【Grant-in-Aid for Scientific Research (S)】

Establishment of fundamental principle on material strengthening mechanisms based on nano-dynamics observations

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Project Information	Project Number : 22H04960 Keywords : Mechanical properties, Lattice defects, TEM/STEM, In situ	Project Period (FY) : 2022-2026

Purpose and Background of the Research

●Outline of the Research

Deformation and fracture of crystalline materials proceed by the nucleation and propagation of lattice defects, such as dislocations, twins, and cracks. The propagation of these lattice defects tends to be interrupted at grain boundaries or interfaces within crystals. This phenomenon is one of the primary strengthening mechanisms for crystalline materials. Therefore, in order to understand the mechanical strength of materials, it is necessary to investigate the interaction between lattice defects and interfaces upon loading. However, there are still difficulties to analyze the interactions because they are dynamic phenomena at the atomic level. In this research, we will firstly develop a new mechanical testing system for transmission electron microscopy (TEM). Furthermore, through atomic-resolution in situ TEM mechanical experiments and theoretical calculations, we will reveal interfacial nano-dynamics phenomena related to the mechanical interactions between lattice defect–interface (dislocation reactions, crack propagation and interfacial sliding) within crystalline materials.

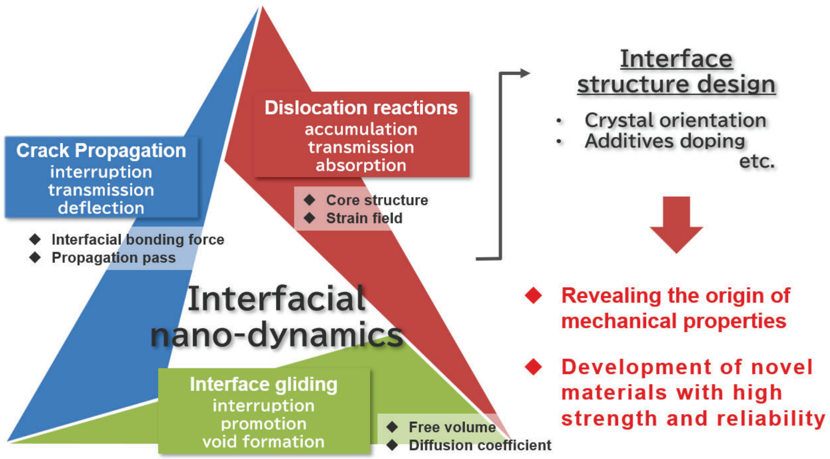

Figure 1. Outline of the project

●Originality and Creatively of the Research

The present research has the originality of investigating the mechanical interaction between lattice defects and interfaces based on dynamic observations at the atomic level. We have a unique experimental technique on atomic-resolution in situ TEM mechanical testing using MEMS (micro electro mechanical systems) loading devices, which provides us a large technical advantage over other research groups in the world. Based on the present experimental technique, a next-generation in situ TEM mechanical testing system will be developed. We aim to acquire cutting-edge achievements on the strength of materials by advanced atomic-resolution in situ observations.

●Background of the Research Planning

The present project has been planned as progressive research from the KAKENHI project: Specially Promoted Research "Atom-by-atom imaging of ion dynamics in nano-structures for materials innovation" (2017-2022) produced by the PI.

To investigate mechanical response of lattice defects, in situ TEM mechanical experiments have been performed for years. However, most of them are nano-scale observations, and there are few reports on atomic-scale in situ observations. Our research group has developed superior experimental techniques including atomic-resolution observation, sample preparation, and precise loading. To lead the present research project to utilize our techniques, we will organize scientific principles on the strength of materials.

Expected Research Achievements

●Development of an Advanced In Situ Mechanical Testing System

It is known that the mechanical response of lattice defects depends on not only load but also deformation rate (strain rate). To reveal mechanical phenomena comprehensively, a loading device with strain rate control is required. In this research, MEMS devices with loading rate control and displacement measurement functions will be designed and fabricated. In addition, to observe high temperature phenomena, a laser irradiation system for TEM will be introduced to enable temperature controlled mechanical experiments (Figure 2).

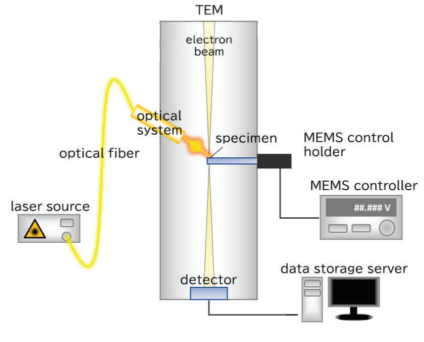

Figure 2. Schematic illustration of a new in situ mechanical testing system with laser irradiation

●Dynamic Observations of Lattice Defect–Interface Interactions

Atomic-resolution in situ TEM mechanical testing is applied to a sample with an interface. The interaction between lattice defects and the interface upon loading is observed at the atomic level (Figure 3). To examine various interfaces with different crystal orientation systematically, the atomic structure changes of the interfaces due to the intersection of lattice defects are analyzed. The experimental results are further examined by theoretical calculations. Finally, we aim to establish the strengthening methods for interfaces.

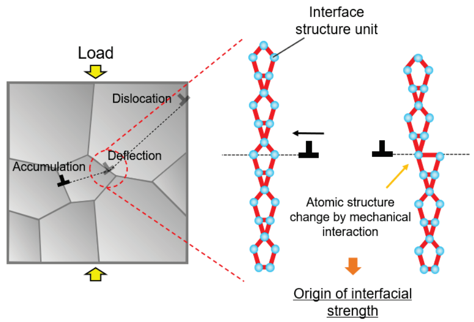

Figure 3. Atomic-resolution observations of interfacial nano-dynamics

●Observations of Nano-dynamics under Actual Environments

With development of the advanced in situ mechanical testing system, in situ TEM observations with precise control of applied load, temperature, and strain rate are performed. In order to investigate interfacial nano-dynamics under actual environmental conditions, we aim to reveal the strengthening mechanisms for practical materials and establish the design principles of high strength and high reliability materials.

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