

## **STEHM Highlights**

### **The best resolution microscope ever built**

The Scanning Transmission Electron Holography Microscope (STEHM) will be the best high-spatial resolution microscope ever constructed and it will maintain its high position at the forefront of this rapidly moving competitive technology for many years. The STEHM will build upon the fundamentals of a standard electron microscope, which uses electrons rather than light, to give unsurpassed capabilities to see and measure the properties of a hidden world that we know exists.

The electron has a wavelength one million times smaller than light and the spatial resolution of the STEHM will approach its wavelength, i.e., approximately two picometers. The electron also carries a charge and magnetic moment, which can be used by electron holography to interrogate the electronic properties of atoms.

### **Opening new worlds**

At the time of van Leeuwenhoek in the 1600's, the light microscope using finely ground lenses was considered to be the highest level of technology made as it was able to resolve living cells. The STEHM is in the same league, relatively speaking, as its lenses will give direct observation of hitherto unobservable quantum phenomena by using electrons [1]. Electron holography is a special method of microscopy measuring both the amplitude and phase of a material. A hologram is created by the interference of two or more beams giving three-dimensional information at the atomic level. The phase is additional information not provided by other forms of microscopy. The phase measures the refractive index or more precisely for electrons, the mean inner potential of the specimen, which can be used to determine the specimen's absolute composition, internal strain, electrostatic fields, magnetic fields and temperature.

### **A little bit about technology**

Recent developments in the modularity of electron microscopes allow this first-of-a-kind microscope to be constructed. These developments, which significantly increase the STEHM's capabilities, include:

- A cold-field emitting electron source to increase its coherence (like a laser) and to decrease the energy spread of the electron beam
- Spherical (Cs), chromatic (Cc) and coma aberration correctors to increase the microscope's information capability
- Multiple electron biprisms to enhance the spatial resolution and to enable the creation of new forms of microscopy for new capabilities
- A large CCD detector to better measure the gray scale of fringes produced in holograms and a fine-movement specimen stage to help invent confocal electron holography

The Cs + Cc correctors improve the spatial resolution to picometers, substantially better than angstroms, which is the recent state-of-the art. The Cs corrector localizes the information in lattice images so the contrast of a lattice position in the image has a one-to-one correspondence with an atomic position, whereas without these correctors this is not possible. A Cs + Cc corrector reduces the point spread function to the dimensions of the electron probe enabling the sampling of the specimen at sub-atomic dimensions. Both aberration correctors will make it possible to see atomic columns that don't have to be interpreted and previously hidden positions of atoms, and, when used by electron holography, measure the electron density between the atoms.

Multiple electron biprisms substantially improve the spatial resolution of holograms by separating the contrast of the fringes from the interference width of the holograms. The use of three biprisms placed below the specimen permits flexible control of all of the interference parameters, ie., the interference region, fringe spacing and fringe angle, involved in electron holography [2]. Scanning-beam electron holography is made possible by placing an additional biprism above the specimen. Multiple biprisms enable many forms of electron holography to be possible, as envisioned by Cowley [3]. For example, holography typically reconstructs its holograms outside of the microscope using Fourier transform methods. Two electron biprisms enable the hologram to be reconstructed inside the microscope so a phase image of the specimen can be directly observed during the experiment. Multiple electron biprisms also enable the creation of confocal electron holography, which will be used to make three-dimensional measurements of the physical, electrostatic and magnetic properties of a specimen.

The cold-field emission source will make it possible to see the bandgap electrons, holes, excitons, phonons and plasmons of materials used in electronic, photonic and magnetic devices so their properties can be measured by energy-filtered electron holography. These measurements will answer many fundamental questions of science and engineering. The phase measurements of the electrostatic field strength existing between atoms provide a direct insight into the basic bonding configurations, which is information currently lacking by science.

### **Measuring material properties**

Energy-filtered electron holography, which combines electron holography with the imaging energy filter (GIF) will make it possible to characterize the coherence properties of surface plasmons and surface phonons (two energy filters used) of carbon nanotubes (CNT) that are responsible for the observed ballistic electron mobility and excellent heat conduction.

Researchers will also use the STEHM to measure the physical properties (strength) of carbon nanotubes using a modified specimen holder. This information will help the implementation of CNTs as field emitters, heat conductors and in structural components.

Also, this configuration of the STEHM will make it possible to measure the coherence of phonons on the B planes in MgB<sub>2</sub> and possibly Cu-O planes in high temperature superconductors that are a possible source of their superconducting properties.

Electron holography is the only means possible to measure the dimension of the electrostatic field between the source and drain of field emission transistors.

Similarly, high-resolution electron holography should be able to measure the orientation of the spinning electron's magnetic field to characterize spintronic devices.

Other unique capabilities include the measurement of the composition and defect density of self-assembled nanodots for nanotechnology, the domain structures of magnetic materials, which when combined with the Cs + Cc correctors may be able to measure the dimension and properties of the domain boundaries and their triple points, which is now not possible by any means.

### **Useful to many research areas**

The new capabilities of the STEHM will make measurements to be used by researchers in engineering, physics, chemistry, materials science, biology and medical sciences. The STEHM will push the boundaries of research in nanotechnology: nanoelectronics, nanochemistry, bionanotechnology, nanophotonics, molecular devices, and diagnostics, for example.

[1] A. Tonomura, *Direct observation of hitherto unobservable quantum phenomena by using electrons*, Proceedings of the National Academy of Sciences of the USA, volume **102**, number 42, pg 14952 (2005).

[2] K. Harada, T. Matsuda, A. Tonomura, T. Akashi, and Y. Togawa, *Triple Biprism Electron Interferometry*, Journal of Applied Physics, volume 99, pg 113502 (2006).

[3] J.M. Cowley, *Twenty forms of electron holography*, Ultramicroscopy, volume **41**, pg 335 (1992).