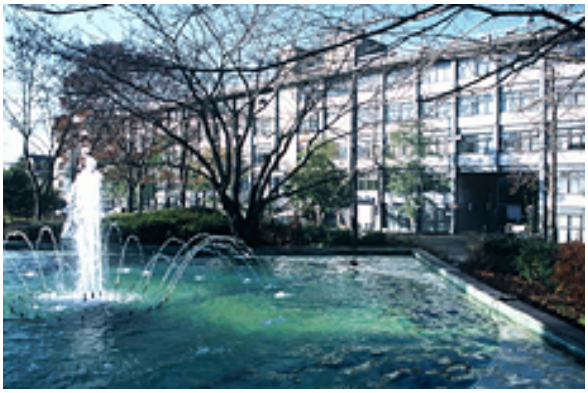
Ajou-Kyoto Joint Symposium

- Next Generation Energy Science and Technology

Aug. 2-3. 2024

Yeonam Hall 104, Ajou University, South Korea



아주대학교 AJOU UNIVERSITY

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Organized by

G-LAMP/Department of Energy Systems Research, Ajou University

Graduate School of Energy Systems Science, Kyoto University

Ajou-Kyoto Joint Symposium - Next Generation Energy Science and Technology

Symposium Program

Time	Aug. 02. 2024 (Day 1)
09:40-10:00	Opening remark
Session 1: Quantum science and technology (Chair: Takashi Sagawa)	
10:00-10:30	Prof. Hideaki Ohgaki (Kyoto) Introduction of Kyoto University MIR-free electron laser facility
10:30-11:00	Prof. Jae-Ung Lee (Ajou) Microspectroscopy investigation of atomically thin quantum materials
11:00-11:30	Prof. Kazunari Matsuda (Kyoto) Optical physics and its application of 2D materials toward quantum science and technology
11:30-13:00	Lunch
Session 2: Advanced energy solutions for sustainable future (Chair: Jin-Sung Park)	
13:00-13:30	Prof. Jongkook Hwang (Ajou) Engineering pore structure of hard carbon anode materials for high-rate capacitive potassium ion storage
13:30-14:00	Prof. Benjamin Craig McLellan (Kyoto) Just zero carbon energy and resource transitions
14:00-14:30	Prof. Chung-Yul Yoo (Ajou) Electrochemical impedance spectroscopy studies of thermoelectric devices and flow-electrode capacitive deionization cells
14:30-14:45	Group photo & Coffee break
Session 3: Composite and complex materials (Chair: Kazunari Matsuda)	
14:45-15:15	Prof. Takashi Sagawa (Kyoto) Composite materials with quantum dots for optical and/or photovoltaic applications
15:15-15:45	Prof. Hyungwoo Lee (Ajou) Exploring functionalities of complex oxide heterostructures with polar point defects
15:45-16:00	Coffee break
16:00-17:30	**Special session for Ajou-Kyoto collaborations (Chair: Sunghun Kim)**
17:30-17:40	Closing remark
18:00-20:00	Dinner

Ajou-Kyoto Joint Symposium - Next Generation Energy Science and Technology

Symposium Program

Time	Aug. 03. 2024 (Day 2)
09:30-12:00	Discussion and consultation for future research on energy science (Prof. Takashi Sagawa, Prof. Benjamin Craig McLellan, Prof. Kazunari Matsuda, Prof. Hideaki Ohgaki)
12:00-14:00	Lab tour (Optional)

Introduction of Kyoto University MIR-free electron laser facility

Hideaki Ohgaki[1], Heishun Zen[1], Ju Yoon Hnin Bo[2], and KU-FEL User Group

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Kyoto University Free Electron Laser (KU-FEL) facility offers Free Electron Lasers (FELs) whose wavelength covers from 3.4 to 28 μm , mid-infrared lights [1]. The maximum macro-pulse energy is around 60 mJ in a 2-μs macro-pulse at the wavelength of 9.8 μm. The KU-FEL consists of a 4.5-cell thermionic RF gun, a 3-m travelling wave accelerator tube, a beam transport system, and a 1.8-m undulator and a 5-m optical resonator which has been constructed by our lab members. After the first lasing in 2007 [2], the KU-FEL is routinely operated and opened for internal and external users [3].

As the improvement of KU-FEL performance, the photocathode operation of the 4.5-cell thermionic RF gun has been established to increase the peak power of FELs [4]. Under this photocathode operation, the micro-pulse energy of 100 μJ and the world highest extraction efficiency (9.4%) of the oscillator-type FEL has been achieved [5]. In this high performance operation mode, the micro-pulse duration was shortened down to 150 fs (~4.2 cycles at 11 μm). For further increase of the peak power of KU-FEL, we installed a 1.6-cell RF gun in 2023.

Several research activities have been carried out in KU-FEL in collaboration with external researchers including energy materials, biological applications, light source development and so on. A few examples, especially mode-selective phonon-excitation experiment[3,6], will be introduced in the presentation.

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Microspectroscopy investigations of atomically thin quantum materials

Seungjae Lim[1], Tae Wan Kim[1], Yoon Seong Heo[1], Seungman Han[1], Jun Won Jang[1], Wooseok Lee[1], Jinsub Jang[1], Jae-Ung Lee[1]

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Solid-state materials that host quantum states are among the most favorable forms to be integrated into existing technologies for applications in quantum information science. Atomically thin materials are promising candidates as host materials for qubits due to their two-dimensional nature, which offers advantages for the deterministic generation of defects with great integrability. However, realizing useful quantum states in solids face challenges to overcome. Both controllable growth/fabrication and proper characterization techniques for atomically thin materials are necessary.

In this presentation, I will introduce the ongoing efforts to experimentally realize atomically thin quantum materials. Metal-organic chemical vapor deposition (MOCVD) is used to grow atomically thin semiconductors controllably. This method has the advantage of precisely controlling the amount of injected precursors, which can be used to realize desired quantum properties. We utilize microspectroscopy to characterize the detailed properties of the grown materials. Various optical techniques can be used to investigate atomically thin materials with micron-scale spatial resolution. We have developed optimized optical methods to characterize these materials.

Optical physics and its application of 2D materials toward quantum science and technology

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Atomically thin low-dimensional semiconductors, such as two-dimensional (2D) transition metal dichalogenides, and nano-carbon materials have intensively studied from viewpoint of fundamental physics and optical applications [1-7]. The optically generated electron-hole pair forms the bound excitonic states in the atomically thin low-dimensional semiconductors. The optically excitonic states with valley degree of freedom (valley exciton) and in the moiré potential (moirés exciton) provide the platform for studying novel optical physics of 2D materials.

Here, I will talk about the recent topics of optical physics arising from these novel exciton systems including moiré excitons toward quantum science and technology and its applications in artificial van der Waals semiconducting heterostructures [8-14].

References

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Engineering pore structure of hard carbon anode materials for high-rate capacitive potassium ion storage

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Potassium ion hybrid supercapacitors (PIHCs) have received great attention because of the low redox potential of K/K^+ as well as the wide availability and low cost of potassium resources. However, the development of high power PIHCs has been largely limited by the sluggish K^+ storage kinetics in battery-type carbon anode materials. Among the various strategies to improve the electrochemical performance of carbon anodes, pore structure engineering has been emphasized as an effective solution. Although several previous studies have reported the relationship between pore structure and K^+ storage behavior, there is no consensus on the exact role of pores of different sizes. This is due to (i) the difficulties in preparing suitable model carbon materials with controlled porestructures, and (ii) the limited understanding of the role of pore structure in capacitive-controlled and diffusion-controlled K^+ storage, respectively.

In this presentation, I will showcase the latest advancements from our research group in understanding the influence of pore structures on the K^+ storage behaviors of hard carbon anode materials. We have developed carbon materials with controlled pore sizes (namely, micropore-dominated, ultramicropore/mesopore-mixed, and mesopore-dominated), and revealed a notable positive correlation between ultramicropore volume and enhanced capacitive K^+ capacity. Additionally, our research team has successfully synthesized mesoporous carbon spheres with controlled mesopore openings. We found that prominently exposed mesopores significantly enhance the capacitive K^+ storage capacity. This enhanced capacitive contribution in turn contributes to increased power densities in PIHC devices. These insights are pivotal in guiding the strategic design of pore structures to maximize capacitive K^+ storage in carbon anode materials, thus propelling the development of high-power PIHCs.

Just Zero Carbon Energy and Resource Transitions

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The transition to net-zero carbon societies requires a shift from conventional fossil fuel technologies to technologies that will require a different mix of materials – including an anticipated increase in metal requirements. The transformation of supply chains will have implications for social equity and environmental impacts. Downstream in the supply chain, a change of energy-utilising technologies, such as a shift to battery and fuel cell vehicles, may cause inequitable outcomes – as energy devices and services may become unaffordable for some parts of society. Upstream in the supply chain, the change in energy mix and the required mineral resources will reshape the flows of money, materials and environmental impacts. This will bring further inequities for those who rely on or live near power stations, mines and mineral processing facilities. This ongoing research seeks to identify these changes in the impacts of linked energy and resource supply chains.

Electrochemical impedance spectroscopy studies of thermoelectric devices and flow-electrode capacitive deionization cells

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Electrochemical impedance spectroscopy has been widely used in the field of energy storage materials since the analysis of the impedance spectrum enables the investigation of elementary electrochemical reaction of electrode, electrolyte, electrode/electrolyte interfaces to understand and develop battery, fuel cell, and supercapacitor materials and devices. Recently, the electrochemical impedance spectroscopy measurements enable the determination of three key parameters-the Seebeck coefficient, thermal conductivity, and electrical conductivity-by employing a one-dimensional heat equation. This part focuses on the theory, data validation, and applications of electrochemical impedance spectroscopy in order to interpret the thermoelectric devices. The effects of temperature and thermoelectric materials on the impedance spectroscopy data of thermoelectric devices are also discussed in detail.

Flow-electrode capacitive deionization (FCDI) offers infinite ion adsorption for continuous desalination of high-concentration saline water by supplying a flow-electrode to the cell. Although extensive efforts have been made to maximize the desalination rate and efficiency of FCDI cells, the electrochemical properties of these cells are not fully understood. This part focuses on the electrochemical properties of FCDI cells using electrochemical impedance spectroscopy. The impedance spectra have been deconvoluted into the electrochemical resistances and capacitances of the ion-exchange membranes and ionic transport at the pores on the surface of the activated carbon particles in the flow-electrode. Furthermore, it has been comprehensively investigated the effect of the amount of activated carbon, ion concentration, and flow rate of the flow-electrode on the impedance spectra of FCDI cells.

Composite materials with quantum dots for optical and/or photovoltaic applications

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Quantum dots (QDs) are used as the absorbing photovoltaic material and QDs-based solar cells have been expected as one of the alternatives for conventional silicon solar cells beyond the Shockley-Queisser efficiency limit [1] because of their potentials through "multiexciton generation" and "hot carriers" in quantum confined nanostructures [2]. In addition, QDs can also be adjustable by tuning the bandgap and harvest various regions of the solar spectrum. However, there are still remaining the drawbacks of QDs-based devices with regards to insufficient carrier management and light management, which result in the low current density relative to the maximum possible current density and minimum dark recombination current density relative to the recombination current density in the devices [3]. Those drawbacks derived from longer interdot distance and disordered alignment of QDs. Therefore, novel procedures for preparation of densely packed and highly oriented QDs in the active layer are required. In this context, preparation of QDs composites have been developed and their optical and photovoltaic properties have been characterized.

Surface passivation through partial ligand exchange and taking the convective deposition, PbS QDs can be densely packed and infiltrated into the interrod space of vertically aligned ZnO nanorod arrays as the ordered bulkheterojunction solar cells, which resulted in the improvement of photoconversion efficiency *ca* 10% [4]. Reorganization of QDs for formation of superlattice during the thin film making process might be affected through quantum resonance (coherence) for photogenerated carrier transport of the device. Helical $CsPbBr_3$ nanocrystals were prepared using silica helical ribbons as platforms [5]. They show strong induced circular dichroism and induced circularly polarized (CP) luminescence signals. Instead of silica helical ribbons, titania hollow nanotubes was also possible to act as the platforms and was found that acceleration of the charge transport from $CsPbBr_3$ to TiO_2 confirmed by remarkable photoluminescence (PL) quenching. Electrospun CdSe@CdS core@shell quantum rods (QRs)-poly methyl metacrylate nanofibers were prepared and energy dependence of the PL excitation spectra was observed, in which the quantum resonance might have occurred. While yellow-, orange-, and red- CdSe@CdS QRs were prepared and they oriented by 1D stretching of the composite films with poly(ethylene-*co*-vinyl acetate) [6]. Specific anisotropy with high light intensity through a luminescence-based CP conversion was confirmed.

References

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Exploring Functionalities of Complex Oxide Heterostructures with Polar Point Defects

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Two-dimensional electron gases (2DEGs) in complex oxide heterostructures, such as $LaAlO_3/SrTiO_3$ (LAO/STO) heterostructures, have attracted extensive attention because of their interesting physical properties. In particular, the conducting 2DEG with a high carrier density at the LAO/STO interface has made the oxide systems an attractive candidate for ultrathin devices applications. However, since the electric field-driven switching of the metallic 2DEG is quite challenging, practical device applications are still limited. In this talk, we introduce the improved functionality of the 2DEG in LAO/STO heterostructures, enabled by controlling polar point defects. We present that the conductivity and the persistent photoconductivity (PPC) of the 2DEG can be precisely controlled by the cation and anion off-stoichiometry. The collective control of oxygen vacancies enabled the resistive switching devices with a high accuracy and reproducibility. The separate control of the cation and anion deficiencies enabled the optoelectronic synaptic devices and neuromorphic applications. These works will provide insight into designing functional oxide heterostructures using polar point defects, and thereby offer a promising way to develop oxide-based device applications.