Long-wavelength VCSELs for gas sensing

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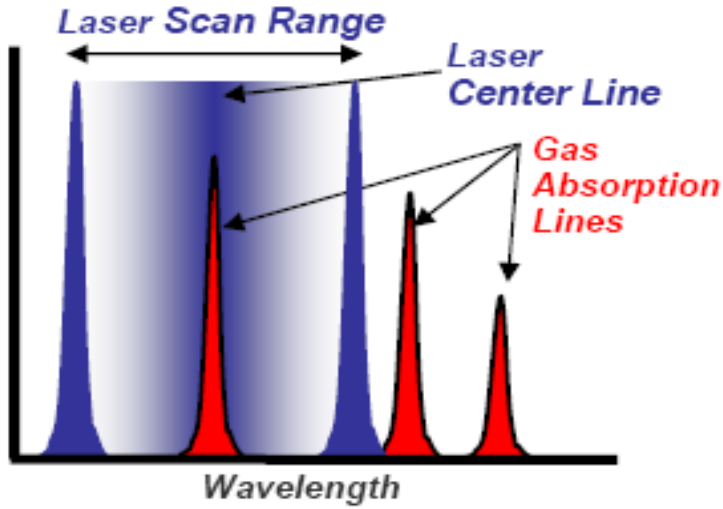
Outline

- VCSEL fabrication approach;
- Results at 1550 nm;
- Results at 2000 nm;
- CO_2 sensing results;
- Summary.

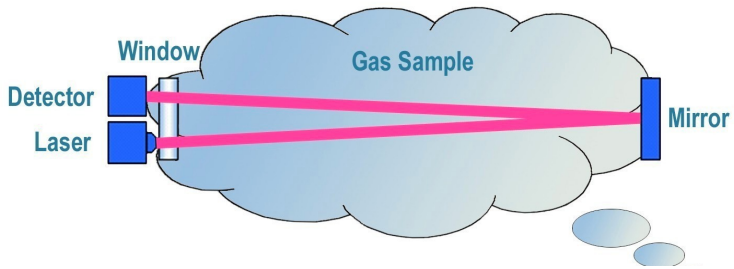
Tunable laser diode spectroscopy , TLDS with long-wavelength VCSELs in the 1500-2000 nm range

Gas	Symbol	Absorption line, nm
Methane	CH_4	1650
Ammonia	NH_3	1512, 1540
Hydrogen sulphide	H_2S	1578
Carbon Monoxide	CO	1570
Carbon Dioxide	CO_2	2004, 1953
Water	H_2O	2003, 1953
Ethylene	C_2H_4	1617
Hydrochloride	HCl	1740



The fine structure of the gas absorption peak consists of single absorption lines.

gas-cell sensing

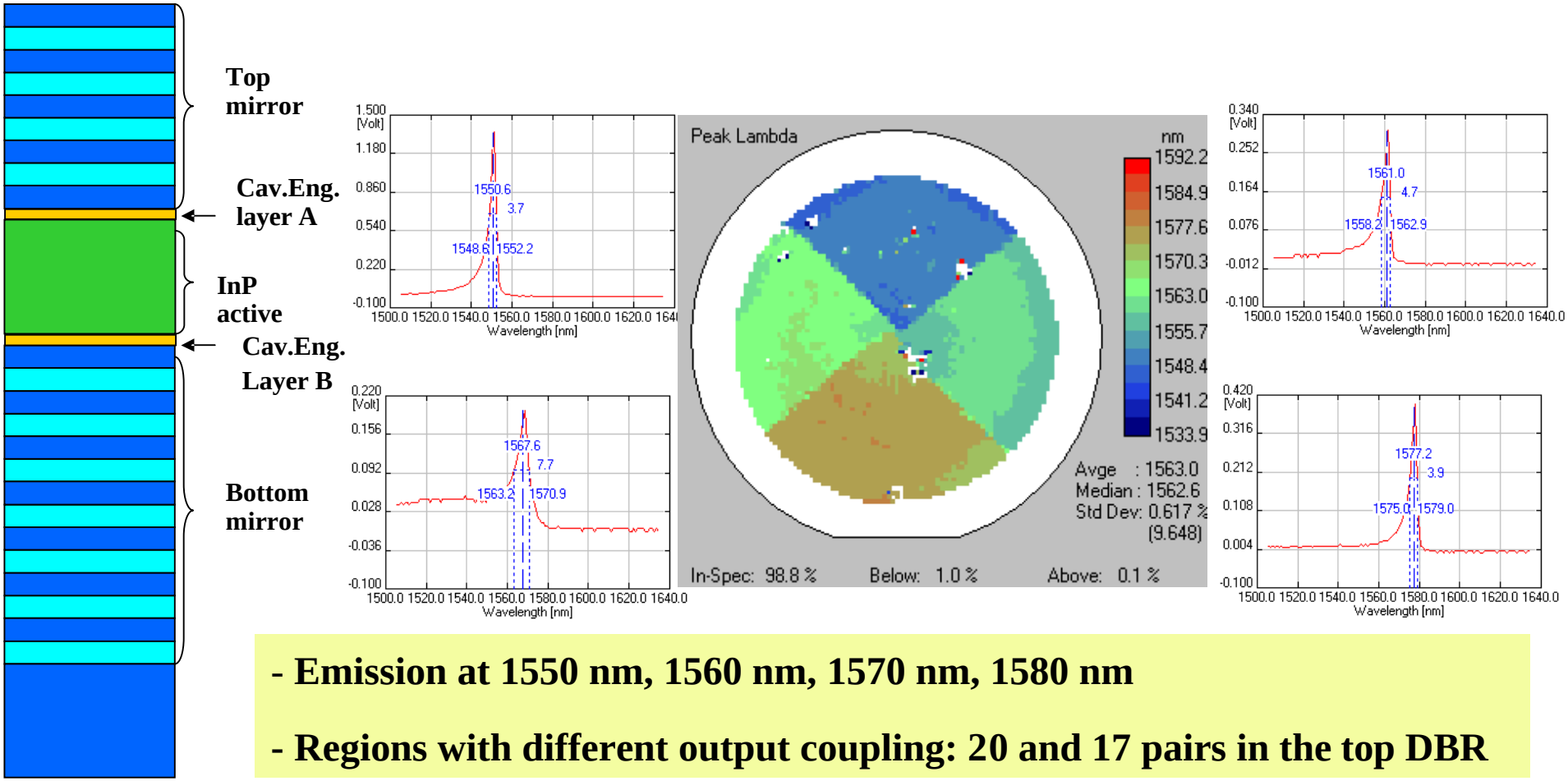


•Typical VCSEL RIN= -130 dB/Hz corresponds to the shot noise of the photo-detector at ~3 μA that corresponds to 3 μW incident power;

•1 mW SM output for optical path length of the order of 10 cm at specified wavelengths is OK;

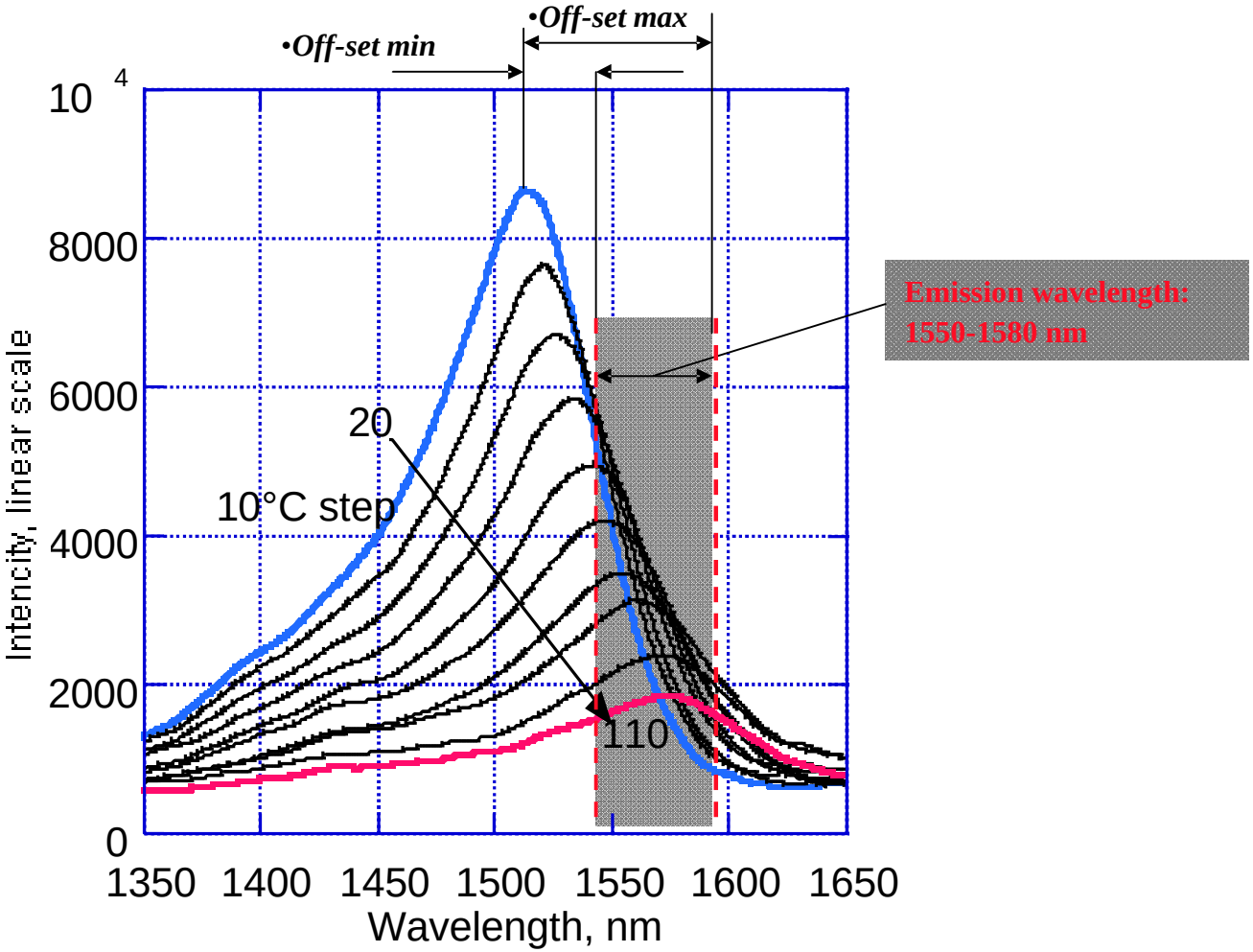
•A cost-effective technology for building a wavelength inventory is important for large-scale applications.

4 regions on the wafer with different emission wavelengths



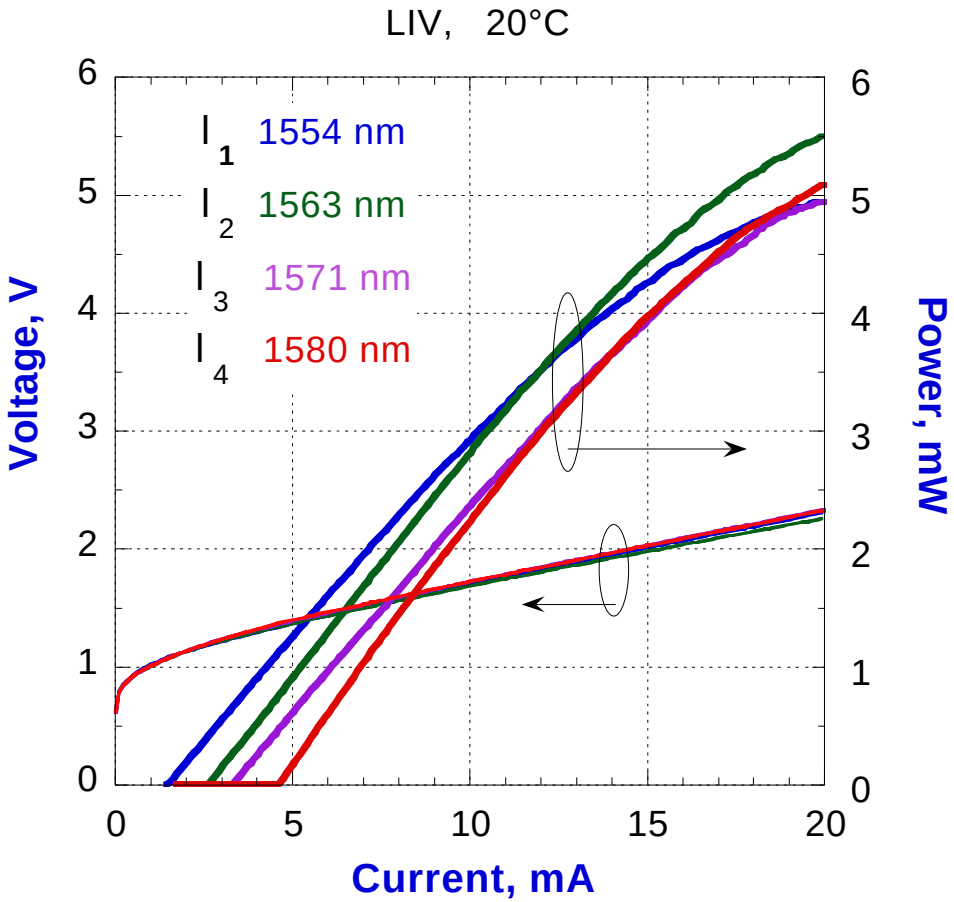
- Emission at 1550 nm, 1560 nm, 1570 nm, 1580 nm
- Regions with different output coupling: 20 and 17 pairs in the top DBR

Photoluminescence spectra of InAlGaAs quantum wells at different temperatures

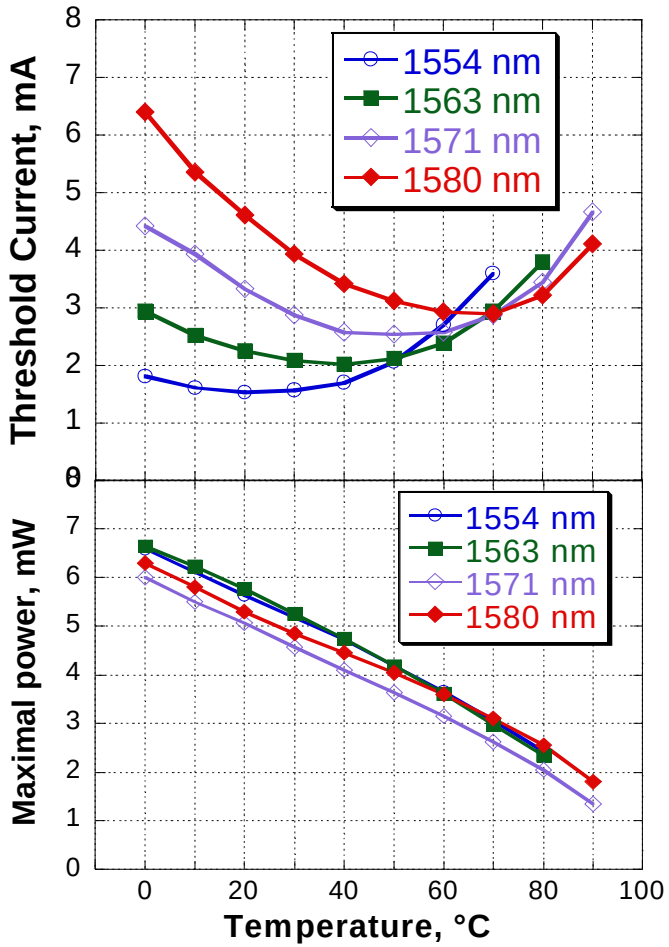


- **Gain medium: InAlGaAs 5 QWs, 1.1% compressive strain, grown by LP MOCVD**

Overview of VCSELs characteristics
(20 pairs top DBR)

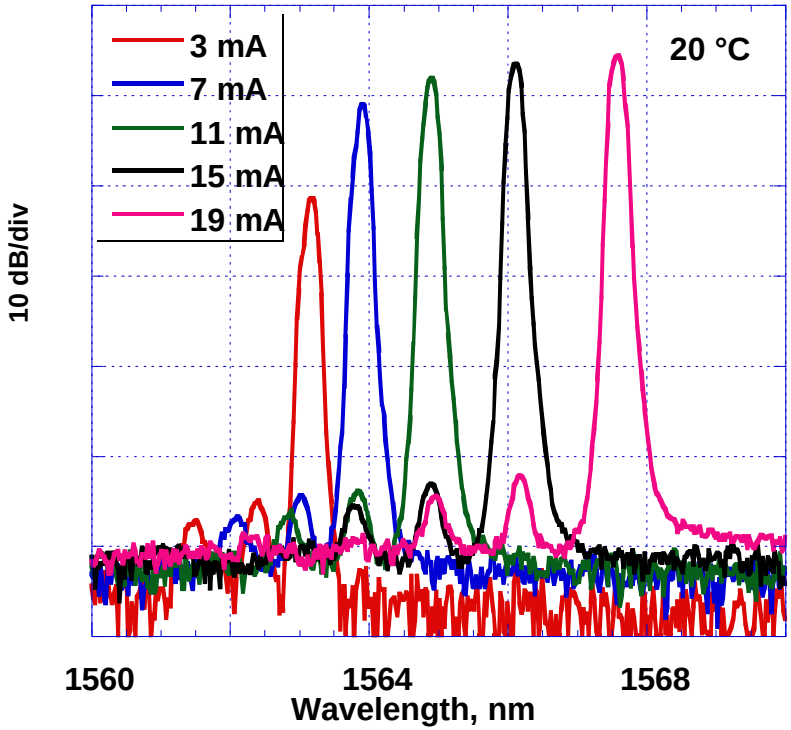


Similar LIV characteristics for different wavelengths

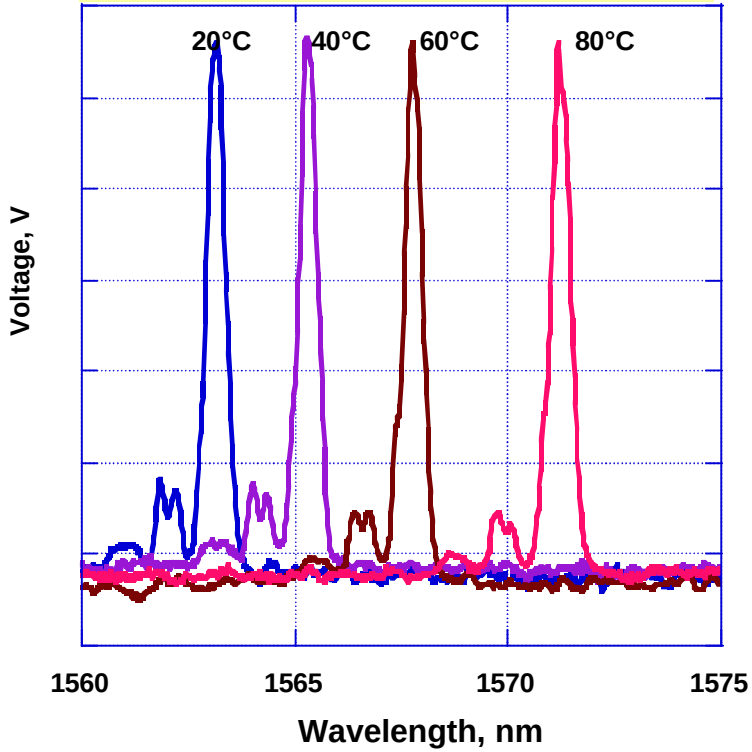


I_{th} and P_{max} variations with temperature

Spectral characteristics at 1560 nm

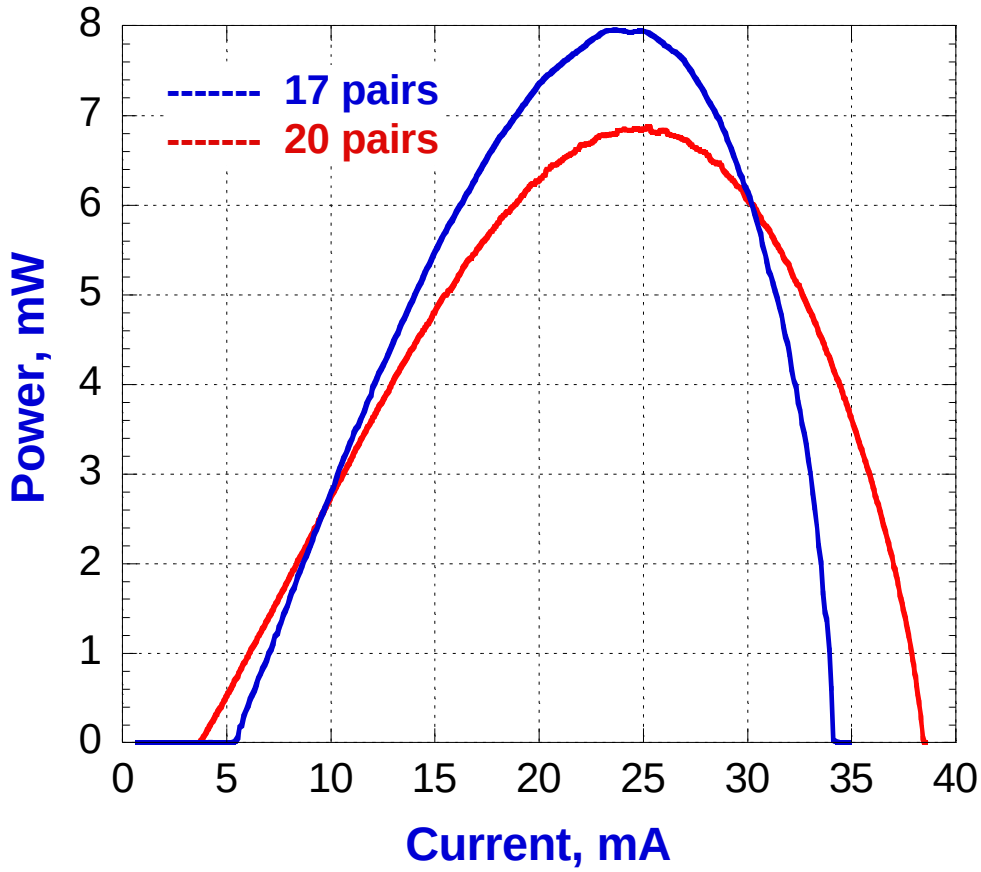


•Spectra at 2 mW output



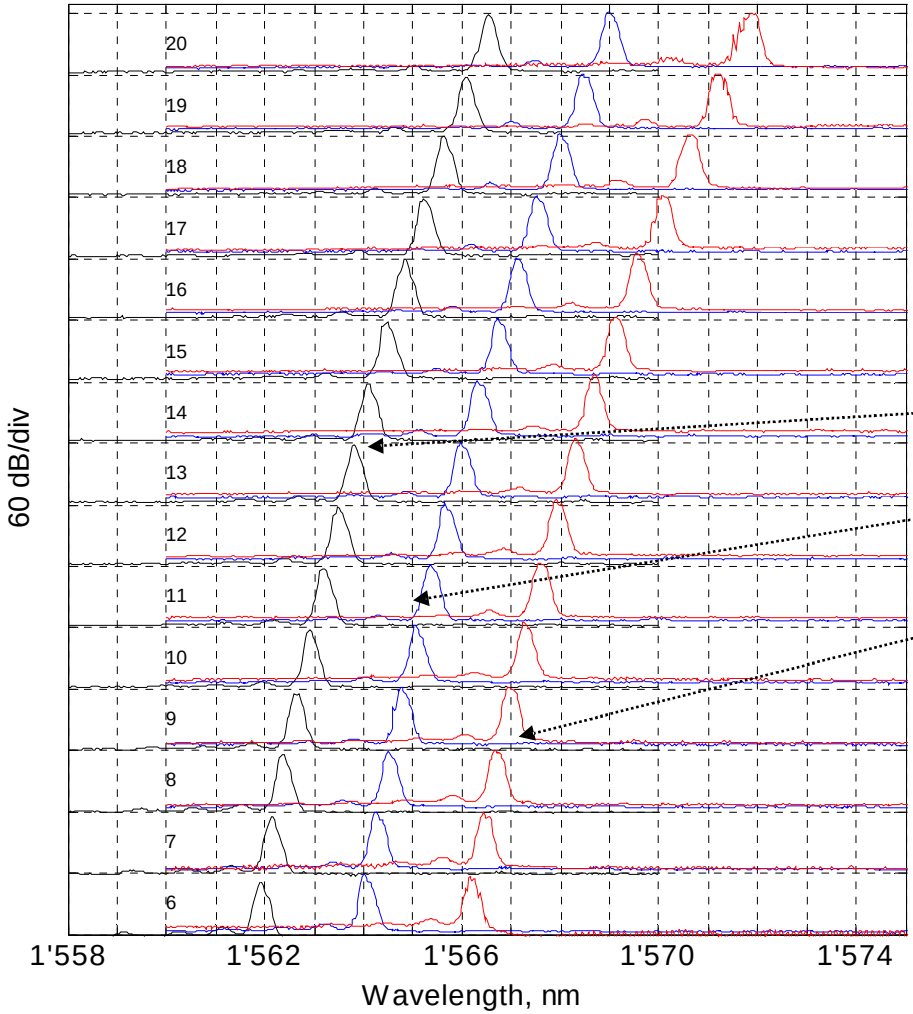
- Single-mode emission in the full operation range;
- At low currents optical guiding is due to lateral refractive index variation, while at higher currents is due thermal lens;
- Wavelength tuning: 0.4 nm/mA; 0.15 nm/ºC

Impact of output coupling



0 °C	P_{max}	I_{th}	DP/DI
20 pairs	6.8 mW	3.5 mA	0.43
17 pairs	8 mW	5 mA	0.58

Wavelength inventory



SM operation with SMSR more than 40 dB

0.3 nm/mA;

0.1 nm/°C

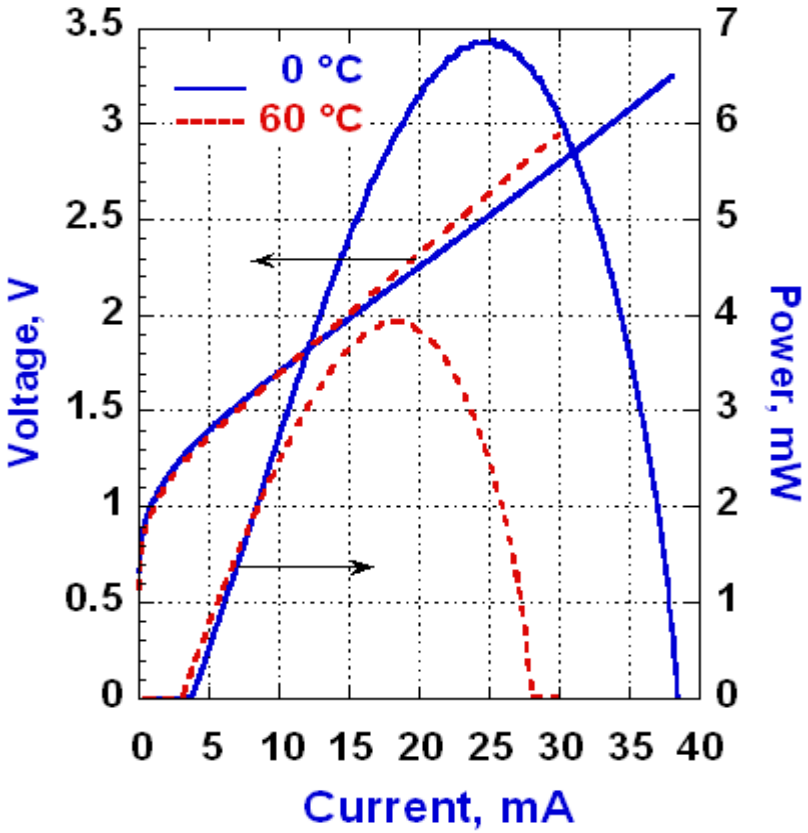
20°C

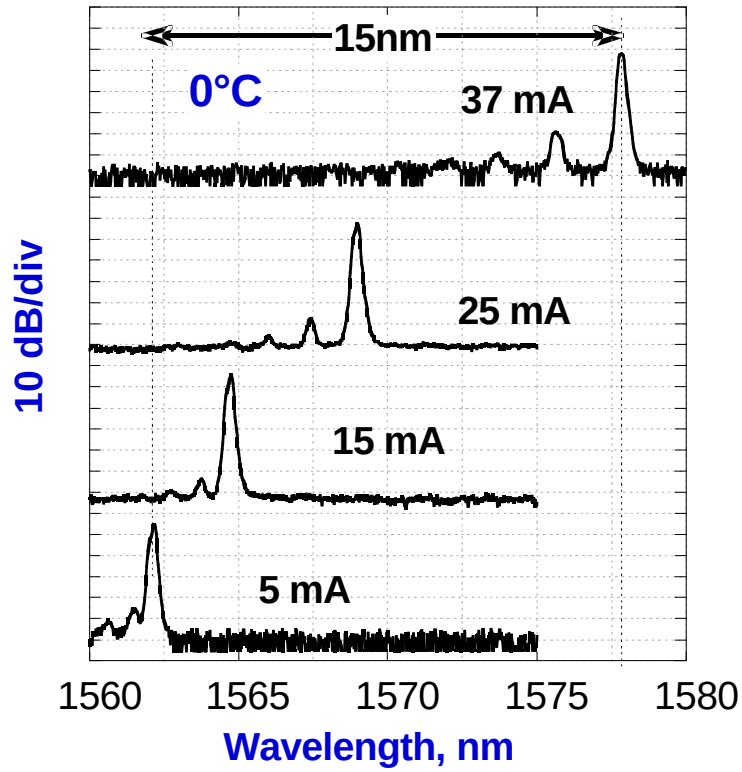
40°C

60°C

Wavelength tuning

LIV and spectral characteristics of 7 ㎜ tj diameter device

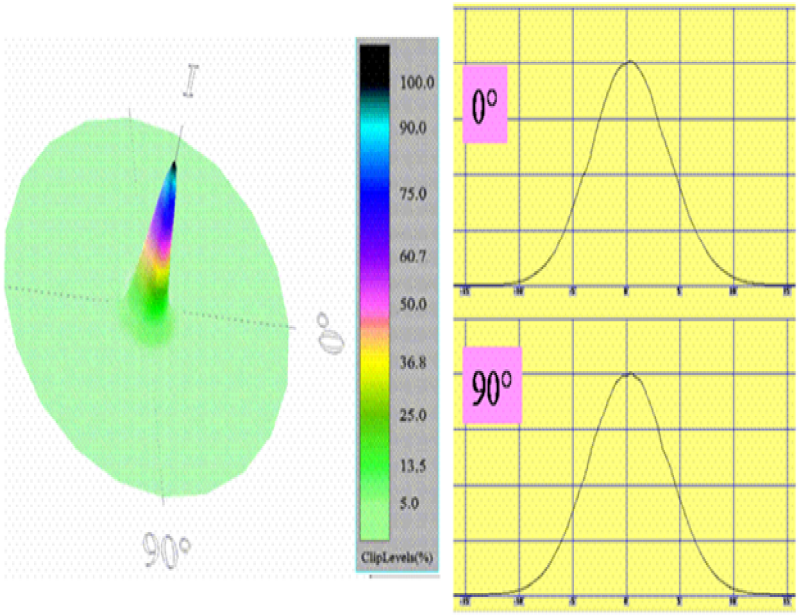


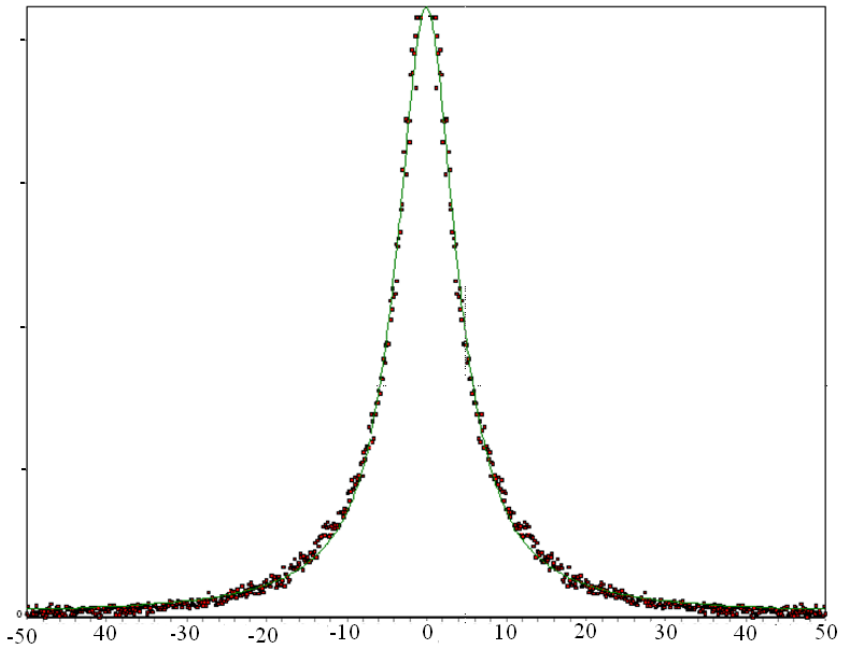


15 nm tuning

1550 nm far-field and line-width

Far-field and line-width measurements performed at 2 mW output, RT





FWHM=9°

Lorentzian line-shape; • n = 4.5 MHz

Self-homodine line-width measurements performed by M.Grossenbacher, ED EPFL

Wavelength selection in the 2000 nm band

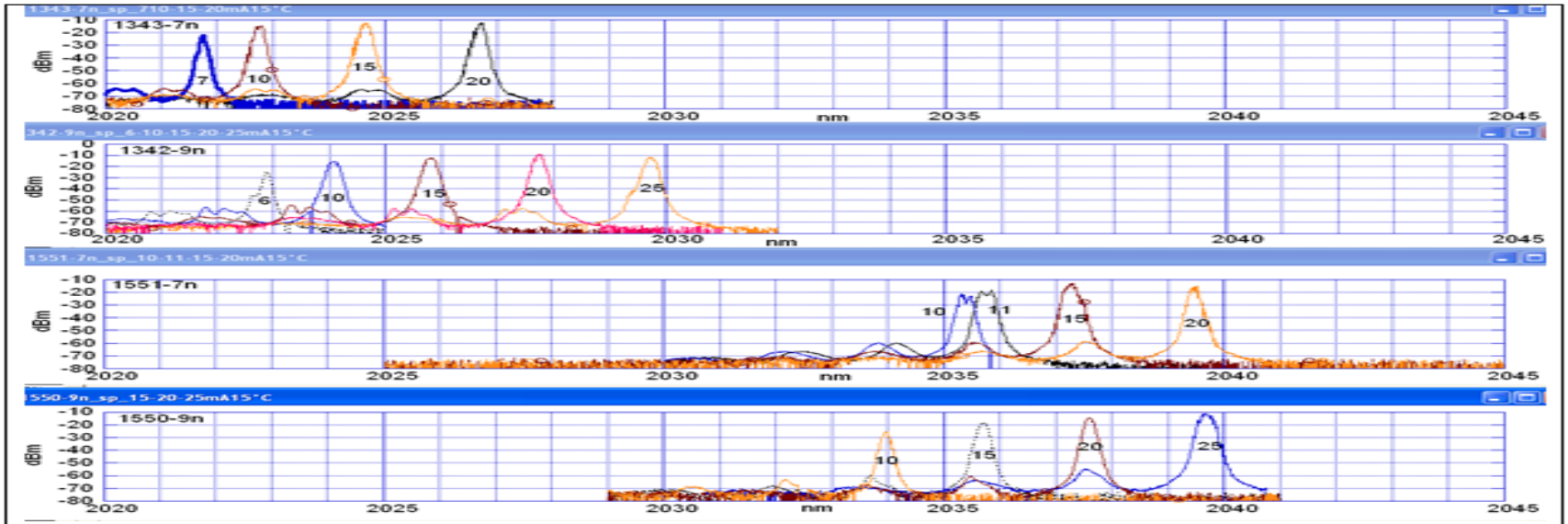


Figure 1 spectra

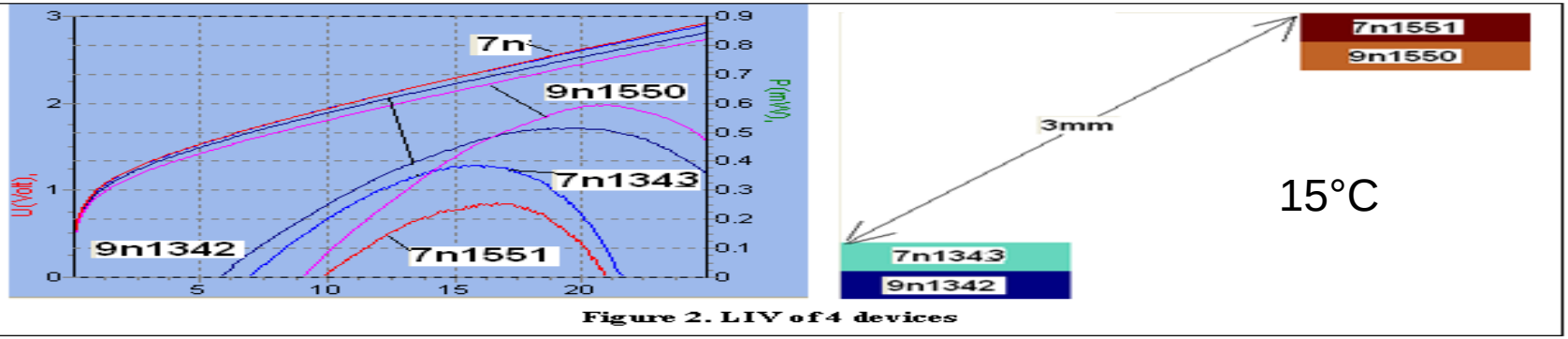
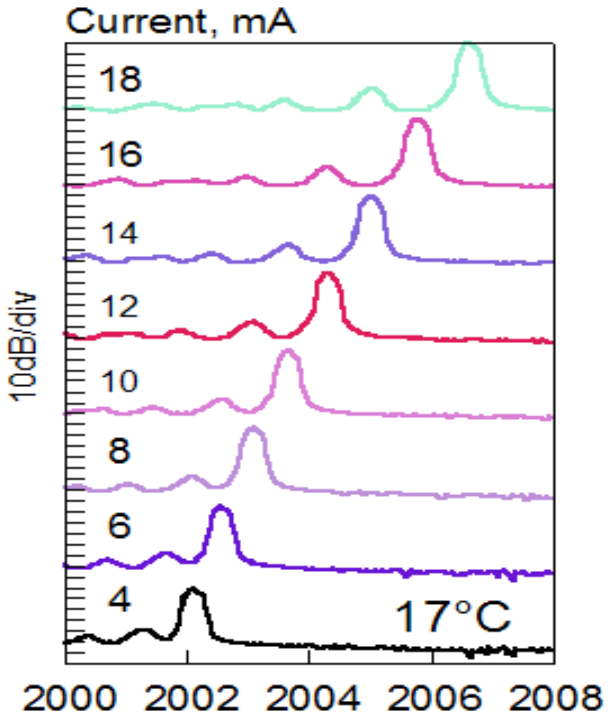
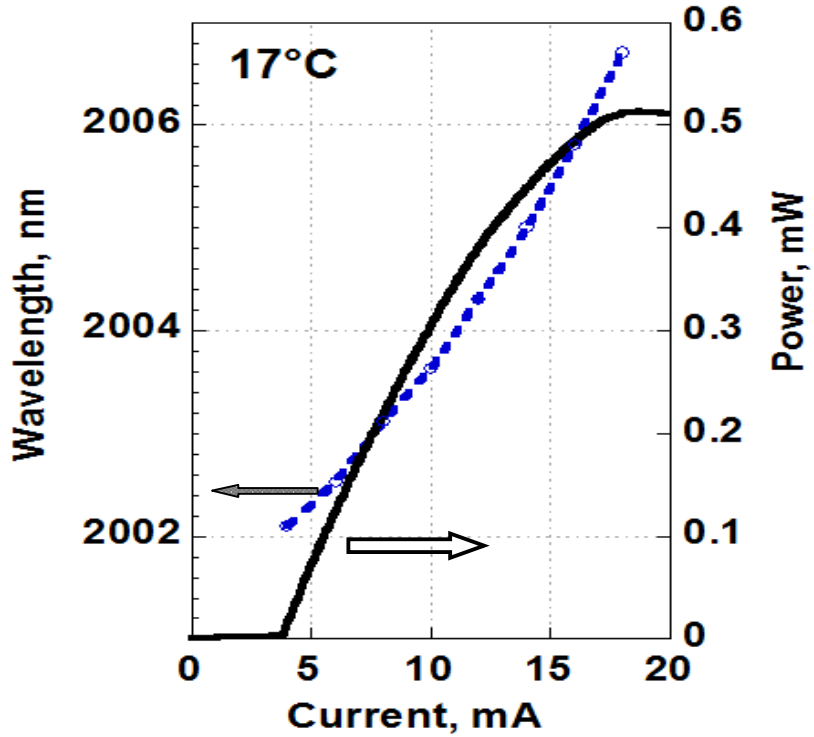


Figure 2. LIV of 4 devices

V. Iakovlev, Internal report

Wavelength tuning





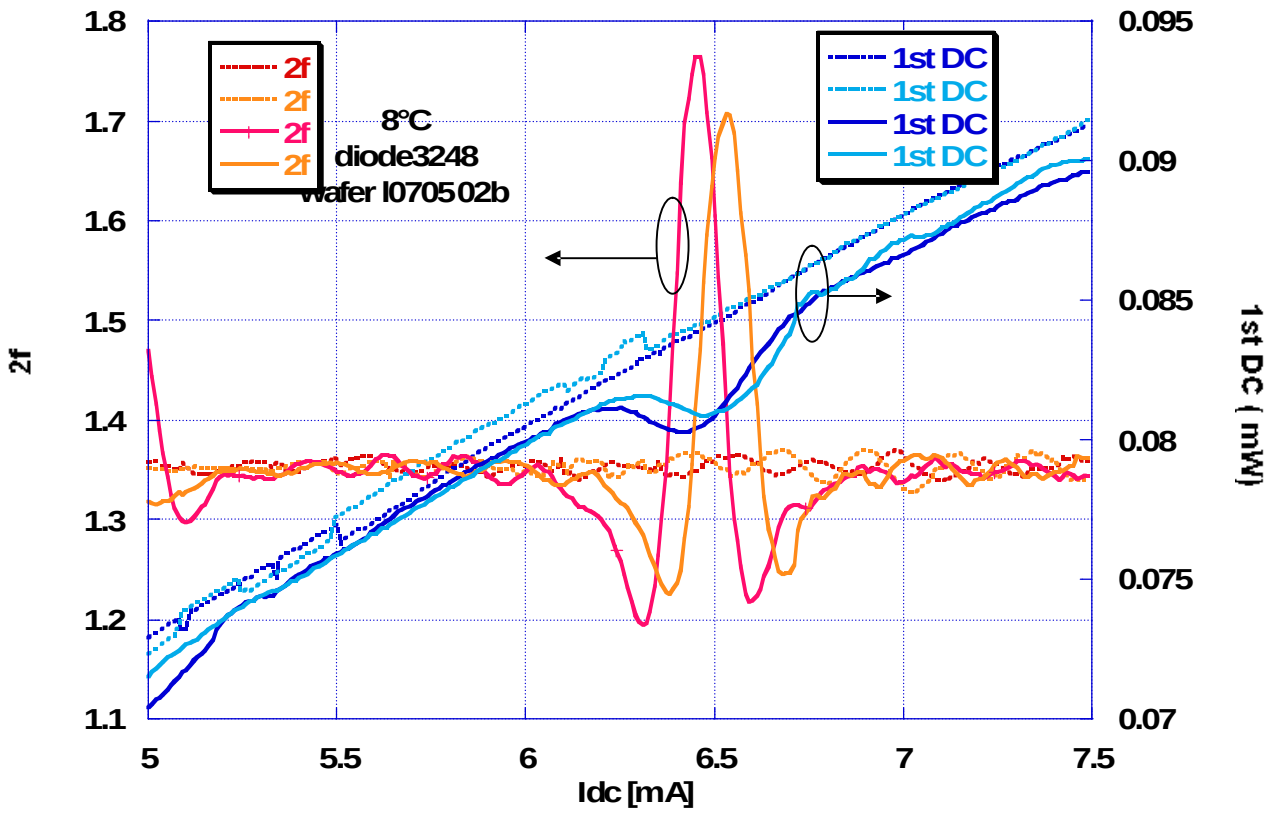
Wavelength tuning range ~ 5 nm

Single mode emission in the 4-18 mA current range

A. Mereuta et al. PTL 2008, IPRM-2008

Wavelength tuning rates:
- $\Delta\lambda/\Delta I$ ~ 0.31 nm/mA
- $\Delta\bullet/\Delta T$ ~ 0.14 nm/°C

CO_2 detection with LPN/BX VCSEL



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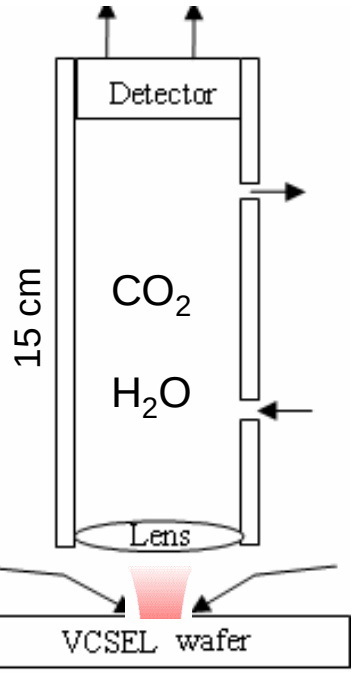
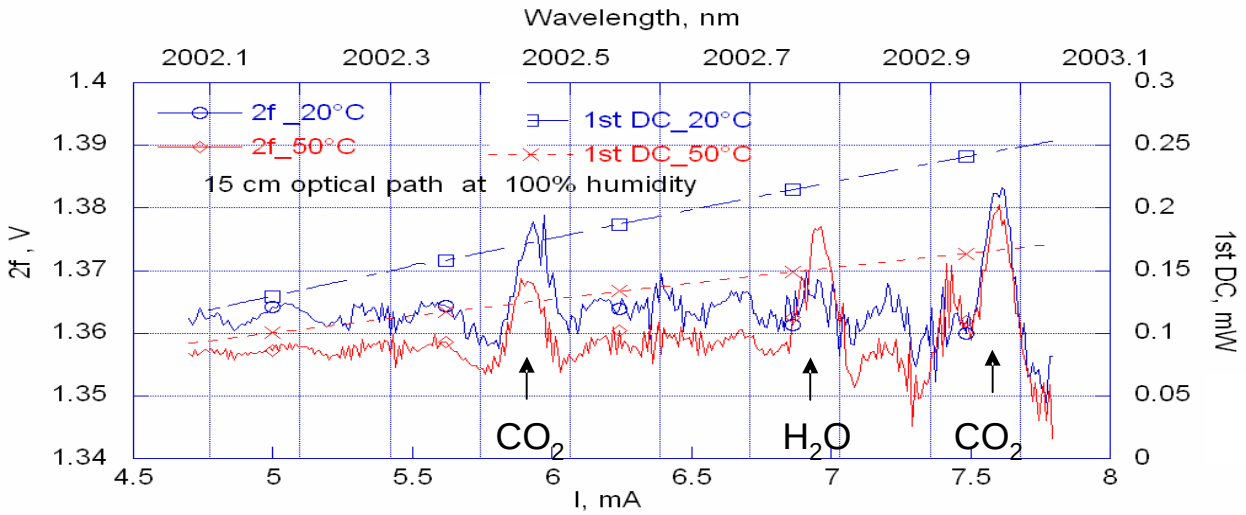
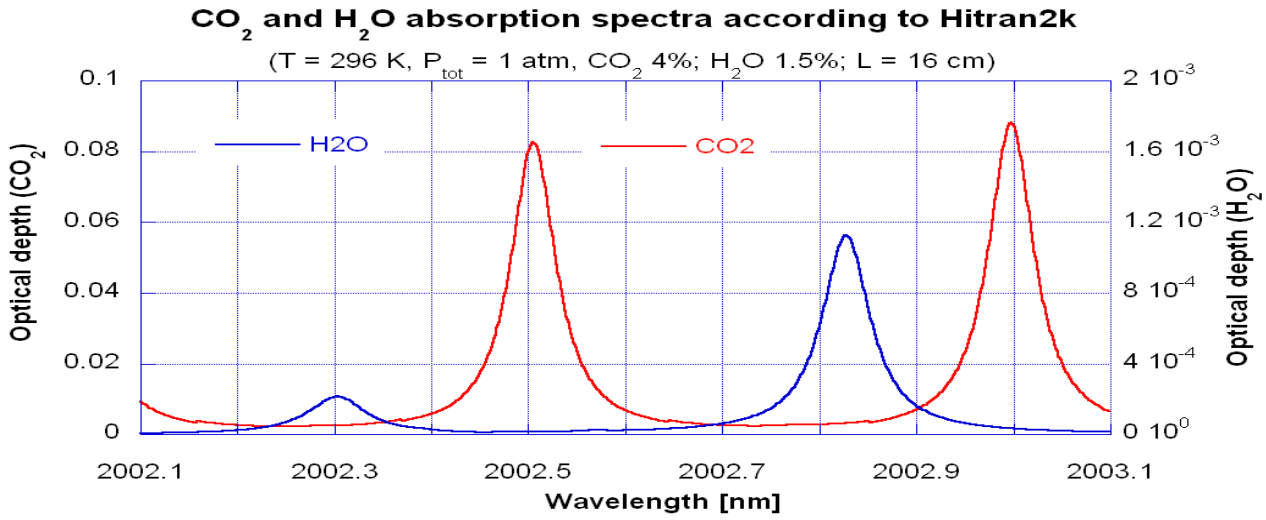
Dashed lines– ordinary room air
Solid lines– 10 mbar CO_2
Optical path length - 10 cm

Two-species detection: CO_2 and H_2O







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Summary

- **1.5 ㎛ VCSELs are produced with a broad range of wavelength inventory on the same wafer of 40 nm, high SM output power of 6.9 mW @ 0°C and 2.5 mW @ 80°C with line-width of 4.5 MHz and 15 nm of tuning range with current;**
- **Capability of fabrication of 2 ㎛ VCSELs with 0.5 mW SM output;**
- **2003-nm VCSELs detection of carbon dioxide (CO_2) and water (H2O) molecules in air is demonstrated.**