Researchers synthesize artificial solid-state crystal structures using laser light

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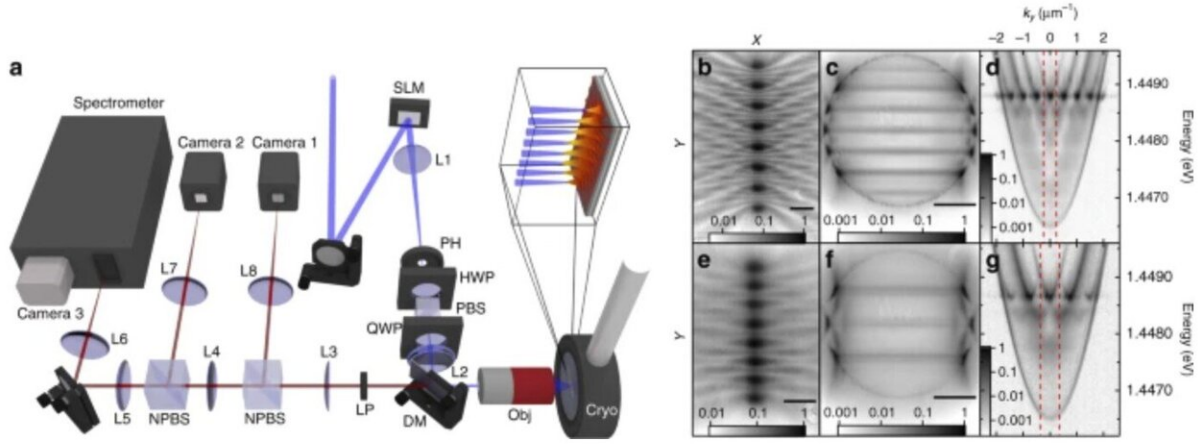

Schematic representation of an experimental system. Credit: Pickup, L. et. al./*Nature Communications*

Researchers at the Hybrid Photonics Laboratories in Skoltech and Southampton (U.K.), in collaboration with Lancaster University (U.K.), have demonstrated a new optical method to synthesize artificial solid-state crystal structures for cavity polaritons using only laser light. The results could lead to the realization of field-programmable polariton circuitry and new strategies to create guided light and robust confinement of coherent light sources. The results were recently published in the journal *Nature Communications*.

Creating artificial lattices for quantum particles permits researchers to explore physics in an environment that might not be conventionally found in nature. Artificial lattices are especially appealing since their symmetries often lead to exactly solvable models and a transparent understanding of their properties. Designing them, however, is a challenging task with limited flexibility. Materials need to be irreversibly engineered to get the job done, and even optical lattice techniques for cold atoms cannot produce arbitrary lattice shapes.

The researchers, Dr. Lucy Pickup (Southampton), Dr. Helgi Sigurdsson (Southampton and Skoltech), Prof Janne Ruostekoski (Lancaster), and Prof Pavlos Lagoudakis (Skoltech and Southampton), overcame this challenge by developing a new method to create arbitrarily shaped and reprogrammable artificial lattices using only structured laser light. The reprogrammability meant that the cavity-polariton system could be changed from one lattice to another without the costly need to engineer a new system from scratch.

When the laser light hits a semiconductor quantum well, it excites electrons and holes, as well as bound states of the two known as excitons. When the quantum well is placed between two mirrors, forming a trap (or a cavity) for the photons, some of the exciton particles become dressed in photons, forming exotic half-light, half-matter quasiparticles known as exciton-polaritons or cavity polaritons.

Exciton-polaritons are interactive and bounce frequently off one another. However, they also bounce off normal electrons, holes and excitons in the background. The researchers showed that by applying laser light in a geometrically structured fashion, the exciton-polaritons started bouncing of the excited electrons, holes, and excitons following the shape of the laser. In other words, the exciton-polaritons started experiencing a synthetic potential landscape imprinted by the laser.

The laser-generated potential landscapes are only felt by the exciton-polaritons and not the photons inside the cavity, distinguishing the system from photonic crystals. By creating a laser pattern with translational symmetry, the researchers produced the fundamental signature of solid-state systems, the formation of crystal energy bands for exciton-polaritons like those for electrons in solid-state materials.

"The results open a path to study dissipative many-body quantum physics in a lattice environment with properties that cannot be reproduced in normal Hermitian quantum systems," Dr. Lucy Pickup, article co-author, says.

Dr. Helgi Sigurdsson adds: "It is an exciting development for the relatively new field of non-Hermitian topological physics."

The produced bands could be reconfigured by simply adjusting the laser pattern, permitting a non-invasive method to access quantum physics in artificial lattices. The results could be useful in a variety of applications, including optical-based communications, information processing, high sensitivity detectors for biomedical purposes and topologically protected lasing. The results also open a path to study fundamental many-body lattice physics in an open (non-Hermitian) quantum environment.

More information: L. Pickup et al. Synthetic band-structure engineering in polariton crystals with non-Hermitian topological phases, *Nature Communications* (2020). DOI: 10.1038/s41467-020-18213-1

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