はじめに

理化学研究所の新領域開拓課題として「物質階層原理研究（正式名称：“Fundamental Principles Underlying the Hierarchy of Matter: A Comprehensive Experimental Study（物質階層の原理を探求する統合的実験研究）” ）」と「ヘテロ界面研究（正式名称：“Heterogeneity at Materials Interfaces（物質界面の不均一性がもたらす構造および機能の制御と解明）”）」は、2017年度及び2018年度にそれぞれ5年プロジェクトとしてスタートしました。前者は次年度、いよいよ5 年目最終年度を迎えます。

持続可能な社会の実現に向け、物質科学がエネルギー・環境・情報・医療技術等への基幹的な寄与を行うためには、その基盤をなす「物質」が如何に構築され如何に振る舞うかを総合的に理解することが必須です。両プロジェクトは、理研が有する他に類を見ない総合性を最大限に発揮して、ハドロンから生体分子に至る物質階層の原理と機能を、物理・化学的な実験的アプローチを用いて探求しています。「物質階層原理研究」は、各物質階層において、その構造・機能を定める「相互作用」に関する実験研究に始まり、より複雑で未だその全容を理解していない「励起現象」の探索と解明に取組むものです。このプロジェクトで分野を越えた新たな相互連携の基盤を構築しつつ、それぞれの物質階層における先端的な研究を実施しています。こうして構築された理研横断的な物質科学研究ネットワークを活用し、電子デバイスや生体膜等の高度な機能を有する系における構造の「不均一性」に基づく機能発現の原理に迫るのが「ヘテロ界面研究」です。「ヘテロ界面研究」では、“Atomic-scale Interfaces”、“Molecular Interfaces”、“Device Interfaces” の3つの主要テーマに沿って独自の連携研究を展開しています。

両プロジェクトでは、独自の研究推進や新たな横断的研究ネットワークの構築に加え、新しい研究環境の中での若手研究者の育成も大きな目標の一つです。その一環として、両プロジェクト合同で若手向けミニ ワークショップ シリーズ「ExpRes道場」を開催してきました。また、二日間合宿形式でじっくりと議論を行う「春合宿」も毎年開催しています。ここでは口頭発表だけでなく、パネルディスカッションや若手研究者中心のポスターセッションがあり、例年非常に活発な研究交流が行われています。今後も引き続きこれらの活動を通じ、先端的計測技術の共有・開発・展開のネットワーク化による物質科学の新しい知的基盤の構築を目指します。

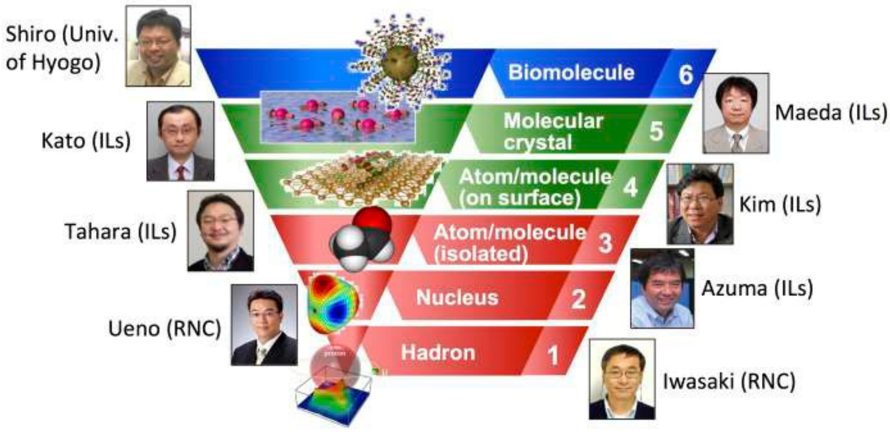
COVID-19の影響で残念ながら昨年度の春合宿は中止となり、今年度の春合宿も延期となってしまいました。しかしこれ以上研究交流を停滞させないため、今回、冬（←春）研究会と称して「春合宿」を開催することにいたしました。このような状況にもかかわらず、所内外から多くの方々に参加していただけました。異なる研究室・組織・研究分野の連携は、本プロジェクトの根幹をなすものです。今回、オンラインを併用したハイブリッド開催となりますので、通常に比べて分野間の交流は限定的となってしまいますが、分野・組織の枠組みをこえた活発な議論を通じ、今回の合同春合宿が新たな研究・技術交流の機会となることを期待いたします。

2021年11月24日
「物質階層原理研究」＆「ヘテロ界面研究」合同冬研究会
上野秀樹

Fundamental Principles Underlying the Hierarchy of Matter: A Comprehensive Experimental Study

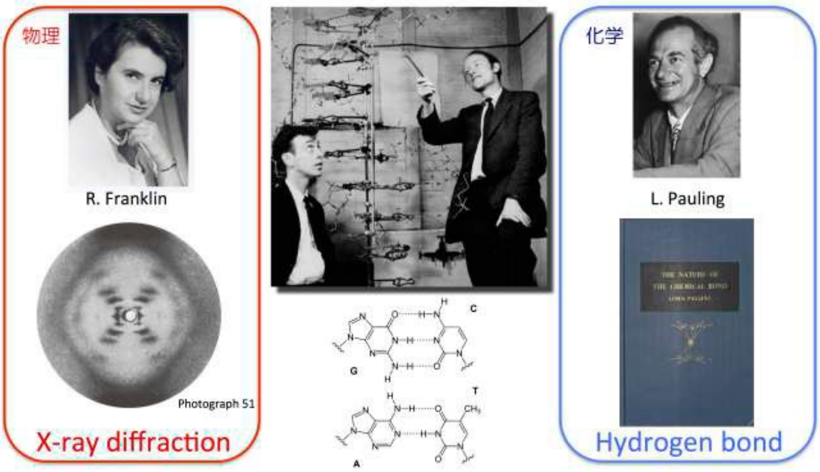
• Organization

This project is being carried out as a collaboration involving eight participating laboratories, in which we treat the hierarchy of matter from hadrons to biomolecules with three underlying and interconnected key concepts: *interaction*, *excitation*, and *heterogeneity*. The project consists of experimental research conducted using cutting-edge technologies, including lasers, signal processing and data acquisition, and particle beams at RIKEN RI Beam Factory (RIBF) and RIKEN Rutherford Appleton Laboratory (RAL).



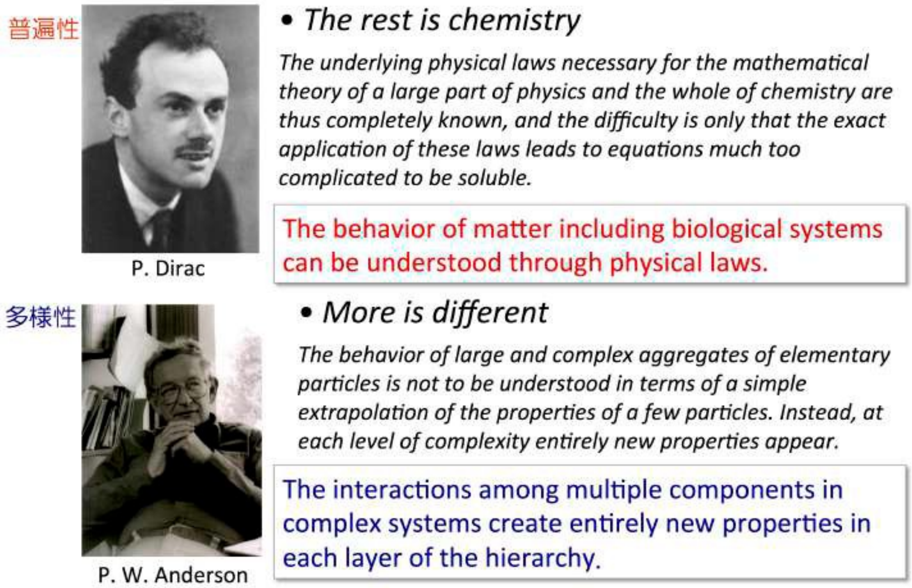
• Physical and chemical views of matter lead to major discoveries

Although this project is based on the physics and chemistry of non-living systems, we constantly keep all types of matter, including living matter, in our mind. The importance of analyzing matter from physical and chemical points of view was demonstrated in the case of DNA. The Watson-Crick model of DNA was developed based on the X-ray diffraction, which is a physical measurement. The key feature of this model is the hydrogen bonding that occurs between DNA base pairs. Watson and Crick learned about hydrogen bonding in the renowned book "The Nature of the Chemical Bond," written by their competitor, L. Pauling, who was a leading authority on chemical bonding. This important lesson in history teaches us that viewing matter from physical and chemical perspectives can lead to dramatic advances in science.



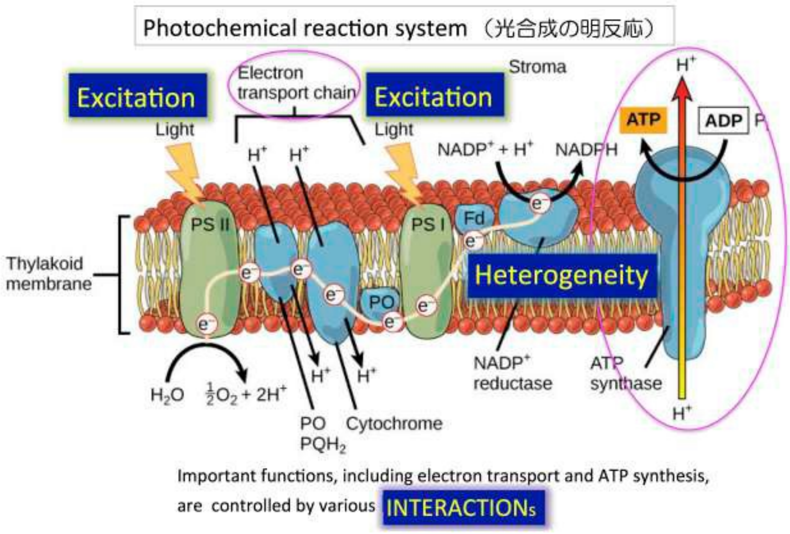
• Hierarchy of Matter: Universality vs. Diversity

We believe that the behavior of matter, including biological systems, can be understood through physical laws. P. Dirac, a great physicist, stated this universality as follows: "once we know the underlying physical laws*, the rest is chemistry*." On the other hand, P. W. Anderson, another great physicist, claimed that the interactions among multiple components in complex systems create entirely new properties in each layer of the hierarchy, with his famous phrase "*More is different*". This means that the science governing each layer is different, and it is not until we understand this diversity that we understand the universal principles completely. Therefore, we have selected "interaction" as the first key concept of this project. In addition, we selected "excitation" and "heterogeneity" as the other important key concepts to understand diversity in the hierarchy.



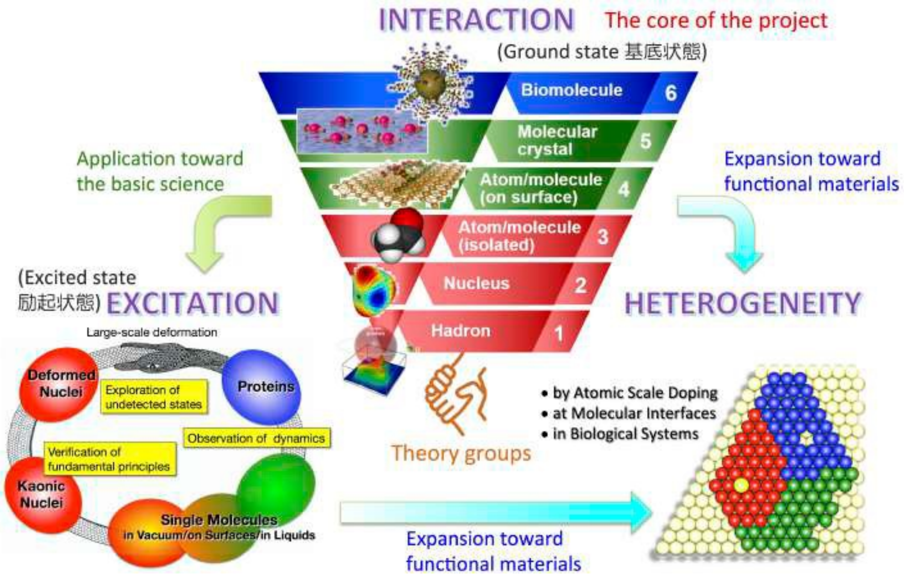
• Three Key Concepts: Interaction, Excitation, and Heterogeneity

The importance of these three key concepts is well illustrated by the photochemical reaction system, involved in photosynthesis. First, the photosynthesis proceeds in the thylakoid membrane, which has a heterogeneous structure. This *heterogeneity* is essential for the emergence of the functionality of the membrane. *Excitation* by light is the most important step in photosynthesis. Finally, important processes, including electron transport and ATP synthesis, are controlled by various *interactions*.



• Three Key Concepts and Sub-projects

The three key concepts are associated with three sub-projects: "Interaction in matter" lead by Dr. Ueno, "Excitation in matter" lead by Dr. Azuma, and "Heterogeneity in matter" lead by Dr. Kim. As mentioned, the "Interaction" sub-project is the core of this project. To comprehensively understand the nature of interactions that take place in each layer, it is essential to collaborate with theory groups. The knowledge obtained by the "Interaction" sub-group will be applied toward the basic science of excitation. The "Interaction" sub-project investigates the ground state of systems, and the "Excitation" sub-project focuses on the excited states of systems. The results obtained by these two sub-projects will be expanded towards the development of functional materials by the “Heterogeneity” sub-group. A unique point of this project is that almost all members participate in more than two sub-projects, which enhances comprehensive understanding of these concepts.



• Interaction in Matter

The “Interaction” sub-group investigates the diversity of phenomena caused by interactions that occur in each level in the hierarchy of matter. The strong interaction and the electromagnetic interaction give rise to a variety of phenomena depending on many-body effects, geometry, dimensionality, external conditions and so on. The interactions studied by each team range from the strong interaction between quarks to the van der Waals interaction between single-stranded DNA molecules, with a focus on how interactions in systems with multiple degrees of freedom lead to a diversity of phenomena. This means that many-body effects and multiple degrees of freedom are key issues in every layer of the hierarchy.

• Excitation in Matter

Excitation is a key step for the emergence of functionality, but knowledge on this topic is surprisingly limited. Thus, in this sub-group, we carry out three types of research on excitation, “Exploration of undetected excited states” in deformed nuclei, “Verification of fundamental principles through excited states” in kaonic nuclei, and “Observation of excited state dynamics” in excited molecules in liquids, on surfaces, and in vacuum. We study excitation over a wide range of energies, sizes, and time scales. At the same time, we study universality as indicated by the large-scale deformations observed in both excited-state nuclei and proteins.

• Heterogeneity in Matter

Heterogeneity is an important spatial property for the emergence of functionality as well as a challenging research target that drives the development of cutting-edge measurement technologies. This sub-group will apply the results of the “Interaction” and “Excitation” sub-groups toward the development of functional materials. In this sense, the “Heterogeneity” sub-group is closely tied to practical applications. The main topics investigated are superconducting doped diamond (as “Heterogeneity by Atomic Scale Doping”), electrical double layers in the field effect transistors (as “Heterogeneity at Molecular Interfaces”), and lipid membranes in solution (as “Heterogeneity in Biological Systems”), which are tackled through a wide range of collaborations.

• Goal of the Project

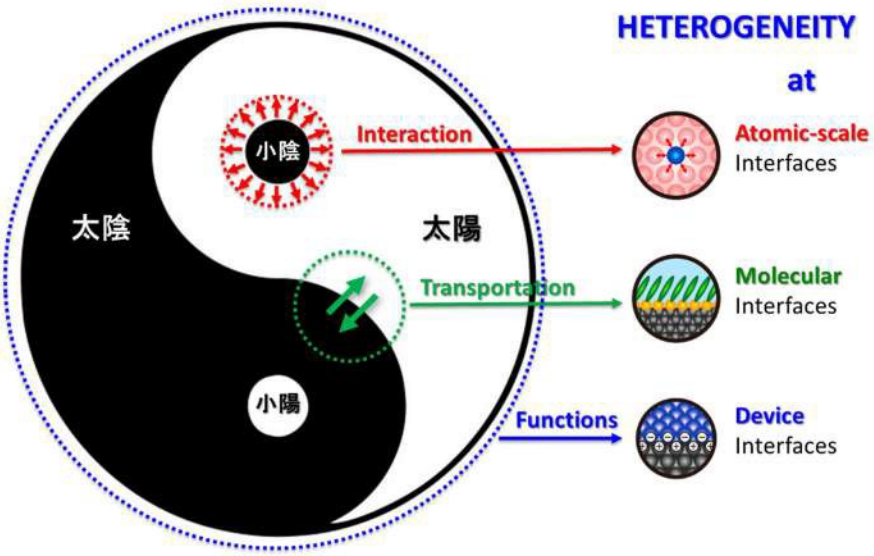
The most important goal of the project is the construction of a new cross-disciplinary research network based on the bottom-up style research activities at RIKEN, which will drive a dramatic evolution of science and lead to unpredictable by-products. This network includes *ExpRes Dojo* where we share, learn, and report information on cutting-edge experimental technologies, primarily laser and signal processing and data acquisition technologies. This consists of school-type meetings and workshops. An important output of the *ExpRes Dojo* is the application of new technologies developed thorough the physics and chemistry research to biological systems. At the same time, we nurture young researchers with wider and deeper views of matter. We believe that the scientific community is one where innovative discoveries are frequently achieved by newcomers in different research fields. The present project will maintain the diversity of science at RIKEN and ensure an environment in which young researchers with high ambitions can easily cross over the boundaries between disciplines.

Project Leader

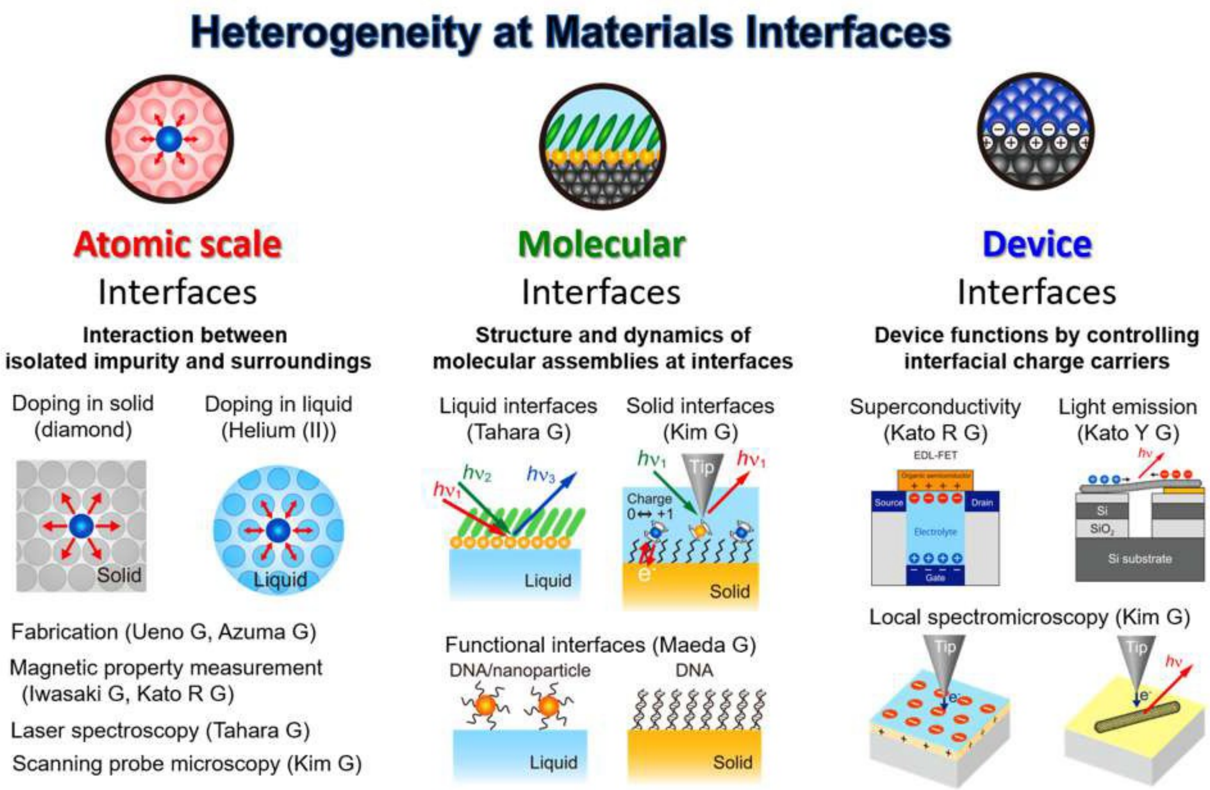
Dr. Hideki Ueno

Heterogeneity at the interface

Heterogeneity at the interface between two different materials plays pivotal roles in transport of charge, matter, and energy across the interfaces, chemical reactions and interactions, functions of materials and devices, and biological activities in living systems. The heterogeneity is frequently associated with functions of the materials systems. For example, the doping that effectively modulates electrical properties of various solids (semiconductor, metal, and superconductor) induces heterogeneous distribution of atoms/molecules. The heterogeneity is also a key concept in the evolution of matter from non-living matter to life. Field effect transistor and biological membrane are artificial and natural examples of functional heterogeneous systems, respectively. The heterogeneity, where the periodicity is missing to reveal gradients, is a challenging research target of the cutting-edge measurement technology, mainly due to its structural and phenomenal complexity. Especially, we focus on the heterogeneity at interfaces in various kinds of materials systems, regarding how it affects the functions accompanying with the peculiar chemical/physical properties.



In this project, we investigate the heterogeneity at three kinds of interface systems by three sub-projects. At **atomic-scale interfaces**, isolated impurities are introduced to solid (single-crystal diamond) and to liquid (He II) to understand the quantum-level interactions between each dopant with surrounding atoms. We challenge to realize superconducting diamond by high-concentration doping of nitrogen (n-type) for the first time, although superconductivity of boron-doped (p-type) diamond has been reported. It is still unknown how the quantum interaction occurs among the dopants and surrounding atoms to evolve unprecedented phenomena, which is a crucial issue to understand and utilize heterogeneity at atomic-scale interfaces in matters. At **molecular interfaces**, our knowledge and ability to control the molecular interfaces at the molecular-level are very immature, compared to those for the molecules in the bulk, although the molecular interfaces play



essential roles in various phenomena such as wetting, adhesion, biocompatibility, tribology, electrical properties as well as complex reactions in living things. Therefore, a concerted spectroscopic and microscopic study is highly desired for elucidating structural and functions of molecular interfaces. At **device interfaces**, the heterogeneity of electric field at the electrode interface largely influences on the various kinds of charge carrier dynamics, such as electron/hole injection, trapping, recombination and transport, which play a central role in device performance. We will evolve novel functions of organic transistor devices, such as superconductivity and light emission, by controlling charge carriers at the interface between electrodes and materials, based on the atomic/molecular-level understanding of charge carrier distribution and dynamics at the device interface.

As a strong novelty of this project, we propose a comprehensive solution for long-standing issues regarding influence of atomic/molecular level structures and charge carrier dynamics resulting from the heterogeneity at interfaces on macroscopic properties and functions of a variety of materials systems by cutting-edge spectroscopic and microscopic techniques in RIKEN.

Project Leader
Dr. Yousoo Kim

合宿主催者

東　俊行

理化学研究所 開拓研究本部 東原子分子物理研究室

toshiyuki-azuma@riken.jp

2009 –　現在 理化学研究所 主任研究員
2000 – 2009 都立大学准教授を経て首都大学東京 教授
1998 – 2000 筑波大学 助教授
1989 – 1998 東京大学 助手
1988.3 東京大学 工学系研究科博士課程修了 (工学博士)

岩崎 雅彦

理化学研究所 開拓研究本部 / 仁科加速器科学研究センター

masa@riken.jp

1987～1997 年 東京大学理学部付属中間子科学研究施設 助手

1997～2002 年 東京工業大学理工学部 助教授

2002～ 年 理化学研究所 主任研究員

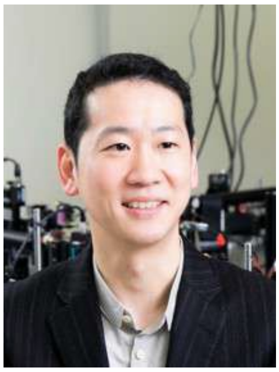
上野 秀樹

理化学研究所 上野核分光研究室

ueno@riken.jp

1995 年 東京工業大学大学院博士退（1996 博士（理学）
1995 年 阪大理 助手
2000 年 理研 応用原子核物理研究室 研究員
2009 年 理研 仁科セ偏極 RI ビーム生成装置開発チームリーダー
2010 年 理研 仁科セ共用促進・産業連携部 副部長
2013 年 理研 上野核分光研究室 主任研究員（現職）
2016 年 理研 仁科セ実験装置運転・維持管理室長
2018 年 理研 仁科セ共用促進室長（現職）／同アウトリーチチームリーダー（現職）

加藤 雄一郎



理化学研究所 加藤ナノ量子フォトニクス研究室

yuichiro.kato@riken.jp

2005 年 カリフォルニア大学サンタバーバラ校
物理学科博士課程修了(Ph. D.)
2005 年 スタンフォード大学 化学科 博士研究員
2006 年 科学技術振興機構さきがけ研究者
2007 年 東京大学 大学院工学系研究科 総合研究機構 准教授
2016 年 理化学研究所 准主任研究員
2017 年 理化学研究所 主任研究員

金 有洙

Kim 表面界面科学研究室
ykim@riken.jp

2015 年～ Kim 表面界面科学研究室 主任研究員
～2015 年 Kim 表面界面科学研究室 准主任研究員
～2009 年 川合表面化学研究室 研究員・先任研究員・専任研究員
～2002 年 表面化学研究室 協力研究員・基礎科学特別研究員
1999 年 東京大学大学院 工学系研究科 応用化学専攻 博士課程修了
1993 年 M.S., Dept. of Chemistry, Seoul National University
1991 年 B.S., Dept. of Chemistry, Seoul National University

田原 太平

理化学研究所 田原分子分光研究室

tahei@riken.jp

1989 年 東京大学理学系大学院化学専攻 博士課程修了
1989 年 東京大学理学部化学教室 助手
1990 年 神奈川科学技術アカデミー 極限分子計測プロジェクト 研究員
1995 年 岡崎国立共同研究機構 分子科学研究所 助教授
2001 年 理化学研究所 主任研究員