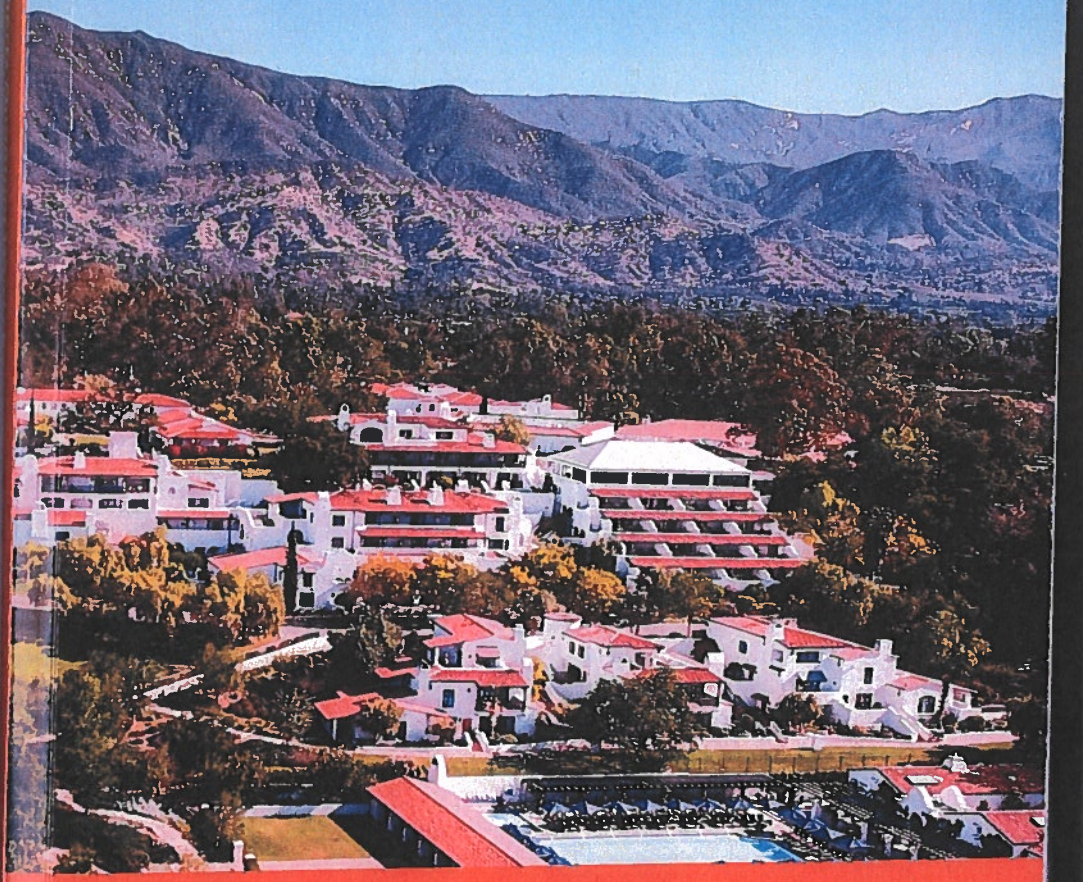
ITQW 2019

Infrared Terahertz Quantum Workshop

September 15-20, 2019
Ojai, California, USA



ITQW
OJAI, CA 2019

Program and Abstract Catalog

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

Actively mode-locked mid-infrared quantum cascade laser

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Short Abstract Mode-locking of mid-infrared quantum cascade lasers (QCL) remains challenging to date due to their ultrafast gain dynamics. We report on active mode-locking of mid-infrared QCLs resulting in the emission of intense picosecond pulses. We investigate the temporal dynamics of the QCL using both linear and quadratic autocorrelation techniques. Both methods confirm independently that the QCL emits a train of isolated pulses.

1. Introduction

The majority of semiconductor lasers relies on interband transitions to create optical gain. In such lasers, the upper-state lifetime is generally much longer than the cavity roundtrip time. As a consequence, the longitudinal cavity modes of most interband lasers can be mode-locked by introducing a fast saturable absorber in the cavity or by modulating the gain or losses at the roundtrip frequency resulting in the emission of short pulses.

In contrast to this, the optical gain in quantum cascade lasers (QCL) is provided by intersubband transitions. This has important consequences for the temporal dynamics of the QCL. Due to fast intersubband scattering and tunneling, both the upper-state lifetime and gain recovery time of mid-infrared (MIR) QCLs are typically orders of magnitude shorter than the cavity roundtrip time.

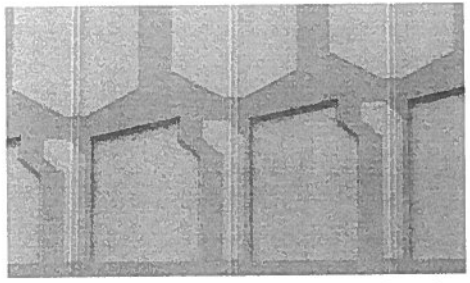

Figure 1: Scanning electron microscope image of the modulation section of three adjacent QCLs.

Hence, the QCL acts as a fast saturable gain. In contrast to a fast saturable absorber, the fast QCL gain dynamics are highly unfavorable for the formation of short pulses. As a consequence, mode-locking of MIR QCLs remains challenging to date. A possible solution is to increase the upper-state lifetime artificially by designing a very diagonal optical transition [1]. However, the necessary modifications of the laser design strongly degrade its overall performance and mode-locking was only observed close to lasing threshold with relatively small peak powers.

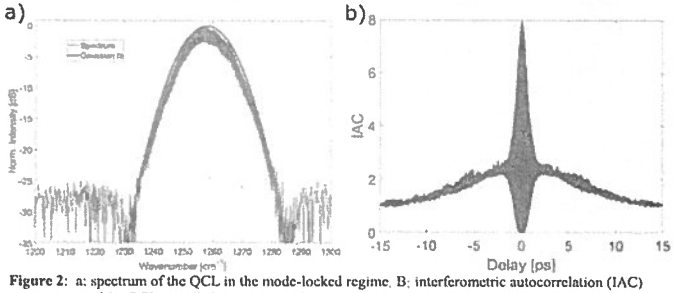

Figure 2: a: spectrum of the QCL in the mode-locked regime. B: interferometric autocorrelation (IAC) of the QCL recorded using a two photon quantum well infrared photodetector.

Here, we demonstrate active mode-locking of a MIR QCL without requiring a long upper-state lifetime. The investigated QCLs are two-section devices (Fig. 1), which allow efficient RF injection [2]. The electronic bandstructure of the QCLs was optimized to enable high modulation depth. When the frequency of the injected RF signal is close to the roundtrip frequency, the spectrum of the QCL consists of a single lobe with a Gaussian envelope (Fig. 2a), as expected for an actively mode-locked laser.

We investigate the temporal profile of the pulses using quantum well infrared photodetectors (QWIP) optimized for high bandwidth and quadratic detection. The high-speed QWIP allows characterization of the QCL using 'Shifted Wave Interference Fourier Transform Spectroscopy' (SWIFTS). The SWIFTS characterization reveals that the output of the QCL consists of a train of isolated pulses with full-width half-maximum on the picosecond level. The interferometric autocorrelation of the QCL recorded with the two-photon QWIP (Fig. 2b) shows a ratio of 8:1 between peak and background, which proves unambiguously that the QCL operates in the mode-locked regime. Finally, we show that the mode-locked regime spans over the entire dynamic range of the QCL. The average power in the mode-locked regime can be as high as roughly half of the maximum average power of the QCL at the thermal rollover. Our results demonstrate that QCLs provide a platform for compact generation of mid-infrared picosecond pulses.

References

[1] Wang et al. "Mode-locked pulses from mid-infrared quantum cascade lasers." *Optics Express* 17.15 (2009): 12929-12943.

[2] Hillbrand et al. "Coherent injection locking of quantum cascade laser frequency combs." *Nature Photonics* 13.2 (2019): 101-104.