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)

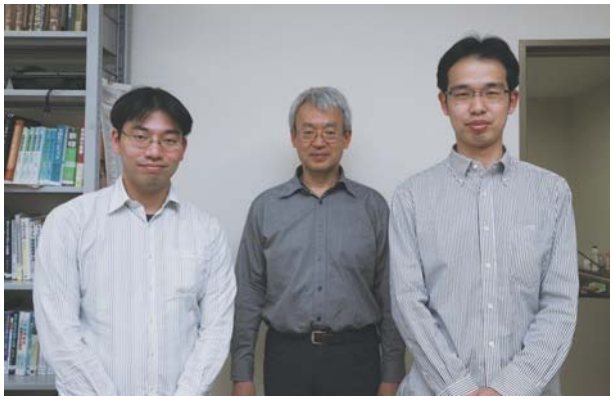
Program-Specific Assist Prof
OKANO, Makoto
(D Sc)

Prof (Supporting Factulty 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 spaceresolved 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
Solar Energy Conversion
Laser Spectroscopy



Selected Publications

Okano, M.; Sakamoto, M.; Teranishi T.; Kanemitsu, Y., Assessment of Hot-Carrier Effects on Charge Separation in Type-II CdS/CdTe Heterostructured Nanorods, *J. Phys. Chem. Lett*., **5,** 2951-2956 (2014).

Yamada, Y.; Nakamura, T.; Endo, M.; Wakamiya, A.; Kanemitsu Y., Photocarrier Recombination Dynamics in Perovskite $CH_3NH_3PbI_3$ for Solar Cell Applications, *J. Am. Chem. Soc*., **136,** 11610-11613 (2014).

Okano, M.; Takabayashi, Y.; Sakurai, T.; Akimoto, K.; Shibata, H.; Niki, S.; Kanemitsu, Y., Slow Intraband Relaxation and Localization of Photogenerated Carriers in $CuIn_{1-x}GaxSe_2$ Thin Films: Evidence for the Existence of Long-lived High-energy Carriers, *Phys. Rev. B*, **89,** [195203-1]-[195203-6] (2014).

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]-[047403-4] (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).

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.

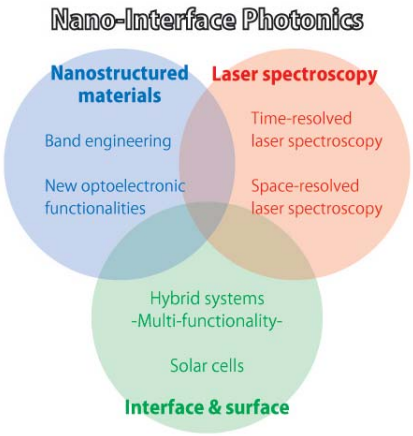


Figure 1.

Assessment of Hot-carrier Effects on Charge Separation in Type-II CdS/CdTe Heterostructured Nanorods

Recently, hot carrier effects on charge separation at heterointerfaces have been of great interest from the viewpoints of fundamental physics and potential device applications. Semiconducting heterostructured nanocrystals provide an excellent platform for studying the influence of hot-carriers on charge separation because of their long lifetimes. We studied the charge-separation dynamics in type-II CdS/CdTe heterostructured nanorods (HNRs) revealed by femtosecond transient-absorption (TA) measurements with a broadband white-light probe. Under selective excitation of the CdTe segment, bleaching signals at the band gap energy of CdS were clearly observed with a rise component on a subpicosecond time scale, which indicates efficient electron transfer from CdTe to CdS. The TA spectra and dynamics due to CdS bleaching in CdS/CdTe HNRs were insensitive to the pump energy, in stark contrast to those in directly photoexcited CdS NRs. Based on the dynamical analysis and the TA spectral change, we conclude that a major portion of hot electrons rapidly thermalizes to the bottom of the conduction band, after which electron transfer from CdTe to CdS takes place.

Photocarrier Recombination Dynamics in Halide Perovskite Semiconductor $CH_3NH_3PbI_3$

Lead halide-based perovskite semiconductor $CH_3NH_3PbX_3$ (X=Cl, Br, and I) recently attracts growing interests because of its high performance as a solar-cell material. The power conversion efficiency of perovskite solar cells currently attains nearly 20 %. We studied the photocarrier recombination processes in $CH_3NH_3PbX_3$ thin films by means of time-resolved photoluminescence and transient absorption measurements at room temperature. The photocarrier dynamics are well described by considering single-carrier trapping and electron–hole radiative recombination. This result provides clear evidence that the photoexcited electrons and holes behave as free carriers and do not form exciton at room temperature. Our findings provide useful information about the dynamical behaviors of photoexcited carriers, which is needed for developing high-efficiency perovskite solar cells.