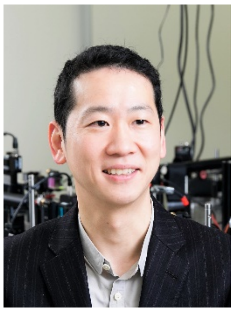
Nanoscale Quantum Photonics Laboratory
Chief Scientist: Yuichiro Kato (Ph.D.)



(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 (FY2019) and plan (until Mar. 2025)

High Efficiency Dark-to-Bright Exciton Conversion in Carbon Nanotubes

A. Ishii, H. Machiya, and Y. K. Kato, *Phys. Rev. X* **9**, 041048 (2019).

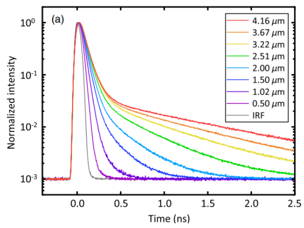


Fig. 1: Emission decay curves from same-chirality nanotubes with various suspended lengths.

We report that a considerable fraction of light emission can originate from dark states of excitons in carbon nanotubes. We use time-resolved photoluminescence measurements to study decay dynamics and diffusion properties of excitons (Fig. 1), and we systematically investigate how nanotube structure impacts intrinsic lifetimes and diffusion coefficients for both bright and dark excitons as well as state transition rates. In long nanotubes, we find that the dark-to-bright transition rates can be considerably high, and that more than half of the dark excitons can be transformed into the bright excitons. Adsorbed air molecules on the surface of the nanotubes also significantly enhance the transition rate. Our findings show the nontrivial significance of the dark excitons on the emission kinetics in low-dimensional materials and demonstrate the potential for engineering the dark-to-bright conversion process by using surface interactions.

Super-resolution fluorescence imaging of carbon nanotubes using a nonlinear excitonic process

K. Otsuka, A. Ishii, Y. K. Kato, *Opt. Express* **27**, 17463 (2019).

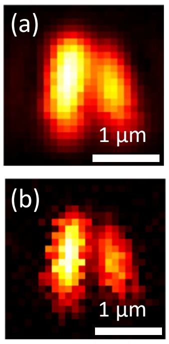


Fig. 2: (a) Conventional photoluminescence image and (b) Super-resolution image of two nanotubes.

We have demonstrated super-resolution imaging of air-suspended carbon nanotubes over trenches in photoluminescence imaging. The spatial resolution in confocal imaging is restricted by the size of laser beam for excitation. Excitons in carbon nanotubes recombine nonradiatively upon collision with each other. Strong photoluminescence saturation due to high efficiency of this annihilation process in a one-dimensional body allows us to have resolution beyond the diffraction limit. Through the comparison of photoluminescence signals in linear and sublinear regimes at different excitation powers, we extract the efficiency of the annihilation processes using conventional confocal microscopy (Fig. 2), where the resolution enhancement of $\sqrt{2}$-fold is achieved. Highly mobile excitons in nanotubes enable subdiffraction imaging at a power density as low as ~300 W/cm^2.

(3) Members as of March, 2020

(Chief Scientist)
Yuichiro Kato

(Research scientist)
Wataru Terashima

(Postdoctral researcher)
Akihiro Ishii, Nan Fang, Daiki Yamashita, Zhen Li

(Visiting researcher)
Keigo Otsuka, Alka Sharma

(Student Trainee)
Hidenori Machiya

(Assistant)
Yoriko Nissaka

(4) Representative research achievements

1. A. Ishii, H. Machiya, Y. K. Kato: "High efficiency dark-to-bright exciton conversion in carbon nanotubes", Phys. Rev. X 9, 041048 (2019).
2. K. Otsuka, A. Ishii, Y. K. Kato: "Super-resolution fluorescence imaging of carbon nanotubes using a nonlinear excitonic process", Opt. Express 27, 17463 (2019).

Group Photo

Group Webpage
https://www.riken.jp/en/research/labs/chief/nanosc_qtm_photon/index.html
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