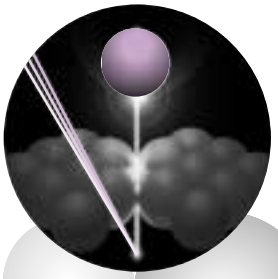


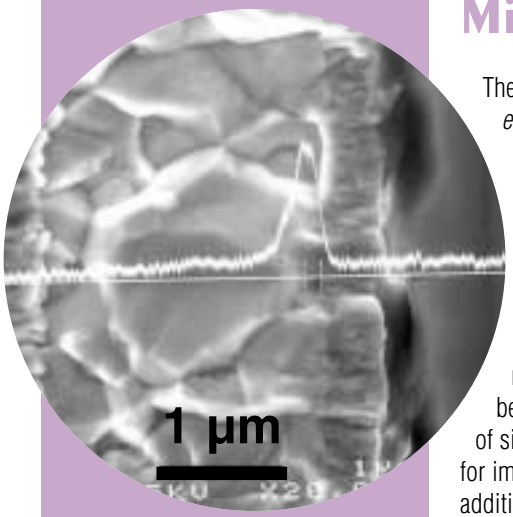
Analytical Microscopy

The Division has two state-of-the-art scanning electron microscopes. This one, which employs a field-emission source, is used for topographical, compositional, and electrical analyses. It can magnify images up to 650,000x. (Jim Yost Photography/PIX02021.)

In simple terms, *microscopy* provides magnified images of features that are beyond the resolution of the human eye (approximately 100 µm). How the image is produced depends on the technique used. Light microscopes, for example, rely on visible light as a signal source; other microscopy techniques rely on different signal sources, such as electrons. Microscopy becomes *analytical* by applying one or more analytical tools or methods, such as additional contrast mechanisms, diffraction techniques, cathodoluminescence, and energy dispersive spectrometry to yield information on a wide range of material properties.

The Measurements and Characterization Division combines two complementary areas of analytical microscopy: *electron microscopy* and *proximal probe techniques*. In both areas we employ a variety of state-of-the-art imaging and analytical tools. We have also designed and built customized instrumentation and have developed novel techniques that give us unique capabilities for fundamental material studies and for analyses on a scale ranging from centimeters to atoms (10^{-2} to 10^{-10} m) — eight orders of magnitude.

Electron Microscopy

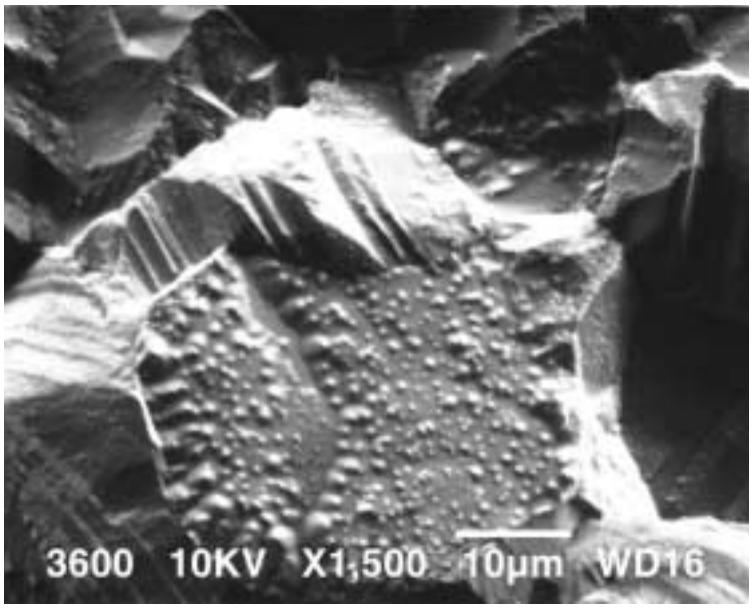


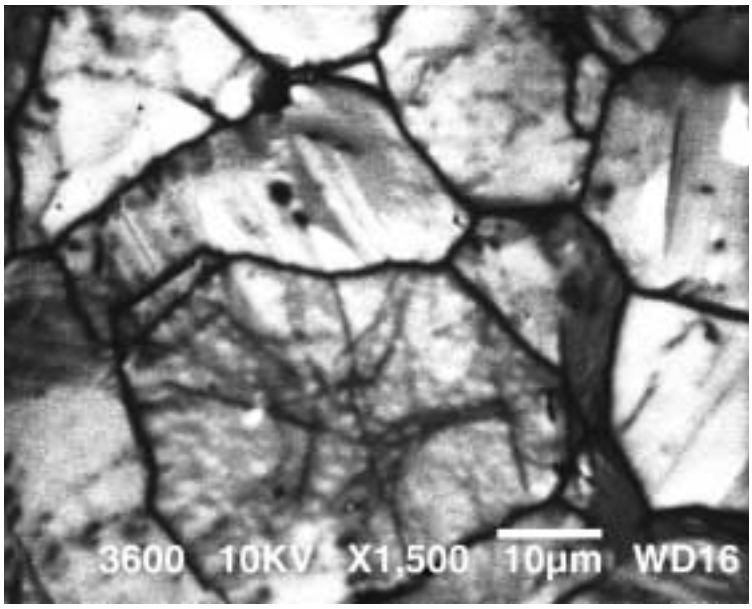
With analytical attachments, SEM becomes an extremely versatile technique. Here, SEM uses a superimposed EBIC line scan to indicate the location of a shallow buried junction (about 3000 Å from the transparent conducting oxide interface) in a copper indium diselenide thin-film device.

The defining feature of *electron microscopy* is that each analytical technique employs an electron beam as a source for bombarding the sample under investigation. Through its interaction with matter, the electron beam produces a variety of signals that may be used for imaging and that, with additional analytical attachments, are used to study a material's topographical, crystallographic, and structural properties — all of which can be correlated with the material's chemical, electrical, optical, and luminescence properties. Among the techniques we use are *scanning electron microscopy, electron probe microanalysis,* and *transmission/scanning transmission electron microscopy*. These microscopy techniques are augmented by *X-ray diffraction.*

Scanning Electron Microscopy (SEM)

Because of its versatility and the wide range of information it can provide, the scanning electron microscope is often the preferred starting tool for analytical microscopy. With SEM, a focused beam of high-energy electrons is scanned over the surface of a material. The electron beam interacts with the material, causing a variety of signals — secondary electrons, backscattered electrons, X-rays, photons, etc. — each of which may be used to characterize a material with respect to specific properties. The signals are used to modulate the brightness on a display CRT, thereby providing a high-resolution map of the selected material property. The Division has two state-of-the-art SEMs, providing





By using different analytical capabilities with SEM, one can correlate properties of a material. Here, a topographical image of CdTe (upper micrograph) is correlated with a cathodoluminescence image (lower micrograph), to indicate those areas that are active (brighter areas) and those that represent recombination centers (darker areas).

MAJOR INSTRUMENTATION FOR ELECTRON MICROSCOPY

System	Analytical Technique	Typical Applications	Signal Source	Accelerating Voltage	Signal Detected	Elements Detected
JEOL JXA-8900L	Electron probe microanalysis	Quantitative compositional analysis for elements heavier than boron	Beam of high-energy electrons	0.2 to 40 kV	X-rays, photons, electrons	B to U
JEOL JSM-5800	Scanning electron microscopy	Topographical, compositional, electrical, structural, and luminescence analyses	Narrow beam of electrons	0.3 to 30 kV	X-rays, photons, electrons	—
JEOL 6320F	Field-emission scanning electron microscopy	Topographical, compositional, and electrical analyses	Narrow beam of electrons	0.5 to 30 kV	X-rays, photons, electrons	—
Philips CM-30	Transmission and scanning transmission electron microscopy	Microstructural, crystallographic, lattice imaging; compositional analysis of thin films, semiconductors, metals, ceramics, and particulates	Highly focused monoenergetic beam of electrons	50 to 300 kV	Transmitted electrons and X-rays	F to U (STEM)
Scintag	X-ray diffraction	Compositional and phase identification; texture, stress, and thin-film analyses	Monochromatic beam of X-rays	—	X-ray diffraction patterns	All; but not element-specific

remarkable analytical versatility and a wide magnification range: from 20x to 650,000x.

Applications

- Topographical imaging. Scans the surfaces of materials with a highly focused beam of energetic electrons to produce topographical images, resolving features on the order of 2 nm.
- Microcharacterization. The SEM employs a number of possible modes or techniques for microcharacterization, including:
  - Compositional analysis. Using energy-dispersive X-ray spectrometry (EDS), the SEM provides chemical spectra and elemental line scans and maps that show the spatial distribution of specific chemical elements on a submicron scale.
  - Electrical microcharacterization. A number of material and device parameters can be characterized through the creation of electron-hole pairs by the electron beam, including charge collection efficiency (electron-beam-induced current, or EBIC), diffusion length, minority-carrier lifetime, device junction properties, conductivity, potential distribution (voltage contrast, or EBIV), and grain-boundary activity.
  - Luminescence analysis. Wavelength-dispersive and/or integrated electron-beam-stimulated photon emission (cathodoluminescence) can be used to study the identity, recombination efficiency, and the distribution of material defects.
  - Structural microcharacterization. Through the use of electron channeling or electron backscattering diffraction, the specific crystalline type, orientation, and crystalline quality of individual crystals ("grains") in microcrystalline materials can be characterized, along with the structural properties of the grain boundaries, which are germane to polycrystalline devices.
- Analytical synergy. At one sitting and with one instrument, a variety of fundamental properties can be studied and correlated on a scale ranging from millimeters to nanometers, greatly augmenting the power of any one or all of the measurement or characterization modes.

Special Features

- Field-emission SEM. Enables high resolution (~1 nm at a magnification of ~ 650,000x) and low beam-voltage imaging, in addition to high-resolution EBIC characterization.
- Variety of analytical configurations — all computer-controlled through one platform:
  - EDS. For determining spatial distribution of specific chemical elements.
  - Temperature- and bias-dependent EBIC. For electrical analysis.
  - Electron Back-Scattered Diffraction (EBSD). For determining crystal type, crystal orientation, lattice parameters, strain, crystal quality of the near surface, grain orientation, and grain mismatch.
- Temperature-dependent cathodoluminescence (CL). For analysis of luminescence properties, using integrated and spectrally resolved (SRCL) cathodoluminescence.
- Virtual microscopy. Enables clients to observe the analysis of their samples at their own computer via the Internet while interacting with the analyst via telephone, all in real time. This allows for timely co-investigation of clients' samples. (See *Data Transfer and Virtual Lab* insert.)

Electron Probe Microanalysis (EPMA)

As with the SEM, the electron probe microanalyzer probes the surface of a sample with high-energy electrons, thereby stimulating inner shell ionization in the atoms. This results in the emission of characteristic X-rays that serve as signatures of the elements present. Either EDS or WDS (wavelength-dispersive spectrometers) are used to detect and identify the emitted X-rays.

Applications

- Compositional analysis. The primary application of the EPMA is compositional analysis of a sample, either for the sample as a whole or with respect to a local feature on the micron scale. With a sensitivity of ±0.2 at. %, it is the most convenient, accurate, and rapid method for compositional analysis — especially with respect to microanalysis.
- Compositional mapping. Employing either EDS or WDS, the EPMA is used to produce line scans or area scans that can be superimposed on topographic maps, thereby correlating topographical features with their chemical composition.

The EPMA is used to map the chemical composition of the top surface layer of solid-state materials. (Jim Yost Photography/PIX02019.)

Detection Limits	Imaging/ Mapping?	Lateral Resolution	Magnification	Special Features
1000 ppm	Yes	Energy/matrix dependent, 100 nm to 5 µm	To 100,000x	WDS and EDS analyses accurate to ±0.2 at.%
—	Yes	Energy/matrix dependent, 3.5 nm to 1.0 µm	To 200,000x	EBIC and EDS; (EBSD and CL/SRCL are planned features)
—	Yes	12 Å @ 1.5 kV 25 Å @ 1 kV	To 650,000x	Field-emission source; EBIC and EDS
0.5 at.% (EDS); monolayer (TEM)	Yes	2.3 Å (TEM); 50 nm (EDS)	To 800,000x	Lattice imaging; STEM capabilities with light-element EDS; digital image acquisition and processing
Material dependent	No	—	—	Four-circle X-ray diffractometer; thin-film attachment; grazing angle; transmission and back-reflection Laue

Using electron diffraction and electron imaging, the TEM/STEM analyzes the crystallographic structure, microstructure, and composition of a wide range of organic and inorganic materials. (Jim Yost Photography/PIX02016.)

Special Features

- EDS. For simultaneous display of most of the chemical spectrum (from boron to uranium) and for quick surveys of the area of interest before performing a more accurate quantitative analysis with WDS.
- WDS. Four spectrometers with ten diffracting crystals. The use of a single-channel analyzer allows much better peak resolution and, therefore, helps to resolve peak overlap problems that are common in PV materials.
- Extensively computerized. Computer system controls the electron beam, spectrometers, specimen stage, and data processing.

Transmission and Scanning Transmission Electron Microscopy (TEM/STEM)

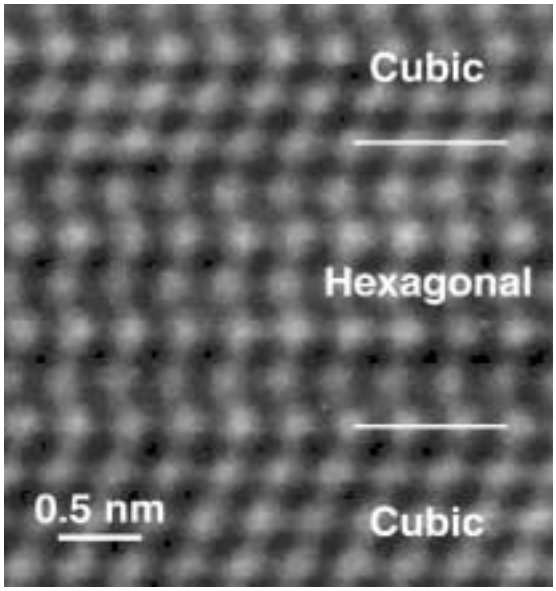
With *transmission electron microscopy* (TEM), a thin (<200 nm) sample is bombarded by a highly focused beam of single-energy electrons. The beam has enough energy for the electrons to be transmitted through the sample. The transmitted electron signal is greatly magnified by a series of electromagnetic lenses. The magnified transmitted signal may be observed in two ways, through electron diffraction or direct electron imaging. Electron diffraction patterns are used to determine the crystallographic structure of the material. Direct electron images yield information about the microstructure of the material and about its defects. With *scanning transmission electron microscopy* (STEM), the electron beam is raster-scanned across the material. This produces a variety of electron and X-ray signals that may be used for compositional analysis.

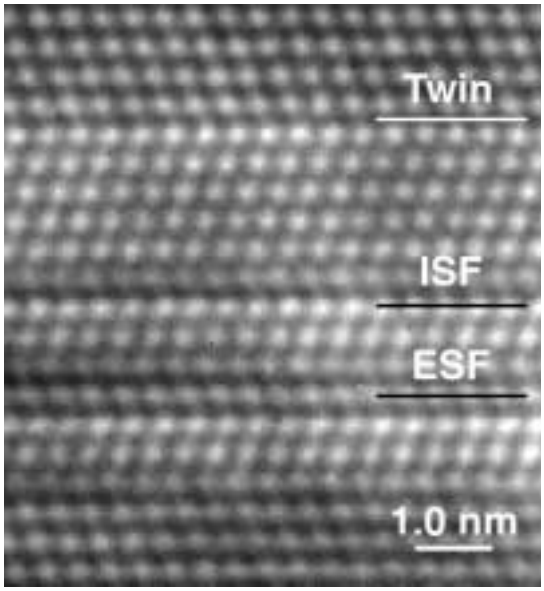
Applications

- Structural analysis. Yields information on the microstructure and defects of materials.
- Compositional analysis. Using EDS, provides small-spot (30 nm) qualitative or quantitative compositional analysis of materials, detecting elements from fluorine to uranium.
- High-resolution imaging. Can produce images of atomic lattices with 2.3 Å point-to-point resolution.
- Cross-sectional analysis. Used for investigating the structure and imperfections of multilayer films.
- Wide range of materials. Analyzes the structure and composition of thin-film or bulk organic and inorganic materials, including electronic materials, ceramics, metals, biological samples, and particulates.

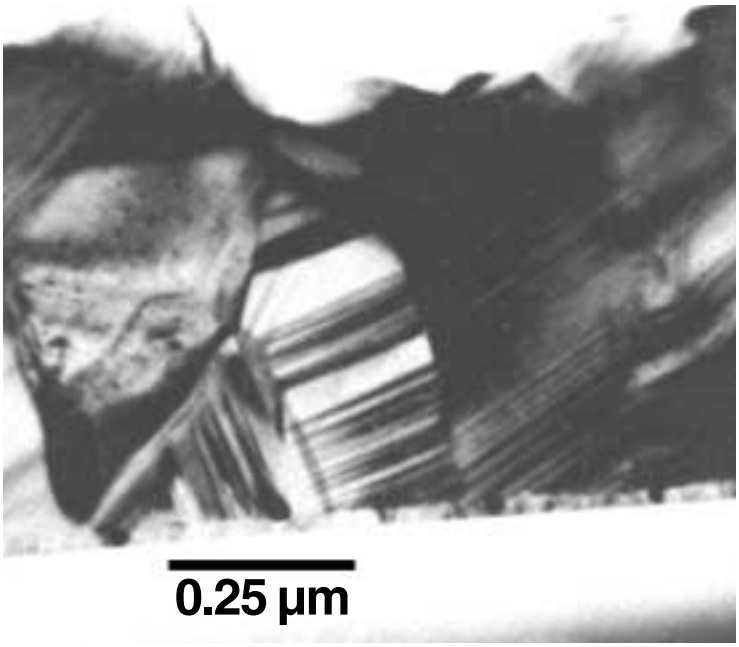
Special Features

- STEM. Images are formed by raster-scanning the electron beam across the sample and collecting the transmitted or scattered electrons. Many signals may be collected, including bright- and dark-field images, and X-rays for EDS.
- EDS. Performs qualitative or quantitative compositional analysis for elements from fluorine to uranium.
- 300 kV acceleration potential. Produces a highly focused beam containing coherent monoenergetic electrons with a small wavelength (about 0.002 nm). This promotes high point-to-point resolution and high electron mean free path for greater penetration depth.
- 2.3 Å point-to-point resolution. Enables in-depth information on atomic structure of samples using lattice imaging.
- Complete processing lab. For producing both negatives and positives of images and diffraction patterns.





Two HRTEM (high-resolution TEM) images. The left image reveals a buried hexagonal phase in cubic CdTe. The right image shows the atomic structure of planar defects in thin-film silicon: a twin defect (in which the upper layers are rotated 180° from the lower layers), an intrinsic stacking fault (ISF — in which adjacent layers are shifted slightly), and an extrinsic stacking fault (ESF — in which there is an intervening layer between two layers slightly shifted from each other).



As revealed in this TEM cross-sectional image, the microstructure of a polycrystalline CdTe thin film exhibits a high density of structural defects, such as grain boundaries, stacking faults, and twins. These defects can have an adverse effect on the performance of CdTe solar cells.

- CCD digital imaging. For acquiring and processing images and electronically transmitting them to customers.
- Complete sample preparation lab. Allows the preparation of any sample for TEM/STEM analysis.
  - Four ion-beam milling systems. Samples may be milled at low angles using either argon or reactive iodine (good for compounds containing phosphorous) and at either room-temperature or liquid-nitrogen temperature.
  - Tripod polish. Used to prepare samples for cross-sectional analysis — of integrated circuits, semiconductors, multilayer structures, gate oxides, and more.
  - Wet chemistry lab. For thinning samples with chemical etches.
- Tilt angle of ±45%. For varying the orientation of a crystal with respect to the incident beam. Enables the sample to be tilted to the appropriate orientation to reveal crystallographic defects.
- Operating modes. The TEM/STEM has two basic operating modes, with the ability to easily switch between the two.
  - Diffraction mode. Produces diffraction patterns useful for crystallographic analysis.
  - Image mode. Produces images with enough detail to relate to the specimen's microstructure.

X-Ray Diffraction (XRD)

X-ray diffraction is a versatile, non-destructive technique used for identifying the crystalline phases present in solid materials and powders and for analyzing structural properties (such as stress, grain size, phase composition, crystal orientation, and defects) of the phases. The method uses a beam of X-rays to bombard a specimen from various angles. The X-rays are diffracted (according to Bragg's law) as they are reflected from successive planes formed by the crystal lattice of the material. By varying the angle of incidence, a diffraction pattern emerges that is characteristic of the sample. The pattern is identified by comparing it with an internationally recognized data base containing tens of thousands of reference patterns.

Applications

- Structural analysis. Determines the crystal structure of a material by comparing its generated diffraction patterns with reference diffraction patterns.
- Stress measurements. Measures the strain in a sample by recording the angular shift of a given Bragg reflection as a function of angle of incidence. Strain is then used to calculate the stress.
- Phase analysis. Determines the crystalline phases present in a sample.
- Texture analysis. Determines the texture (orientation of the crystallites) in the sample using several diffractometer techniques. Texture can range from completely ordered to partially ordered to completely random.
- Bulk materials to powders. Analyzes bulk samples, powders, single crystals, polycrystalline materials, and thin films.

Special Features

- Four-circle X-ray diffractometer. Detects diffracted X-rays with a photon counter, for accurate, quantitative data. Has four axes through which the sample or source and detector are rotated, enabling sophisticated measurements of thin films, polycrystalline samples, and epitaxial films.
- Grazing angle. Relying on a small incidence angle and an X-ray penetration of only a few hundred angstroms into the specimen, this is a method used for investigating ultrathin films.
- Pole figure. Automatically measures the variations in intensity of a single Bragg reflection as the sample is tilted and rotated. Used primarily for texture analysis.
- Rocking curve. Measures a single Bragg peak as the sample is tilted within the diffraction plane. Useful for determining crystalline perfection, texture, epitaxy, and lattice constants for epitaxial films.
- Phi scan and chi scan. High-accuracy "slices" of pole figures are used to provide quantitative data for crystalline perfection, texture, and epitaxy.
- Transmission and back-reflection Laue detector. An area detector that uses either reflected X-rays or transmitted X-rays to show the Laue pattern of single-crystal materials.

This XRD is used for identifying the crystalline phases in solid materials and powders. It also analyzes structural properties of the phases. (Jim Yost Photography/PIX04835.)

Proximal Probe Techniques

Scanning tunneling microscopy is used for imaging, three-dimensional profiling, and spectroscopic studies of material surfaces on the nanoscale and atomic levels. (Jim Yost Photography/PIX02031.)

Proximal probe techniques employ probes that scan extremely close to the material being analyzed — just a few angstroms away from the surface or even in contact with the material. The signal used to map and analyze the surface may be generated in a number of ways — electric current, attractive/repulsive forces (including magnetic forces), or even friction. The techniques we use include *scanning tunneling microscopy* and *atomic force microscopy*. With lateral resolutions to 1 Å and vertical resolutions to 0.1 Å, these are extremely sensitive techniques that enable us to perform topographical imaging and three-dimensional profiling on the atomic and nanoscales. We have also designed and built a customized proximal probe instrument for *near-field optical microscopy*, which gives us the unusual capability to investigate submicron spatial variations and electron relaxation states.

Scanning Tunneling Microscopy (STM)

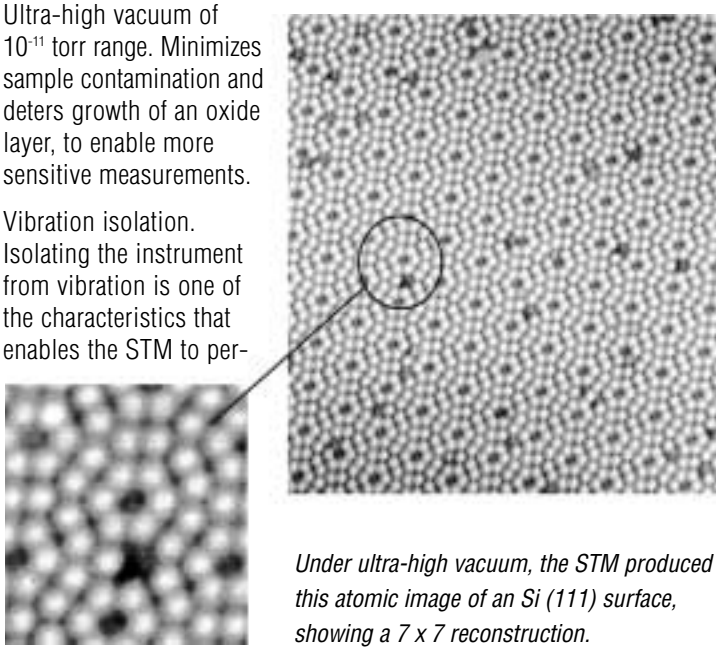
The scanning tunneling microscope uses an atomically sharpened tungsten or platinum-iridium tip that is scanned within a few angstroms of a sample surface. A bias voltage is applied between the sample and the tip, producing a quantum-mechanical tunneling current across the gap. The magnitude of the tunneling current depends on the distance between the tip and the surface and on the local density of states. A piezoelectric transducer scans the tip across the sample surface. In topographic mode, a feedback loop operated with the scanner maintains a constant distance between the tip and the surface. A monitor measures the precise position of the scanner that, together with the sensitivity of the tunneling current, enables the STM to produce real, three-dimensional images of the surface topography. In current mode, the fast response of the feedback loop is disabled and the variation in the current with surface topography is measured, also producing a three-dimensional image. In both modes, the STM has the ability to resolve single atoms. Because the tunneling current also depends on the local density of states, the STM can be used for nanoscale spectroscopic studies. For instance, the STM can generate current-versus-voltage curves, and their derivatives, for different points of the surface.

Applications

- Surface Imaging. Scans the surface of materials to produce topographic images with atomic lateral resolutions.
- Three-dimensional profiling. Can profile samples in real, three-dimensional space with vertical resolutions to 0.1 Å. Through storage of digital information, the three-dimensional image may be manipulated — rotated, enhanced with color, filtered, enlarged, and displayed from any altitude or azimuth.
- Materials. Used for investigating a wide range of materials, including semiconductors, conducting samples, and features of microelectronic devices.
- Spectroscopic studies. By measuring variations in current, voltage, tip/surface separation, and their derivatives, the electronic properties of the surface can be studied.

Special Features

- Ultra-high vacuum of 10^{-11} torr range. Minimizes sample contamination and deters growth of an oxide layer, to enable more sensitive measurements.
- Vibration isolation. Isolating the instrument from vibration is one of the characteristics that enables the STM to per-



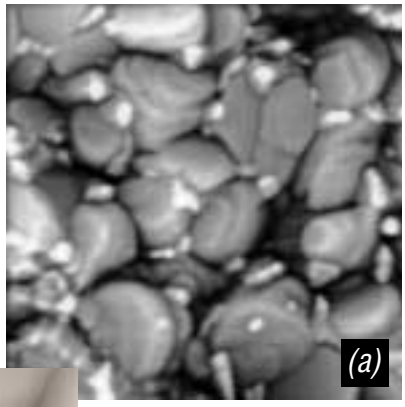
Under ultra-high vacuum, the STM produced this atomic image of an Si (111) surface, showing a 7 x 7 reconstruction.

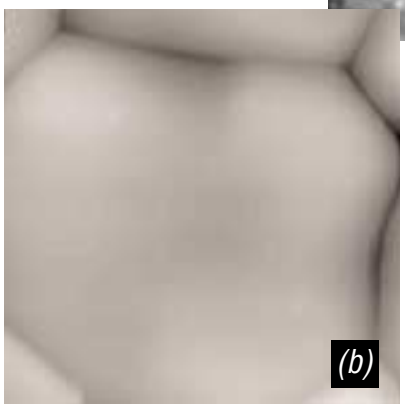
MAJOR INSTRUMENTATION FOR PROXIMAL PROBE TECHNIQUES

System	Analytical Technique	Typical Applications	Signal Source	Signal Detected
Customized NSOM	Near-field optical microscopy	Submicron spatial variations in optical properties	Continuous-wavelength laser	Light
ThermoMicroscopes AutoProbe VP	Vacuum atomic force microscopy and scanning tunneling microscopy	Nanoscale and atomic characterization of conducting and non-conducting surfaces	Atomic forces between probe and surface/bias voltage	Tip deflection (voltage)/ tunneling current
ThermoMicroscopes AutoProbe CP	Air-ambient atomic force microscopy and scanning tunneling microscopy	Nanoscale and atomic characterization of conducting and non-conducting surfaces	Atomic forces between probe and surface/bias voltage	Tip deflection (voltage)/ tunneling current
RHK 100 STM	Vacuum scanning tunneling microscopy	Nanoscale and atomic level imaging of conductive samples	Bias voltage	Tunneling current

form extremely sensitive measurements.

- Image manipulation. Allows the three-dimensional exploration of a sample from all angles and allows various kinds of manipulation that enhance analysis.





Imaging with AFM shows recrystallization of CdTe films grown by PVD. After treatment with $CdCl_2$/methanol at 350°C, small grains (a) of the new CdTe structure begin recrystallization. After treatment at 400°C, recrystallization is complete (b) — the small grains increased in size to consume the original film.

- Field of view — from atoms to about 100 µm. This type of range enables the STM to address larger-scale problems, making it a complementary technique to scanning electron microscopy and transmission electron microscopy.
- Lateral resolution to 1 Å. Allows atomic-scale topographic imaging.
- Vertical resolution to 0.1 Å. Along with the sensitive lateral resolution, this feature allows three-dimensional profiling on the atomic scale.

Atomic Force Microscopy (AFM)

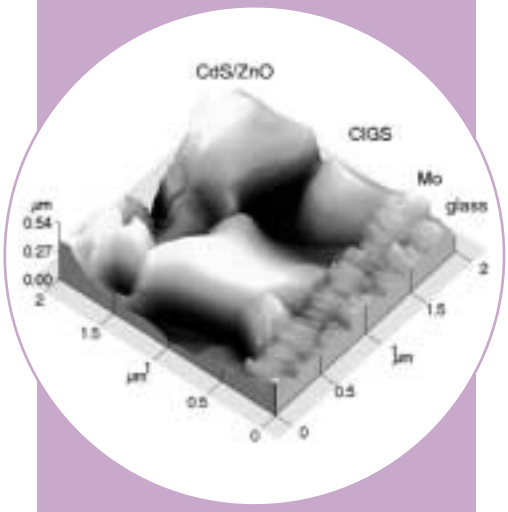
The atomic force microscope can be operated under two different conditions (in air or in a vacuum) and via two primary modes (contact or non-contact). Whatever the condition or mode, the basic operating principles of the AFM remain the same: the AFM uses a probe that has a microfabricated tip mounted on a flexible cantilever. The tip is slowly scanned across the surface of a material, just a few angstroms away from the surface (non-contact mode) or in contact with it (contact mode). The force between the atoms on the surface of the material and those on the tip cause the tip to deflect. The magnitude of the deflection depends on the separation between the surface atoms and the tip atoms and on the atomic forces between them (van der Waals forces or Pauli exclusion forces, etc.) This deflection can be recorded in various ways, the most common of which uses a laser focused on the top of the cantilever and reflected onto photodetectors. The photodetector signals are used to map the surface topography of samples with resolutions down to the atomic and nanoscales. The lateral and vertical movements of the tip or sample are controlled by piezoelectric transducers and a feedback loop that produce voltage differences proportional to the movement.

Applications

- Surface imaging. Scans the surfaces of materials to produce topographical maps with lateral resolutions down to 30 Å. Used to determine roughness, grain size, and features on the nanoscale. Can resolve individual holes, defects (such as pinholes), and atomic clusters.
- Three-dimensional profiling. Can profile samples in real, three-dimensional space with vertical resolutions to 0.1 Å. Through storage of digital information, the three-dimensional image may be manipulated — rotated, enhanced with color, filtered, enlarged, and displayed from any altitude or azimuth.
- Materials. Used to investigate a wide range of materials, including semiconductors, non-conducting surfaces, biological samples, high-resistivity materials, insulators, conducting samples, and features of microelectronic devices.

Special Features

- Two operating conditions:
  - Air AFM. Used primarily for nanoscale characterization of a material's topography. Although not as sensitive as vacuum AFM, largely because of an oxide layer that forms, air AFM nonetheless achieves lateral resolutions to 30 Å.
  - Vacuum AFM. Analyses with vacuum AFM are more difficult to perform than those with air AFM, but are more sensitive, with near atomic-scale lateral resolutions.
- Several operating modes:
  - Two primary modes: contact and non-contact.
  - Topography mode. The most common mode, in which the scan is performed slowly, and



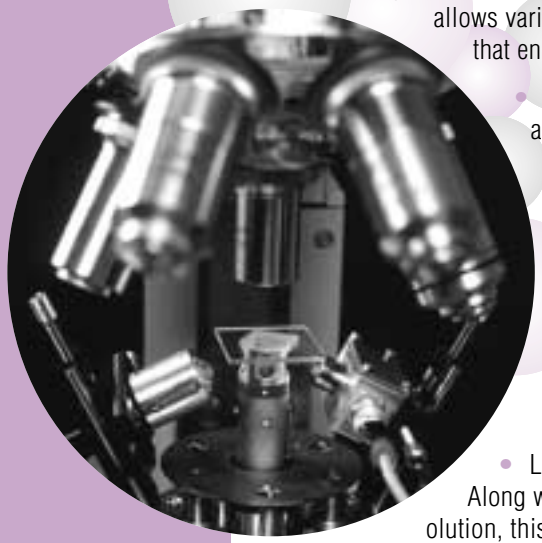
Non-contact AFM image of the cross-section of a glass/Mo/CIGS/CdS/ZnO solar cell. It shows the columnar growth of the molybdenum double layer, the large CIGS grains, and the thin CdS/ZnO layers.

Lateral Resolution	Vertical Resolution	Imaging/ Mapping?	3-D Profiling?	Vacuum	Sample/Tip Transfer
λ/10	—	—	—	—	—
Up to 1 Å (STM), 30 Å (AFM)	Up to 0.1 Å	Yes	Yes	10^{-11} torr range	Yes
Up to 1 Å (STM), 30 Å (AFM)	Up to 0.1 Å	Yes	Yes	—	Yes
Up to 1 Å	Up to 0.1 Å	Yes	Yes	10^{-10} torr range	Yes

the tip follows the surface contour. Used for analyzing rough surfaces, it produces high-resolution images that can be manipulated.

- Error mode. A technique that is performed more quickly than topography mode, by disabling the fast response of the feedback loop. This mode requires flat or polished specimens.
- Friction mode. A contact technique in which AFM records the friction between the material and the probe tip as the tip is scanned across the surface.
- Electrostatic force mode. A voltage applied between the sample and the tip induces an extra electrostatic force, which is linked to the surface potential and surface charge on the sample.
- Cross-section mode. Uses conventional contact or non-contact mode to analyze samples in cross-section. The cross-section is prepared by cleaving or breaking the original sample.

- Ultra-high vacuum of 10^{-11} torr range (vacuum AFM). Minimizes contamination of sample and deters the growth of an oxide layer. This enables more sensitive measurements.
- Vibration isolation. Isolating the instrument from vibration is one of the characteristics that enables the AFM to perform extremely sensitive measurements.
- Image manipulation. Allows the three-dimensional exploration of a sample from all angles and allows various kinds of manipulation that enhance analysis.
- Field of view — from atoms to about 100 µm. This type of range enables the AFM to address larger-scale problems, making it a complementary technique to scanning electron microscopy and transmission electron microscopy.
- Lateral resolution to 30 Å. Along with the sensitive vertical resolution, this feature allows topographic imaging and three-dimensional profiling on the nanoscale.



The NSOM, an NREL-designed and built instrument, is used for nanoscale characterization and for investigating submicron spatial variations in optical properties of materials. (Warren Gretz, NREL/PIX04542.)

Near-Field Optical Microscopy-Spectroscopy (NSOM)

This custom-designed analytical instrument is unique to the Measurements and Characterization Division. It uses a probe with a very narrow, extruded optical fiber tip coated with aluminum. Laser light is sent through the optical fiber, into the tip, and onto the surface of the material being analyzed. The tip, held just a few nanometers above the material, is scanned across the surface. As it is scanned, the laser light interacts with the surface, while a microscope monitors the interaction. Because it uses a tip that has such a narrow aperture that is scanned so closely to the surface, the spatial resolution obtained by the NSOM far exceeds that achievable with normal optical microscopes, which is fundamentally limited to half a wavelength (1/2 λ).

Applications

- Fundamental material studies. Used for investigating submicron spatial variations in optical properties of materials or devices.
- Nanoscale studies. Used to examine the optical absorption of individual defects and impurities, and thus, study their role in semiconductor materials. Also used for analyzing the PV effect on the nanoscale.
- Optical and spectroscopic studies. Valuable tool for exploring fundamental optical and spectroscopic properties of semiconductors.

Special Features

- Lateral resolution better than 1/10 λ.
- Continuous-wavelength laser source.
- Near-field optical-beam-induced current (NOBIC). Used for investigating the PV effect on the nanoscale and for examining the influence that individual defects or impurities may have on the PV effect.
- Nanoscale photoluminescence (PL).

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