

Nanoscale Quantum Photonics Laboratory (2024)

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

Quantum technologies are expected to make important developments in various fields of engineering including computing, sensing, metrology, and communication. Since quantum effects become more evident and more robust as the system scales down, devices with atomically precise elements could provide a route for quantum technologies operating at elevated temperatures. Our research focuses on the optical properties of nanomaterials and the physics of nanoscale photonic devices, investigating new approaches for utilizing their quantum properties. By engineering atomically defined nanostructures and integrating them into nanoscale devices, we explore novel concepts in photonics for future quantum technologies.

(2) Current research activities (FY2024) and plan

Room-temperature quantum emission from interface excitons in mixed-dimensional heterostructures

N. Fang, Y. R. Chang, S. Fujii, D. Yamashita, M. Maruyama, Y. Gao, C. F. Fong, D. Kozawa, K. Otsuka, K. Nagashio, S. Okada, Y. K. Kato, *Nature Commun.* **15**, 2871 (2024).

We report on the observation of multiple emergent excitonic peaks in the 1D-2D CNT/tungsten diselenide (WSe_2) heterostructures at room temperature. These peaks appear exclusively at the interface region with a broad energy range lower than CNT E_{11} states, and their dependence on the chirality of CNTs and the layer number of WSe_2 is investigated. The emergence of the peaks is found to be highly correlated with the band alignment, and they are interpreted as interface excitons. Prominent linear polarization, low excitation saturation power, and a long lifetime are characteristic of low-energy interface excitons, suggesting strong confinement. Through photon correlation measurements, room-temperature antibunching has been confirmed. These findings expand the existing concept of spatially indirect excitons based on 2D heterostructures to 1D systems, demonstrating significant potential of the interface excitons for nanophotonics and quantum information processing.

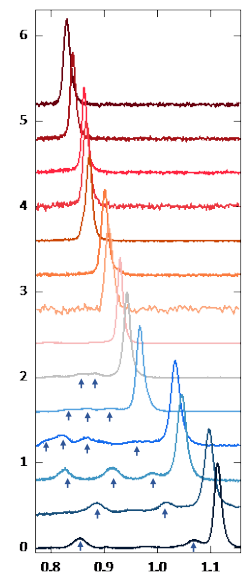


Fig. 1: Chirality-dependent PL spectra of heterostructures. Arrows indicate interface excitons.

Self-aligned hybrid nanocavities using atomically thin materials

C. F. Fong, D. Yamashita, N. Fang, S. Fujii, Y.-R. Chang, T. Taniguchi, K. Watanabe, and Y. K. Kato, *ACS Photonics* **11**, 2247 (2024).

We demonstrate a novel approach to form a hybrid nanocavity by placing a suitably sized 2D material flake to partially cover a photonic crystal waveguide. The presence of the flake modulates the local refractive index which causes optical confinement and thus cavity formation. We successfully fabricated such hybrid nanocavity devices with hBN, WSe_2 , and MoTe_2 flakes on silicon photonic crystal waveguides, obtaining cavity quality factors as high as 4.0×10^5 . Remarkably, even mono- and few-layer flakes can provide sufficient local refractive index modulation to induce nanocavity formation. Since the 2D material is spatially self-aligned to the nanocavity, we managed to observe cavity light-matter coupling effect including enhanced photoluminescence intensity and a reduced decay time.

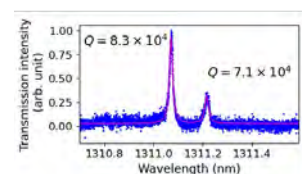
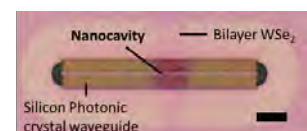


Fig. 2: (Top) Optical micrograph of a self-aligned hybrid nanocavity with a bilayer WSe_2 flake. (Bottom) Transmission spectra showing the cavity peaks and the corresponding Q factors.

(3) Members

(Chief Scientist)

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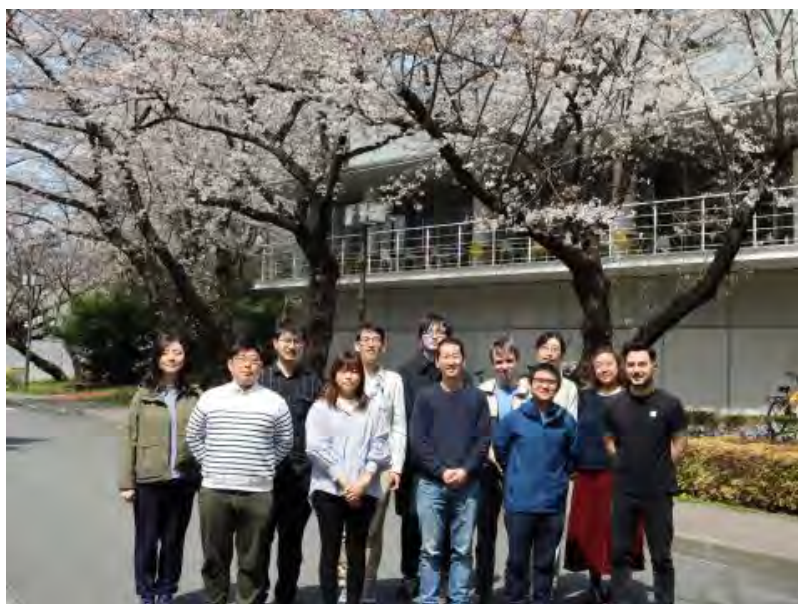
Yih-Ren Chang

Kenichi Cho

(4) Representative research achievements

1. D. Yamashita, N. Fang, S. Fujii, Y. K. Kato, "Hybrid silicon all-optical switching devices integrated with 2D material," *Adv. Opt. Mater.* **13**, 2402531 (2025).
2. D. Kozawa, S. Fujii, Y. K. Kato, "Intrinsic process for upconversion photoluminescence via K -momentum-phonon coupling in carbon nanotubes," *Phys. Rev. B* **110**, 155418 (2024). [Editors' Suggestion]
3. C. F. Fong, D. Yamashita, N. Fang, S. Fujii, Y.-R. Chang, T. Taniguchi, K. Watanabe, Y. K. Kato, "Self-aligned hybrid nanocavities using atomically thin materials," *ACS Photonics* **11**, 2247 (2024).
4. N. Fang, Y. R. Chang, S. Fujii, D. Yamashita, M. Maruyama, Y. Gao, C. F. Fong, D. Kozawa, K. Otsuka, K. Nagashio, S. Okada, Y. K. Kato, "Room-temperature quantum emission from interface excitons in mixed-dimensional heterostructures," *Nature Commun.* **15**, 2871 (2024).
5. S. Fujii, N. Fang, D. Yamashita, D. Kozawa, C. F. Fong, Y. K. Kato, "van der Waals decoration of ultra-high-Q silica microcavities for $\chi^{(2)}$ - $\chi^{(3)}$ hybrid nonlinear photonics," *Nano Lett.* **24**, 4209 (2024).

Group Photo



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