【Grant-in-Aid for Specially Promoted Research】

Construction of a platform for visualization of microscopic non-equilibrium states using super ptychography

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Purpose and Background of the Research

●Outline of the Research

Many of the practical materials are heterogeneous and complex systems with domain structures on the nanometer to sub-micron scale. By tracking the time evolution of these domain structures and analyzing the multidimensional correlation between structure-time-function, we can understand the mechanisms of material function and degradation. In this research project, we will demonstrate a scheme of "super ptychography," which surpasses the time resolution of "ptychography," a nanostructure visualization technique using synchrotron radiation coherent X-rays, and realize moving image imaging of nanoscale microstructure and chemical state changes buried inside bulk functional materials. Then, a platform for visualization of microstructures and non-equilibrium states will be established at the 3GeV high-brilliance synchrotron radiation facility, NanoTerasu, by applying super ptychography to various material systems.

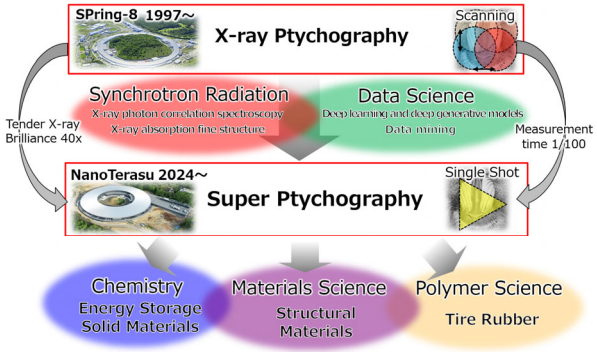

Figure 1. Diagram of the research

● Spatiotemporal resolution of microscopy

High-speed imaging methods using electron microscopes and X-ray microscopes have been developed as techniques for observing dynamic changes in samples ranging from nano to meso scales, achieving millisecond time resolution. However, electron microscopy is difficult to observe samples thicker than several tens of nanometers, and X-ray microscopy has a practical spatial resolution of only several tens of nanometers. On the other hand, X-ray ptychography provides nanoscale spatial resolution and allows observation of thick samples, but lacks temporal resolution on the order of a few minutes.

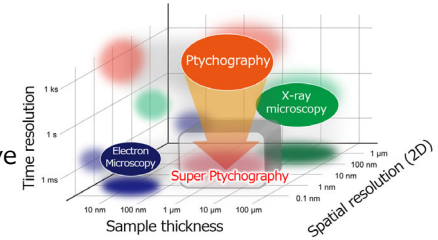

Figure 2. Spatiotemporal scales to be visualized by super ptychography and their relationship to electron and X-ray microscopy

●Non-equilibrium states at nano/meso scale buried within bulk materials

The nanoscale motion of silica particles in tire rubber under stress and the accompanying spatially heterogeneous viscoelasticity are indispensable information for the design of next-generation eco tires. The formation process of two-phase-separated structure and atomic-scale fluctuation of phase interfaces associated with lithium ion diffusion in cathode active materials of lithium-ion batteries during charging and discharging are essential information for the search of new cathode active materials.

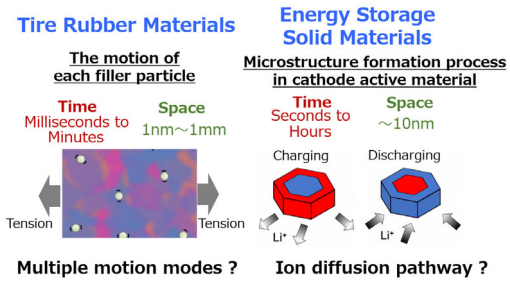

Figure 3. Examples of microscopic and non-equilibrium states in practical materials

Expected Research Achievements

● Demonstration of super-ptychography scheme and construction of a platform for visualizing nonequilibrium state from nano to meso scale

To establish a platform for visualizing of non-equilibrium states from nano to meso scale by demonstrating a scheme of "super ptychography" based on the synchrotron radiation moving imaging method "dynamic coherent diffraction imaging (dynamic CDI)" and promoting applied research on analysis of various practical materials at the 3GeV high-brilliance synchrotron radiation facility NanoTerasu. The scheme of super ptychography consists of the following three elements.

(1) Acquisition of moving images: Dynamic CDI measurement and deep neural networks are used to acquire moving images of nanoscale microstructural and chemical state changes of practical materials.

(2) Spatio-temporal scale extension: By performing image generation AI and XPCS fitting analysis, extend the spatio-temporal scales from 0.1 s to 1 ms and from 10 nm to 1 nm, respectively.

(3) Mechanism analysis: Data mining can be used to analyze phase distribution in multidimensional space based on time, space, and functional parameters to discover the mechanism factors involved in the development and degradation of material functions.

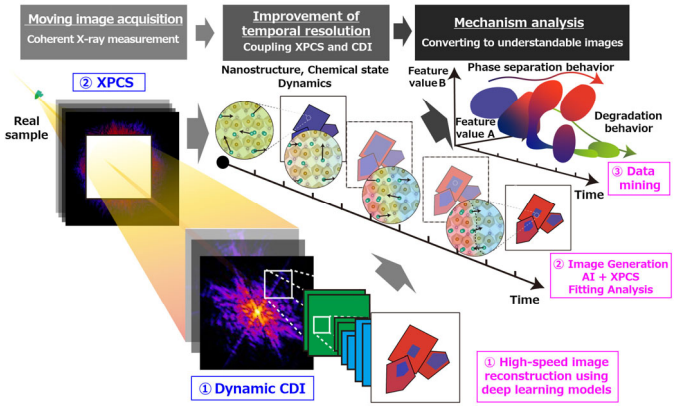

Figure 4. Conceptual diagram of the super-ptychography scheme

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