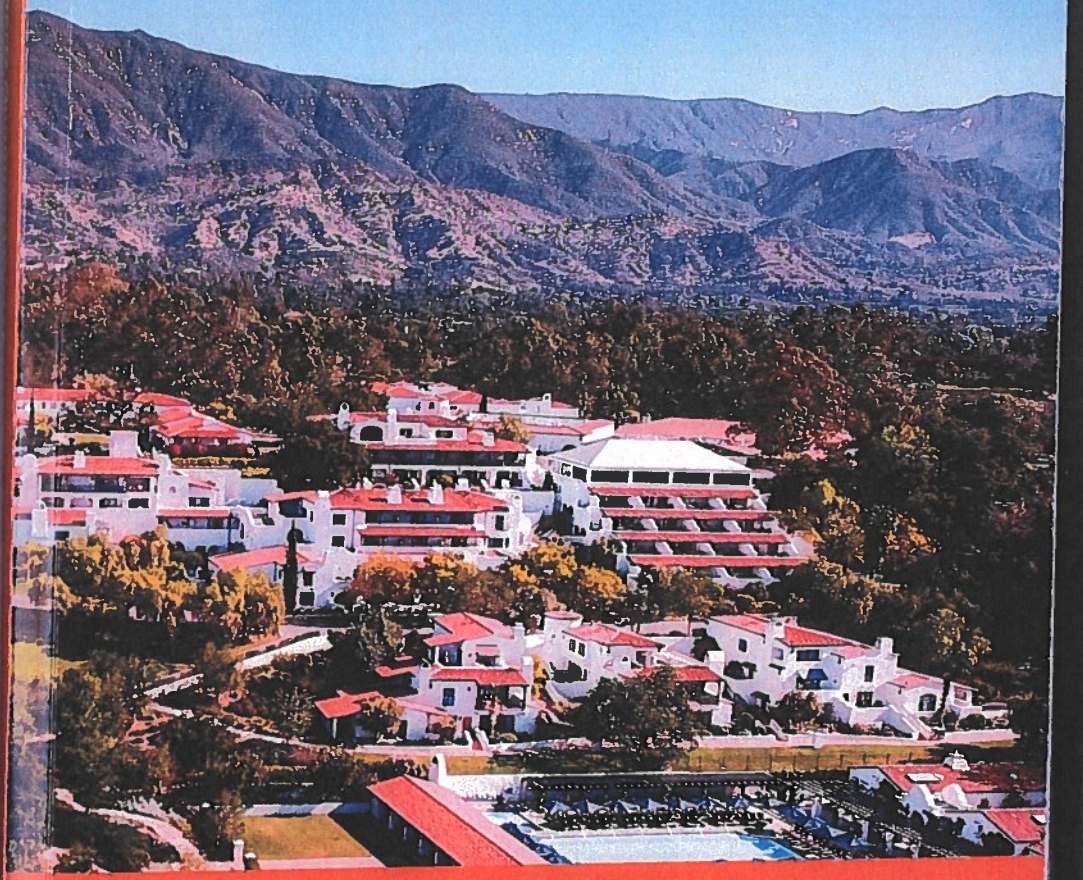
ITQW 2019

Infrared Terahertz Quantum Workshop

September 15-20, 2019

Ojai, California, USA



ITQW OJAI, CA 2019

Program and Abstract Catalog

Mode Switching of a Dual-color Terahertz Quantum Cascade Laser

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1. Introduction

Quantum cascade lasers (QCLs) are powerful semiconductor devices and fill the lack of efficient light sources in the so called terahertz (THz) gap. Currently, THz QCLs achieve a pulse mode operating temperature up to 200 K [1] and octave spanning emission [2]. To further improve these properties, detailed knowledge of the involved electronic states and the scattering mechanisms is required.
Here we study the interaction of two energetically close electronic states and how these two states are involved in the lasing emission of a two color THz QCL.

2. Experiment and Results

The active region studied is a high-temperature three-well GaAs/AlGaAs THz QCL lasing up to 196 K [3]. The high Al (21 %) concentration in the barrier decreases the energy separation of the injector and upper laser state and also results in a similar wave function for the two states $|4\rangle$ and $|3\rangle$. Figure 1 shows the band structure for two bias fields and thus two different matrix elements for the transitions LT_{32} and LT_{42}. The right panel of Fig.1 shows the measured simultaneous emission spectrum of the two transitions, which agrees with the calculated band structure.

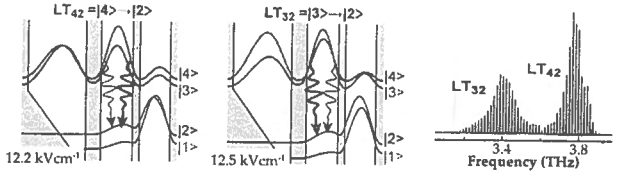

Figure 1: Band structure for two bias fields with different matrix elements for LT_{32} and LT_{42} . Spectrum shows simultaneous emission from both transitions.

The temperature dependent LIV behavior shows a typical increase of the lasing threshold J_{th} for higher heat sink temperatures, while the peak output power and dynamic range is decreasing (see Fig.2(a)). The spectra below show for all temperatures lasing emission of the LT_{42} (3.8 THz) transition at threshold, due to the greater dipole matrix element. With increasing bias, the LT_{32} emerges at low temperatures, while it is largely suppressed at higher temperatures.
To determine whether the two laser states occur next to each other in the same active region or in neighboring periods, a magnetic field of 0–7.5 T was applied to the QCL. Figure 2(b) shows the magnetic field dependent LIV and the measured emission spectra. Due to the low energy separation between state $|4\rangle$ and $|3\rangle$, this is an efficient scattering process. The applied magnetic field hinders the scattering from level $|4\rangle \rightarrow |3\rangle$ and thus increases progressively the population of state $|4\rangle$. This results in a reduced emission at 3.4 THz and simultaneously in a higher emission signal at 3.8 THz.

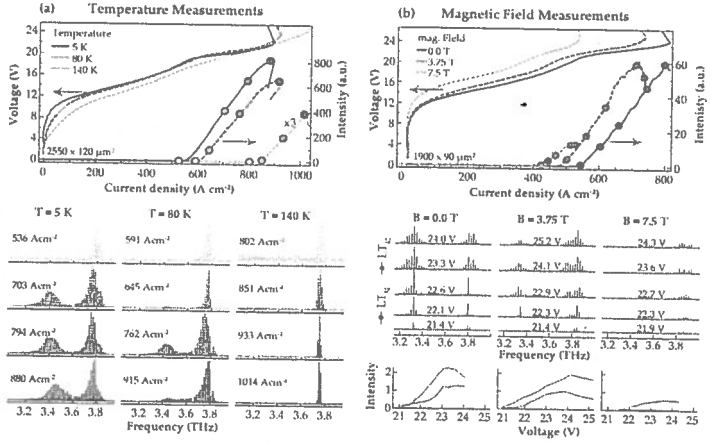

Figure 2: (a) temperature and (b) magnetic field dependent LIV with measured spectra.

References

[1] S. Fathololoumi, E. Dupont, C. Chan, Z. Wasilewski, S. Laframboise, D. Ban, A. Mátyás, C. Jirauschek, Q. Hu, and H. C. Liu, "Terahertz quantum cascade lasers operating up to ~ 200 K with optimized oscillator strength and improved injection tunneling," *Opt. Express*, vol. 20, no. 4, pp. 3866–3876, Feb. 2012.

[2] M. Rösch, G. Scalari, M. Beck, and J. Faist, "Octave-spanning semiconductor laser," *Nat. Photonics*, vol. 9, no. 1, pp. 42–47, Nov. 2014.

[3] M. A. Kainz, S. Schönhuber, A. M. Andrews, H. Detz, B. Limbacher, G. Strasser, and K. Unterrainer, "Barrier Height Tuning of Terahertz Quantum Cascade Lasers for High-Temperature Operation," *ACS Photonics*, vol. 5, no. 11, pp. 4687–4693, Nov. 2018.

Photonic

Conference Program

All conference presentations sessions will be held in the Anacapa Ballroom rooms 1-4.
The industrial exhibit will be held in the Anacapa Ballroom rooms 5-8 on Tuesday-Thursday
The registration table is in the Anacapa Foyer. It will be open at 5-8pm on Sunday, and will open at 8am on Monday-Friday.

Sunday, September 15th

17:00-20:00 Registration Table open in the Anacapa Foyer.

18:00-20:00 Welcome Reception. Beer and wine with light hors d'oeuvres.
Location: Anacapa Foyer and Terrace.

Monday, September 16th

08:30 Welcome and Opening Remarks by the conference chairs.

08:45-09:30 Session 1: Plenary Talk – Frank Koppens
Chair: Benjamin Williams

08:45 **Frank Koppens**
Nano-lego for light with (twisted) 2D materials (Plenary Talk)

09:30-10:30 Session 2: Nanoscopy
Chair: Alexander McLeod

09:30 **Tobias Gokus**, Stefan Mastel, Alexander Govyadinov and Andreas Huber
THz near-field imaging and spectroscopy with nanoscale spatial resolution

09:45 **Andrea Ottomaniello**, James Keeley, Pierluigi Rubino, Lianhe H. Li, Edmund H. Linfield, Giles A. Davies, Paul Dean, Alessandro Pitanti and Alessandro Tredicucci
Self-mixing optomechanics with nanometer resolution in a Terahertz quantum cascade laser

10:00 **Qianchun Weng** and Susumu Komiyama
Terahertz nanoscopy of non-equilibrium carrier dynamics: A thermometric approach ***(Invited)***

10:30-10:50 Coffee Break

10:50-12:20 Session 3: THz quantum cascade lasers
Chair: Iwao Hosako

10:50 **Lutz Schrottke**, Xiang Lue, Benjamin Röben, Klaus Biermann, Till Hagelschuer, Heinz-Wilhelm Hübers and Holger Grahn
High-performance GaAs/AlAs terahertz quantum-cascade lasers

11:05 **Yuan Jin**, John Reno and Sushil Kumar
Multi-watt terahertz distributed-feedback lasers

11:20 **Asaf Albo**, Yuri Flores, Qing Hu and John Reno
Advances in Terahertz Quantum Cascade Lasers with Room-Temperature Negative Differential Resistance

11:35 **Martin A. Kainz**, Aaron Maxwell Andrews, Sebastian Schoenhuber, Benedikt Limbacher, Michael Jaidl, Dominik Theiner, Hermann Detz, Gottfried Strasser, Gerald Bastard and Karl Unterrainer
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