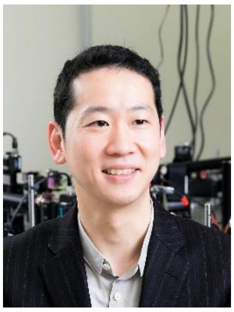
Nanoscale Quantum Photonics Laboratory (2022)
Chief Scientist: Yuichiro Kato (Ph.D.)



(0) Research fields

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 (FY2022) and plan

<u>Quantization of mode shifts in nanocavities integrated with atomically thin sheets</u>
N. Fan, D. Yamashita, S. Fujii, K. Otsuka, T. Taniguchi, K. Watanabe, K. Nagashio, Y. K. Kato, *Adv. Opt. Mater.* **10**, 2200538 (2022).

We have developed an air-mode cavity for integration with 2D materials. By investigating various 2D material types and thickness dependence, we show that the fabricated 2D/cavity hybrids have a giant wavelength tunable range of over 200 nm. We observe a clear quantization behavior of the wavelength shift for tungsten disulfide (WSe_2) where each step represents an effect from an additional monolayer. The in-plane dielectric constant of WSe_2 can be extracted because of the high surface sensitivity of the air-mode cavity, and shows a thickness independent characteristic down to the monolayer. By stacking and removing the transferred flakes, we demonstrate that the hybrids benefit from the versatile manipulation capabilities of the 2D materials. These findings reveal fascinating features of the cavity that is efficiently controlled by 2D materials, and provide a universal design strategy for enhancing the light-matter interaction with nanomaterials.

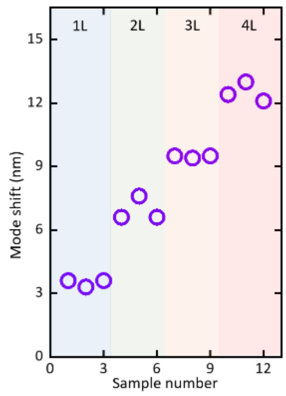


Fig. 1: Resonant wavelength shifts for one-, two-, three-, four-layer WSe_2/cavity hybrids.

<u>Near-unity radiative quantum efficiency of excitons in carbon nanotubes</u>
H. Machiya, D. Yamashita, A. Ishii, Y. K. Kato, *Phys. Rev. Research* **4**, L022011 (2022).

We have experimentally determined the radiative quantum efficiency of bright excitons in carbon nanotubes which ultimately limits the performance of light-emitting devices. Silicon photonic crystal nanobeam cavities are used to induce the Purcell effect on individual carbon nanotubes. Spectral and temporal behavior of the cavity enhancement is characterized by photoluminescence microscopy, and the fraction of the radiative decay process is evaluated. We find that the radiative quantum efficiency is near unity for bright excitons in carbon nanotubes at room temperature. Our results open a pathway towards high-efficiency photonic devices at the nanoscale.

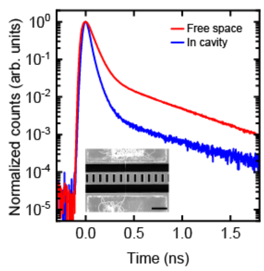


Fig. 2: Comparison of PL decay curves. Inset: A scanning electron micrograph of a device.

(3) Members

(Chief Scientist)
Yuichiro Kato
(Research scientist)
Wataru Terashima
Daichi Kozawa
(Special Postdoctoral Researcher)
Nan Fang
Chee Fai Fong

(Visiting Researcher)
Yih-Ren Chang
(Visiting Scientist)
Keigo Otsuka
(Assistant)
Yoriko Nissaka

(4) Representative research achievements

1. N. Fang, D. Yamashita, S. Fujii, K. Otsuka, T. Taniguchi, K. Watanabe, K. Nagashio, Y. K. Kato, "Quantization of mode shifts in nanocavities integrated with atomically thin sheets," Adv. Opt. Mater. **10**, 2200538 (2022).
2. D. Kozawa, X. Wu, A. Ishii, J. Fortner, K. Otsuka, R. Xiang, T. Inoue, S. Maruyama, Y-H. Wang, Y. K. Kato, "Formation of organic color centers in air-suspended carbon nanotubes using vapor-phase reaction," Nature Commun. **13,** 2814 (2022).
3. H. Machiya, D. Yamashita, A. Ishii, Y. K. Kato, "Evidence for near-unity radiative quantum efficiency of bright excitons in carbon nanotubes from the Purcell effect," Phys. Rev. Research **4**, L022011 (2022).

Group Photo

Group Webpage

https://www.riken.jp/en/research/labs/chief/nanosc_qtm_photon/
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