Quantum Phenomena Visualized by Electron Waves

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We have developed bright and monochromatic field-emission electron beams over 40 years and used them to observe quantum phenomena by utilizing the wave nature of electrons. As it turns out, every time we developed a brighter electron beam, electron interference experiments became easier to perform and the precision in the phase measurements increased, thus opening up new application fields. For example, we can now carry out fundamental experiments in quantum mechanics that were once regarded as thought experiments. Examples include a single-electron build-up of an interference pattern [Figure1] [1] and conclusive experiments on the Aharonov-Bohm effect [Figure2] [2]. Also, visualizing magnetic lines of force in *h/e* flux units by interference microscopy and visualizing quantized vortices in superconductors by Lorentz microscopy have become possible [3]. The pinning mechanism of vortices has industrial importance for high-magnetic field application of superconductor such as MRI magnet and linear motor cars. Also, visualizing skyrmions as topological objects in MnSi by Lorentz microscopy have recently become possible [4].

In this talk, I present the historical development of electron holography with advances in coherence and brightness of electrons, since a bright electron source using field-emissions was the most decisive factor in the development of electron holography. We are now developing an atomic-resolution holography electron microscope with an acceleration voltage of 1200 kV under the FIRST Tonomura project [Figure 3], which will provide the world's highest spatial coherence, in addition to the ultimate spatial resolution of 40 pm. Using high-voltage holography electron microscopes (1 MV and 1.2 MV), future studies spanning from basic science to technological applications will be addressed, i.e., energy materials, rare-earth magnets, catalysis and spintronics.

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References

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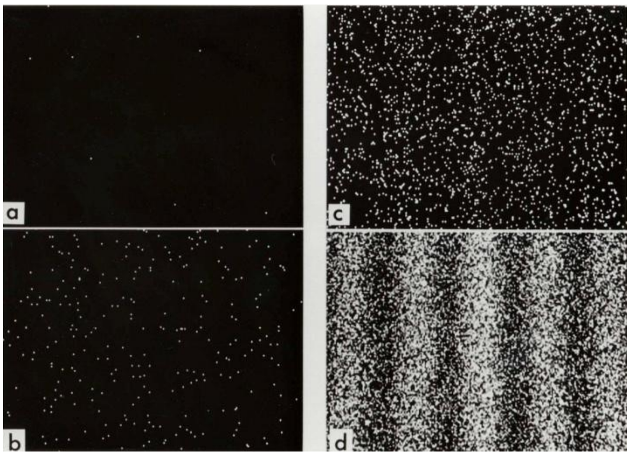

FIG. 1. Build-up of an electron interference pattern.
Numbers of electrons are (a) 10, (b) 100, (c) 3,000, (d) 70,000.

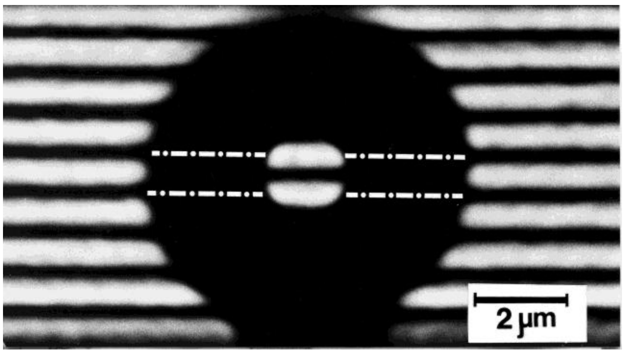

FIG. 2. The Aharonov-Bohm (AB) effect.

FIG. 3. 1.2-MV field-emission holography electron microscope.