NANYANG TECHNOLOGICAL UNIVERSITY
SINGAPORE

ITQW 2017

10 – 15 Sep, Singapore

14th International Conference on Intersubband Transitions in Quantum Wells

Sands Expo and Convention Center
Singapore

CONFERENCE PROGRAM

12:30 – 12:45 Sukhdeep Dhillon (Laboratoire Pierre Aigrain)
Short THz pulse generation from a dispersion compensated mode locked quantum cascade laser
12:45 – 13:00 Petar Tzenov (Technical University of Munich)
Gain recovery dynamics and passive mode locking of THz quantum cascade lasers
13:00 – 14:30 Lunch
14:30 – 17:00 Social Events (Free)

Wednesday 13 September 2017
Session 7 **THz Frequency Comb-Chair: Harald Schneider**
09:00 – 09:30 **Jacob Khurgin (Johns Hopkins University) - Invited talk**
Frequency comb-theory
09:30 – 09:45 Yang Yang (Massachusetts Institute of Technology)
Full dynamic range comb formation in terahertz quantum cascade laser
09:45 – 10:00 Benedikt Schwarz (Technische Universität Wien)
High power frequency comb based on a bi-functional QCLD
10:00 – 10:15 Hua Li (Shanghai Institute of Microsystem and Information Technology)
Terahertz intersubband photonic devices for frequency comb operation and fast detection
10:15 – 10:45 Tea break

Session 8 THz Frequency Comb and Spectroscopy-Chair: Jacob Khurgin
10:45 – 11:30 **Qing Hu (Massachusetts Institute of Technology) - Plenary talk**
THz frequency comb
11:30 – 12:00 **Harald Schneider (Helmholtz-Zentrum Dresden-Rossendorf) - Invited talk**
THz-spectroscopic studies on electron dynamics in a GaAs single quantum well and an InAs single quantum dot
12:00 – 12:15 Jonas Westberg (Princeton University)
Terahertz multiheterodyne spectroscopy of molecular samples with quantum cascade laser frequency combs
12:15 – 12:30 Alexander Valavanis (University of Leeds)
Frequency-monitored gas spectroscopy through self-mixing interferometry in a terahertz quantum-cascade laser
12:30 – 12:45 Till Hagelschuer (German Aerospace Center)
Real-time spectroscopy of various gas species through optical feedback in a terahertz quantum-cascade laser
12:45 – 13:00 Miriam Serena Vitiello (NEST, CNR)
Spectral purity of terahertz quantum cascade laser sources based on intra-cavity difference frequency generation
13:00 – 14:30 Lunch
14:30 – 17:00 Excursion starts (S.E.A. Aquarium)
18:00 – 21:00 BBQ at beach

Thursday 14 September 2017
Session 9 THz Quantum Cascade Lasers-Chair: Harald Schneider
09:00 – 09:15 Ji Chen (Lehigh University)
High brightness THz quantum-cascade lasers utilizing inexpensive custom-made lenses
09:15 – 09:30 Huan Zhu / Gangyi Xu (Shanghai Institute of Technical Physics)
Terahertz master-oscillator power-amplifier quantum cascade laser with improved output power
09:30 – 09:45 Yongquan Zeng (Nanyang Technological University)
Two-Dimensional Multimode Terahertz Random Lasing with Metallic Pillars
09:45 – 10:00 Simone Biasco (NEST, CNR)
High-power, low-divergent, single-mode THz quantum cascade wire lasers operating in pulsed and continuous-wave regime
10:00 – 10:30 Tea break

Session 10 Photodetectors-Chair: Yanko Todorov
10:30 – 11:15 **Philippe Bois (Thales Research & Technology) - Plenary talk**
Infrared PDs
11:15 – 11:45 **Kaz Hirakawa/Zhang Ya (University of Tokyo) - Invited talk**
Novel bolometric THz detection by MEMS resonators
11:45 – 12:00 Behnam Mirzaei (Delft University of Technology)
An 8-Beam, 4.7 THz Local Oscillator Using a Quantum Cascade Laser and a Phase Grating
12:00 – 12:15 Pedro Pereira (Pontifícia Universidade Católica do Rio de Janeiro)
Photovoltaic asymmetric superlattice QWIP with confined states in the continuum
12:15 – 12:30 Zahra Asghari (University Paris Diderot- Paris 7)
Room Temperature High Performances Quantum Cascade Detectors
12:30 – 14:00 Lunch

Session 11 Mid-IR Quantum Cascade Lasers-Chair: Igor Vurgaftman
14:00 – 14:30 **Liu Fengqi (Institute of Semiconductors, CAS) - Invited talk**
History and recent development of QCLs in China
14:30 – 14:45 Dan Botez (University of Wisconsin-Madison)
4.7 μm-Emitting In-Phase Resonant-Coupled, Phase-Locked Arrays of QCLs: 3.6 W Near-Diffraction-Limited Power
14:45 – 15:00 Marco Piccardo (Harvard University)
Beat spatial hole burning
15:00 – 15:15 Frederic Demmerle (Technische Universität München)
Surface Emission by Transversally Superimposed Gratings in Nonlinear Quantum Cascade Lasers
15:15 – 15:30 Dan Botez (University of Wisconsin-Madison)
High Internal Efficiency Mid-IR Quantum Cascade Lasers

High power frequency comb based on a bi-functional QCLD

Benedikt Schwarz[1,*], Christine Wang[2], Leo Missaggia[2], Tobias S. Mansuripur[3], Paul Chevalier[4], Michael K. Connors[2], Daniel McNulty[2], Jeffrey Cederberg[2], Gottfried Strasser[1], and Federico Capasso[4]

[1] *Institute of Solid State Electronics, TU Wien, 1040 Vienna, Austria*

[2] *Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, MA 02420, USA*

[3] *Department of Physics, Harvard University, Cambridge, MA 02138 USA*

[4] *John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, USA*

**Contact Email:benedikt.schwarz@tuwien.ac.at*

Frequency combs based on QCLs open an alternative and elegant way to facilitate mid-infrared spectroscopy for compact or ultimately single-chip sensing instruments [1,2]. The detection of the beating between laser lines in a multi-heterodyne scheme allows the simultaneous down-sampling of the entire optical spectrum to the RF-domain, where state-of-the-art FPGA based electronics can be used to recover the spectral information.

The idea of this work is to merge our efforts on bi-functional devices [3,4] with frequency combs for future integrated sensors. The on-chip detection capability allows a straightforward integration and quantum cascade detectors are ideal candidates for multi-heterodyne detection. They allow direct and efficient on-chip coupling from the strong local oscillator and due to the short intersubband lifetimes, they have high electric bandwidths in the gigahertz range, as well as saturation intensities that allow linear detection over a large dynamic range.

Our new device generation is capable of room-temperature operation in continuous wave at 8 µm with watt level output power. The achieved continuous wave wall-plug efficiency of 7% is the highest reported value for lattice matched material at this wavelength. In detector operation, the device has a responsivity of 14 mA/W at the emission wavelength and a noise equivalent power of 0.14 $nW/\sqrt{Hz}$, which results in a dynamic range of 9 orders of magnitude.

In frequency comb operation the devices emit up to 400 mW in epi-side down and 80 mW in epi-side up mounted configuration. Beyond 400 mW, the device switches to the noisy dense regime, where phase locking is lost due to the larger affect of self-phase modulation onto the dispersion. The epi-side up mounted device are frequency combs in the entire bias region between the single mode regime and roll-over. The harmonic mode regime, which seems to be present in nearly all conventional QCLs [5], has not been observed in any of those devices and the second threshold of the frequency comb regime is extremely low (30-50 mA above laser threshold). This shows, that four-wave mixing induced phase-locking can kick in at relatively low power levels close to threshold in dispersion compensated QCLs and dominates their spectral behavior.

In conclusion, we demonstrate a quantum cascade device with record laser performance, as well as high speed zero bias detection and frequency comb operation capabilities. This makes our device a perfect candidate to realize a dual comb spectroscopy on a single chip.

This material is based upon work supported by the Assistant Secretary of Defense for Research and Engineering under Air Force Contract FA8721-05-C-0002 and/or FA8702-15D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the Assistant Secretary of Defense for Research and Engineering.

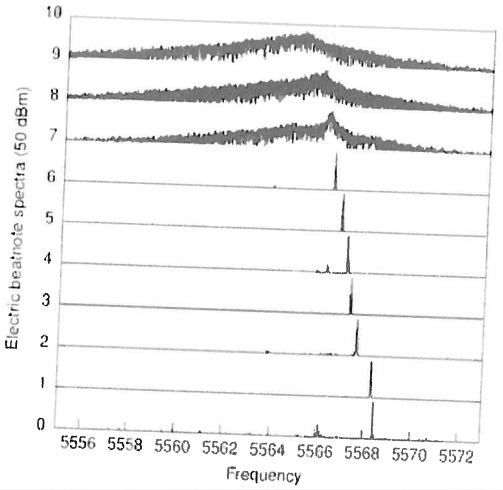

Fig. 1: Beat-note measurement of an epi-side down mounted device showing narrow beat nodes on a 50dB scale. At high intensities the comb regime switches off due to the lack of dispersion compensation owning to an increased self-phase modulation. This occurs at output powers between 200–400mW for the tested devices.

References

[1] A. Hugi, G. Villares, S. Blaser, H. C. Liu, and J. Faist, "Mid-infrared frequency comb based on a quantum cascade laser", Nature 492, 229, (2012)

[2] G. Villares, A. Hugi, S. Blaser, and J. Faist, "Dual-comb spectroscopy based on quantum-cascade-laser frequency combs" Nature Communications 5, 5192, (2014)

[3] B. Schwarz, P. Reininger, D. Ristanić, H. Detz, A. M. Andrews, W. Schrenk, and G. Strasser, "Monolithically integrated mid-infrared lab-on-a-chip using plasmonics and quantum cascade structures," Nature Communications 5, 4085, (2014).

[4] B. Schwarz, D. Ristanic, P. Reininger, T. Zederbauer, D. MacFarland, H. Detz, A. M. Andrews, W. Schrenk, and G. Strasser, "High performance bi-functional quantum cascade laser and detector," Applied Physics Letters 107, 071104, (2015).

[5] T. S. Mansuripur, C. Vernet, P. Chevalier, G. Aoust, B. Schwarz, F. Xie, C.Caneau, K. Lascola, C. Zah, D. Caffey, T. Day, L. J. Missaggia, M. K. Connors, C. A. Wang, A. Belyanin, and F. Capasso, "Single-mode instability in standing-wave lasers: The quantum cascade laser as a self-pumped parametric oscillator", Physical Review A 94,063807, (2016)