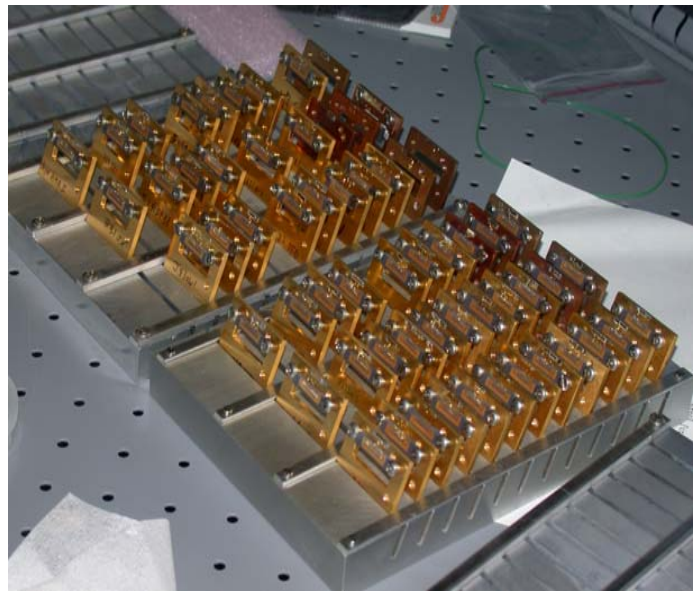


- **Device fabrication —**
  - » typically processed into relatively broad-area laser without facet coating
  - » epilayer-side-up mounting onto a Cu sheet

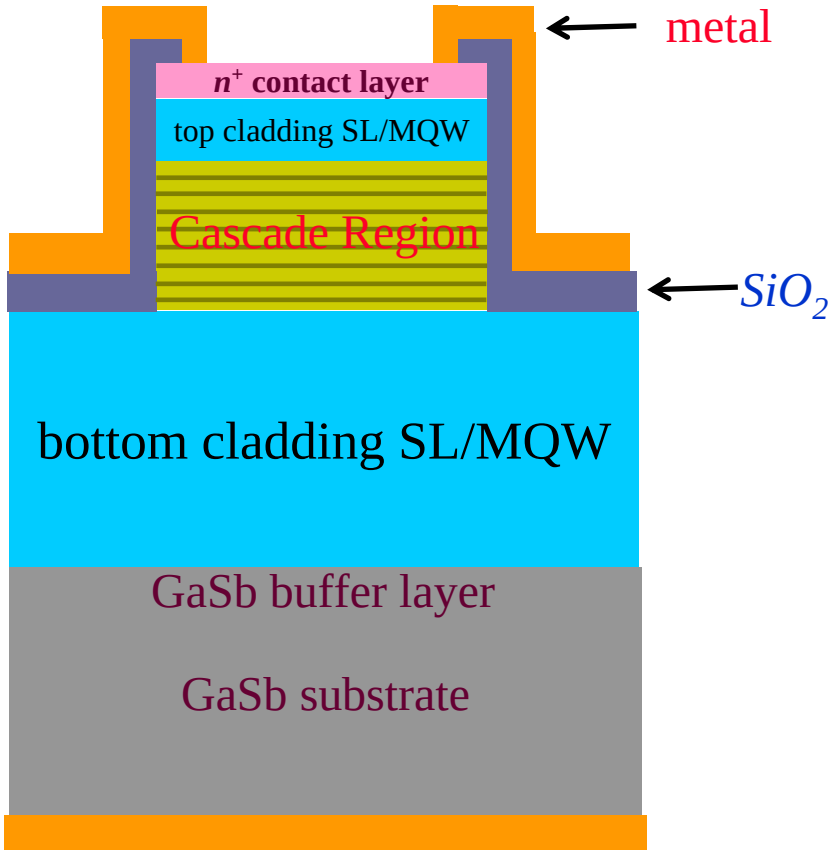
Current JPL Laser Status in terms of Max. *T*

(compared to open literature as of 2/2004)

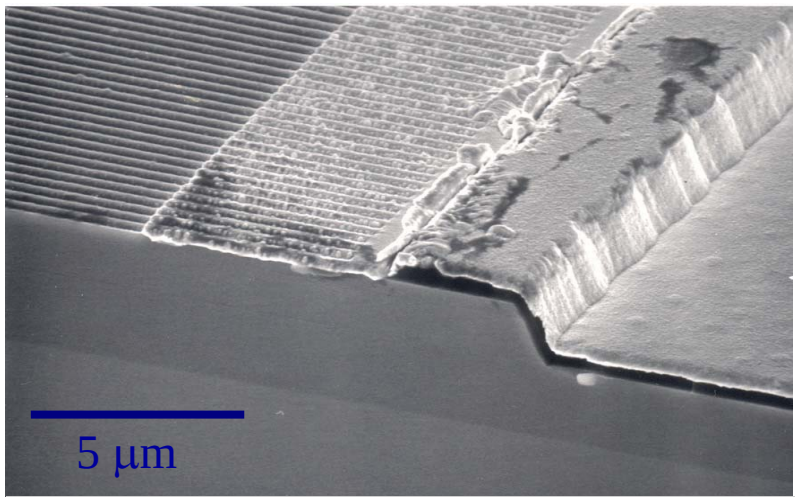




Typical distributed feedback (DFB) IC laser structure

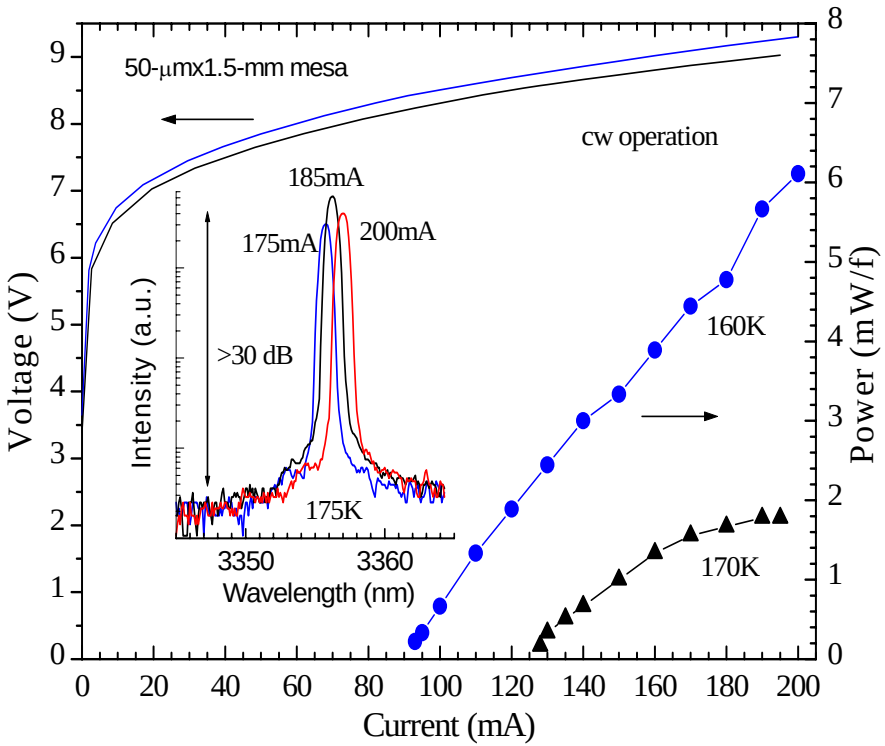


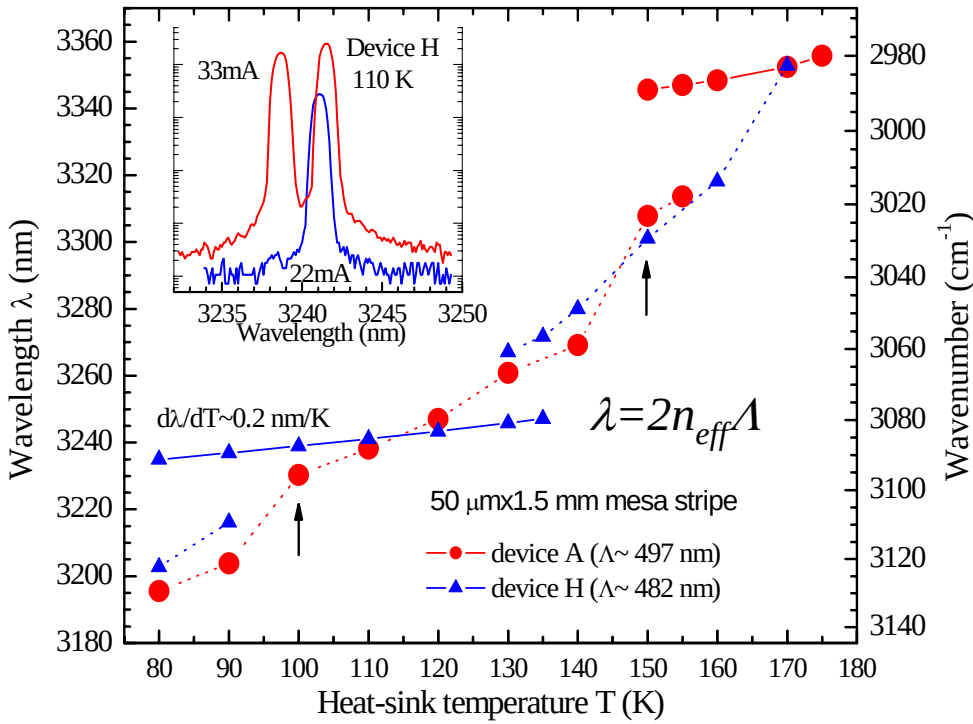
- Thin top-cladding InAs/AlSb SL
  - » Facilitate the integration of DFB gratings into the laser without the need of deep etching
  - » Use SiO_2 layers for insulation and edge metal contacts to minimize the loss
  - » In-plane conductivity is much higher than the vertical one, leading to excellent lateral current injection



SEM image of a DFB laser. The grating was formed with e-beam writing and RIE etching into the top cladding layer

Distributed feedback (DFB) IC Lasers near 3.3 μm



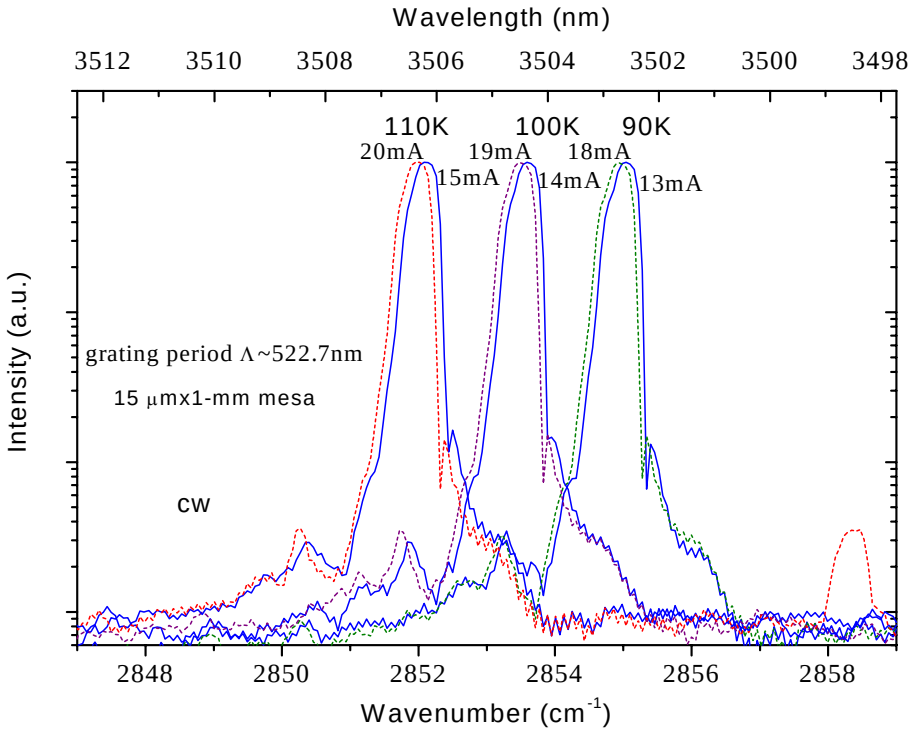


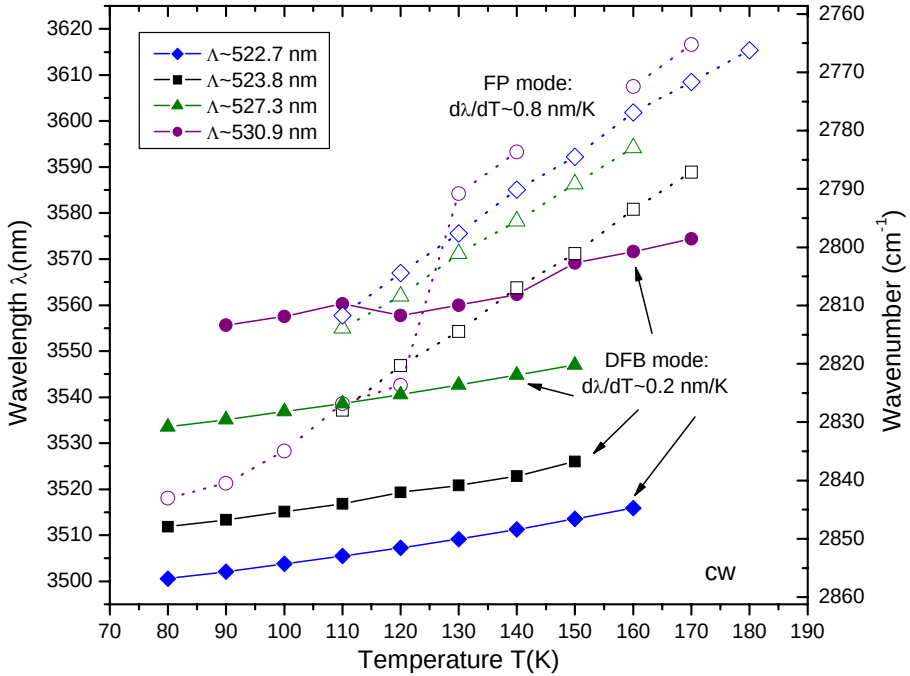
- Single-mode DFB lasers were observed at temperatures up to 175 K in cw mode
- wavelength can be tuned with current at a rate of ~0.05 nm/mA
- output power >1 mW, enough for gas sensing

- DFB mode is determined by grating period Λ
- temperature tuning coefficient ~0.2 nm/K
- both DFB and FB modes exist at certain temperatures and currents
- two degenerate DFB modes

Yang, *et al*. Appl. Phys. Lett. **84**, 3699 (2004)

Distributed feedback IC Lasers near 3.5 μm

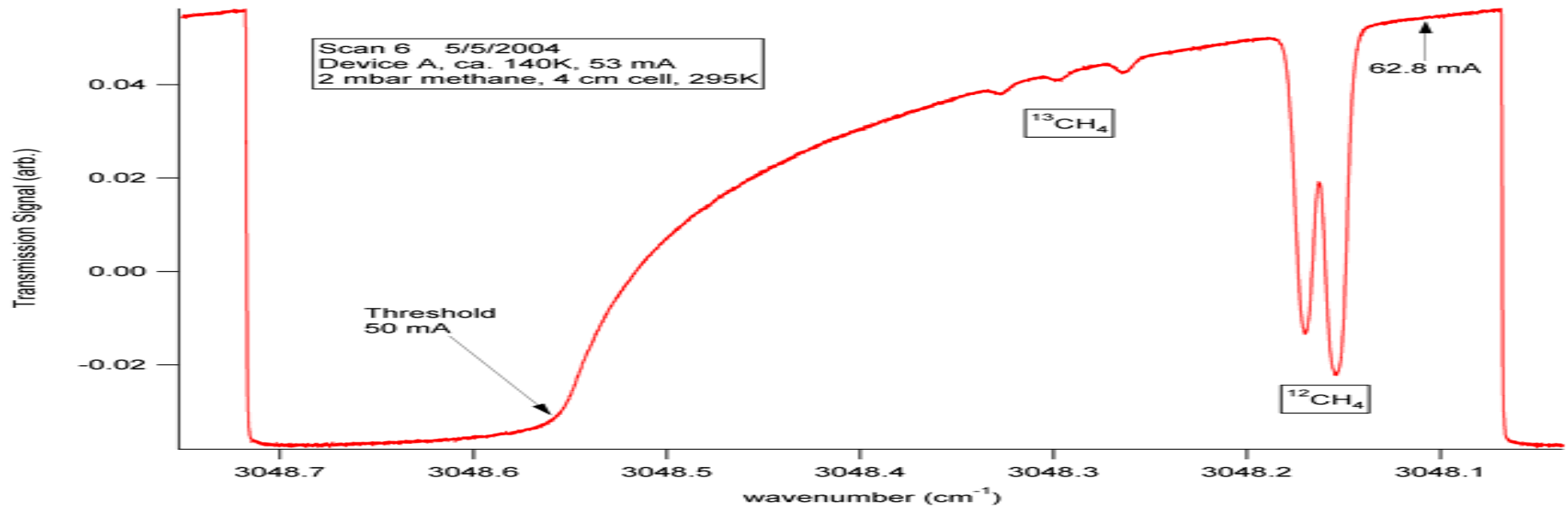


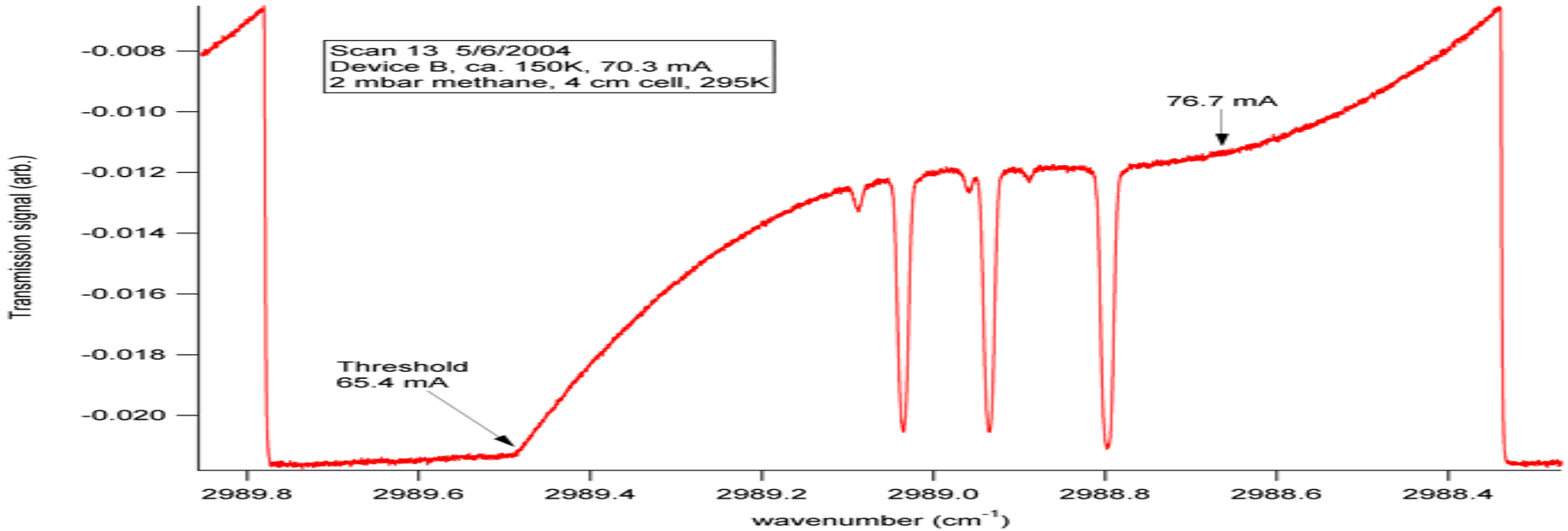


- Single-mode DFB lasers were observed near 3.5 μm
- wavelength can be tuned with current at a rate of ~0.03 nm/mA
- output power >1 mW, enough for gas sensing

- DFB mode is determined by grating period Λ
- temperature tuning coefficient ~0.2 nm/K
- both DFB and FB modes exist at certain temperatures and currents

Detection of CH4 using DFB IC lasers





Summary

- Single-mode DFB IC lasers have been made near 3.3 and 3.5 μm
- Continuous wave operation has been demonstrated at temperatures up to 175 K
- DFB IC lasers have been applied for the detection of trace gases such as CH4

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