ITQW 2019

Infrared Terahertz Quantum Workshop

September 15-20, 2019
Ojai, California, USA

ITQW
OJAI, CA 2019

Program and Abstract Catalog

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

Florian Pilat[1,2]*, Benedikt Schwarz[1], Hermann Detz[3], Aaron M. Andrews[1], Bettina Baumgartner[4], Bernhard Lendl[4], Gottfried Strasser[1], Borislav Hinkov[1,*]

[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] *CEITEC, Brno University of Technology, Brno, Czech Republic*
[4] *Institute of Chemical Technologies and Analytics, TU Wien, Vienna, Austria*
**Contact Email: florian.pilat@tuwien.ac.at; borislav.hinkov@tuwien.ac.at*

Short Abstract Quantum cascade 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 μl-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 aluminum 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-Pérot laser was operated at 15 °C with 100 ns 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 isopropyl 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 constants 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.

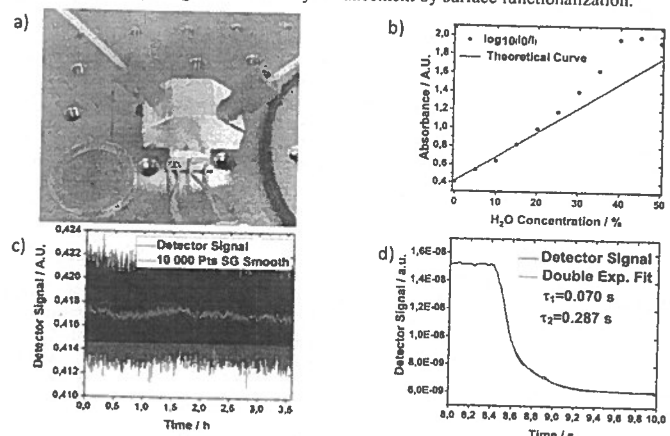

Figure 1: a) Custom made fluid cell housing a QCLD sensor chip; b) Absorbance calculated for water and IPA at the laser wavelengths theoretically (red) and from the experimental detector signal (black); c) Pure IPA detector signal, 75 data points / s, mean = 0.4170 A.U., std. dev. = 0.0014 A.U. (black), smoothed data (red); d) Detector response to rapid concentration change (0 % to 20 % water in IPA, black), double exponential fit (red)

References

[1] B. Schwarz et al., "Monolithically integrated mid-infrared lab-on-a-chip using plasmonics and quantum cascade structures". Nat. Commun. 5, 4085 (2014).

[2] A. Schwaighofer, et al. External cavity-quantum cascade laser infrared spectroscopy for secondary structure analysis of proteins at low concentrations. Sci. Rep. 6, 33556 (2016).

Thursday, September 19th

09:00-09:10 Session 13: Industry Presentation

Chair: Heinz-Wilhelm Hübers

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 Hübers

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, Gottfried Strasser and Borislav Hinkov
QCLD-based lab-on-a-chip for μ-fluidic sensing

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

10:00 **Alexandra Werth**, Yasin Kaya, Kalil Shaw, Noah Apthorpe, James Lee, Nsomma Alilonu, Sofia Inglessis and Claire Gmachl
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 Opacak, 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)***

11:20 **Lukasz Sterczewski**, Mahmood Bagheri, Clifford Frez, Chadwick Canedy, Igor Vurgaftman, Mijin Kim, Chul Soo Kim, Charles Meritt, William Bewley and Jerry Meyer
Injection locking of interband cascade laser frequency combs

11:35 **Bo Meng**, Mattias Beck and Jérôme Faist
Mid-Infrared Frequency Comb from a Ring Quantum Cascade Laser

11:50 **Johannes Hillbrand**, Aaron Maxwell Andrews, Hermann Detz, Harald Schneider, Gottfried Strasser, Federico Capasso and Benedikt Schwarz
Actively mode-locked mid-infrared quantum cascade laser

12:05 **Andres Forrer**, David Stark, Martin Franckié, Tudor Olariu, Mattias Beck, Jérôme 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 **Mercedeh 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, Xiahui Chen, Jiawei Zuo, Pouya Amrollahi, Joe Carpenter, Zachary Holman, Chao Wang and Yu Yao
Circularly Polarized Light Detection Based on Efficient Chip-Integrated Metasurface