QCLD-based lab-on-a-chip for μ-fluidic sensing

Florian Pfli1,2, Benedikt Schwarz1, Hermann Detz1, Aaron M. Andrews3, Bettina Buengartner1, Bernhard Lendl1, Gottfried Strasser1, Borislav Hinkov1,2

1 Institute of Solid State Electronics and Center for Micro- and Nanostructures, TU Wien, Vienna, Austria
2 Institute of Solid State Physics, Graz University of Technology, Graz, Austria
3 CITEC, Biele University of Technology, Biele, Czech Republic
4 Institute of Chemical Technologies and Analytics, TU Wien, Vienna, Austria

Email: florian.pfli@tuwien.ac.at; borislav.hinkov@tuwien.ac.at

Short Abstract: Quantum cascade laser technology provides innovative devices for experiments in the mid-infrared spectral region where molecules show their unique fundamental absorption features. In this work we present a room-temperature monolithically-integrated quantum cascade laser detector device for liquid-sensing of μ-samples so compact it can easily fit inside a golf ball. In the first experiments, concentration-dependent absorption, rapid-response and long-term-stability measurements are shown.

1. Introduction

With the rise of quantum cascade technology, valuable instruments for chemical sensing in the mid-infrared spectral region emerged. Molecules show strong fundamental absorption features in this so-called characteristic fingerprint region, enabling sensitive and non-destructive detection.

Quantum cascade lasers and detectors can be designed to directly address these absorption features, allowing measurements of e.g. low target molecule concentrations [1] or the analysis of the secondary structure of proteins [2].

Appropriately designing the active region of quantum cascade lasers and detectors can lead to efficient emission and detection of identical wavelength radiation [1]. Coupling efficiencies of up to 50% for a gap between on-chip laser and detector longer than 100 μm can be achieved in a monolithically integrated quantum cascade laser detector (QCLD) device with the use of surface plasmon polariton (SPP) waveguides [1]. More than 90% of the laser mode is located outside these waveguides which accounts for a large interaction volume with an adjacent analyte.

A monolithic approach offers the possibility to easily increase the number of QCLD devices on a single chip. Applying different distributed feedback (DFB) gratings to each individual QCLD unit enables targeting multiple wavelengths simultaneously, yielding a small and very cost-efficient sensor array.

2. Results

A QCLD device has been implemented into a custom made μ-fluidic aluminium cell, designed to fulfill several criteria such as a small sample volume (< 120 μl) comparable to two drops of blood, chemical and mechanical stability and external access to the electrical, fluidic, and thermal links (Figure 1a).

The sensor used in our experiment has a 100 μm long SPP waveguide connecting the laser and the detector. The Fabry-Perot laser was operated at 15 °C with 100 ms pulses at a repetition frequency of 5 kHz which resulted in a spectral emission showing two main peaks (1515 cm⁻¹, 1562 cm⁻¹).

Absorption measurements were performed with mixtures of DI water (high absorption) and isopropl alcohol (IPA, low absorption). The absorbance was calculated for the detector signal and the weighted absorption coefficients for the mixture at varying concentrations (Figure 1b). At low concentrations the measured absorbance is in good agreement with the theoretical model. Deviations partially originate from inaccurate liquid preparation. For higher concentrations the result is currently limited by electrical crosstalk and thermal fluctuations.

For stability evaluation the detector signal was recorded for over 3.5 h with pure IPA (Figure 1c). The standard deviation corresponds to a difference in water concentration of 0.05 % only. Figure 1d shows the response of the sensor to an abrupt change in the concentration of the liquid (pure IPA to 20 % water in IPA). The time constant of an exponential fit to the changing detector signal show a very fast response time of 70 ms which relates to the mixing of liquids within the cell. The response time is limited by the setup, not the laser/detector system itself.

A compact, fast and stable liquid absorption sensor has been shown. The initial proof-of-principle experiments indicate the great potential of quantum cascade technology in liquid sensing. Several improvements are subject to ongoing investigations including electrical crosstalk-reduction by optimized contacting schemes, thermal fluctuation compensation, precise laser emission control by implementing DFB gratings and sensitivity enhancement by surface functionalization.

References


Thursday, September 19th

09:00-09:10 Session 13: Industry Presentation
Chair: Heinz-Wilhelm Hübner
09:00  **Bob Shine**, Dave Caffey and Jeremy Rowlette
*Markets and Applications of Commercial Quantum Cascade Laser Based Systems (Industry Presentation)*

09:15-10:15 Session 14: Spectroscopy and Sensing
Chair: Heinz-Wilhelm Hübner
09:15  **Pierre Jouy**, Andreas Hugi, Markus Geiser, Raphael Horvath, Christopher Strand, Nico Pinkowski, Yiming Ding and Ronald K. Hanson
*Dual comb spectroscopy with QCLs: shock tube applications and challenges for QCL frequency comb sources*

09:30  **Florian Pilat**, Benedikt Schwarz, Hermann Detz, Aaron Maxwell Andrews, Bettina Baumgartner, Bernhard Lendl
*QCL-based lab-on-a-chip for µ-fluidic sensing*

09:45  **Osunuki Yang**
*Hetero-cascading Quantum Cascade Lasers and their Application in Realtime Spectroscopy*

10:00  **Aleksandra Werth**, Yasin Kaya, Kaif Shaw, Noah Aptorpe, James Lee, Nsonna Ailionu, Sofia Inglessis and Claire Gnacl
*Implementation of quantum cascade laser spectroscopy and multivariate analysis for noninvasive glucose monitoring*

10:15-10:50 Coffee Break (Exhibition is open)

10:50-12:20 Session 15: Frequency Combs 2
Chair: David Burghoff
10:50  **Benedikt Schwarz**, Johannes Hillbrand, Maximilian Beiser, Nikola Opacik, Aaron Maxwell Andrews, Hermann Detz, Gottfried Strasser, Anne Schade, Robert Weih and Sven Höfling
*Towards monolithic and battery driven mid-infrared dual-comb spectrometers (Invited)*

11:05  **Jakub Sterczewski**, Mahmood Bagheri, Clifford Frez, Chadwick Caneled, Igor Vurgaftman, Mijin Kim, Chul Soo Kim, Charles Meritt, William Bewley and Jerry Meyer
*Injection locking of interband cascade laser frequency combs*

11:20  **Bo Meng**, Matthias Beck and Jérome Faist
*Mid-Infrared Frequency Comb from a Ring Quantum Cascade Laser*

11:35  **Johannes Hillbrand**, Aaron Maxwell Andrews, Hermann Detz, Harald Schneider, Gottfried Strasser, Federico Capasso and Benedikt Schwarz
*Actively mode-locked mid-infrared quantum cascade laser*

11:50  **Andres Forger**, David Stark, Martin Franckie, Tudor Olariu, Matthias Beck, Jérome Faist and Giacomo Scalari
*Injection locking and bi-stable operation of a homogeneous bound-to-continuum THz Quantum Cascade Laser spanning up to 1.65 THz*

12:20-13:30 Buffet Lunch

14:30-16:00 Session 16: Metasurfaces and Topological Photonics
Chair: Carlo Sirtori
14:30  **Mercedes Khajavikhan**
*Topological and Supersymmetric Laser Arrays (Invited)*

15:00  **Leland Nordin**, Kun Li, Andrew Briggs, Evan Simmons, Seth Bank, Viktor Podolskiy and Daniel Wasserman
*Enhanced Emission from a Long Wavelength Infrared Emitter*

15:15  **Yue Shen**, Christopher Curwen, Luyao Xu and Benjamin Williams
*THz time-domain characterization of amplifying quantum cascade metasurface*

15:30  **Ali Basiri**, Jing Bai, Xiaohui Chen, Jiawei Zuo, Pouya Amrollahi, Joe Carpenter, Zachary Holman, Chao Wang and Yu Yang
*Circularly Polarized Light Detection Based on Efficient Chip-Integrated Metasurface*