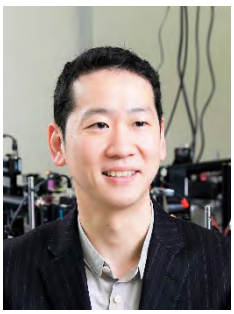
Nanoscale Quantum Photonics Laboratory (2021)
Chief Scientist: Yuichiro Kato (Ph.D.)



(0) Research field

CPR Subcommittee**:** Engineering
Keywords: condensed matter physics, nanoscale device physics, carbon nanotubes, photonic crystals, microspectroscopy

(1) Long-term goal of laboratory and research background

Control over the quantum nature of photons at the nanoscale opens up unique opportunities in quantum information processing. We study the physics underlying the operation of nanoscale photonic devices to explore new approaches for manipulating quantum states, with focus on devices that make use of individual single-walled carbon nanotubes. By combining microspectroscopy with electronic techniques, we investigate unconventional methods for manipulating the optical properties of nanomaterials within device structures, which should form the basis for future quantum technologies employing integrated quantum photonic circuits.

(2) Current research activities (FY2021) and plan (until Mar. 2025)

Chiral modes near exceptional points in symmetry broken H1 photonic crystal cavities
C. F. Fong, Y. Ota, Y. Arakawa, S. Iwamoto, Y. K. Kato, *Phys. Rev. Research* **3**, 043096 (2021).

We propose a scheme to induce chiral modes in a H1 photonic crystal cavity. In our scheme, two selected air holes near the cavity (Fig. 1) are modified to induce non-Hermitian backscattering between the cavity modes. As the cavity modes approaches the exceptional point with suitable air holes modifications, the modes become highly degenerate as well as chiral in nature. We confirmed such chirality by performing finite-difference time-domain simulations, showing that the dominant field intensity is circularly polarized with the degree of circular polarization approaching unity even in the farfield. The handedness of the chirality can be switched by selecting a different pair of air holes for modifications.

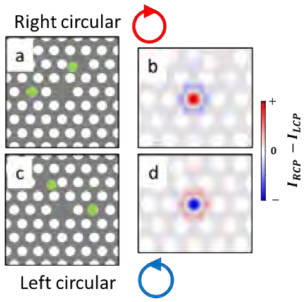


Fig. 1: Schematic of the modified H1 photonic crystal cavity and the intensity difference in the orthogonal circularly polarized cavity field for the (a, b) right circular and (c, d) left circular chiral cases, respectively.

Deterministic transfer of optical-quality carbon nanotubes for atomically defined technology
K. Otsuka, N. Fang, D. Yamashita, T. Taniguchi, K. Watanabe, Y. K. Kato, *Nature Commun.* **12**, 3138 (2021).

We have developed a versatile dry transfer technique for deterministic placement of optical-quality carbon nanotubes and other low-dimensional materials. Single-crystalline anthracene is used as a medium which readily sublimes by mild heating, leaving behind clean nanotubes and thus enabling bright photoluminescence on a wide variety of substrates. We are able to position nanotubes of a desired chirality with a sub-micron accuracy under in-situ optical monitoring, thereby demonstrating deterministic coupling of a specific nanotube to a photonic crystal nanobeam cavity (Fig. 2). A cross junction structure is also designed and constructed by repeating the nanotube transfer, where intertube exciton transfer is observed at a controlled interface. Our results represent an important step towards development of devices consisting of atomically precise components and interfaces.

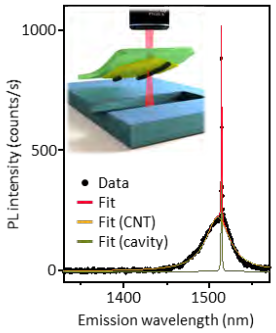


Fig. 2: Photoluminescence spectrum of nanotube emission coupled with the fundamental mode of a microcavity. Inset: Schematic showing a part of nanotube transfer process.

(3) Members

(Chief Scientist)
Yuichiro Kato
(Research scientist)
Wataru Terashima
(Special Postdoctoral Researcher)
Nan Fang
Chee Fai Fong
(Student Trainee)
Nicolas F. Zorn
(Assistant)
Yoriko Nissaka

(4) Representative research achievements

1. C. F. Fong, Y. Ota, Y. Arakawa, S. Iwamoto, Y. K. Kato, “Chiral modes near exceptional points in symmetry broken H1 photonic crystal cavities,” Phys. Rev. Research **3**, 043096 (2021).
2. Z. Li, K. Otsuka, D. Yamashita, D. Kozawa, Y. K. Kato, “Quantum emission assisted by energy landscape modification in pentacene-decorated carbon nanotubes,” ACS Photonics **8**, 2367 (2021).
3. K. Otsuka, N. Fang, D. Yamashita, T. Taniguchi, K. Watanabe, Y. K. Kato, “Deterministic transfer of optical-quality carbon nanotubes for atomically defined technology,” Nature Commun. **12**, 3138 (2021).

Group Photo

Group Webpage

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