nano-tera.ch
swiss scientific initiative in health / security / environment systems

IrSens 2 RTD 2013

FNSNF

Neighbour Quantum Cascade Lasers: multicolour, single-mode devices for gas trace spectroscopy

Filippos Kapsalidis[1], Martin J. Süess[1], Johanna M. Wolf[1], Emilio Gini[2], Mattias Beck[1] and Jérôme Faist[1]

[1]Quantum Optoelectronics Group, [2]FIRST Center for Micro- and Nanoscience, CH-8093 Zurich, Switzerland

Introduction:

- For most gas molecules, their fundamental and characteristic roto-vibrational transitions occur at energies that correspond to the mid-infrared (MIR) region of the electromagnetic spectrum, roughly defined as the part from *4* to *10 μm*.
- Laser-light absorption spectroscopy techniques can be applied for the *detection* and *analytical monitoring* of pollutant and greenhouse gases. However, these techniques are usually complicated, and especially multi-gas detection requires a combination of several detection schemes.
- The IrSens 2 project aims to provide a solution for a *single-instrument*, *portable* and *low consumption* multi-gas detection system.

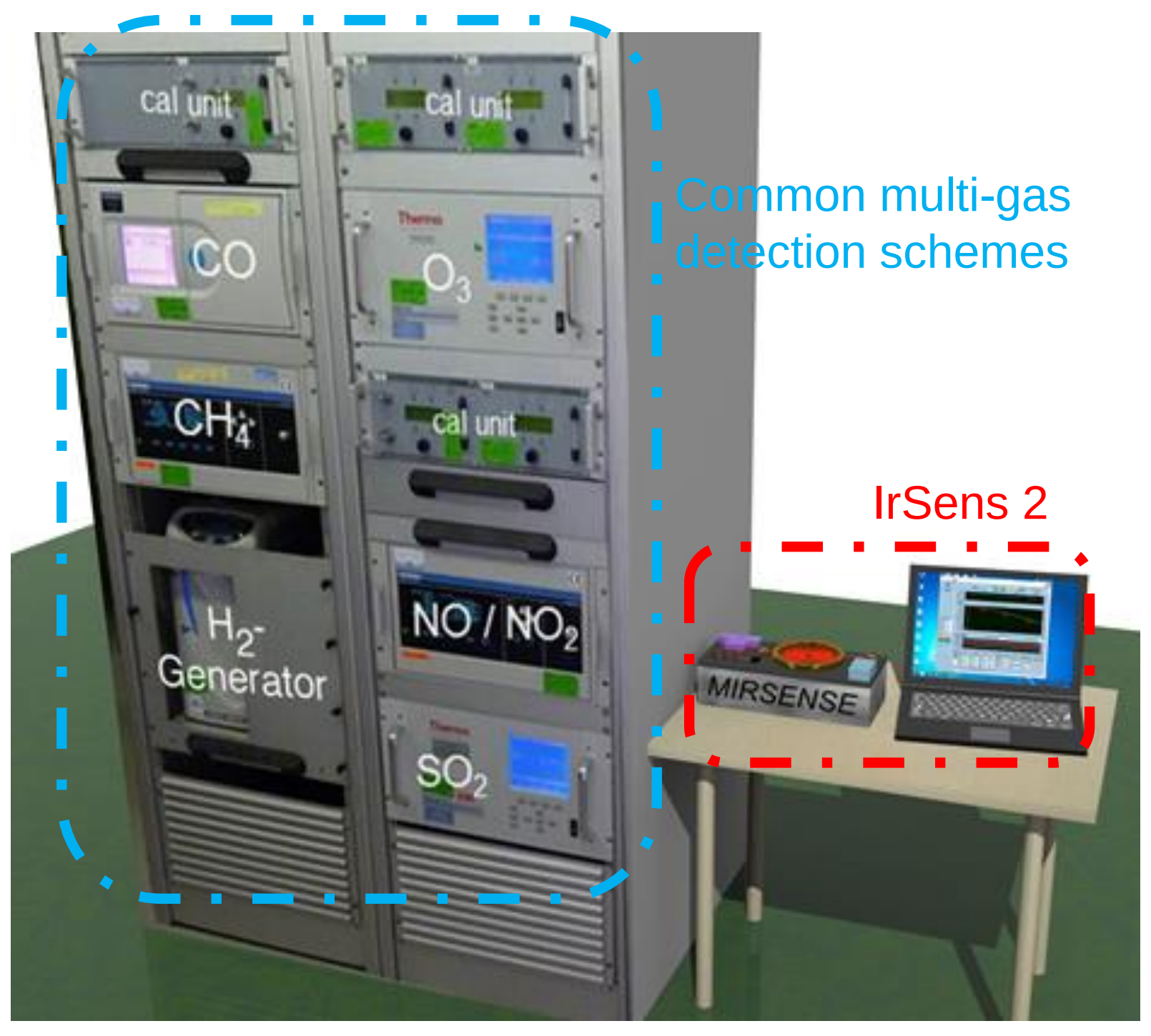

Figure 1: Comparison of a conventional multi-gas detection scheme to the IrSens 2 proposal.

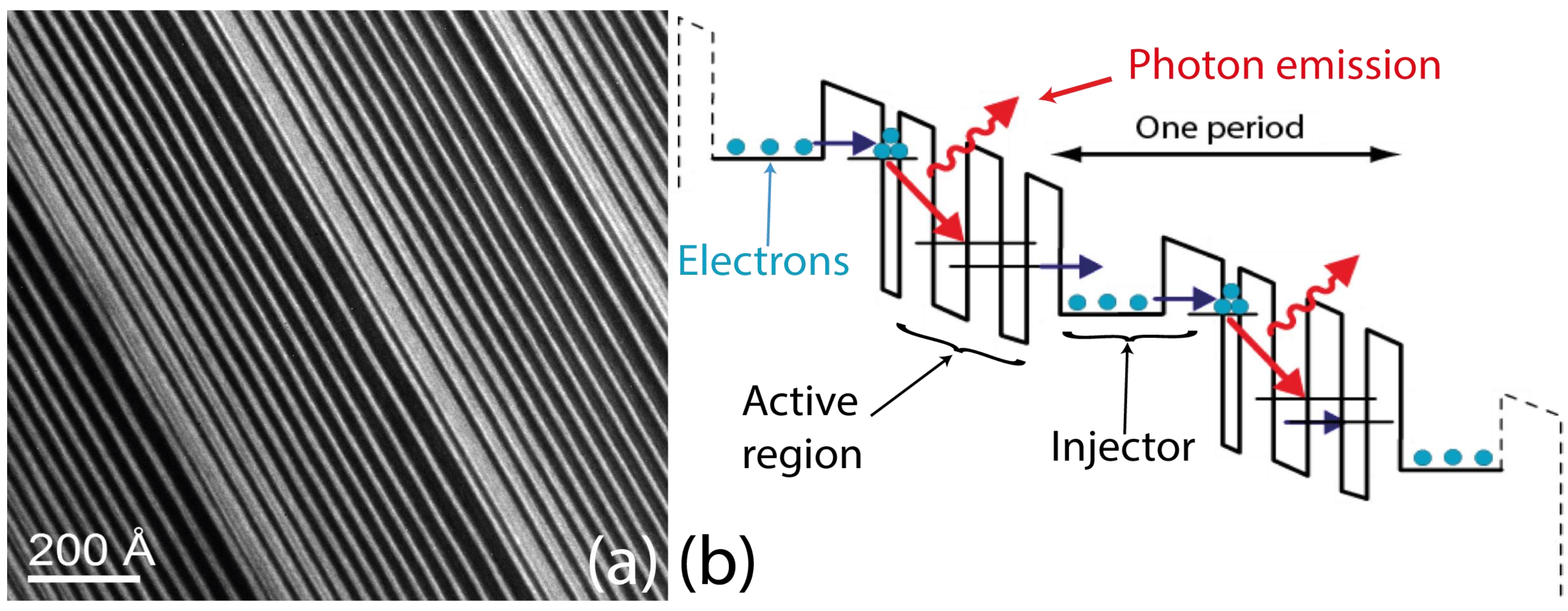

Figure 2: (a) TEM image of a QCL active region. (b) Conduction band diagram of a QCL.

Multi-colour quantum cascade lasers (QCLs):

- QCLs are semiconductor light sources, based on intersubband transitions, operating in the MIR range [1].
- Standard distributed-feedback (DFB) QCLs are tuneable only within a narrow spectral range, thus restricting the measurement to one gas species per device [2].
- Multi-colour QCL devices have been developed: multicolour array lasers [3], dual-section DFB QCLs [4].
- In this work, a novel design of multicolour devices, *neighbouring pairs of DFB QCLs,* is presented.

Neighbour Quantum Cascade Lasers design:

- Design is based on an inverted buried hetero-structure protocol [5]:
  - Active regions, consisting of a double heterogeneous quantum cascade stack of InGaAs and InAlAs quantum wells, are grown on an InP substrate.
  - Width of active regions transversal profile is 3.8μm and length 3.24mm. Lateral distance between the active regions is 45μm.
  - Wet-etch was used to electrically separate the two devices (devices decoupled from each other).
  - The two active regions feature each a different wet-etched DFB grating with a λ/4 shift, allowing for single-mode emission at 1600 cm^{-1} and 1900 cm^{-1}.
  - High-reflectivity coating was applied to the back facet, to increase output optical power efficiency.

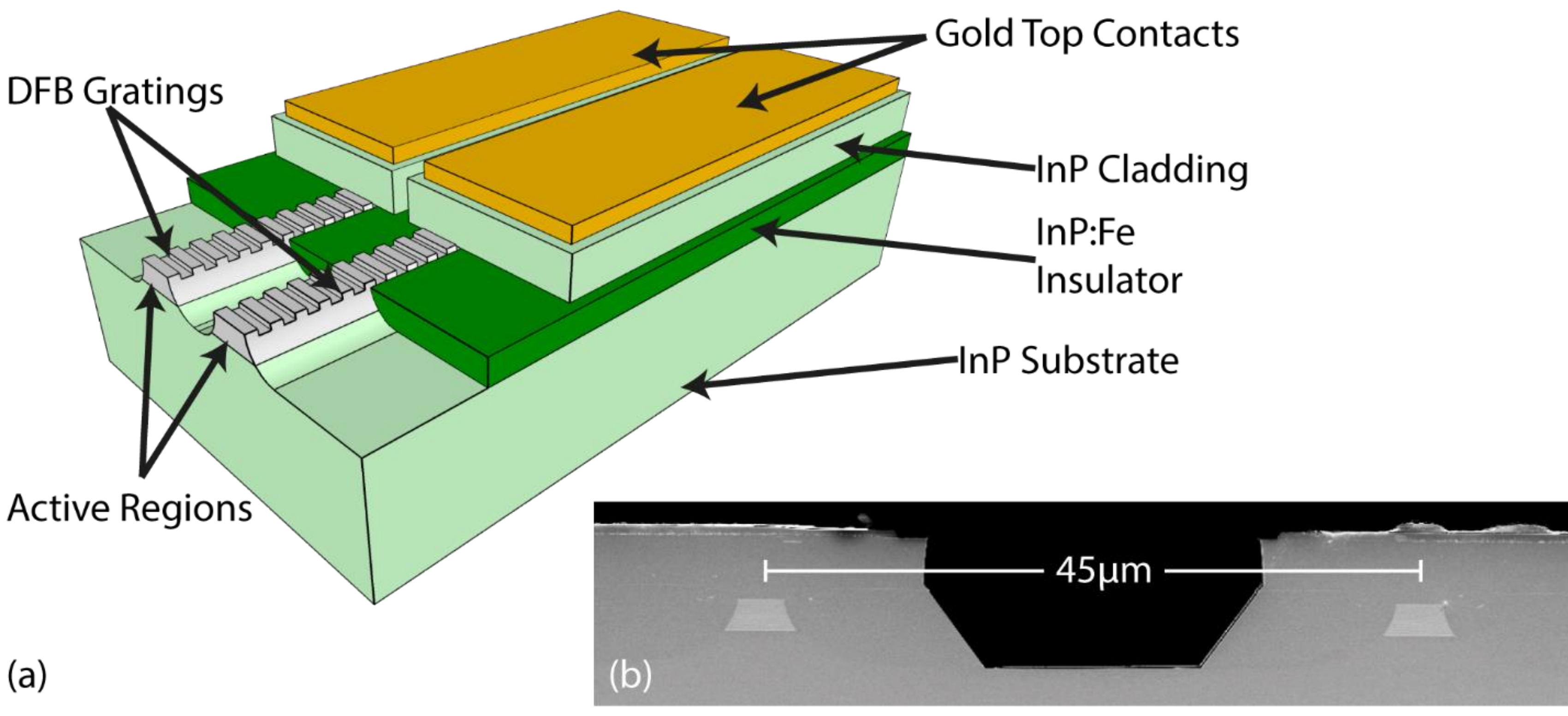

Figure 3: (a) Schematic drawing of the neighbouring DFB QCLs device. (b) SEM image of the lasers' front facets. Active regions' separation distance is 45 μm. The width of their profile is 3.8μm.

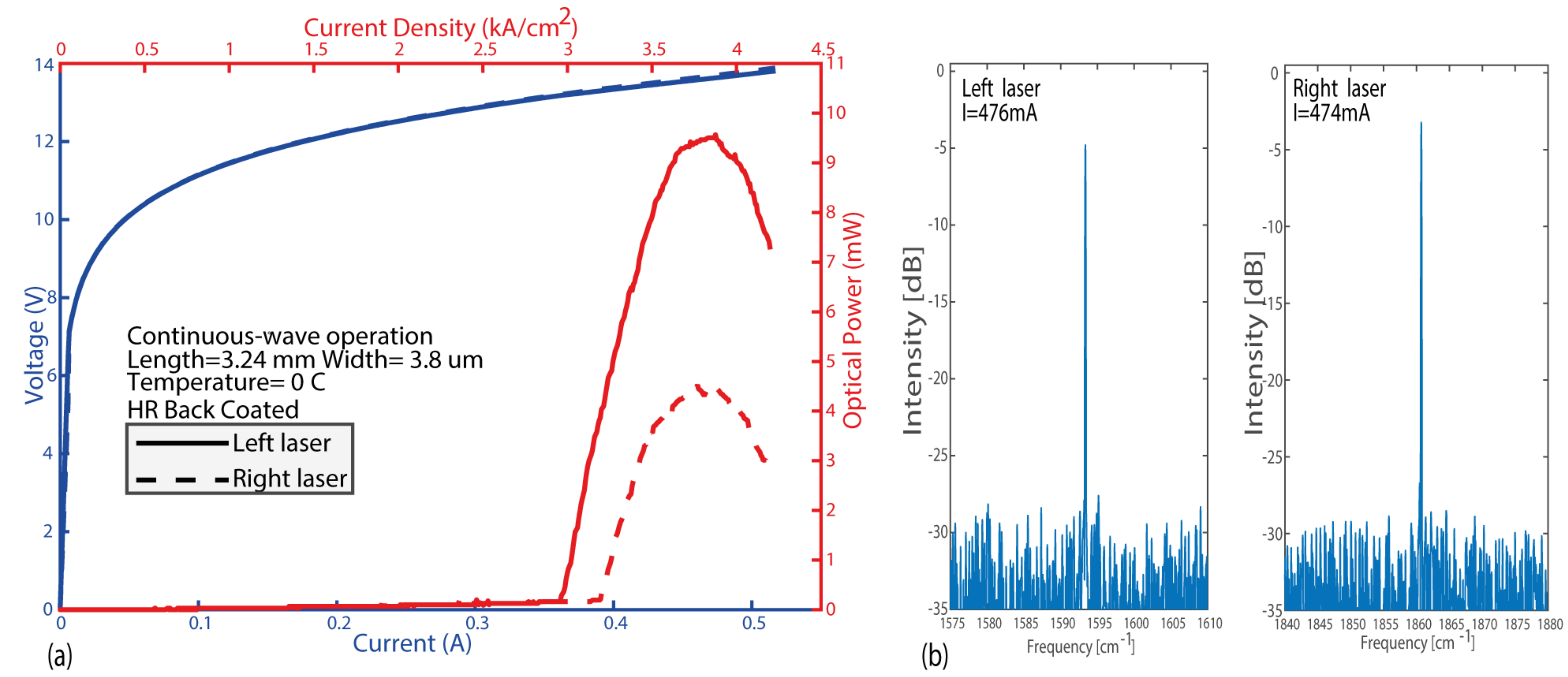

Figure 4; (a) Light-Current-Voltage curves of the left (solid lines) and right lasers (dashed lines) (b) Emission spectra of the lasers: the single modes correspond to the etched DFBs on their active regions.

Device Characterization – Results

- Light-current-voltage characterization and MIR spectroscopic measurements reveal continuous-wave, single-mode operation at 0°C.
- Comparable laser current thresholds: *363mA* (*2.9kA/cm²*) and *390mA* (*3.2kA/cm²*) at *1600cm⁻¹* and *1900cm⁻¹* respectively.
- Peak optical output power: *10mW* for the left laser and *5mW* for the right laser, observed at a pump current of *475mA* (*3.9 kV/cm²*) for both.
- The spectra of the devices, for a pump current value near to the optical power maximum, show that both lasers provide a clear emission line at about *25dBs* above the noise ground level.
- Can be used for pollutant gas spectroscopy, specifically for **NO** and **NO_2**.

References:

[1] J. Faist, F. Capasso, D. Sivco, C. Sirtori, A. Hutchinson and A. Cho, "*Quantum Cascade Laser*", Science **264**, 533 (1994).

[2] P. Jouy, M. Mangold, B. Tuzson, L. Emmenegger, Y. Chang, L. Hvozdara, H. P. Herzig, P. Wägli, A. Homsy, N. F. de Rooij, A. Wirthmueller, D. Hofstetter, H. Looser, J. Faist, "*Mid-infrared spectroscopy for gases and liquids based on quantum cascade technologies*", Analyst **139(9)**, 2039-46 (2014).

[3] P. Rauter, S. Menzel, A. K. Goyal, C. A. Wang, A. Sanchez, G. Turner, and F. Capasso "*High-power arrays of quantum cascade laser master-oscillator power-amplifiers*", Optics Express **21**, 4518 (2013).

[4] J. Jágerská, P. Jouy, A. Hugi, B. Tuzson, H. Looser, M. Mangold, M. Beck, L. Emmenegger, and J. Faist, "*Dual-wavelength quantum cascade laser for trace gas spectroscopy,*" Applied Physics Letters **105**, 161109 (2014).

[5] M. Beck, D. Hofstetter, T. Aellen, J. Faist, U. Oesterle, M. Ilegems, E. Gini, and H. Melchior, "*Continuous Wave Operation of a Mid-Infrared Semiconductor Laser at Room Temperature*", Science **295**, 301 (2002).