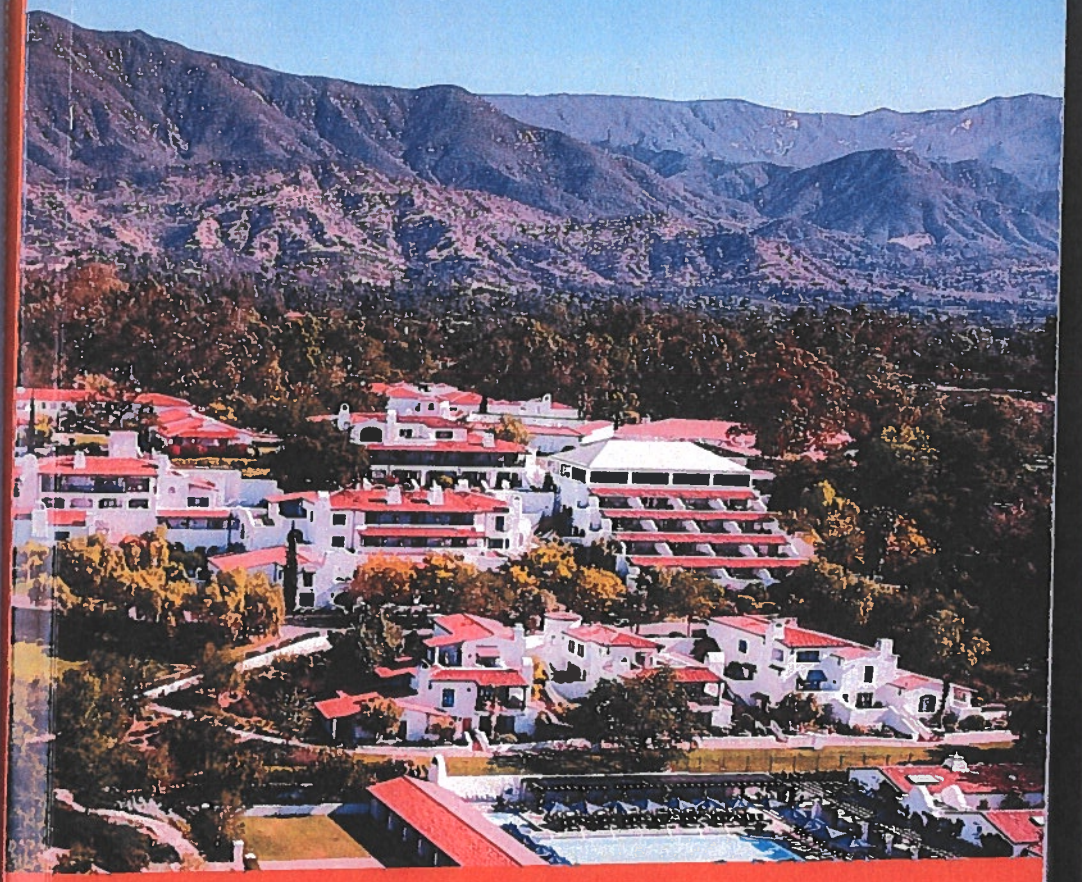
# ITQW 2019

## Infrared Terahertz Quantum Workshop

September 15-20, 2019
Ojai, California, USA



ITQW
OJAI, CA 2019

Program and Abstract Catalog

15:45 **Nishant Nookala**, Sander Mann, Stephen March, Seth Bank, John Klem, Igal Brener, Andrea Alù and Mikhail Belkin
*Optical power limiting from intersubband polaritonic metasurfaces*

**16:00-16:20 Coffee Break (Exhibition is open)**

### 16:20-17:35 Session 17: New Intersubband Materials

Chair: Gottfried Strasser

16:20 Arnaud Jollivet, Maria Tchernycheva, Enrico Di Russo, Lorenzo Rigutti, Miguel Montes Bajo, Julen Tamayo Arrola, Adrian Hierro, Borg Vinter, Nolwenn Le Biavan, Maxime Hugues, Jean-Michel Chauveau and **Francois Julien**
*Room temperature excitonic transitions induced by intersubband absorption in m-plane ZnO/ZnMgO quantum wells.*

16:35 **Thomas Grange**, David Stark, Giacomo Scalari, Jérôme Faist, Luca Persichetti, Monica De Seta, Luciana Di Gaspare, Giovanni Capellini, Douglas Paul, Michele Ortolani, Stefan Birner and Michele Virgilio
*Comparing III-V and group-IV terahertz quantum cascade lasers using non-equilibrium Green's functions*

16:50 **Trang Nguyen**, Alexander Senichev, Brandon Dzuba, Yang Cao, Michael Manfra and Oana Malis
*Non-polar strain-balanced AlGaN/InGaN superlattices for infrared optoelectronic devices*

17:05 **Monica De Seta**, Michele Montanari, Chiara Ciano, Luca Persichetti, Luciana Di Gaspare, Michele Virgilio, Giovanni Capellini, Marvin Zoellner, Oliver Skibitzki, David Stark, Giacomo Scalari, Jerome Faist, Douglas J. Paul, Thomas Grange, Stefan Birner, Oussama Moutanabbir, Samik Mukherjee, Leonetta Baldassarre and Michele Ortolani
*High-quality n-type Ge/SiGe multilayers for room temperature THz emission*

17:20 **David Stark**, Luca Persichetti, Michele Montanari, Chiara Ciano, Luciana Di Gaspare, Monica De Seta, Marvin Zoellner, Oliver Skibitzki, Giovanni Capellini, Michele Ortolani, Leonetta Baldassarre, Michele Virgilio, Thomas Grange, Stefan Birner, Kirsty Rew, Douglas Paul, Jérôme Faist and Giacomo Scalari
*Si-based n-type Quantum Cascade Structures for THz Emission*

**19:00-22:00 Banquet**

Banquet will be held at the Ojai Valley Inn and Spa in the Hacienda Ballroom.

Award for Best Student Poster will be presented by the conference chairs along with DRS Daylight Solutions.

## Friday, September 20th

### 09:00-10:30 Session 18: Detection

Chair: Daniel Wasserman

09:00 **David Ting**
*Type-II superlattice unipolar barrier infrared detectors **(Invited)***

09:30 **Azzurra Bigioli**, Djamal Gacemi, Daniele Palaferri, Yanko Todorov, Angela Vasanelli and Carlo Sirtori
*Mixing properties of room temperature patch-antenna receivers in a mid-infrared (9 um) heterodyne system*

09:45 **Changyun Yoo**, Mengchen Huang, Jonathan Kawamura, Ken West, Boris Karasik, Loren Pfeiffer and Mark Sherwin
*Tunable Antenna-Coupled Intersubband Terahertz (TACIT) Mixers*

10:00 **Borislav Hinkov**, Arnaud Jollivet, Hanh T. Hoang, Stefano Pirotta, Maria Tchernycheva, Raffaele Colombelli, Maxime Hugues, Nolwenn Le Biavan, Miguel Montes Bajo, Adrian Hierro, Jean-Michel Chauveau, Gottfried Strasser and Francois H. Julien
*Quantum cascade detectors based on non-polar ZnO/ZnMgO quantum wells*

10:15 Johannes Hillbrand, Sandro Dal Cin, Aaron Maxwell Andrews, Hermann Detz, Erich Gornik, Benedikt Schwarz and **Gottfried Strasser**
*High bandwidth quantum cascade detectors*

**10:30-10:50 Coffee Break**

Award for Best Student Presentation will be presented by the conference chairs along with DRS Daylight Solutions.

### 10:50-12:20 Session 19: New Physics

Chair: Mark Sherwin

10:50 **Ileana-Cristina Benea-Chelmus**, Francesca Fabiana Settembrini, Giacomo Scalari and Jerome Faist
*Electric field correlation measurements on the electromagnetic vacuum state **(Invited)***

# Quantum cascade detectors based on non-polar ZnO/ZnMgO quantum wells

**Borislav Hinkov[1*], Arnaud Jollivet[2], Hanh T. Hoang[1], Stefano Pirotta[2], Maria Tchernycheva[2], Raffaele Colombelli[2], Maxime Hugues[3], Nolwenn Le Biavan[3], Miguel Montes Bajo[4], Adrian Hierro[4], Jean-Michel Chauveau[3], Gottfried Strasser[1], and Francois H. Julien[2]**

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[3]*Université Côte d'Azur & CNRS/CRHEA, Valbonne, France*

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**Short Abstract** The performance of state-of-the-art THz optoelectronic devices is limited by parasitic LO phonon transitions, e.g. preventing the operation of GaAs-based THz-QCLs above ~200 K. This can be overcome by using alternative, novel material systems with higher LO-phonon energies like ZnO [1]. Here we present the first mid-IR ZnO/ZnMgO-based QCD with a peak responsivity of 0.15 mA/W at 77 K.

## 1. Introduction

Wurzite ZnO/ZnMgO is a new material system for quantum cascade devices. Due to its large LO-phonon energy, it was predicted that THz quantum cascade lasers could be operated above room temperature [1], which is not the case for the current technology based on GaAs/AlGaAs materials. Intersubband absorption in m-plane ZnO structures has been shown recently [2].

We report in this paper on the first demonstration of ZnO/ZnMgO-based quantum cascade detectors (QCD) grown on m-plane substrate by molecular beam epitaxy (MBE). As inherent to wurzite heterostructures, the m-plane [10-10] crystallographic orientation allows to avoid the internal electric field, thus simplifying the design of the QCD. The layer structures of our QCD is shown in Fig. 1(a) together with the conduction band profile of one of the 20 periods of the $ZnO/Zn_{0.6}Mg_{0.4}O$ active region (see Fig. 1(b)). The target wavelength, not accounting for the depolarization shift, is 3.7 µm.

We developed a device fabrication process for square MESAs, using a dry etching process in an ICP-RIE based on a $CH_4$ chemistry [3]. Applying non-annealed Ti/Au contacts results in typical contact resistances on the order of ~mid $10^{-4}$ Ω cm². The inset of Figure 1(c) shows a top-view microscope image of the final device

## 2. Results

Figure 1(c) shows typical room temperature (300 K) J-V plots for differently sized MESA-QCDs between 10 x 10 µm² and 100 x 100 µm². As can be seen, the curves overlap nicely which means that there is no significant surface leakage current in these devices. This is the result of an additional surface passivation step using high temperature $H_2O_2$ at 95°C [4], which reduces the leakage current in our devices by 2-3 orders of magnitude.

In addition, we also measured and analyzed the polarization-dependent photocurrent spectra. As can be seen in Fig. 1(d), the photocurrent is peaked at 3 µm wavelength. The blue-shift with



respect to the targeted wavelength is explained by the depolarization shift. As can be seen in the same figure, the main contribution of the photocurrent signal originates from TM-polarized light, as it is expected for a detector based on intersubband transitions. Further details can be found in [5]. The responsivity of the devices has been calibrated and persists up to room temperature ($R_{77K}$ = 0.15 mA/W).

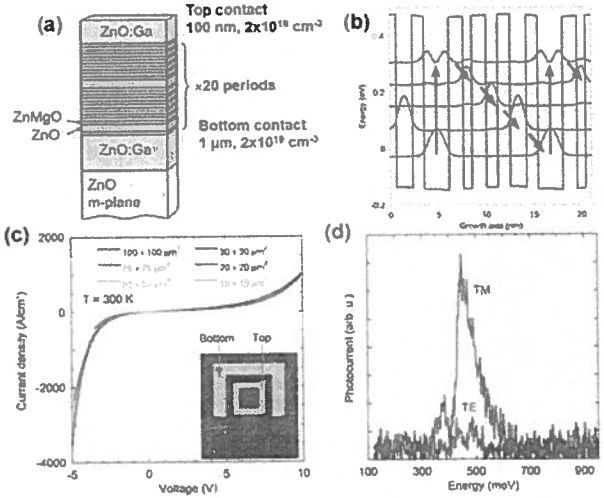


**Figure 1(a)** Layer sequence of the QCD with a 20 period active region sandwiched between two ZnO:Ga contact layers. **(b)** Conduction band profile of one period of the $ZnO/Zn_{0.6}Mg_{0.4}O$ QCD structure. Inset: top-view image of the final device. **(c)** Room temperature J-V characteristics of MESA QCDs sized between 10 x 10 µm² and 100 x 100 µm² **(d)** Photocurrent spectra at 77 K analyzing the TM- (red) and TE-polarization (green) contribution.

## References

[1] E. Bellotti, K. Driscoll, T. D. Moustakas, R. Paiella, *J. Appl. Phys.* 105, 113103 (2009).

[2] N. Le Biavan, M. Hugues, M. Montes Bajo, J. Tamayo-Arriola, A. Jollivet, D. Lefebvre, Y. Cordier, B. Vinter, F.-H. Julien, A. Hierro, J.-M. Chauveau, *Appl. Phys. Lett.* 111, 231903 (2017).

[3] S.-W. Na, M. H. Shin, Y. M. Chung, J. G. Han, N.-E. Lee, *J. Vac. Sci. Technol.* 23(4), 898 (2005).

[4] S. K. Mohanta, A. Nakamura, G. Tabares, A. Hierro, A. Guzman, E. Munoz, J. Temmyo, *Thin Solid Films* 548, 539 (2013).

[5] A. Jollivet, B. Hinkov, S. Pirotta, H. Hoang, S. Derelle, J. Jaeck, M. Tchernycheva, R. Colombelli, A. Bousseksou, M. Hugues, N. Le Biavan, J. Tamayo-Arriola, M. Montes Bajo, L. Rigutti, A. Hierro, G. Strasser, J.-M. Chauveau, and F. H. Julien, *Appl. Phys. Lett.*113, 251104 (2018).