Direct electromagnetic field imaging of materials by advanced differential phase contrast STEM

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Scanning transmission electron microscopy (STEM) boosted by aberration-correction technology has made possible to direct characterize atomic and electronic structures of interfaces in many materials and devices where very interesting properties emerge. In STEM imaging, a very finely focused electron probe is scanned across the specimen and the transmitted and/or scattered electrons at each raster position are detected by the post-specimen detector(s) to form images. STEM image contrast is known to be strongly dependent on the detector geometries, and in turn we gain flexibility in determining the contrast characteristics of the STEM images by controlling the detector geometry. By elaborating special detector geometries, we can now not only image atomic structures of materials, but also can image local electromagnetic fields inside materials and interface regions through differential phase contrast (DPC) imaging techniques [1]. We have been continuously developing segmented-type STEM detectors that are capable of atomic-resolution STEM imaging. By applying these segmented-type STEM detectors for DPC imaging, atomic-resolution DPC STEM has been realized [2] and electric field distribution even inside a single atom is directly visualized in quantitative manner [3]. Having applied DPC STEM to the characterization of materials and devices, the local electric and magnetic field distribution inside materials can be simultaneously obtained with ADF STEM images. We found that DPC STEM imaging is very powerful to directly characterize many interesting internal electromagnetic structures such as pn junctions in semiconductor devices [4], polar oxide interfaces and magnetic materials and Skyrmions [5,6], which cannot be observed by normal STEM imaging techniques using annular type detectors. In this presentation, current status of our DPC STEM developments and future direction of their materials application will be also discussed. This work was supported by the SENTAN, JST. A part of this work was supported by the JSPS KAKENHI Grant number JP17H01316 and JP17H06094.

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