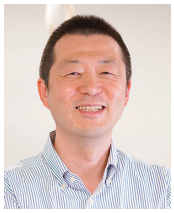
Unveiling Complex Phenomena at Solid–Liquid Interfaces by Scanning Probe Microscopy

Instrument Center



MINATO, Taketoshi
Senior Researcher

The solid–liquid interface serves as a reaction field for a wide range of phenomena, including electro- chemical reactions, dissolution and crystallization, catalysis, and hydrophilicity.[1–3] Despite extensive research, many fundamental aspects of these interfaces remain poorly understood due to their complex and dynamic nature. Scanning probe microscopy (SPM) represents a rare and powerful technique that can directly access the solid–liquid interface, allowing for detailed analysis of geometric structures, mechanical properties, electronic properties, magnetic properties, and even reaction mechanisms with exceptionally high resolution and sensitivity. In our studies, we have applied SPM to investigate electrochemical reactions as well as the physical properties of ice–liquid interfaces, providing new insights into interfacial behavior at the nanoscale.

At the electrode–electrolyte interface in electrochemical systems, the spatial distribution of interfacial structures strongly influences reaction kinetics and mechanisms. However, conventional spectroscopic analyses often fail to provide precise information on local variations in the interfacial structure due to limitations in spatial resolution. To overcome this challenge, we employed force curve measurements using SPM to analyze the local interfacial structure. By examining the distance between plateaus in the force curves, we were able to characterize the distribution of interfacial species (Figure 1). Notably, we observed that changes in the potential of a gold electrode led to significant alterations in the distribution of ionic liquid structures at the interface. This approach demonstrates the potential for probing more complex electrochemical reactions and understanding how local structural changes influence reaction pathways.

In addition to electrochemical systems, we have investigated the interface between ice and liquids. While the physical properties of ice have been extensively studied under ultra-high-vacuum conditions, many ice-related phenomena in nature occur at the interface between ice and liquid. In collaboration with Professor Hiroshi Onishi (Kobe University and IMS), we developed an analytical system based on amplitude-modulation atomic force microscopy to study the interfacial state between ice and liquids. Using this system, we successfully characterized both the structural and mechanical properties of the interface between alcohols and ice.[4–5] To obtain even more detailed information, we further developed a frequency-modulation atomic force microscopy system capable of operating in sub-zero antifreeze liquids. This system was applied to investigate the interface between octanol and graphite, enabling the successful observation of interfacial structures.[6–7] We anticipate that this technique will be widely applicable to studying ice–liquid interfaces and other low-temperature interfacial systems.

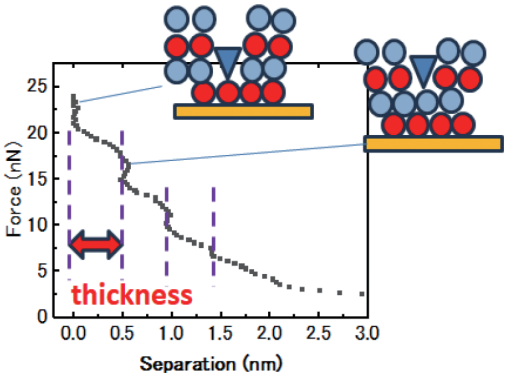


Figure 1. A typical force curve obtained at the interface between an ionic liquid and a gold electrode. The distances between the plateaus correspond to the thickness of the first layer of ionic species.

Our works highlight the importance of combining high-resolution force microscopy with carefully designed experimental systems to advance the understanding of complex interfacial phenomena across a broad range of materials and conditions.

References

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