GET THE PICTURE?

Seeing the World through Chemical Imaging

A picture's worth a thousand words—and a thousand data points too. Nothing conveys information to the human eye like a picture. We're all accustomed to photographs, which are optical images stored either on plastic film or digitally, but what about things that can't be seen with the naked eye? For example, X-rays don't really "see" your bones, but rather they interact with your bones in such a way that produces an image, in this case, a kind of density map of your bones. Methods of creating a "chemical image" are now so sophisticated that we can track the individual location of atoms or molecules in a given sample—such as a chemical mixture, a cell, or a silicon chip—and even how the atoms are moving and interacting within in the sample. As shown on this poster, chemical imaging is being used at the cutting edge of science and technology in many applications that improve our daily lives.

WHAT IS CHEMICAL IMAGING?

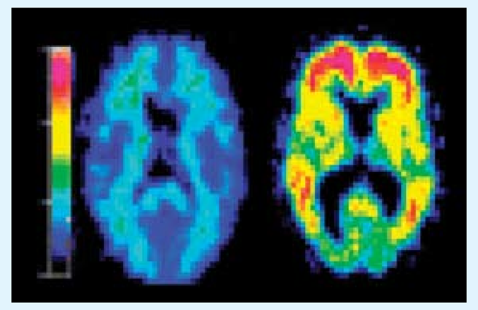
Chemical images create ways to visualize the chemistry of samples and reactions. They take advantage of a wide range of techniques, all of which rely on the interaction of light, radiation, or a probe with a given sample. Those interactions generate data that measure the sample in the three dimensions of space as well as time, and reveal other information about the sample including the chemical composition, the vibration between atoms in a molecule, and how complex molecules in the sample are arranged. The data are then processed to create an image, most often digital.

MEDICAL DIAGNOSTICS: THE PICTURE OF HEALTH

Most people probably aren't aware that the diagnostic procedures they undergo at the doctor's office are often chemical imaging techniques. X-rays are the most familiar, having been used since World War I to diagnose injuries and illnesses. Today, a variety of techniques including MRI, ultrasound, and PET scans are all standard diagnostic tools that are based on imaging. All provide doctors with a "picture" for assessing patient health.

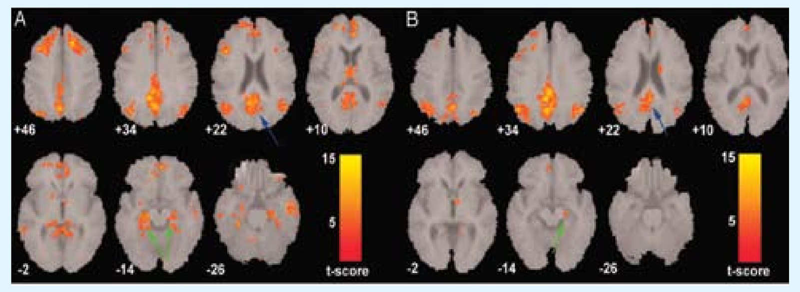
The first X-ray

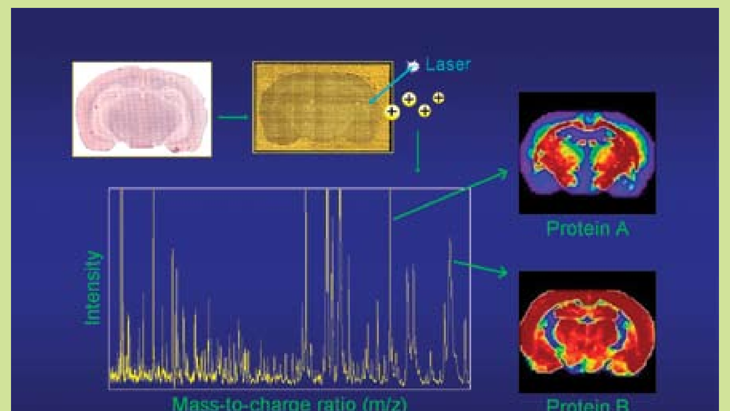
X-ray imaging has come a long way since the first X-ray taken in the late 1890s by Wilhelm Roentgen of his wife Bertha's hand. X-ray technology is still widely used in medical diagnostics but has also been developed for other uses including determining the molecular structures of various materials and creating 3D images of individual cells.



Two ways of looking at Alzheimer's disease

The image at left shows amyloid plaques in the brain of a patient with Alzheimer's disease. It was produced using positron emission tomography (PET), a technique that literally generates an image from the inside out: patients are injected with a short-lived radioactive isotope which emits positrons that are then detected with a scanner. **The image below**, produced through "functional" magnetic resonance imaging (MRI), compares fluctuations in the brain activity of healthy patients with those suffering from Alzheimer's disease. MRI uses a strong magnetic field and radio waves to excite, or "resonate," the protons of hydrogen atoms in the body. The amount and frequency of resonance provides information on the types of tissues present.



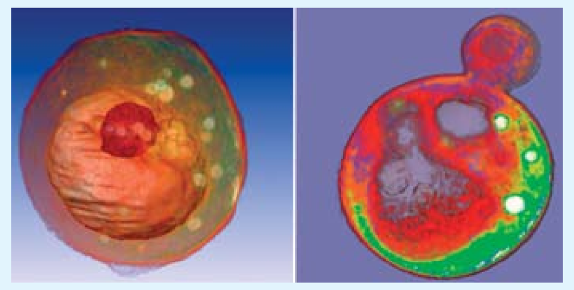


Extrapolating from your chemistry lab

Many students are familiar with spectroscopy and spectrometry tools used to identify chemicals in a given sample. These tools underlie many imaging techniques. In this figure, rat brain tissue is analyzed with mass spectrometry. A solution is used to create a "dotted array" over a thin slice of tissue. A laser then bombards the sample, producing a readout for each point in the dotted array. Each peak on the readout represents a different chemical species (protein in this case), identified by its unique "mass-to-charge ratio (m/z)." The height of each peak represents the intensity, or concentration, of protein at that point. These concentrations are then "color mapped" to create the images shown on the right, which represent two unique proteins in the tissue.

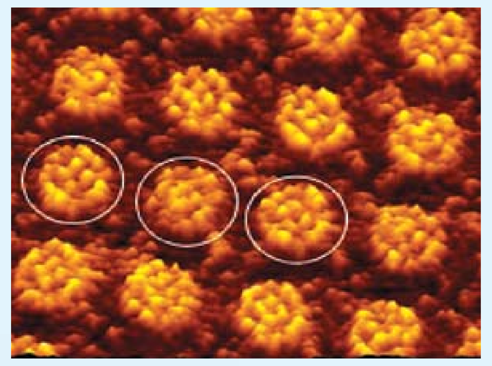
CELLULAR PROCESSES: IMAGING LIFE

Understanding and advancing the life sciences—including human and animal biology, agriculture, ecology, and environmental health—are dependent on our ability to visualize cellular processes in increasing detail. Chemical imaging is being used to reconstruct 3-D cells at 100 nanometer resolution that reveal important information about how different biological systems function.



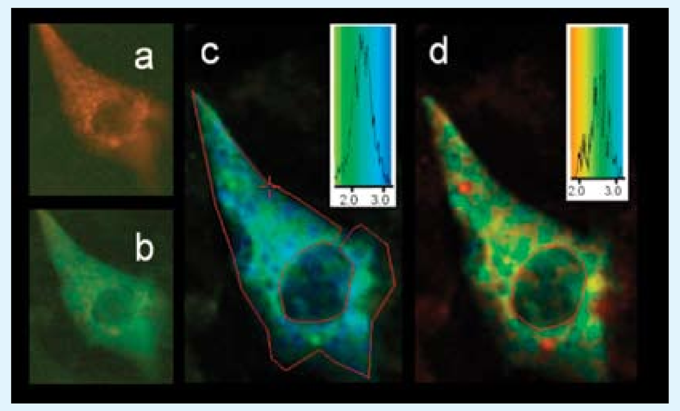
3-D image of a yeast cell

The process known as X-ray tomography produced this image of a frozen yeast cell. It is actually a series of images from X-ray data that have been combined to create a 3-D image. These types of high-resolution images make it possible to learn about individual structures in biological tissues.



Probes "read" a biological surface

Imaging helps us to understand important biological surfaces, such as this protein crystal thought to play a role in neurodegenerative diseases such as multiple sclerosis. This image was created using atomic force microscopy (AFM), a technique that drags or taps a tiny probe—only nanometers in diameter—across a sample's surface to measure peaks, valleys, and other features.

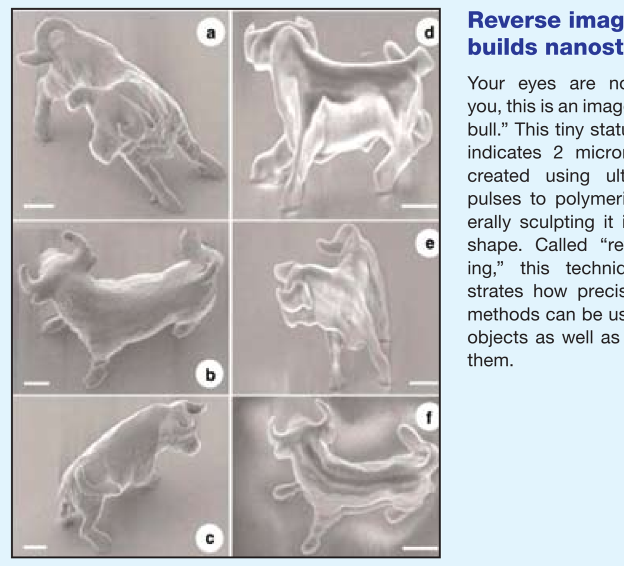


Fluorescent proteins "mark" biological structures

Various colors of fluorescent proteins (top) are now available to researchers to act as biological "markers" of processes in the body. The fluorescent proteins attach to specific proteins in the body so that they can be seen and studied. In the image (bottom), fluorescent molecules were used to study proteins in Chinese Hamster ovary cells. The image was created using two-photon fluorescence lifetime imaging (FLIM), which excites fluorescent molecules attached to the ovary proteins and creates a protein map. This technique can also be used to observe biological changes over time.

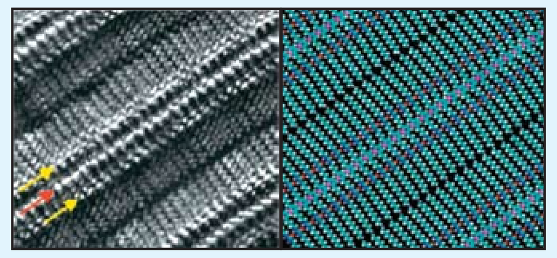
MICROELECTRONICS: SMALLER, MORE POWERFUL PARTS

The holy grail of electronics is the ability to make components smaller and smaller while increasing processing rate and improving other measures of performance. In microelectronics, not only do researchers need to "see" things on small scales, but the imaging technologies can actually be used "in reverse" to build tiny structures. Reverse imaging is now routinely used to pattern a surface in order to place tiny metal parts where they are needed on electronic components.



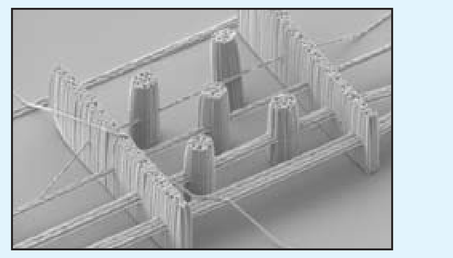
Reverse imaging builds nanostructures

Your eyes are not deceiving you, this is an image of a "nanobull." This tiny statue (scale bar indicates 2 micrometers) was created using ultrafast laser pulses to polymerize resin, literally sculpting it into this tiny shape. Called "reverse imaging," this technique demonstrates how precision imaging methods can be used to create objects as well as characterize them.



Using organic materials in electronic devices

Scanning tunneling microscopy can be used to study the orientation of individual molecules on a surface. This image shows a thin layer of organic material (sulfur-containing compounds) on a hard surface. The image shows how the long molecular "tails" of the compound align with each other on the surface, which is critical to how well the material can transport current within an electronic device. The image on the right is colorized to make it easier to identify different parts of the molecule.

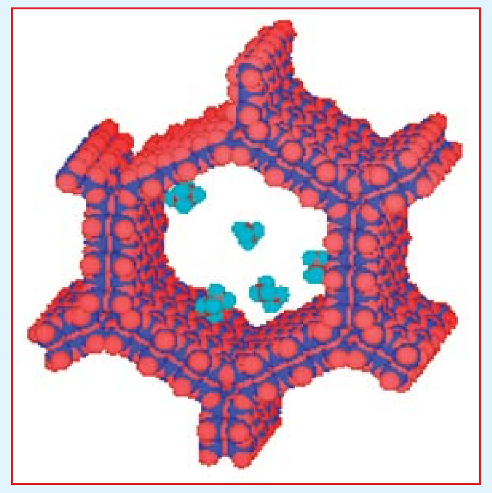


X-rays create tiny circuit boards

In this example of X-ray nanolithography, directed electron beams and X-rays were used to precisely machine a pattern, which was then used to create this structure of pillars and wires, another example of reverse imaging.

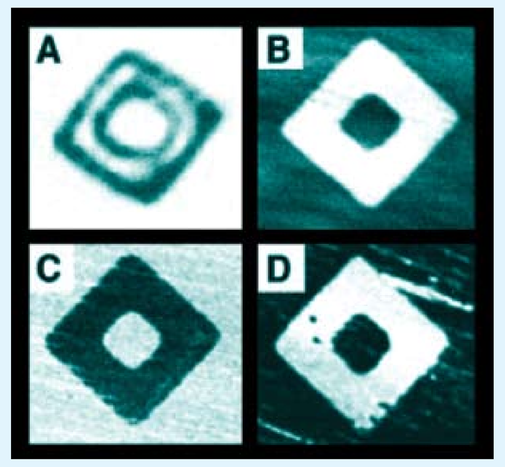
ADVANCED MATERIALS: FOR BETTER LIVING

Plastics, Teflon®, and special paints are just a few of the advanced materials that have brought new conveniences and advantages to our lives. All these products have been engineered to give them desired characteristics. The science of advanced materials is increasingly happening at the nanoscale level and by mimicking the "self-assembly" of molecules that occurs in nature. Scanning probe imaging is being used to better understand self-assembly with the hope that Mother Nature's ways might be harnessed to make new materials in the laboratory.



Self-assembled molecule structure

This colorized image depicts a structure called MCM-41, which is a self-assembled molecule. MCM-41 is of interest because the insides of the honeycomb structure can be manipulated so that confined catalytic reactions can take place within it. The image was produced from an accumulation of X-ray crystallographic data that was then fed into a computer program and modeled.

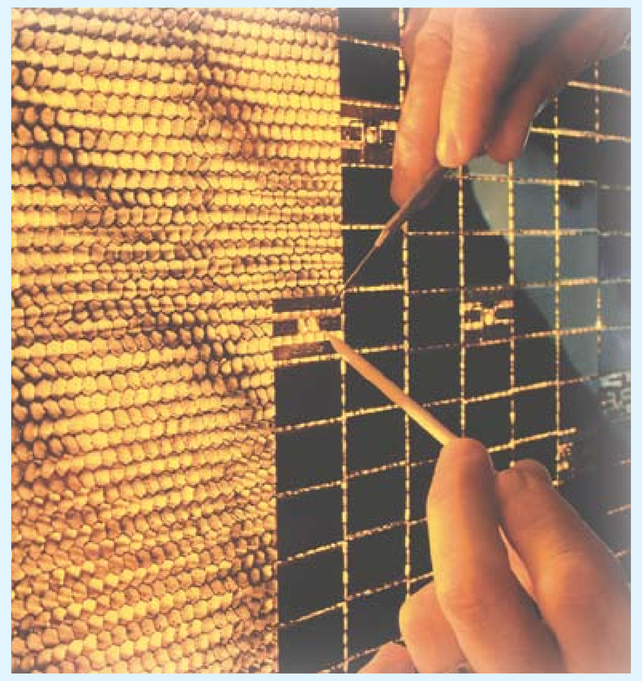


Chemically-fitted probes read detailed surfaces

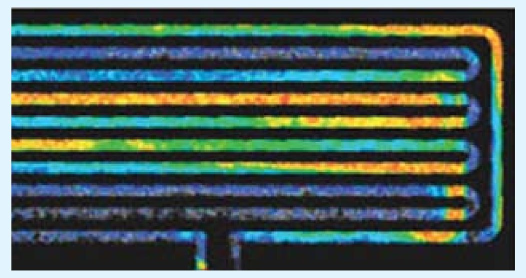
The clear chemical pattern on this self-assembled organic surface was obtained by scanning the surface with probes fitted with specific chemicals. The amount of friction force measured between the surface and the probe generates the image.

ENERGY TECHNOLOGIES: EFFICIENT REACTIONS FOR EFFICIENT ENERGY SOURCES

Fuel cell technology is considered by many to be the key to developing a sustainable energy future. Fuel cells, batteries, and solar panels transform and store energy through the creation of a reaction within the fuel cell of a solid, liquid, or a gas with a surface. The more efficient these reactions are made, the more efficient the energy source. In these applications, imaging is used to understand and manipulate the reactions taking place on a surface.



Manufacturing of a solar cell

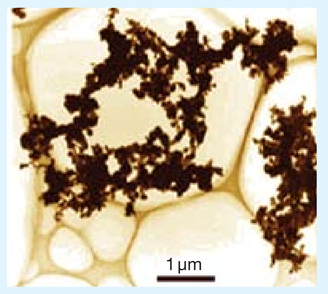


Neutron diffraction of fuel cells

Seeing the location and movement of water in a fuel cell is important to understanding whether the fuel cell is functioning efficiently. This image was created using neutron diffraction, a process in which the fuel cell is bombarded with neutrons and the resulting diffraction pattern shows where the nuclei of water molecules are located. Pseudo-color has been added to make the image easier to interpret.

High energy images of a rechargeable battery

These high-resolution images were produced using scanning transmission electron microscopy (STEM), a technique that sends high-energy electrons through a sample. In this case, STEM was used to help visualize the structure of nickel powders in rechargeable batteries. Note the tiny size of the sample being studied here: 1 micrometer (μm) = 10^{-6} meter; 1 nanometer (nm) = 10^{-9} meter.



A BRIEF HISTORY OF MRI

In 1946, Felix Bloch and Edward Purcell discovered that when hydrogen atoms in a strong magnetic field were bombarded with radiowaves, the unpaired proton in the hydrogen nucleus produces a "nuclear magnetic resonance (NMR)" signal that could be measured. From 1950-1970, NMR was developed and used for molecular analysis. In 1971 Raymond Damadian showed that the nuclear magnetic resonance relaxation times of tissues and tumors differed, motivating scientists to consider magnetic resonance for the detection of disease. The advantage of NMR, or magnetic resonance imaging (MRI) as it has come to be known, is that unlike X-rays, MRI poses no health risks to the patient. Throughout the 1970s, researchers worked on reducing the time it took to image the human body using NMR. By 1986, tissues of the human body could be imaged in only 5 seconds. As of 2003, there were approximately 10,000 MRI units worldwide, and approximately 75 million MRI scans per year performed.

1946	1950 — 1970	1971	1970s	1986 — Today
NMR concept discovered	NMR developed for use in molecular analysis	Proof of MRI concept for medial applications	Application development	Widespread use of MRI.

This poster is based on the 2006 National Research Council report, *Visualizing Chemistry: The Progress and Promise of Advanced Chemical Imaging*. The report reviews the state of the science of chemical imaging and identifies the improvements that, if made, could best advance our ability to solve the most critical science and technology problems. The report was sponsored by the National Science Foundation, U.S. Department of Energy, U.S. Army, and the National Cancer Institute of the National Institutes of Health. The National Research Council is the operating arm of the National Academies.

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