量子の状態制御と機能化
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実績報告書

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励起子 − ポラリトンにおける強相関トポロジカルハルデーンモデルの実現

§1. 研究成果の概要

The research conducted in FY2018 consisted of efforts in three parallel aspects of this project, including (a) Theoretical developments, (b) sample fabrication progress and (c) Experimental apparatus developments and measurements.

(a) Theoretical developments

Primarily using the technique of the open-dissipative Gross-Pitaevskii equation, which has been shown to accurately capture the main influences determining the dynamics of off-resonantly pumped polariton condensates, I have studied various designs for non-Hermitian potential landscapes, studied the realistic polariton dynamics in such potentials, and determined their usefulness for creating engineered topological states, specifically the Haldane model.

I have made two key developments in this area. The first is that for a balanced and symmetric 3-node real potential structure with inherent triangular (rotation and reflection) symmetry, the addition of an appropriate design of imaginary potential on top of this real potential can efficiently and robustly break the symmetry between the left and right rotational modes, thus allowing us to engineer vorticity and control the handedness of off-resonantly pumped polariton states. Iterations of the design of the imaginary landscape allow us to create such a symmetry breaking potential with minimal impacts on the polariton density variations between each of the three real potential sites.

The second development is the extension of this non-Hermitian 3-node potential structure to a design for a large scale non-Hermitian Kagome lattice structure, which is believed to contain the necessary elements to exhibit topologically-nontrivial Haldane-model like dynamics. Modeling of this structure, specifically a demonstration of its topological character, is on-going.

These results are being prepared for publication, and so images are presented in section §3.

(b) Sample fabrication progress

Significant progress has been made in the design and fabrication of potential lattices in polariton microcavities, with current designs including real-valued potential lattices of square, honeycomb and Kagome layouts, in addition to various circular single trap potentials ranging from 1um to 50um in diameter and further, parallel progress has been made in fabricating dual-layer masks for non-Hermitian (complex-valued) landscapes.

To create these potential landscapes, I use high-energy beams of protons, which are fired through a specially fabricated mask on the microcavity sample surface. Depending on the energy of the proton beams chosen, large and controllable shifts can be made selectively to both the exciton energy as well as the photon energy. By using dual layer masks (where the thin layer acts as a proton beam attenuator), dual-energy implants can be completed with a single mask and implantation process, and thus a simple and reliable method for fabricating arbitrary non-Hermitian potential lattices.

Using new microcavity samples from the University of Wurzburg, I have successfully fabricated the masking regions (consisting of $4\mu m$ tall SiO_2 pillars of $1.4\mu m$ diameter) for real-valued potential lattices and landscapes. Initial tests of the dual-layer masks were also successfully completed.

These results are being prepared for publication, and so images are presented in section §3.

(c) Experimental apparatus developments and measurements

The experimental apparatus was significantly enhanced during this fiscal year including the following additions:

- Full computer control using Python
- Automated control of the Streak camera time-dependent measurements
- Introduction of a top-hat beam shaping optic for transformation of a Gaussian pumping bean to a flat-topped pumping beam
- Stabilization of the CW laser to ～100kHz linewidth

- Introduction of a computer-controlled pin-hole filter in k-space for measuring k-vector dependence on condensate spatial dynamics
- Purchase and set up of a 4MP high-sensitivity imaging camera

Notable measurements on this apparatus included:

- Characterization of the condensate properties, temporal and spatial dynamics of microcavity sample M6115 - this sample is currently being fabricated into lattice structures
- Measurements of the strain splitting inherent in etched micro-pillar cavity structures, using optical tomography - these structures will be compared with single traps in the ion-implanted samples, which are not expected to have such problems.

§2. 研究実施体制

① 研究者： Michael Fraser （科学技術振興機構　さきがけ研究者）

② 研究項目

・ Conceived the original project of using proton-beams to create complex potentials in polariton microcavities

・ Conceived the use of non-Hermitian potentials to realize a topological Haldane model.

・ Design and construction of experimental apparatus

・ Fabrication and charactization of proton-implanted lattices in polariton microcavities

・ Theoretical design and simulation of complex potential polariton dynamics

・ Measurements of time-dependent polariton dynamics in polariton trap and lattice structures

・ Optical band-structure tomography of polariton lattices