

Si-based n-type THz Quantum Cascade Emitter

D. Stark¹, L. Persichetti², M. Montanari², C. Ciano², L. Di Gaspare², M. De Seta²,
M. Zöllner³, O. Skibitzki³, G. Capellini^{2,3}, M. Ortolani⁴, L. Baldassarre⁴, M. Virgilio⁵,
T. Grange⁶, S. Birner⁶, K. Rew⁷, D.J. Paul⁷, J. Faist¹, G. Scalari^{1*}

¹ Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

² Dipartimento di Scienze, Università di Roma Tre, 00154 Rome, Italy

³ IHP-Leibniz-Institut für innovative Mikroelektronik, 15236 Frankfurt (Oder), Germany

⁴ Dipartimento di Fisica, Università di Roma “La Sapienza”, 00185 Rome, Italy

⁵ Dipartimento di Fisica “E. Fermi”, Università di Pisa, 56127 Pisa, Italy

⁶ nextnano GmbH, 85748 Garching b. München, Germany

⁷ School of Engineering, University of Glasgow, G12 8LT Glasgow, United Kingdom

Abstract—Employing electronic transitions in the conduction band of semiconductor heterostructures paves a way to integrate a light source into silicon-based technology. To date all electroluminescence demonstrations of Si-based heterostructures have been p-type using hole-hole transitions. In the pathway of realizing an n-type Ge/SiGe terahertz quantum cascade laser, we present electroluminescence measurements of quantum cascade structures with top diffraction gratings. The devices for surface emission have been fabricated out of a 4-well quantum cascade laser design with 30 periods. An optical signal was observed with a maximum between 8-9 meV and full width at half maximum of roughly 4 meV.

I. INTRODUCTION

THE indirect bandgap of group IV materials hinders the realization of Si-based semiconductor lasers relying on electron-hole transitions. Using unipolar transitions, the quantum cascade laser (QCL), so far only realized in III-V materials, represents a promising candidate to build integrated Si-based lasers. Terahertz (THz) electroluminescence due to hole-hole transitions has been observed in p-type Si-based quantum cascade devices [1]. Valavanis et al. predict that n-type SiGe-based heterostructures exploiting L-valley transitions is the best material configuration for achieving a THz laser [2]. Experimentally, narrow intersubband transitions and electron tunneling have been observed in n-type strain compensated Ge/SiGe multi-quantum well structures [3,4].

II. RESULTS

We report the characterization of a Ge/SiGe QCL structure by Fourier transform infrared spectroscopy (FTIR). The QCL structure was designed with non-equilibrium Green's functions (see Fig1(a)) [5] and grown epitaxially by means of UHV-CVD. The 1.6 μm thick active region (AR) with 30 periods was fabricated to mesa devices with top diffraction gratings to measure the surface emission (see inset of Fig. 1(c)). The observed spectra at different bias points are shown in Fig. 1(d). The spectra show well-defined peaks with FWHM of roughly 4 meV and maxima between 8-9 meV. The measured interferograms are similar to the one in Fig. 1(b). The V-I characteristics and the measured bias points are shown in Fig. 1 (c). The relatively narrow spectral peaks could indicate electroluminescence and that the optical signal is originating from intersubband transitions. These results are promising for future experimental work with the proposed QCL structure and a step towards Si-based lasers.

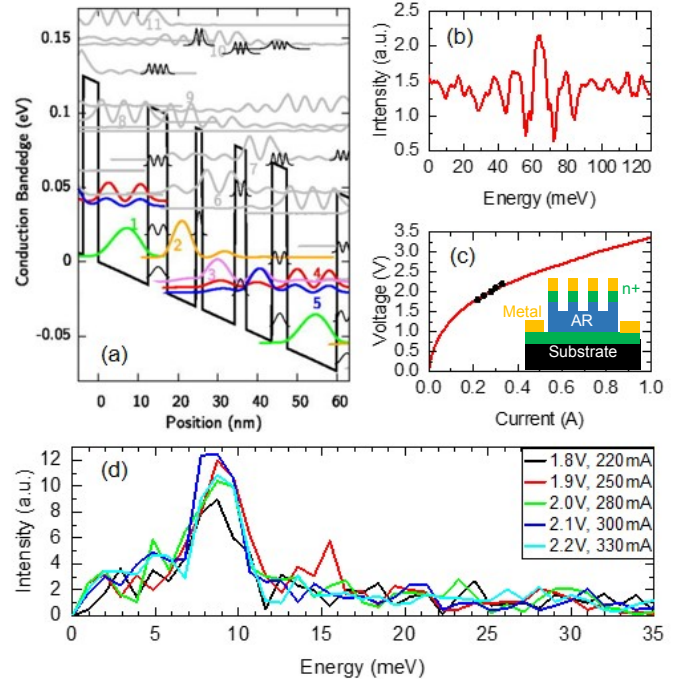


Fig. 1. (a) Simulated bandstructure of the 4-quantum well Ge/SiGe QCL design [5]. (b) Interferogram corresponding to 330 mA. (c) Pulsed V-I curve and the measured bias points (indicated with black dots). Inset: Cross section of the mesa device with top diffraction grating. (d) FTIR spectra measured at 9 K. To avoid heating effects a micro-macro voltage pulse scheme with 415 Hz repetition frequency, 1.92 μs period and 90% duty-cycle is applied. Each spectrum is the average of one hour acquisition.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 766719 - FLASH.

REFERENCES

- [1] S.A. Lynch, *et al*, "Intersubband electroluminescence from Si/SiGe cascade emitters at terahertz frequencies", *Appl. Phys. Lett. Phys.* **81**, 1543 (2002).
- [2] A. Valavanis, *et al*, "Material configurations for n-type silicon-based terahertz quantum cascade lasers", *Phys. Rev. B* **83**, 195321 (2011).
- [3] M. De Seta, *et al*, "Narrow intersubband transitions in n-type Ge/SiGe multi-quantum wells: control of the terahertz absorption energy trough the temperature dependent depolarization shift", *Nanotechnol.* **23**, 465708 (2012).
- [4] C. Ciano, *et al*, "Control of Electron-State Coupling in Asymmetric Ge/Si-Ge Quantum Wells", *Phys. Rev. Applied* **11**, 014003 (2019).
- [5] T. Grange *et al*, "Room temperature operation of n-type Ge/SiGe terahertz quantum cascade lasers predicted by non-equilibrium Green's functions", *Appl. Phys. Lett. Phys.* **114**, 111102 (2019).