Endowed Research Section
– Nano-Interface Photonics –
(SEI Group CSR Foundation)

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

Program-Specific Assoc Prof
YAMADA, Yasuhiro
(D Sc)

Program-Specific Assist Prof
OKANO, Makoto
(D Sc)

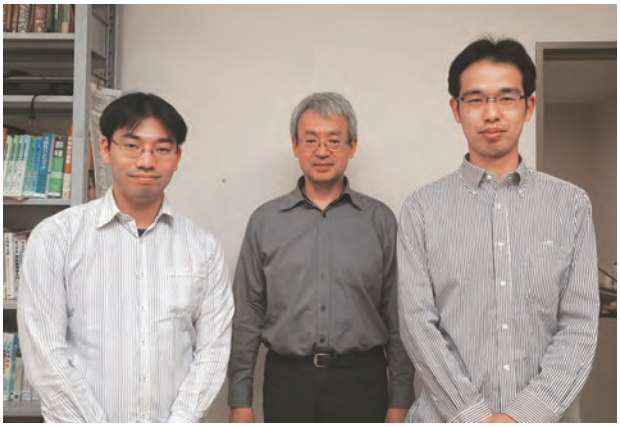
Prof (Supporting Faculty Member)
KANEMITSU, Yoshihiko
(D Eng)

Scope of Research

Nanostructured materials are one class of the most promising candidates for future device materials because of their unique electronic and optical properties beyond the bulk crystals. Our research aim is to open up new research fields of nanomaterials science, by focusing on nano-interface as a platform to develop novel optical functionalities. We study optical properties of semiconductor nanomaterials by means of time- and space-resolved spectroscopy, leading to new solar energy conversion technologies. The main subjects are (1) photocarrier dynamics and photovoltaic effects in transition metal oxides and (2) ultrafast carrier dynamics and unique optical properties of one-dimensional materials.

KEYWORDS

Nano-interface
Photovoltaic Science
Nanocarbon Materials
Laser Spectroscopy
Solar Energy Conversion



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, *Physical Review Letters*, **111,** [047403/1]-[047403/4] (2013).

Yamada, Y.; Kanemitsu, Y., Determination of Electron and Hole Lifetimes of Rutile and Anatase TiO_2 Single Crystals, *Appl. Phys. Lett.*, **101,** [133907-1]-[133907-4] (2012).

Okano, M.; Kanemitsu, Y.; Chen, S.; Mochizuki, T.; Yoshita, M.; Akiyama, H.; Pfeiffer, L. N.; West, K. W., Observation of High Rydberg States of One-dimensional Excitons in GaAs Quantum Wires by Magneto-photoluminescence Excitation Spectroscopy, *Phys. Rev. B*, **86,** [085312-1]-[085312-5] (2012).

Yamada, Y.; Kanemitsu, Y., Band-edge Luminescence from $SrTiO_3$: No Polaron Effect, *Thin Solid Films*, **520,** 3843-3846 (2012).

Okano, M.; Matsunaga, R.; Matsuda, K.; Masubuchi, S.; Machida, T.; Kanemitsu, Y., Raman Study on the Interlayer Interactions and the Band Structure of Bilayer Graphene Synthesized by Alcohol Chemical Vapor Deposition, *Appl. Phys. Lett.*, **99,** [151916-1]-[151916-3] (2011).

Nanointerface as a Platform to Develop Novel Optical Functionalities

Solar energy conversion is a key technology to solve the world-wide and emergent energy problems, such as fossil fuel exhaustion and global warming. However, the conversion efficiency of practically used solar cell is still less than 30%, and thus there is a compelling need for the development of highly-efficient and cost-effective solar cells.

Nanostructured materials, such as nanoparticles, nanotubes, and nanowires, are the most promising candidates for the next-generation solar cells because of their unique electronic and optical properties beyond the bulk crystals. For example, plasmon resonance in metal nanoparticles enhances the light absorption efficiency, and carrier multiplication due to strong carrier confinement and Coulomb interactions in the semiconductor nanoparticles can improve the light conversion efficiencies.

To take more advantages of nanomaterials, it is significant to understand the role of their surface and interface. Nanomaterials have large surface-to-volume ratios, and thus their optoelectronic properties are strongly affected by the surrounding materials and interface states. This indicates that the novel optoelectronic properties can be developed by controlling the nano-interface. Moreover, in the practical nanomaterial-based devices, the energy and carrier transport processes are dominated by the characteristics of the interface between nanomaterials.

In our research group, we focus on such nano-interface as a platform to develop novel optical functionalities. Using advanced time- and space-resolved spectroscopy, we study the optical properties of unique nanomaterials and their nanocomposites. Through the studies on the nano-interface photonics, we aim to open up new research fields of nanomaterials science, leading to new solar energy conversion technology.

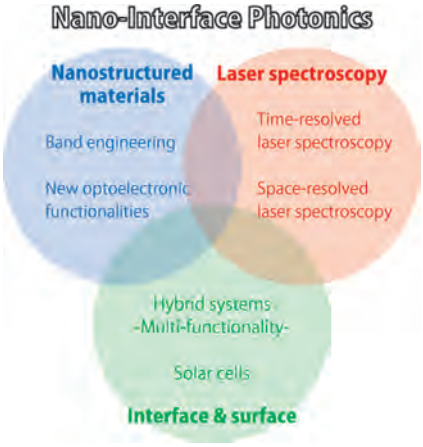


Figure 1.

Observation of Band-gap Renormalization in Hole-doped Carbon Nanotubes Using Photoluminescence Excitation Spectroscopy

Band-gap renormalization, where the band-gap energy is modified by high-density excitons or carriers, is one of the most interesting phenomena due to many-body effects in semiconductors. However, in one-dimensional semiconducting materials, it is difficult to directly determine the band-gap energy owing to extremely weak optical absorption. Therefore, we estimated the band-gap energy for hole-doped single-walled carbon nanotubes (SWCNTs) using a relationship of the exciton energy levels, which are measured by one- and two-photon photoluminescence excitation spectroscopy. As the hole-dopant concentration increases, a redshift of the first excited state (2g) and a blueshift of the ground state (1u) of the E_{11} exciton are observed. From the redshift of higher Rydberg states, we found that a reduction of the band-gap energy occurs in hole-doped SWCNTs. These findings show that a small number of holes can modulate the exciton and electronic band structures in the SWCNT one-dimensional structures.

Extremely Slow Electron Relaxation in $LaAlO_3/SrTiO_3$ Heterostructures Studied by Femtosecond Transient Absorption Spectroscopy

The interface between two insulating transition metal recently attracts much attention since the discovery of the quasi-two-dimensional electron-gas at the $LaAlO_3/SrTi_{O3}$ heterointerface. We studied the photocarrier relaxation dynamics of an n-type $LaAlO_3/SrTiO_3$ heterointerface using femtosecond transient absorption (TA) spectroscopy at low temperatures. A Drude-like free carrier absorption is observed in TA spectrum just after the photo excitation in both $LaAlO_3/SrTiO_3$ heterostructures and electron-doped $SrTiO_3$ bulk crystals. In addition, a broad absorption band gradually appears in visible spectral region within 40 ps, which corresponds to the energy relaxation of photoexcited free electrons into self-trapped polaron states. This indicates that the polaron formation time is largely enhanced at the $LaAlO_3/SrTiO_3$ heterointerface as compared to the bulk crystals, which is attributable to the splitting of the t_{2g} subbands due to the interface potential.