Japan Academy Prize to:

Yuichi Ikuhara
Professor, Institute of Engineering Innovation, School of Engineering, The University of Tokyo
Principal Investigator, Advanced Institute for Materials Research, Tohoku University
Visiting Principal Researcher, Japan Fine Ceramics Center

and

Naoya Shibata
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for "Development of State-of-the-Art Electron Microscopy and Contribution to Nano Interface Technology" (Joint Research)

Outline of the work:

Dr. Yuichi Ikuhara has been a leading figure in the field of advanced electron microscopy and nanomaterial science in the 21st century. He has made numerous world-leading contributions, and has ascended to an international leadership role in the field. Specifically, he has pioneered the state-of-the-art development of transmission electron microscopy for more than a quarter of a century. Consequently, he has established innovative methods for the quantitative characterization and analysis of local atomic structures, elemental distributions, and local electronic states at nanointerfaces and lattice defects, both experimentally and computationally.

One of his specific research achievements is the direct observation of atoms related to material functions, such as dopants and impurities at the material interface, using ultra-high resolution scanning transmission electron microscopy (STEM). This study has facilitated a major breakthrough in the field of material science. He was the first in Japan to introduce spherical aberration-corrected STEM for analyzing material interfaces. In addition, he proposed a method that combined electron energy loss spectroscopy (EELS) at the atomic-resolution level with first-principles calculations, and established a quantitative analysis method for atomic structures and electronic states, such as interfaces and dislocations.

In 2017, Dr. Ikuhara collaborated with an electron microscope manufacturer to achieve a spatial resolution of 40.5 pm for STEM, thus setting a world record for the highest performance of a STEM at that time. They also proposed and developed a new annular bright-field (ABF)-STEM technique that facilitated selective capture of electrons transmitted and/or scattered at low angles. This method enabled the first direct observation of lithium atoms in lithium-ion battery materials and hydrogen atom columns in hydrogen storage materials, which have attracted attention as energy and environmental materials. This research led to the worldwide diffusion of this method as a new analytical technique that originated from Japan, which is now routinely used as a general method in overseas research institutes.

Dr. Naoya Shibata has led the world in the advancement of atomic-resolution STEM and its application to the study of material interfaces. Specifically, he has pioneered the development of a method for the direct visualization of electromagnetic field distribution at an atomic scale, which has been extensively used as a new electron microscopy technique in the field of materials and devices. He has reported numerous research results that have contributed to the true and deeper understanding of the mechanisms of interface-originated properties in various materials.

A specific example of Dr. Shibata's research is the development of segmented STEM detector for atomic-resolution imaging. This detector has been used to observe the electric field at the interface of a semiconductor p-n junction and the magnetic field inside a magnetic skyrmion using the differential phase contrast method. Furthermore, he modified this method to precisely measure the slight deflection of the electron beam caused by the existing electric field between the positively charged atomic nucleus and negatively charged electron cloud. Due to his novel discovery the electric field distribution inside an atom can be directly observed in real space for the first time in the world. This is an innovative achievement that is expected to facilitate the use of electron microscopes for real-space observation of intra- and interatomic structures, rather than only observe atomic arrangements.

In 2019, in collaboration with an electron microscope manufacturer, Dr. Shibata successfully developed a new objective lens that realized the atomic-resolution observation while maintaining a sample in magnetic-field-free conditions, which had been a relatively unexplored area of electron microscopy. For the first time, a spatial resolution of less than 1 angstrom was achieved in a magnetic field-free environment, thus rendering the observation of the atomic structure of magnetic materials possible. Furthermore, using this electron microscope, he also realized real-space visualization of the intrinsic magnetic field of an antiferromagnet for the first time in 2022. These achievements are considered groundbreaking breakthroughs in the field of electron microscopy and have received high international acclaim.

Dr. Ikuhara and Dr. Shibata have been conducting research to elucidate various material phenomena that have been previously considered black boxes through the appropriate development of state-of-the-art electron microscopy techniques developed in a complementary and collaborative manner. Their studies have been focused on the correlation between interfacial atomic and electronic structures and functional properties; identification of atomic positions of light elements in inorganic materials and their relationship to physical properties; clarification of dislocation cores and lattice defect structures; understanding material deformation and fracture mechanisms via *in situ* observation; perception of segregation mechanisms at ceramic grain boundaries; studying heterogeneous catalytic interface structures; and the discovery of one-dimensional ordered crystals formed at the grain boundary triple point. Based on the results of such studies, they have designed and created new materials that utilize the functions of interfaces and lattice defects. These results have been published in more than 900 original papers in international journals, and have received extensive appreciation worldwide. Thus, these achievements demonstrate the significant contributions made by them to the fields of advanced electron microscopy and nanomaterial science.

List of Main Publications

[1] T. Futazuka, R. Ishikawa, N. Shibata, and Y. Ikuhara, “Grain boundary structural transformation induced by co-segregation of aliovalent dopants”, ***Nature Communications***, 13, 5299 (2022).

[2] J. K. Wei, B. Feng, E. Tochigi, N. Shibata, and Y. Ikuhara, “Direct imaging of the disconnection climb mediated point defects absorption by a grain boundary”, ***Nature Communications***, 13, 1455 (2022).

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[4] J. K. Wei, B. Feng, R. Ishikawa, T. Yokoi, K. Matsunaga, N. Shibata, and Y. Ikuhara, “Direct imaging of atomistic grain boundary migration”, ***Nature Materials***, 20, 951–955 (2021).

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[14] B. Feng, R. Ishikawa, A. Kumamoto, N. Shibata, and Y. Ikuhara, “Atomic scale origin of enhanced ionic conductivity at crystal defects”, ***Nano Letters***, 19, 2162–2168 (2019).

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