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The Quantum World Unveiled by Electron Waves

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We have developed bright and monochromatic field-emission electron beams over 30 years [1]. Bright beams such as lasers, synchrotron radiation, and neutron beams play a decisive role in opening up new windows for investigating microscopic structures of materials. We have repeatedly developed brighter electron beams to precisely measure the phase information in an electron beam, for visualizing quantum phenomena electrons show and also for investigating other quantum phenomena by using the wave nature of electrons. Every time we developed a brighter electron beam, new possibilities opened. To take recent examples, the dynamics of individual quantized vortices in superconducting thin films became observable using coherent Lorentz microscopy [2]. A vortex having magnetic flux of $h/(2e)$ is a phase object of π for an illuminating electron beam. The principle behind this observation is based on the Aharonov-Bohm effect [3]. The vortices inside superconducting thin films became observable by holographic interference microscopy [4] or defocused Lorentz microscopy [5]. Various kinds of vortex motions in metal- and oxide-superconductors with pinning centers were observed using Lorenz microscopy.

In 2000, we obtained the brightest 1MV electron beam ever [6], and used this 1MV microscope (FIG. 1) to observe various new vortex behaviors inside high-T_c superconductors, such as vortices trapped along tilted columnar defects in Bi-2212 film (FIG. 2) [7]. We are now investigating the vortex behaviors in layered superconductors at an inclined magnetic field.

References

[1] A. Tonomura, Proc. Natl. Acad. Sci. USA **102**, No.42 (2005) 14952-14959.
[2] A. Tonomura: “Electron Holography” 2nd Edition, Springer, Heidelberg (1999).
[3] M. Peshkin and A. Tonomura: “ The Aharonov-Bohm Effect” (Springer-Verlag, Heidelberg, 1989).
[4] J. E. Bonevich *et al.*: Phys. Rev. Lett. **70** (1993) 2952-2955.
[5] K. Harada *et al.*: Nature **360** (5 November 1992) 51-53.
[6] T. Kawasaki *et al.*, Appl. Phys. Lett. **76**, (2000) 1342-1344.
[7] A. Tonomura *et al.*, Nature **412**, (2001) 620-622.

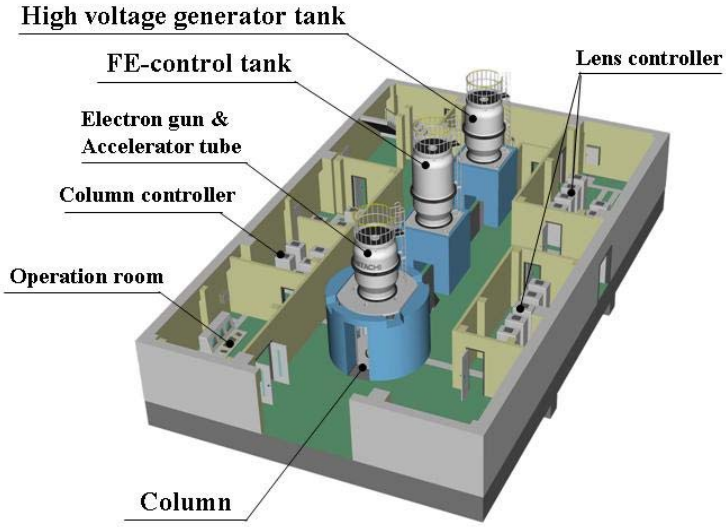

FIG. 1. Schematic of 1-MV field-emission electron microscope.

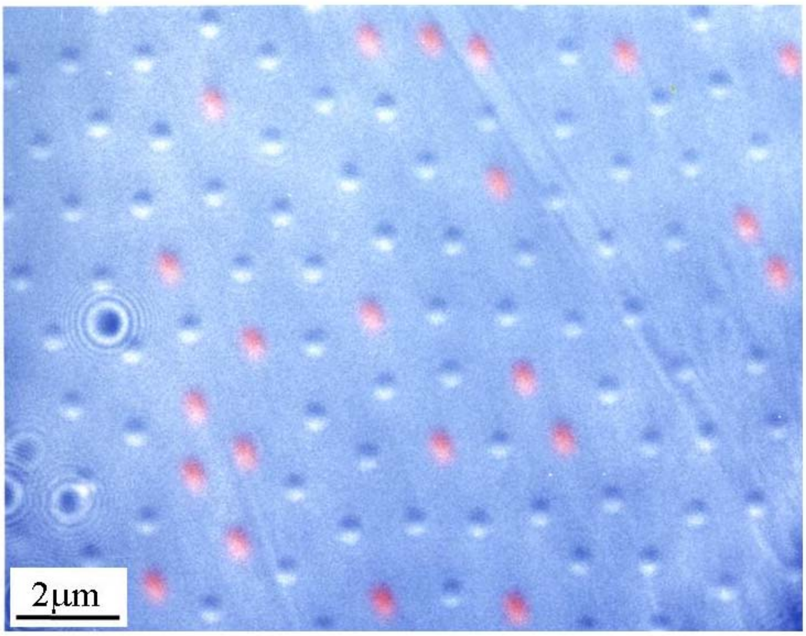

FIG. 2. Lorentz micrograph of perpendicular and tilted vortex lines in YBCO thin film. Red vortex images are elongated since the vortex lines are trapped by tilted columnar defects and titled. Blue vortex images are round since the vortex lines penetrate the film perpendicular to the film plane.