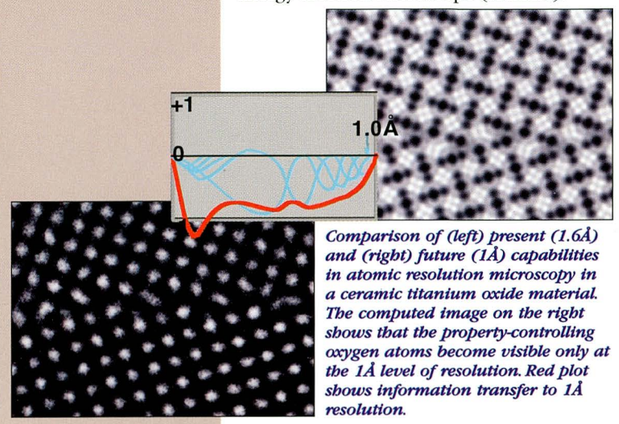
New Instrumentation

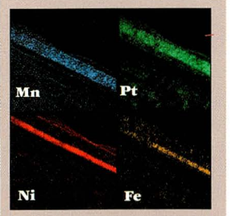
In addition to the Atomic Resolution Microscope and the High Voltage Microscope which first established the facility and remain unique resources, users now have access to an array of other microcharacterization instruments. The most recent additions are the One-Angstrom Microscope (OAM), an advanced analytical microscope (CM200FEG), and a Spin Polarized Low-Energy Electron Microscope (SPLEEM).



Comparison of (left) present (1.6Å) and (right) future (1Å) capabilities in atomic resolution microscopy in a ceramic titanium oxide material. The computed image on the right shows that the property-controlling oxygen atoms become visible only at the 1Å level of resolution. Red plot shows information transfer to 1Å resolution.

OAM

The new One-Angstrom Microscope will provide unprecedented Angstrom-level resolution which is of great importance in materials such as oxide superconductors or structural ceramics. Using computer alignment and reconstruction, the instrument will be used to get a first time view of the oxygen atoms in oxide superconductors.



CM200FEG

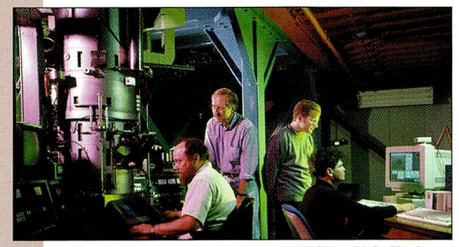
This state-of-the-art analytical microscope is capable of quantitatively obtaining the chemical, physical and magnetic structure of materials at the near-atomic level. It can give scientists a map of atomic bonds at interfaces between different materials, measure the distribution of magnetic particles or determine the presence of trace impurities inside a material. The images on the left show the distribution of four different elements in a magnetic multilayer device.

SPLEEM

The unique SPLEEM instrument provides information on the magnetic and physical structure of surfaces at nanometer resolution and video rates. It can help unravel the mysteries of magnetic behavior at surfaces, which holds the key to advances in reading and writing high-density information on computer disks. The images on the left are taken from a time sequence showing atomic-level steps on the surface of a silicon crystal as a layer of magnetic cobalt metal is growing at the edges of the steps.

New Projects

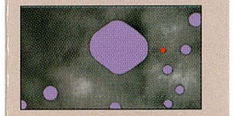
Electron microscopy is not a static technique but continues to develop in new directions. With more powerful computers, better electron optics, new nanofabrication facilities and novel instrumentation, new areas of research can be explored. NCEM is an innovative leader in several areas.



Researchers operating the 1.5 Million Volt High Voltage Microscope (left) via desktop computer (right).

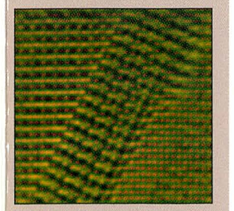
Remote Operation

Berkeley Lab scientists have pioneered a project that makes it possible to operate the NCEM's unique High Voltage Microscope via remote control, using a computer workstation. This capability will be extended to several of the Center's most powerful microscopes to enable scientists to conduct atomic resolution experiments at NCEM from a desktop anywhere in the world.



Nanophase Materials

As a material is made smaller and smaller, its properties can change dramatically. For example, normal lead melts at a fairly low temperature, but electron microscopy has shown that extremely small Pb particles, only a few nanometers in size (left), remain solid up to 100 degrees higher—like a piece of ice refusing to melt in a pot of boiling water. Electron beam microcharacterization will play a central role in the development of the science and technology of the nanophase materials of the future.



Internal Interfaces

The interfaces between different parts of a material often control its behavior. Properties such as strength, ductility, or hardness, their resistance to failure by corrosion, fatigue or electromigration are all greatly affected by the structure and behavior of internal interfaces. Electron microscopy is the only technique that can analyze the atomic structure, and determine chemical composition and bonding at such interfaces with high resolution.

In-Situ Microscopy

In-situ microscopy is a way of observing dynamic changes that occur during processing, such as in this sequence of images of a Ge precipitate during cyclic heating and cooling. As in-situ techniques are being developed, it is becoming possible to observe the mechanisms and dynamics of atomic rearrangements directly and to gain a much better understanding of how materials behave.

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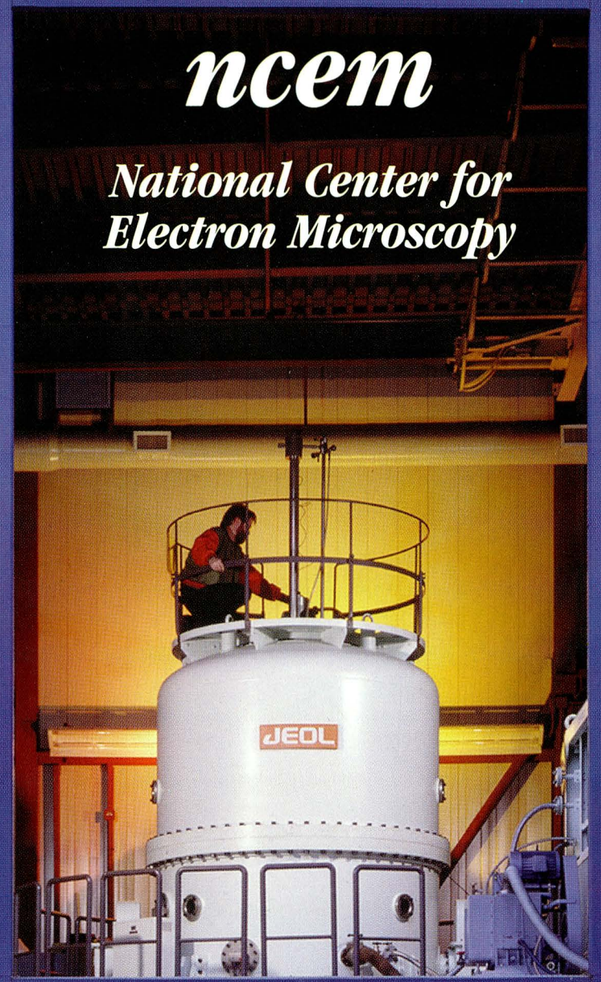
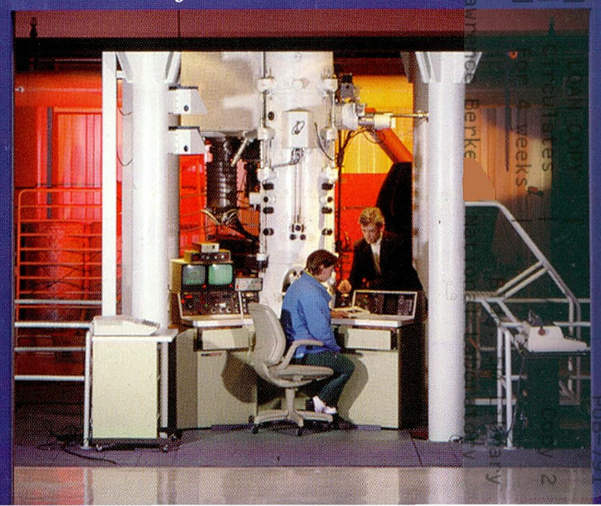
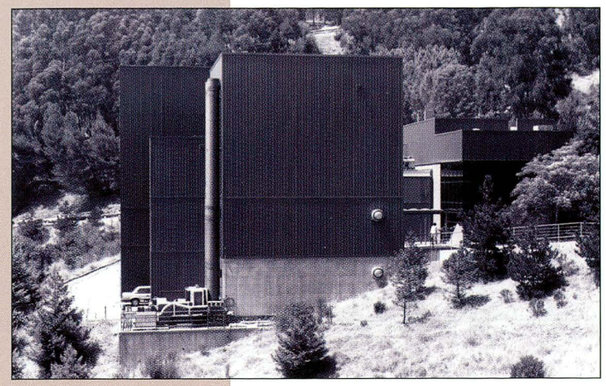


Electron Beam Microcharacterization for Materials Science

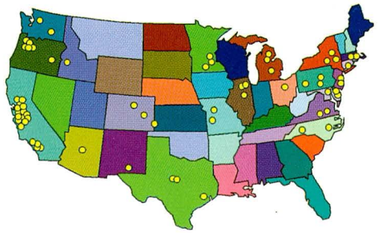




The National Center for Electron Microscopy (NCEM) is a U.S. Department of Energy facility located within the Materials Science division of the Ernest Orlando Lawrence Berkeley National Laboratory in Berkeley, CA. NCEM provides scientists with special instruments for the microcharacterization of materials.

The center was established in 1983 with two high-voltage electron microscopes, each housed in its own 3-story silo—the 1million volt Atomic Resolution Microscope and the 1.5-million-volt High Voltage Electron Microscope. In recent years, several other instruments have been added, the latest being two field-emission instruments, the One-Angstrom Microscope and an advanced analytical microscope. Today, users have access to eight specialized microscopes and a cutting-edge computer facility that helps interpret images and analyze data.

All parts of the Center are available for use at no charge after review of proposals by an external steering committee. NCEM is operated by a small permanent staff providing technical, scientific and administrative support, and hosts well over a hundred visiting users annually from across the nation and around the world.

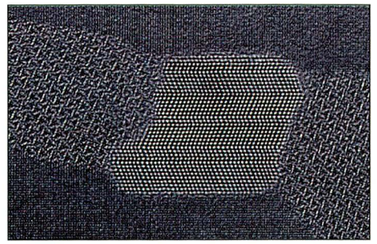


Distribution of NCEM users in the United States.

What Electron Microscopes Do

Transmission electron microscopes are designed to look at the interiors of materials at great magnification. They are capable of probing atomic structure, identifying defects and measuring chemical composition—all features that control the behavior of materials. For this reason, electron microscopy is indispensable for materials research. As a versatile tool for discovery and characterization of materials, it is unmatched by any other technique.

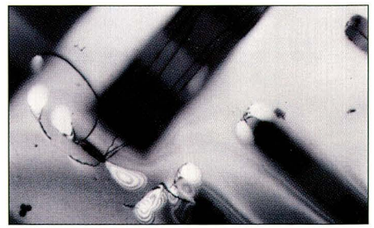
The wide array of electron-optical microcharacterization tools at NCEM allows scientists to analyze the behavior of materials such as magnets, superconductors, ceramics or high-temperature alloys in their pursuit of basic scientific understanding and new, energy-efficient materials. Some examples of work performed at NCEM are illustrated in this brochure, and more can be found in displays throughout the Center.



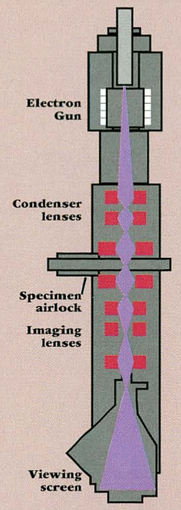
Atomic resolution image investigating the complex microstructure of an advanced aluminum alloy for energy-efficient automobiles.

Comparison to Other Characterization Techniques

Unlike scanning microscopes which "read" the surface of a material by rastering a fine electron beam or an atomically sharp tip across a sample in the manner of a laser scanner, transmission electron microscopes produce an image by illuminating the entire field of view with electrons in the manner of a photographic slide projector. Rather than looking at the surface, electrons pass through material to analyze interior structure, much like X-rays give an image of the bone structure inside the body. Compared to X-rays, however, electrons see the interior of a material with a much higher resolution.



High voltage electron micrograph showing the failure of a semiconductor device due to a dislocation defect (dark line) making a short circuit between metal contacts (dark patches).



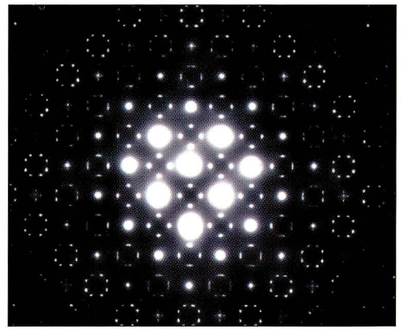
Schematic of an electron microscope.

How Electron Microscopes Work

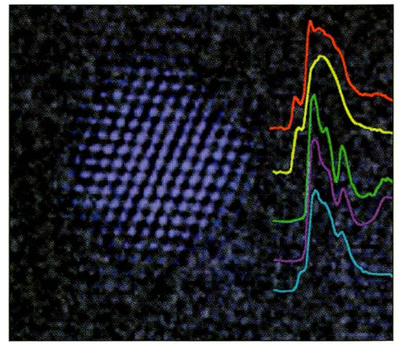
Unlike optical microscopes that use visible light, electron microscopes use high-energy electrons for imaging. When accelerated to nearly the speed of light, a beam of electrons behaves like a wavefront with a wavelength about a million times shorter than lightwaves. When an electron beam passes through a thin-section specimen of a material, electrons are scattered. An elaborate system of electromagnetic lenses focuses the scattered electrons into an image or a diffraction pattern, or a micro-analytical spectrum, depending on the mode of operation.

Each of these modes offers a different insight about the sample's interior. The image mode provides a direct map of atomic arrangements to give scientists a measure of the defects that control a material's behavior. The diffraction mode displays accurate information about the local crystal structure. The microanalytical mode tells researchers which elements are present in the tiny volume of material under the beam's razor-sharp focus.

These different modes of operation provide valuable information for scientists and engineers in search of stronger materials, faster microchips, or smaller nanocrystals.



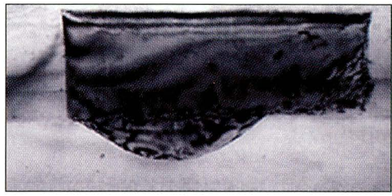
Diffraction patterns offer unique clues to a materials complex crystal structure



Atomic resolution micrograph of a nanosize piece of intersetllar diamond from a meteorite. The spectra comparing its bond structure to that of carbon and natural diamond give clues to its origin in the shockwave of a supernova.

Sample Preparation

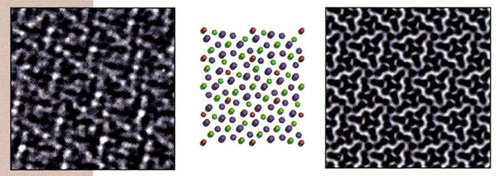
Sample preparation is an essential part of electron microscopy. To be transparent to an electron beam, a sample must be made unimaginably thin, typically 1,000 times thinner than household aluminum foil. This requires sophisticated instruments and techniques, and a great deal of patience and skill.



Electron micrograph of a cross section sample prepared from a metal/semiconductor sandwich, showing how semiconductor devices fail.

Image Simulation and Analysis

To interpret data from an electron microscope, whether it is an image, a diffraction pattern or a microanalytical spectrum, requires careful analysis. Each micrograph contains megabytes of information about the material being analyzed. Computer analysis is an essential part of electron microscopy. Computers can be used to filter images, correct for instrumental imperfections, calculate atomic structures, build models and simulate the complex process of image formation. NCEM scientists develop computer software for the scientific community to help improve quantitative data extraction. The computer analysis lab at NCEM is the most advanced such facility in the nation.



Experimental image, atomic model and resulting inage simulation in an experimrental automobile alloy.

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