# International Research Center for Elements Science – Photonic Elements Science –

http://www.scl.kyoto-u.ac.jp/~opt-nano/index-e.html

Prof
KANEMITSU, Yoshihiko
(D Eng)

Assoc Prof
TAYAGAKI, Takeshi
(D Sc)

Assist Prof
IHARA, Toshiyuki
(D Sc)

PD
TEX, David Michael
(D Eng)

PD
LE, Phuong Quang
(D Eng)

PD (JSPS)
TAHARA, Hirokazu
(D Sc)

### Students

OHNO, Kai (M2)
IBUKI, Hiroto (M1)
YAMADA, Takumi (M1)

## Scope of Research

Our research interest is to understand optical and quantum properties of nanometer-structured materials and to establish opto-nanoscience for creation of innovative functional materials. Optical properties of semiconductor quantum nanostructures and strongly-correlated electron systems in lowdimensional materials are studied by means of space- and time-resolved laser spectroscopy. The main subjects are as follows: (1) Investigation of optical properties of single nanostructures through the development of high-resolution optical microscope, (2) Development of nanoparticle assemblies with new optical functionalities, and (3) Ultrafast optical spectroscopy of excited states of semiconductor nanostructures.

### KEYWORDS

Femtosecond Laser Spectroscopy
Carbon Nanotubes
Semiconductor Nanoparticles
Transition Metal Oxides
Semiconductor Nanostructures

### Selected Publications


Yamada,Y.; Sato, H. K.; Hikita, Y.; Hwang, H. Y.; Kanemitsu, Y., Measurement of the Femtosecond Optical Absorption of $LaAlO_3/SrTiO_3$ Heterostructures: Evidence for an Extremely Slow Electron Relaxation at the Interface, *Phys. Rev. Lett.*, **111,** [047403-1]-[047403-5] (2013).
Matsunaga, R.; Matsuda, K.; Kanemitsu, Y., Observation of Charged Excitons in Hole-doped Carbon Nanotubes Using Photoluminescence and Absorption Spectroscopy, *Phys. Rev. Lett.*, **106,** [037404-1]-[037404-4] (2011).
Yamada, Y.; Yasuda, H.; Tayagaki, T.; Kanemitsu, Y., Temperature Dependence of Photoluminescence Spectra of Undoped and Electrondoped $SrTiO_3$: Crossover from Auger Recombination to Single-carrier Trapping, *Phys. Rev. Lett.*, **102,** [247401-1]-[247401-4] (2009).
Matsunaga, R.; Matsuda, K.; Kanemitsu, Y., Evidence for Dark Excitons in a Single Carbon Nanotube Due to the Aharonov-Bohm Effect, *Phys. Rev. Lett.*, **101,** [147404-1]-[147404-4] (2008).
Hosoki, K.; Tayagaki, T.; Yamamoto, S.; Matsuda, K.; Kanemitsu, Y., Direct and Stepwise Energy Transfer from Excitons to Plasmons in Close-packed Metal and Semiconductor Nanoparticle Monolayer Films, *Phys. Rev. Lett.*, **100,** [207404-1]-[207404-4] (2008).

## Photoluminescence Blinking in CdSe/CdS Dot-in-rods

Semiconductor nanostructures have been extensively studied owing to their interest both in the fundamental physics and potential applications in optoelectronic devices. CdSe/CdS heterostructure nanocrystals with quasi-type-II band alignment provide a platform for studying the photoluminescence (PL) blinking associated with their morphologies. By using simultaneous measurements of the PL intensity, lifetime, and polarization anisotropy, we reveal the role of the electron delocalization during the blinking of single CdSe/CdS dot-in-rods. We found that a significant change in the PL polarization anisotropy distinguishes between two kinds of charged excitons with different electron delocalizations. We observed polarized PL blinking governed by the band alignments and the Coulomb interactions between the charges inside and outside the dot-in-rod.

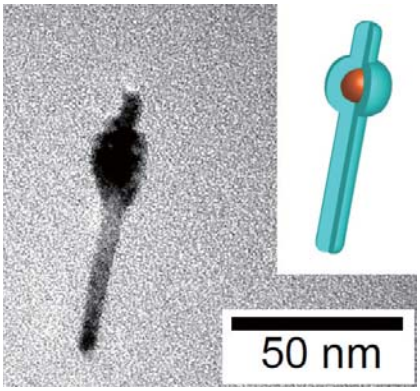


**Figure 1.** Transmission electron microscope image of a CdSe/CdS dot-in-rod and a schematic of its structure.

## Photoluminescence and Photocurrent Imaging Spectroscopy of InAs Nanostructures

Quantum dots (QDs) have attracted attention because of their interesting physical properties and potential applications in optoelectronic devices such as light emitters and solar cells. We performed microscopic imaging of photoluminescence (PL) and photocurrent (PC) on InAs nanostructures including disklike structures (nanodisks) and QDs. The correlation between PL and PC images indicates that the major fraction of upconverted carriers originates from nanodisks. By analyzing the excitation spectra, we find evidence that nanodisks and QDs need to be spatially separated to enhance PC generation via upconversion. The simultaneous use of both QDs and nanodisks is an alternative approach to intermediate-band solar cells, where low-energy photons are upconverted in the QDs and high-energy photons are efficiently upconverted in the nanodisks, resulting in enhanced carrier generation yields. With spatially resolved upconverted PL, we show that PC generation in nanodisks is due to ejection of both electrons and holes.

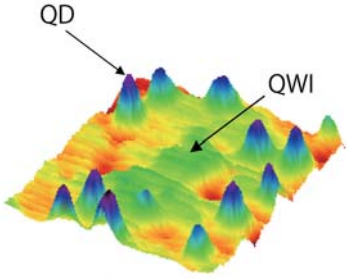


**Figure 2.** 3D AFM image with quantum dots (QDs) and a quantum well island (QWI) on the wetting layer of an InAs/AlGaAs layer without capping.

## Optical Properties in Photonic Nanostructure Fabricated from Quantum Dot Arrays

With the reduced optical thickness of the absorber material, electromagnetic phenomena such as propagating surface plasmons, nano-optic cavities, and photonic crystals have been pursued to enhance the absorption. We demonstrated enhanced photocarrier generation using photonic nanostructures fabricated by a wet etching technique with vertically aligned quantum dots (QDs). Using photoluminescence excitation spectroscopy, we found that the photocarrier generation in Ge/Si QDs placed close to the surface is enhanced below the band gap energy of crystalline silicon. The enhancement is explained by light trapping owing to the photonic nanostructures. Electromagnetic wave simulations also indicate that the photonic nanostructure will be available to light trapping for efficient photocarrier generation.

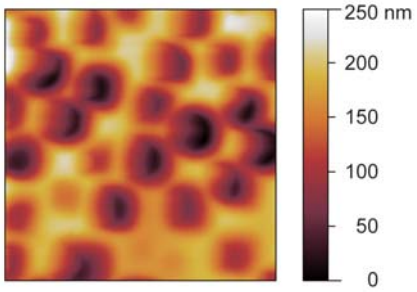


**Figure 3.** Atomic force microscope images of the photonic nanostructures formed by $HF/HNO_3$ etching. Images are ~1 × 1 μm in size.