Interaction Induced Localisation in a 2D Exciton-Polariton Lieb Lattice

Seth Lovett[1], Anthony Ellul[1], Paul M. Walker[1], Maurice S. Skolnick[1] and Dmitry N. Krizhanovskii[1]
[1]*Department of Physics, University of Sheffield, S3 7RH, Sheffield, UK*
p.m.walker@sheffield.ac.uk

Flat energy bands appear in a wide range of semiconductor lattices where geometric frustration quenches the kinetic energy leading to zero dispersion of energy with wavevector. The lack of kinetic energy leaves disorder and inter-particle interactions as the dominant energy scales, leading to fascinating many-body phenomena.

While such effects are challenging to study in purely electronic system, analogies built from coupled 'photonic atom' optical cavities (Fig. 1a) allow direct optical excitation and readout of the system state. Exciton-polaritons are hybrid part-light, part-matter quasi-particles whose photonic component allows imposition of a potential landscape to build these optical analogs, while their excitonic component provides giant interparticle interactions [1].

Here we experimentally study flat-band physics in a polaritonic analogy to a two-dimensional Lieb lattice [2-5]. In particular, we study the effect of interactions on compact localised states (CLS) – maximally localized superpositions of flat band states from the whole Brillouin Zone [6]. We drive the system with a pump localised on a single lattice plaquette and at an energy just above the energy of the flat band. Unlike the 1D Lieb lattice, where previous nonlinear studies were performed [7], the 2D Lieb bandstructure has no band gap between the flat band and the dispersive (propagating) bands, so at low power we excite a mixture of localised and propagating states (Fig. 1b).

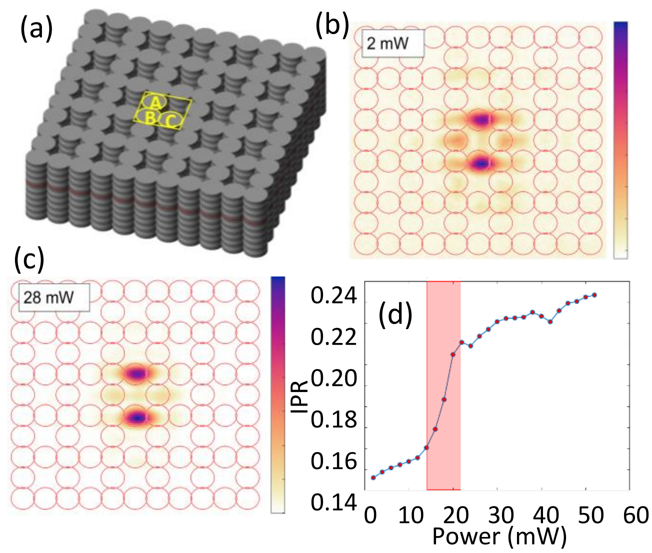

Fig. 1. (a) Schematic of Lieb Lattice of coupled polariton micro-pillar resonators. (b-c) Experimentally measured lattice population for low (a) and high (c) driving fields. (d) Inverse participation ratio vs. driving power.

With increasing particle density the repulsive polariton interactions might be thought to lead to enhanced diffraction away from the localized pump spot. Remarkably, however, we show that the interactions can lead to preferential population of the CLS and increasing localisation of the field with increased pump. With increasing pump (Fig. 1c) the state of the system gradually approaches that of the maximally localised CLS, which has no population on the corner sites (adjacent to 4 other sites). The localization characterized by the inverse participation ratio (IPR) [8] approaches the value of 0.25 for the ideal CLS (Fig. 1d). The experimental results are in good agreement with numerical solution of the driven-dissipative evolution equations for the Lieb lattice of coupled nonlinear resonators. These results have implications for many-body physics in driven-dissipative flat band systems as well as for nonlinear diffraction-less information transport.

References

[1] C. Schneider et. al. *Rep. Prog. Phys.* **80**, 016503 (2016).
[2] S. Klembt et. al. *Appl. Phys. Lett.* **111** 231102 (2017).
[3] C. Whittaker et. al. *Phys. Rev. Lett.* **120** 097401 (2018).
[4] M. Sun et. al. *Phys. Rev. B* **98**, 161204 (2018).
[5] V. Goblot et. al. *Phys. Rev. Lett.* **123**, 113901 (2019).
[6] R. A. Vicencio et. al. *Phys. Rev. Lett.* **114** 245503 (2015).
[7] T. H. Harder et. al. *Phys. Rev. B* **102**, 121302 (2020).
[8] O. Jamadi et. al. *Optica* **9** 706 (2022).