QUANTERA

ERA-NET Cofund in Quantum Technologies

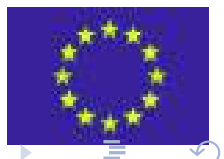
# Mid-term Strategic Conference

**Granada, Spain, Nov. 13-14, 2019**

# CUSPIDOR: CMOS Compatible Single Photon Sources based on SiGe Quantum Dots

Thomas Fromherz

*This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731473.*

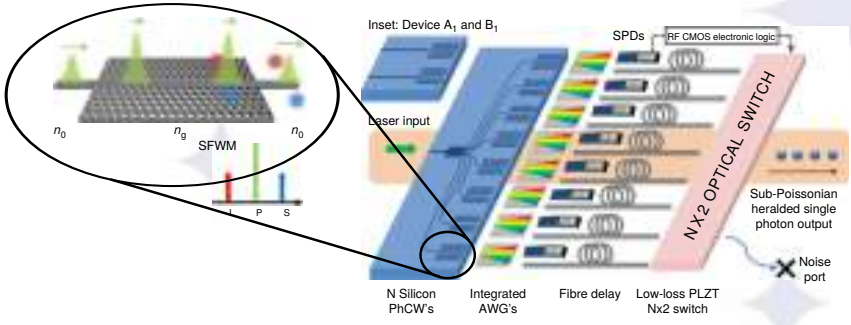


# Introduction

## Integrated quantum optics at telecom wavelengths

- SOI integrated optic extremely mature
- can **compact** quantum optical sources be added to establish **SOI integrated quantum optics** in the telecom wave length region ?
- currently: elaborate building blocks based on spontaneous 4-wave mixing, externally pumped
- SiGe quantum dots as quantum optical sources ?

Intel Silicon Photonics 100 Gb/s optical transceiver

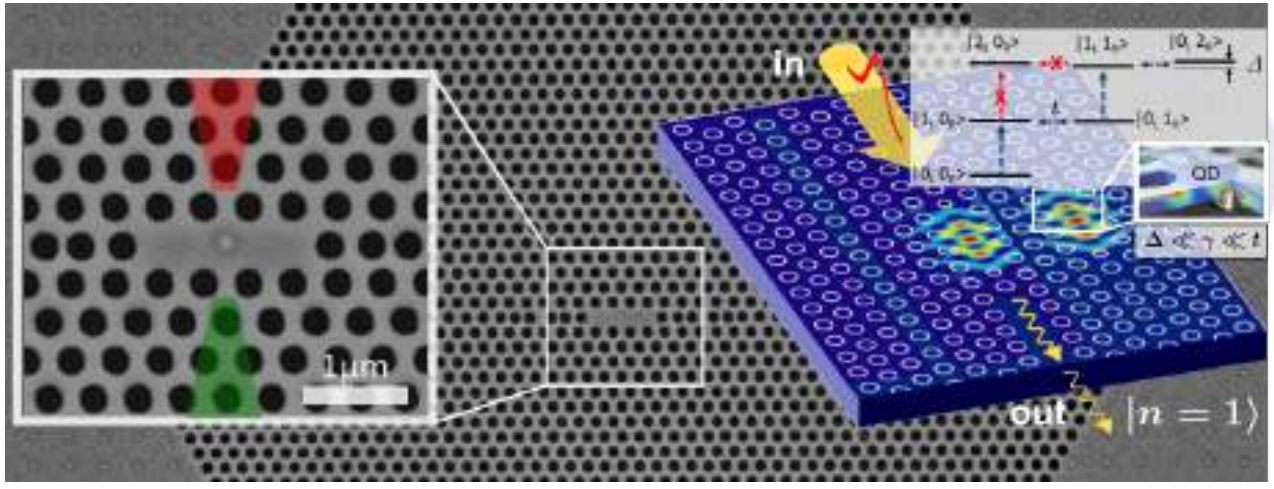



M.J. Collins et al., *Integrated spatial multiplexing of heralded single-photon sources*, Nat. Com. 4: 2582 (2013)

# Main objectives

O1: A room-temperature electrically driven, optical matrix-element enhanced, silicon- germanium quantum dot based deterministic single photon source (SPS) with a generation rate of 50 MHz, with a second-order correlation function, $g^{(2)}(0) < 0.05$ at cryogenic temperatures ($\sim 10K$) and $g^{(2)}(0) < 0.2$ at room temperature, unprecedented for these type of quantum dots;

O2: A single photon source based on the unconventional photon blockade (UPB), with a generation rate of 10 MHz and $g^{(2)}(0) < 0.05$ at cryogenic temperatures ($\sim 10K$) and $g^{(2)}(0) < 0.2$ at room temperature.



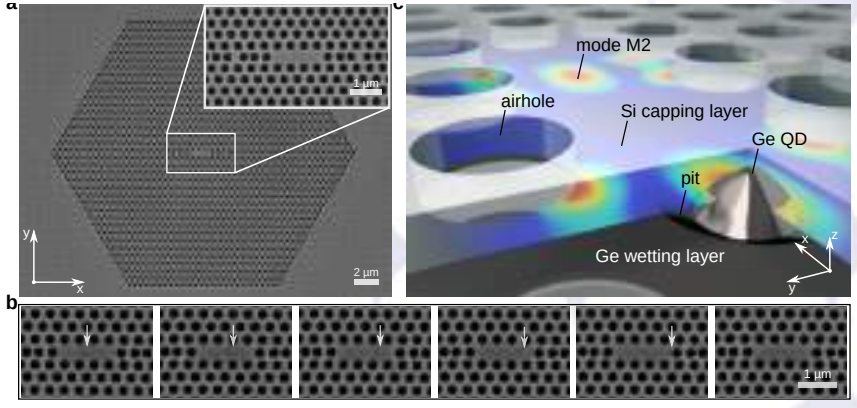
# Consortium

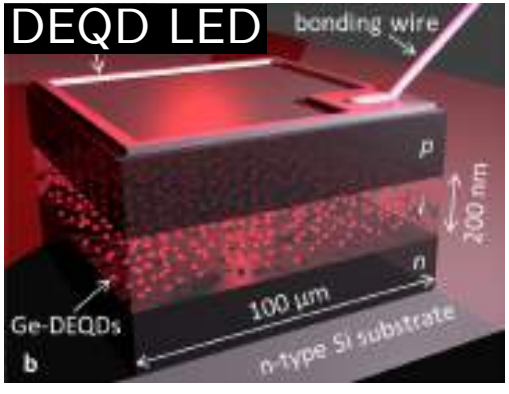
| | | |
|---|---|---|
| Johannes Kepler University Linz | Austria | T. Fromherz |
| Università degli Studi di Pavia | Italy | D. Gerace |
| Cork Institute of Technology | Ireland | L. O'Faolain |
| Masaryk University Brno | Czech Republic | P. Klenovský |
| Tyndall National Institute | Ireland | F. Murphy |

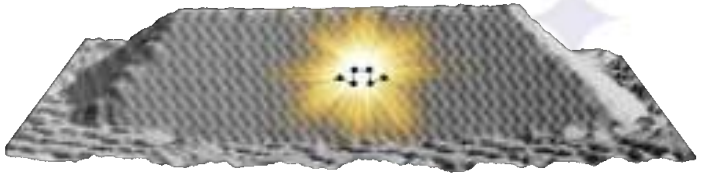
# Role of partners

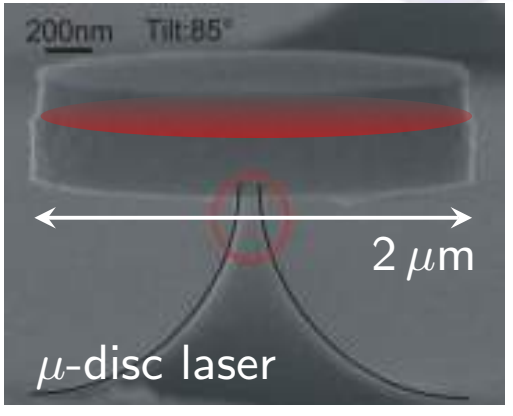
Johannes Kepler University Linz, Austria

- site controlled epitaxial growth of SiGe based nanostructures
- defect engineered SiGe quantum dots (DEQDs)
- SOI integrated nano photonics
- project coordination



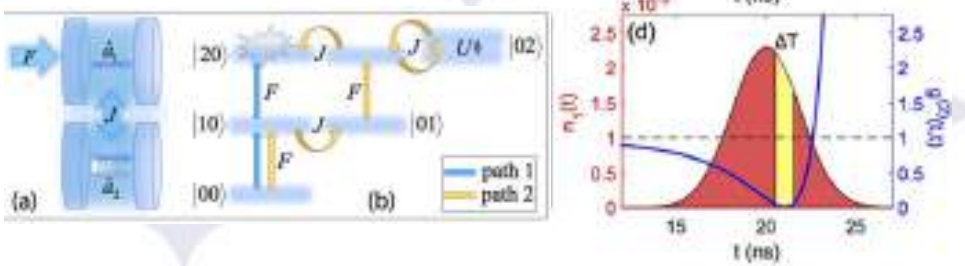


# Role of partners

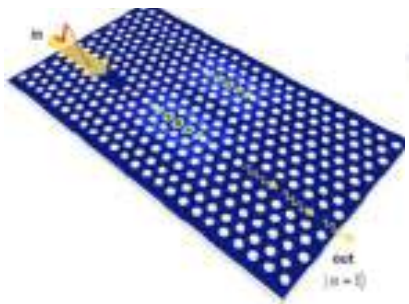
Università degli Studi di Pavia, Italy

- quantum photonics theory
- photonic nanostructures simulations
- quantum optical spectroscopy and characterization in the telecom band.

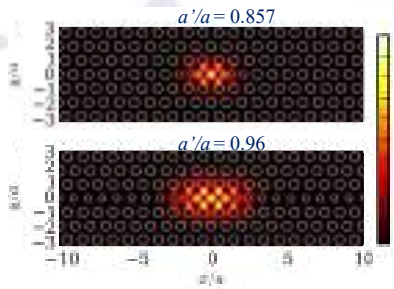
Unconventional photon blockade, pulsed excitation

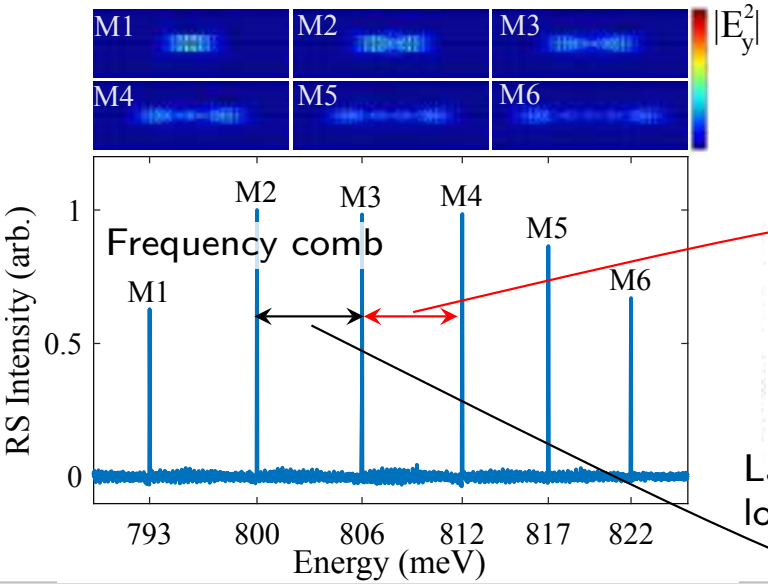



UPB, photonic molecule

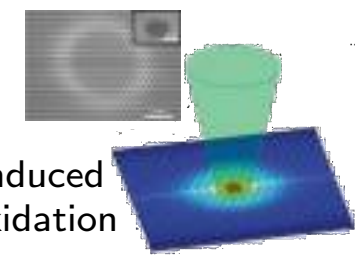


Bichromatic cavity

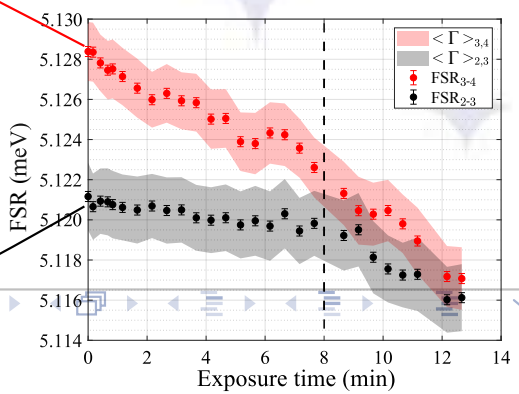



Laser induced local oxidation



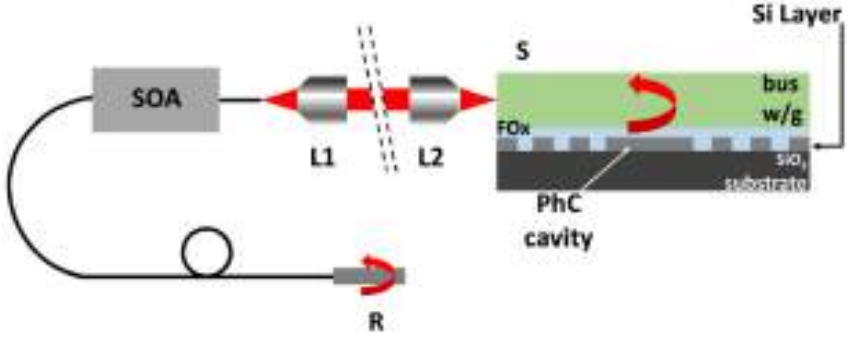
Selective tuning of comb-modes

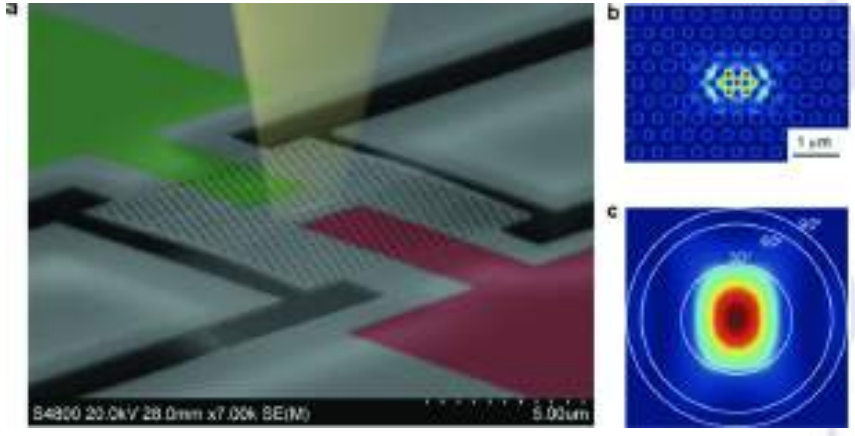


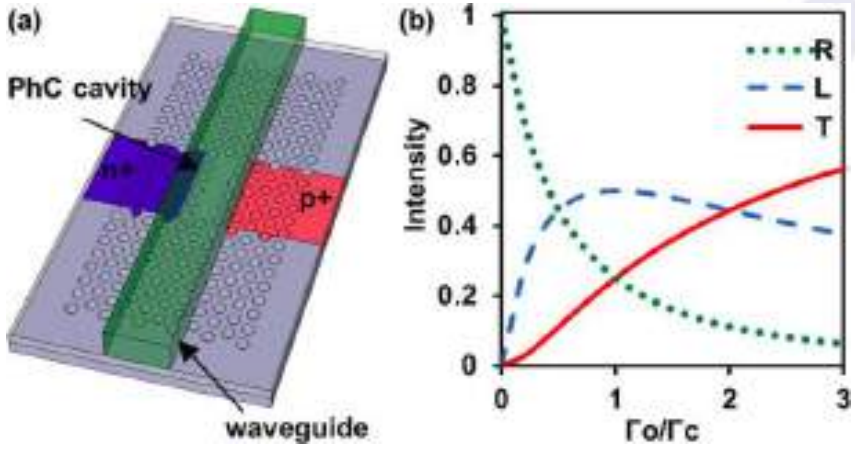
# Role of partners

Cork Institute of Technology, Ireland

- doping of p-i-n structures
- nano-structuring of state-of-art photonic devices
- integrated nano-optical systems



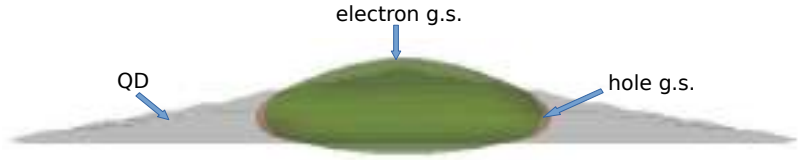



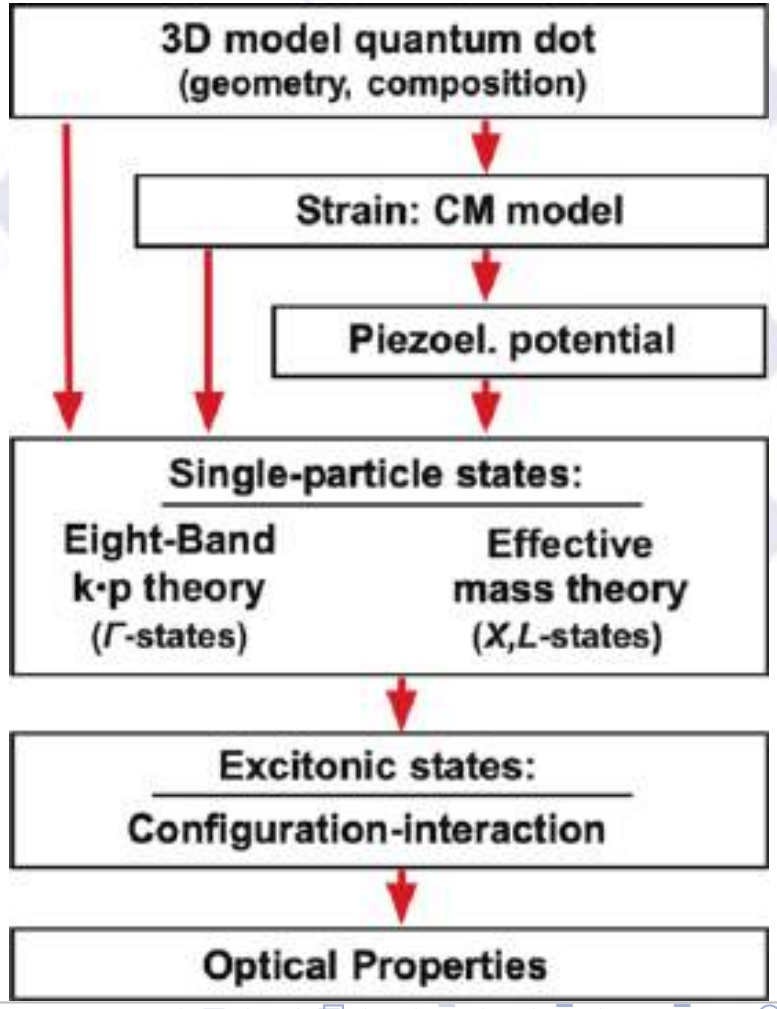
# Role of partners

## Masaryk University Brno, Czech Republic

- interfaceing mircoscopic and mesoscopic simulation methods
- mesoscopic energy level simulations in SiGe DEQDs including strain
- multi-particle effects



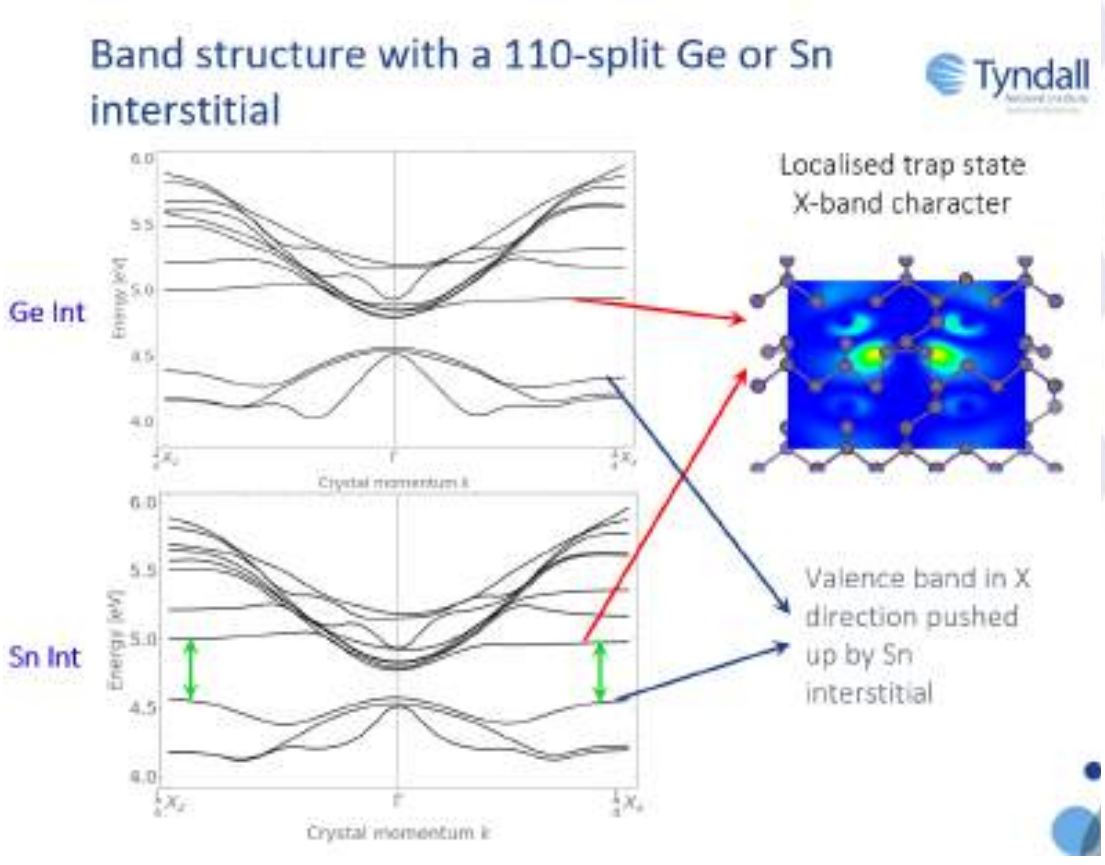

Simulated SiGe QD had a shape of pyramid with base length of 20 nm and height of 2.5 nm. The whole structure is situated in Si; g.s. means ground state in the figure below. The electrons in the dot were considered to have a constant mixture of pure Γ Ge character and that for interstitial being mixed between Γ and X or L bands (this was provided by DFT).



# Role of partners

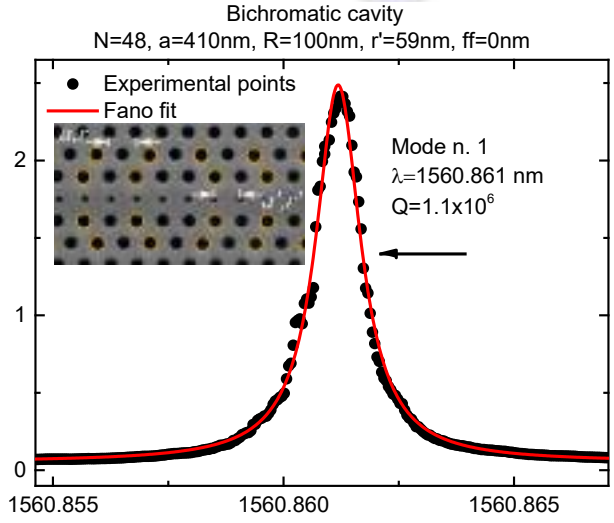
## Tyndall National Institute, Ireland

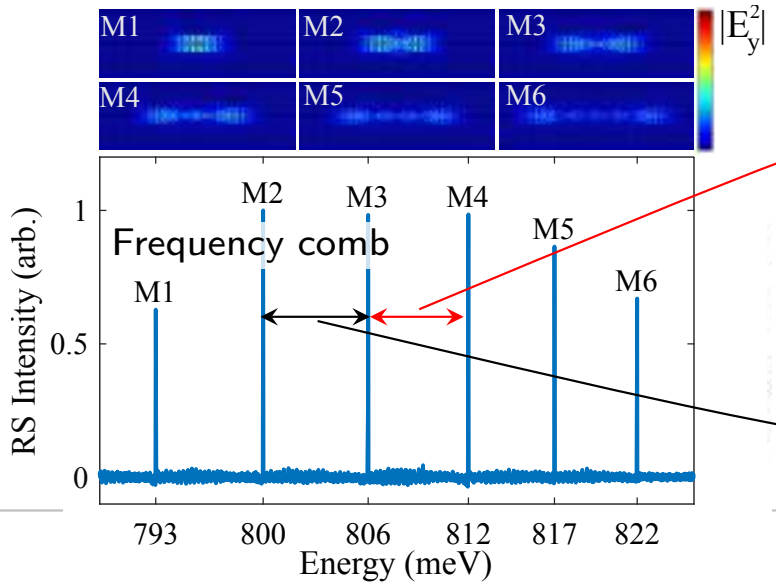
- ab initio electronic structure calculations of the implanted Ge defect levels
- simulations of implanted Si, Sn, Sb defects
- develop interface for mesoscopic $\boldsymbol{k} \cdot \boldsymbol{p}$—simulations
- transport simulations single DEQD pin diode

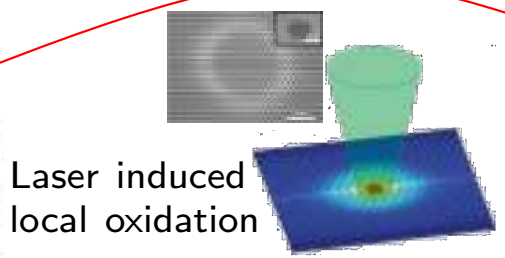


# Main progress

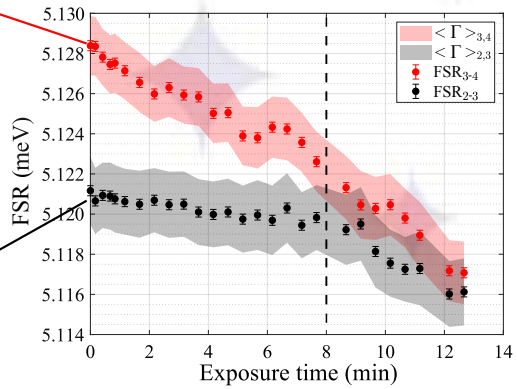
- fabrication of bichromatic cavities with comb-like spectrum, $Q$ >1M and record finesse (Si only)
- permanent tuning of modes in bicromatic photonic crystal cavities with ultra high Q



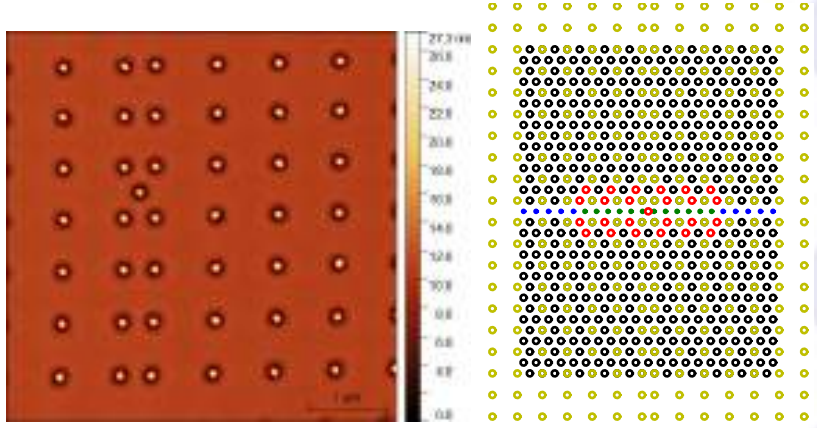




Selective tuning of comb-modes



# Main progress

- site controlled growth of Ge implanted SiGe DEQDs
- nucleation sites in registry with bichromatic PhC design
- realistic DFT modelling of Ge split-[110] interstitial, tracing back increase of optical oscillator strength observed in experiments
- multi-scale modeling: $\boldsymbol{k} \cdot \boldsymbol{p}$ band structure parameters for Ge split-[110] bands from DFT simulations



# Key challenges

- achieving ultra large Q-factors in Ge containing PhC cavities. New route: growth of a single QD per cavity on a 2D wetting layer
- demonstrate single photon emission of DEQDs
- reduce spectral drift resulting in large linewidths of SiGe QDs
- combine large Q factor cavities with contacts for pin diodes
- achieve efficient current injection into single DEQDs embedded in a pin diode

# Dissemination and valorization

List of papers and conference contributions can be found on CUSPIDOR homepage http://www.cuspidor-quantera.eu