QUANTERA

ERA-NET Cofund in Quantum Technologies

Mid-term

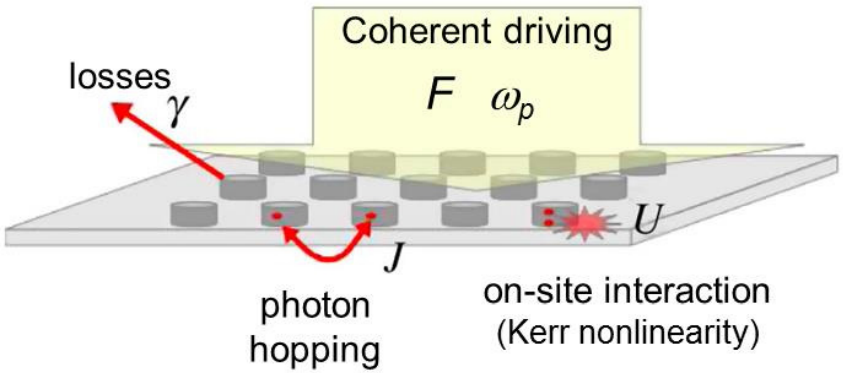
Grenada & 13-14 November 2019

InterPol
Polariton lattices: a solid-state platform for quantum simulations of correlated and topological states

Jacqueline Bloch, C2N-CNRS, France

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

Motivation: exploring many-body physics in driven-dissipative systems



Ciuti & Carusotto, Rev. Mod. Phys. **85**, 299 (2013)
Le Boite *et al.*, PRL 110, 233601 (2013);
M.J. Hartman, Journal of Optics (2016)
C.Noh and DG Angelakis, Report on progress in Physics (2016)

- New phases of light emerge from the interplay between on-site interaction, hopping, drive and dissipation
- Lattices with non-trivial topology?
- Properties are imprinted on the outcoming photons=> Potential ressource for quantum technology

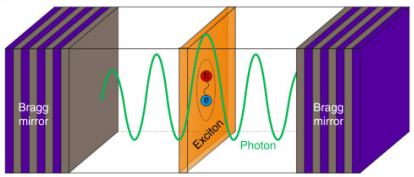
Crucial parameter: U/γ

$U/\gamma << 1$: mean field regime

$U/\gamma > 1$: blockade, quantum correlations

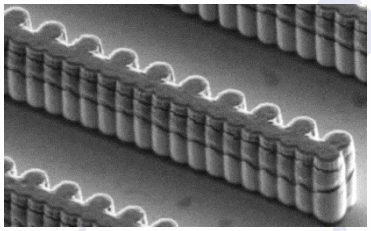
Motivation: exploring many-body physics in driven-dissipative systems

InterPol project: use cavity polaritons in semiconductor lattices

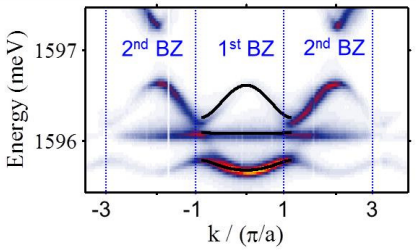


Properties $|pol\rangle = X_k |exc\rangle + C_k |phot\rangle$

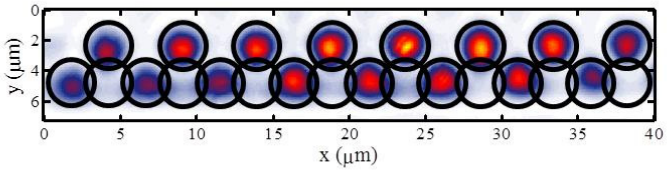
- Photonic component → confinement in microstructures real space, k-space imaging
- Excitonic component → Interactions - $\chi^{(3)}$



K-space imaging

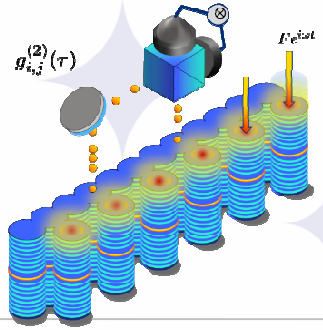


Real space imaging



State of the art:
$U/\gamma \approx 0.1$

Site selective correlation measurements



InterPol partners

Dmitry Krizhanovskii
University of Sheffield, UK

Paulo V Santos
Paul Drude Institut
Berlin, Germany

Michal Matuszewski
Polish Academy
of Science, Warsaw
Poland

Jason Smith
University of Oxford, UK

★ Experiments
★ Theory

Marzena Szymanska
Coordinator
University College
London UK

Jacqueline Bloch
C2N-CNRS,
Palaiseau France

Eytan Grosfeld
Ben Gurion University
of the Negev,
Israel

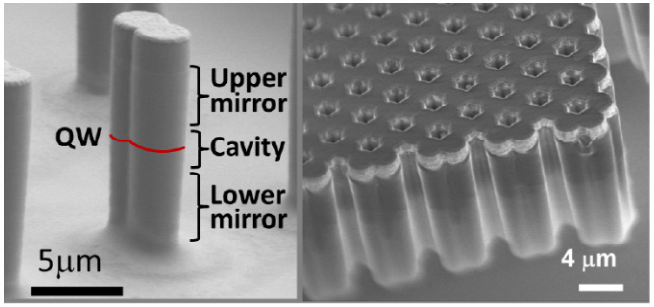
Organization

Work plan :

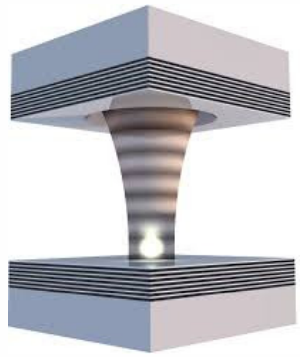
- WP1 : Fabrication of static polariton lattices
- WP2: Fabrication of tunable lattices
- WP3: Quantum correlated phases
- WP4: Topologically protected states
- WP5: Theoretical methods for non-equilibrium systems

Sample design : combine expertise

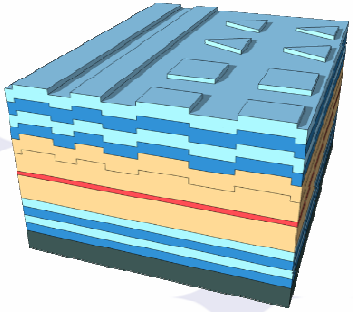
Deep etching
CNRS

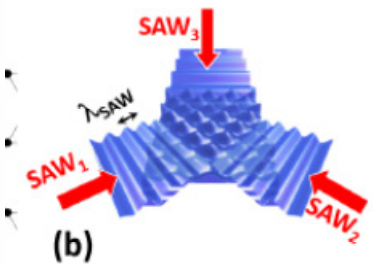


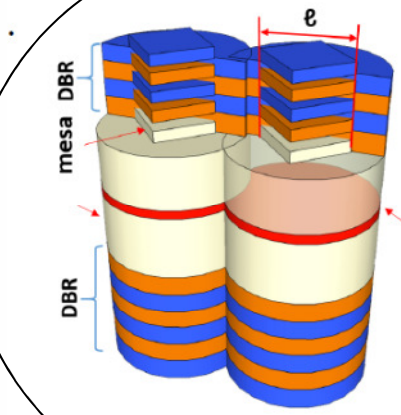
University of Oxford and Sheffield
Open cavities

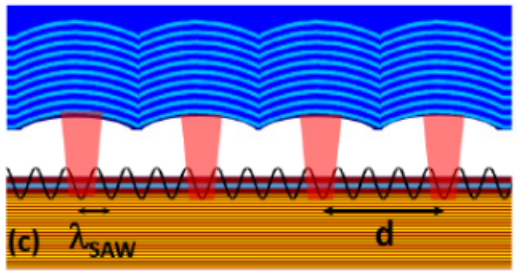


Paul Drude Institut
Surface acoustic waves
and mesa etching

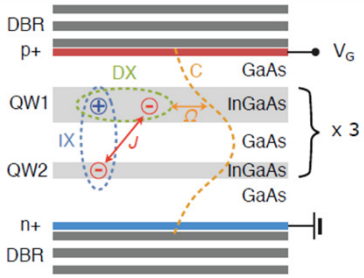






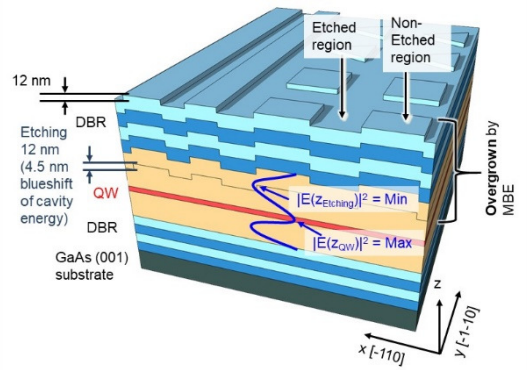


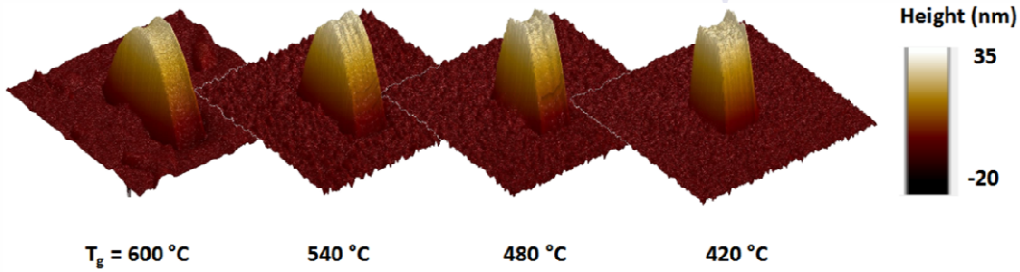
Novel active materials



Sample design : reducing the mode area

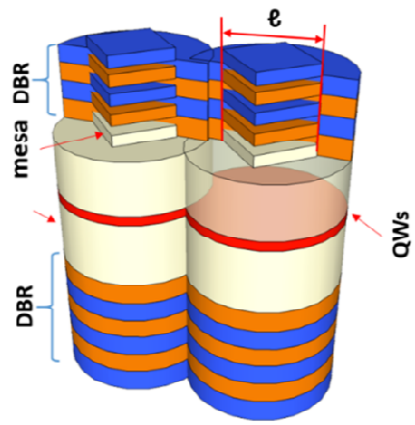
PDU, Berlin





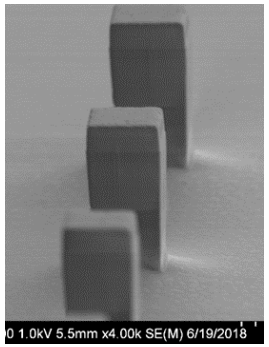
AFM micrograph of a 4 × 4 μm² trap overgrown at different temperatures Tg. Low T_g's suppresses anisotropic elongation and interface smoothing.

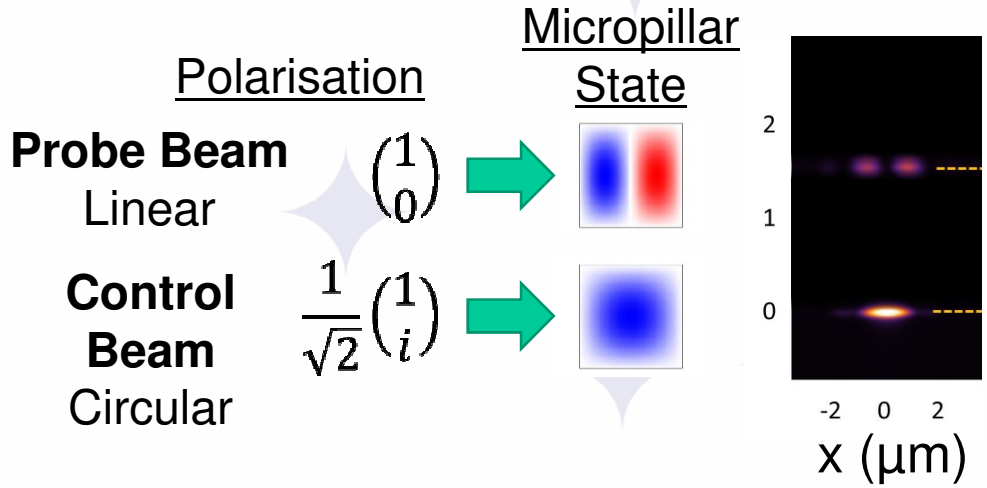
Deep etching at C2N of optimized overgrown mesas

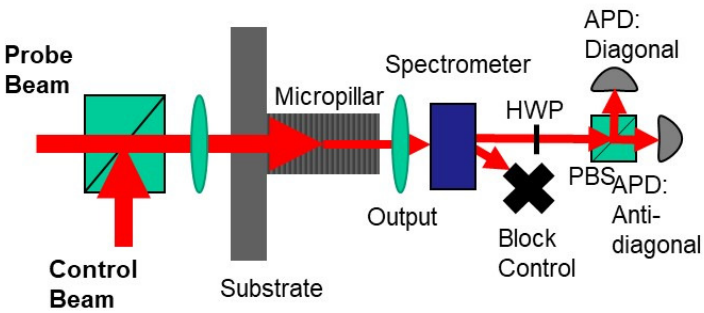


WP3 : Quantum correlations: Sheffield + CNRS

Single Polariton Nonlinear Faraday Rotation





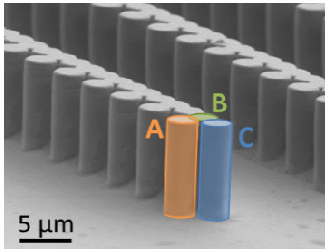


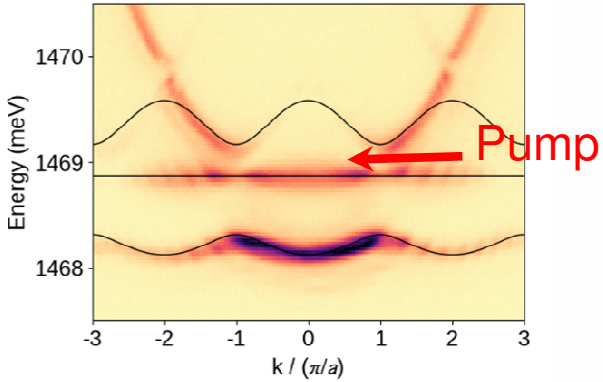
Preliminary results :

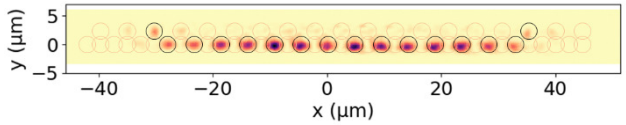
Single polariton phase shift 0.5×10^{-3} rad

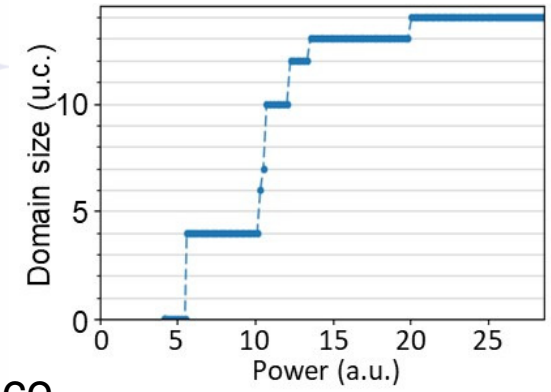
Can be improved by reducing area, increasing exciton content, increase

Flatband non-linear physics: 1D Lieb Lattices



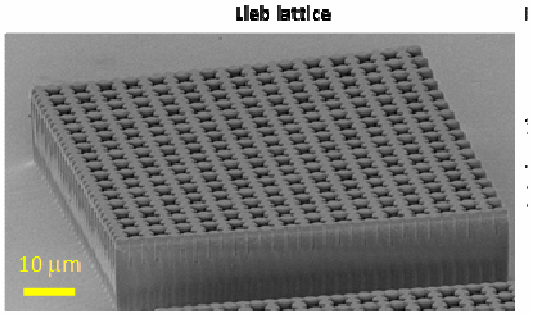






Quantized non-linear domains : frustration in the lattice

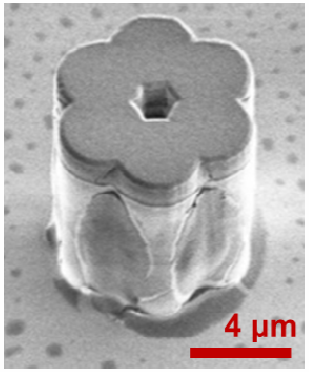
Prospects : 2D Lieb lattices

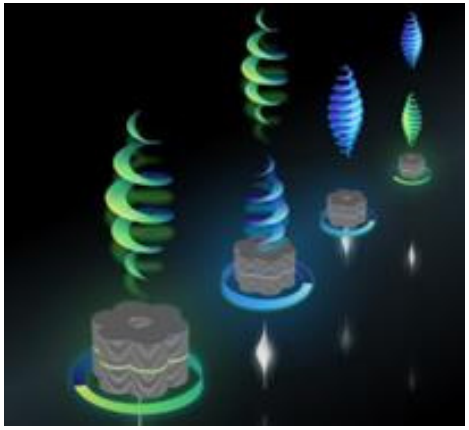


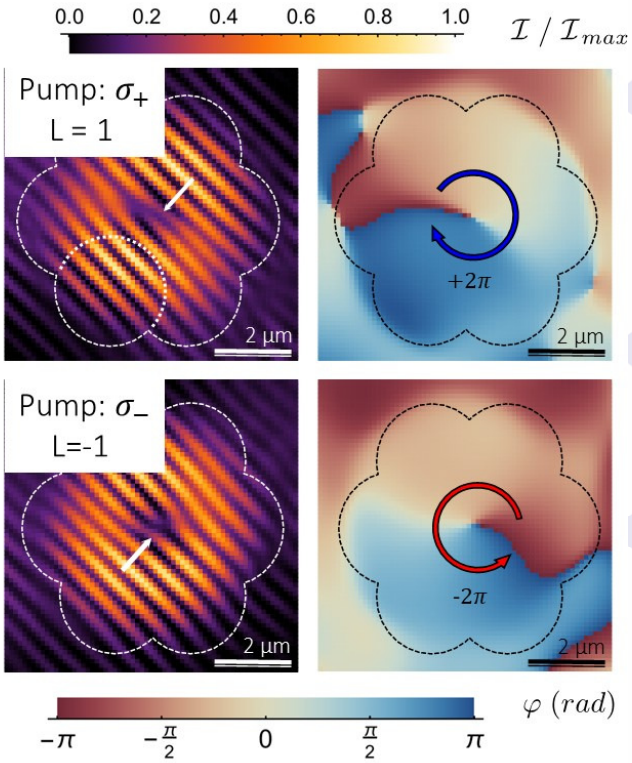
V. Goblot et al, Phys. Rev. Lett. 123, 113901 (2019)

WP4 : Topological lattices: CNRS

Engineering of a spin-orbit coupling for photons







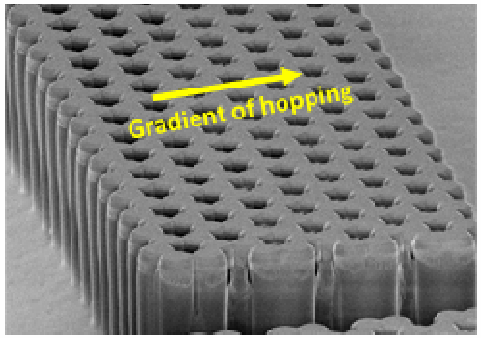
A microlaser with optically controlled OAM

N. Carlon Zambon, et al., **Nature Photonics 13, 283 (2019)**
N. Carlon Zambon et al., **Optics Letters** 44 **(18), 4531 (2019)**

WP4 : Topological lattices:

Artifical gauge field in Photonic graphene (CNRS)

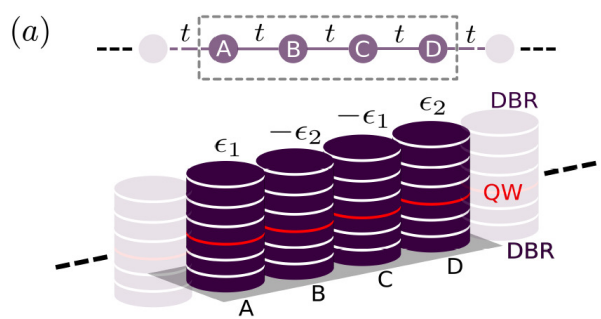
Honeycomb lattice with artificial gauge field



Observation of Landau levels
and edge states

Non hermitian topological edge-mode lasing (Polish Academy of Science - CNRS)

Theory



Manuscripts under preparation

WP4 : Development of theoretical methods

University college, London

- Tensor Networks :
- time dynamics and steady states of strongly correlated systems in 1D
- Lindblad master equation with drive and dissipation
- Positive P (stochastic phase space methods)

Flat bands of quasi 1D Lieb Lattice. Anti-bunching is predicted

BGU, Israel

- Developed tDMRG technique for open systems, to access deep quantum regime for 1D polaritons: **6 coupled micropillars**

- Employ Quantum Monte Carlo to study 2D hard core bosons & methods to extract their topological properties : **Strained honeycomb lattice**

C. Lledó et al., Phys. Rev. B 100, 054303 (2019)

Outreach

Publications

[1] Whittaker, C. E. et al. **Phys. Rev. Lett**. **120**, 097401 (2018).

[2] N. Carlon Zambon et al., **Nature Photonics 13**, 283 (2019).

[3] N. Carlon Zambon et al., **Optics Letters 44**, 4531 (2019).

[4] V. Goblot, et al., **Phys. Rev. Lett. 123**, 113901 (2019).

[5] Whittaker, C. E et al., **Phys. Rev. B 99**, 081402(R) (2019)

[6] C. Lledó, Th. K. Mavrogordatos, and M. H. Szymańska, **Phys. Rev. B 100**, 054303 (2019).

[7] A. Opala, S. Ghosh, T. C.H. Liew, M. Matuszewski, **Phys. Rev. Applied 11**, 064029 (2019)

[8] N. Carlon Zambon et al**.**, **arXiv**:1911.02816

22 invited talks; 5 contributed talks

WILHELM UND ELSE HERAEUS-STIFTUNG

726. WE-Heraeus-Seminar

Lattice-based Quantum Simulation

21 Jun - 24 Jun 2020
Physikzentrum Bad Honnef
Bad Honnef, Germany

Deadline for application: April 20th 2020 !

Topics

Cold atoms for quantum simulation
Superconducting qubits
Photonic quantum simulators
Polariton lattices for simulation
Theoretical methods for correlated systems

Invited lecturers

Andrea Alberti, Bonn, Germany
Jacqueline Bloch, Palaiseau, France
Iacopo Carusotto, Trento, Italy
Ignacio Cirac, Garching, Germany
Tilmann Esslinger, Zürich, Switzerland
Eytan Grosfeld, Beer Sheva, Israel
Sven Höfling, Würzburg, Germany
Andrew Houck, Princeton, USA
Atac Imamoglu, Switzerland
Dmitryi Krizhanovskii, Sheffield, UK
Pavlos Lagoudakis, Southampton, UK
Dieter Meschede, Bonn, Germany
Gil Refael, Pasadena, USA
Vahid Sandoghdar, Erlangen, Germany
Moti Segev, Haifa, Israel
Pascale Senellart, Palaiseau, France
Marzena Szymanska, London, UK
Peter Zoller, Innsbruck, Austria

Further details

Applications: Jan 01-April 20, 2020
Link:

Organization

Marzena Szymanska, London, UK
Jacqueline Bloch, Palaiseau, France
Paulo Santos, Berlin, Germany

InterPol meeting: Palaiseau, February 2019