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Successful observation of a magnetic field with the world's highest resolution of 0.67nm using an atomic-resolution holography electron microscope

Accelerating R&D for next-generation highly-functional materials

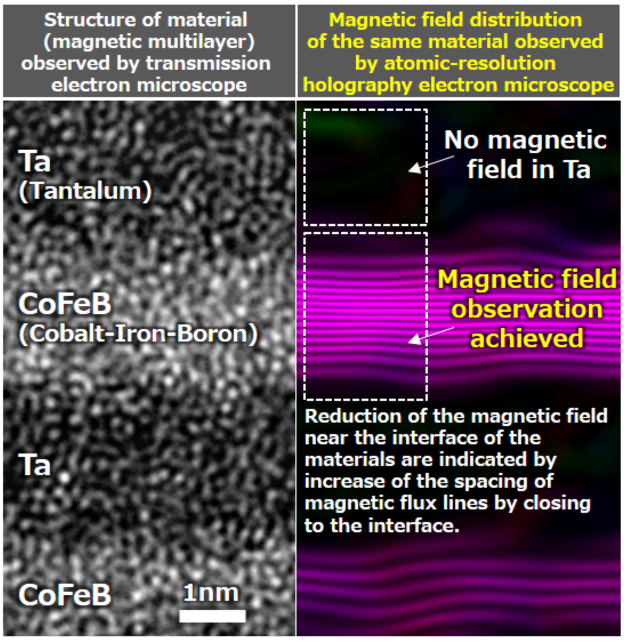

Figure 1. Observed magnetic field distribution within the material

Figure 2. Hitachi's atomic-resolution holography electron microscope

Tokyo, December 6, 2017 --- Hitachi, Ltd. (TSE: 6501, Hitachi) and RIKEN today announced the development of technology to improve observation precision using Hitachi's atomic-resolution holography electron microscope, and the successful observation of magnetic field distributions within magnetic multilayer materials(1) at a world's highest resolution of 0.67nm(2) (Figure 1). This technology enables the observation of the magnitude and direction of magnetic fields that are related to the properties of highly-functional materials, such as permanent magnets, electromagnetic steel sheets, and magnetic thin films, at a level of few atoms at the boundary of the material. Hitachi and RIKEN are looking to contribute to the development of highly functional materials such as high-performance magnets and high-temperature superconducting materials, and progress in fundamental science, by elucidating atomic-scale magnetic phenomena.

The further development of highly-functional materials is essential for improving the performance of products such as electronic equipment, batteries, and motors. For example, the performance of a magnetic material is closely related to the complex magnetic properties that result from the combination of elements from which it is composed. In recent years, interest in the behavior of atomic-scale magnetic fields at material interfaces has risen, and thus there was a need for technology enabling atomic-scale imaging of magnetic fields. Since 1966, Hitachi has been developing the holography electron microscope as an instrument for the direct observation of electric and magnetic fields in extremely small regions, and in 2014, developed an atomic-resolution holography electron microscope (Figure 2) with a grant under the Funding Program for World-Leading Innovative R&D on Science and Technology (the "FIRST Program"), a national project sponsored by the Japanese government. However, this atomic-resolution holography electron microscope could only observe electric and magnetic fields in a mixed state. In order to observe only the magnetic field, it was necessary to independently measure and then subtract the electric field information. Conventionally this involves methods such as flipping the material 180 degrees or raising the temperature of the sample after the first observation, and then observing the material again, which resulted in a significant reduction in resolution.

To realize high resolution observation of magnetic fields using the atomic-resolution holography electron microscope, Hitachi and RIKEN developed a technology to precisely separate the electric field information, while maintaining high resolution. Main features of the technology developed are as described below:

(1) Technology using pulse magnetization reversal to eliminate the electric field information by reversing the magnetic field in the material

Technology was developed to apply alternating high-intensity pulsed magnetic field(3) with opposite magnetic fields to the material to reverse the magnetization of the material (direction of the N and S pole) only. From the difference in observation results before and after this reversal, it then becomes possible by subtraction to remove with high precision only the electric field information.

(2) Technology to compensate the effect of the pulsed magnetic field

When a high-intensity pulsed magnetic field is applied using the above technology, the electron ray path is affected due to changes in the state of the electron microscope, causing misalignment to occur in the observation area or focus. To counteract this, technology to automatically compensate the observation conditions was developed to consider the high-intensity pulsed magnetic field. As a result, it is now possible to conduct continuous observations with high-resolution and low-noise.

The technology developed was applied to the atomic-resolution holography electron microscope to observe magnetic multilayer materials, and was used to successfully observe the magnetic field distribution with high precision(4) and with the world's highest resolution of 0.67nm.

Using this technology, Hitachi and RIKEN will work towards the development of new materials to support a sustainable society. Furthermore, through the national program to support the formation of shared platforms supported by the Ministry of Education, Culture, Sports, Science and Technology, Japan (MEXT), the atomic-resolution holography electron microscope will be used by various parties to contribute to the advancement of science and technology.

These achievements have been published in the online edition of *Scientific Reports*, a scientific journal in the United Kingdom on 5th December 2017[5].

The development of the atomic-resolution electron microscope was supported by a grant from the Japan Society for the Promotion of Science (JSPS) through the "Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST Program)" initiated by the Council for Science, Technology, and Innovation (CSTI). Further, a part of this research was also supported by the "Core Research for Evolutional Science and Technology (CREST)" program of the Japan Science and Technology Agency (JST).

Introduction of Hitachi's atomic-resolution holography electron microscope

- Overview:http://social-innovation.hitachi/en/topics/rd_electronic_microscope/index.html
- Movie:http://www.hitachi.com/rd/portal/video/201603a.html
- 18th February 2015 news release:
  "Development of an Atomic-Resolution Holography Electron Microscope with the World's Highest Point Resolution (43 picometers)"
  http://www.hitachi.com/New/cnews/month/2015/02/150218.html

(1) Magnetic multilayer consisting of magnetic layers of CoFeB (Cobalt-Iron-Boron alloy) with different thickness sandwiched by non-magnetic Ta (tantalum) layers was used as the observation-target material.

(2) Nanometer (nm): 1nm is equal to one billionth (10^{-9}) of a meter.

(3) High-intensity pulsed magnetic field: A high-intensity magnetic field exists only in short time width of a few hundred micro seconds.

(4) The precision of the magnetic observation corresponds to the precision of 0.06T in a sample with the thickness of 45nm. The precision is in the order of 1/3000 of the electron wavelength, which is 15 times higher than the best precision (the order of 1/200 of the electron wavelength) obtained in RIKEN using a conventional magnetic observation technique.

(5) Toshiaki Tanigaki, Tetsuya Akashi, Akira Sugawara, Katsuya Miura, Jun Hayakawa, Kodai Niitsu, Takeshi Sato, Xiuzhen Yu, Yasuhide Tomioka, Ken Harada, Daisuke Shindo, Yoshinori Tokura, and Hiroyuki Shinada, "Magnetic Field Observations in CoFeB/Ta Layers with 0.67-nm Resolution by Electron Holography," *Scientific Reports,* 2017, doi: 10.1038/s41598-017-16519-7

About Hitachi, Ltd.

Hitachi, Ltd. (TSE: 6501), headquartered in Tokyo, Japan, delivers innovations that answer society's challenges. The company's consolidated revenues for fiscal 2016 (ended March 31, 2017) totaled 9,162.2 billion yen ($81.8 billion). The Hitachi Group is a global leader in the Social Innovation Business, and it has approximately 304,000 employees worldwide. Through collaborative creation, Hitachi is providing solutions to customers in a broad range of sectors, including Power / Energy, Industry / Distribution / Water, Urban Development, and Finance / Government & Public / Healthcare. For more information on Hitachi, please visit the company's website at http://www.hitachi.com.

About RIKEN

RIKEN is Japan's largest research institute for basic and applied research. Over 2500 papers by RIKEN researchers are published every year in leading scientific and technology journals covering a broad spectrum of disciplines including physics, chemistry, biology, engineering, and medical science. RIKEN's research environment and strong emphasis on interdisciplinary collaboration and globalization has earned a worldwide reputation for scientific excellence.

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