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

Title of Project : Development of atomic-resolution magnetic field imaging electron microscopy and its application to interface characterization in magnetic materials

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Keyword : Scanning transmission electron microscopy, electromagnetic field, interface, magnetic materials, steel

【Purpose and Background of the Research】

In this research, we will develop a new atomic-resolution electron microscopy method that realizes real-space observation of local atomic structures and related atomic-scale electromagnetic field distribution simultaneously, based on the atomic-resolution magnetic field-free electron microscope that the principal investigators succeeded in development for the first time in the world. We will realize direct observation of atomic magnetic moments, interfacial magnetic structures, electrical polarization, etc., which have been impossible to directly observe by electron microscopy. Furthermore, this method will be used for the interface studies of magnets, spin devices, steels, topological materials, ceramic materials, etc., aiming to understand the interaction mechanisms between the atomic-scale local structures and magnetisms. By doing so, we essentially elucidate the origin of functional properties in magnetic materials, and establish a new magnetic material design strategy based on the interface control. The ultimate goal of this research is to promote the development of functional magnetic materials and contribute to the sustainable growth of society and industry.

【Research Methods】

We will develop an ultra-high resolution electromagnetic field imagnig electron microscopy by fusing the atomic resolution magnetic field-free electron microscope with the differential phase contrast (DPC) scanning transmission electron microscopy (STEM) method. Specifically, we will develop a quantitative electromagnetic field observation method by detecting the center of mass of an electron diffraction pattern using segmented and pixelated detectors, and an electric / magnetic field separation method using a new specimen holder. Furthermore, the developed method will be applied for the interface studies of various magnetic materials (such as rare earth magnets, ferrite magnets, spin devices, electrical steels, topological materials and so on), in order to elucidate the fundamental mechanisms of the interaction between local atomic-scale structures and related magnetisms.

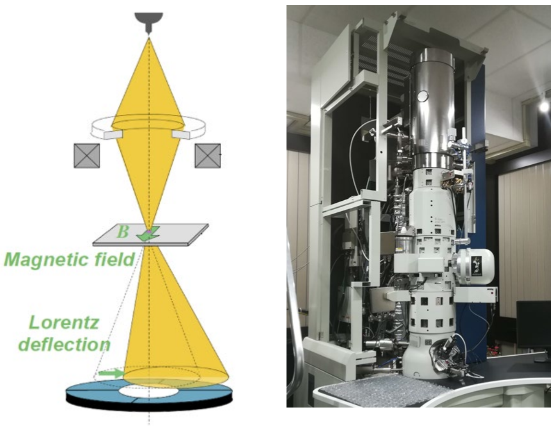

Fig.1 Schematic of DPC STEM and atomic-resolution magnetic field-free electron microscope

【Expected Research Achievements and Scientific Significance】

In order to understand the mechanism of functional properties in magnetic materials, it is essential to elucidate the local electromagnetic field structures induced by the local structure such as interfaces inside the materials. In conventional electron microscopy, direct observation of local electromagnetic fields at atomic resolution has been extremely challenging. In this study, a new electron microscopy method that enables simultaneous measurement of both the atomic-level local structures and the local electromagnetic fields induced by them will be developed. which is expected to open up a new stage of electron microscopy. Furthermore, this research is not limited to the development of microscopy techniques, but is aiming to apply this newly developed method to the interface studies of important magnetic materials. Through these studies, we aim to establish a new material interface design strategy for functional magnetic materials.

【Publications Relevant to the Project】

・ N. Shibata, T. Seki *et al.*, “Atomic resolution electron microscopy in a magnetic field free environment,” *Nature Comm.*, **10**, 2380 (2019).
・ N. Shibata, T. Seki *et al.*, “Direct Visualization of Local Electromagnetic Field Structures by Scanning Transmission Electron Microscopy,” *Acc. Chem. Res.*, **50**, 1502-1512 (2017).

【Term of Project】 FY2020-2024

【Budget Allocation】 148,300 Thousand Yen

【Homepage Address and Other Contact Information】

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