Quantum Phenomena Visualized by Electron Waves

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We have developed bright and monochromatic field-emission electron beams over 30 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 and conclusive experiments on the Aharonov-Bohm effect. Also, visualizing magnetic lines of force in *h/e* flux units by interference microscopy and visualizing the dynamics of quantized vortices in superconductors by Lorentz microscopy have become possible. In 2000, we built a 1-MV electron microscope that has the brightest beam and the highest lattice-resolution ever obtained. We have just begun obtaining various new results [1, 2] on unconventional vortex behaviors inside high-T_c superconductors, such as elucidations on the mechanism for forming the strange arrangement of vortices, the chain-lattice state [3], which reflects the layered structure of the material and has been a mystery for 10 years. This technique is expected to become a useful tool for investigating quantum phenomena that have begun to appear in nanoscopic regions.

[1] A. Tonomura *et al*., Nature **412** (2001) 620.
[2] T. Matsuda *et al*., Science **294** (2001) 2136.
[3] A. Tonomura *et al*., Phys. Rev. Lett. **88** (2002) 237001-1.