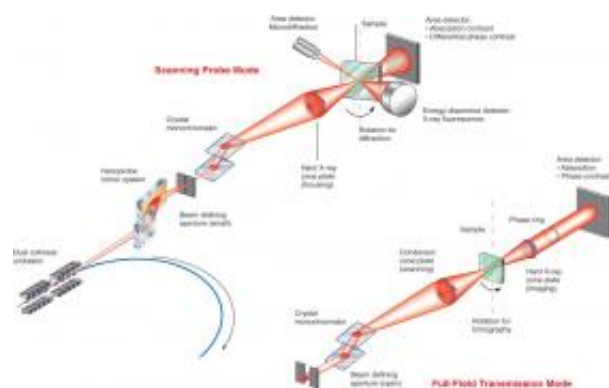


Seeing the small picture: X-ray nanoprobe pushes observation to ever smaller frontiers

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The Hard X-ray Nanoprobe (HXRN) works by focusing a bright X-ray beam onto a tiny spot through a series of mirrors and optical plates. Depending on the sample they wish to study, Argonne researchers can operate the HXRN in one of two different modes.

(PhysOrg.com) -- Try to picture putting some atoms under a microscope. Even if you could pick them up, put them on a slide and get them to stay still, you still could not see them with even the most powerful optical microscope.

The reason? The wavelength of visible light measures hundreds of nanometers, the span of thousands of atoms. To zoom in all the way to the atomic level, scientists from all over the world use the high-energy X-rays produced by Argonne's Advanced Photon Source (APS).

The quest to image tiny structures and their environments presents a complex challenge and valuable scientific opportunity. The molecular processes involved in the functions of our bodies at the cellular level, as well as the chemical and physical properties that characterize materials, depend on compositional, structural and electronic properties at the micro-, nano- and atomic scale.

The frontier of materials science has for some time pushed into the nanoscale, where objects are measured in billionths of a meter. Researchers continually strive to better understand nature at ever smaller length scales and to more precisely manipulate systems to benefit humanity and the environment. From the next generation of superconductors to solar cells to cancer treatments, the ability to image tiny structural features has the potential to make a big impact.

To enrich our understanding of the nanoscale properties of complex systems, materials and devices, scientists come to Argonne to employ the laboratory's new hard X-ray nanoprobe, which is jointly operated by Argonne's Center for Nanoscale Materials and Advanced Photon Source. This system can currently resolve structures as small as 30 nanometers - a distance roughly equivalent to the width of 100 atoms and less than 1/1000 th the diameter of an average human hair.

While other forms of imaging - electron microscopy, for example - can reveal even smaller details close to a sample's surface, the high-energy X-rays generated by the APS can penetrate into a material's bulk to reveal buried structures and interfaces. "X-ray imaging gives scientists a unique window into complex systems, allowing us to see their structure, composition and dynamics," said Argonne nanoscientist Jörg Maser, who runs the nanoprobe.

The nanoprobe works much like an optical microscope, but uses X-rays instead of visible light. These brilliant X-rays are tailored to the

requirements of individual experiments by a series of X-ray mirrors and crystal optics in the nanoprobe beamline. In the final step, a Fresnel zone plate focuses this "conditioned" beam on the specimen.

Unlike refractive lenses used in an optical microscope, Fresnel zone plates focus X-rays using diffraction. In principle, this approach could allow scientists to one day focus X-rays to spot sizes smaller than 10 nanometers. "The smaller the spot to which we can focus our beam, the smaller the structures we can observe," Maser said.

In most of the scattering experiments performed to date, scientists have been able to determine only the intensity of the X-ray that hits the detector. However, by using more sophisticated X-ray techniques - such as coherent diffraction - scientists can extract not only the intensity of the X-rays, but also their phase. "The name of the game is 'how do you determine the phase of your wavefront,'" said Argonne materials scientist George Srajer. "This allows us to fully exploit the information carried from the sample by the X-rays. Amplitude and phase information go hand-in-hand."

By taking advantage of the phase information contained in coherent X-rays, Argonne's researchers can more accurately resolve the structure of their specimens, even without advanced X-ray optics like zone plates. Synchrotron radiation sources like the APS are built expressly to provide X-rays with proper coherence. "In the end, what we are really trying to create is an ultra-high-resolution image in real space, as we would see if we could just take a picture of the sample with a camera," Maser added. "That is possible if we can determine both the amplitude and the phase, which requires coherent X-rays."

By shining hard X-rays instead of visible light onto their small samples, Argonne's scientists can also study biological cells and tissues. In one experiment, Argonne researchers are using the APS' X-rays to image

blood vessels as they form and branch out. This process, known as angiogenesis, occurs as one of the most important steps in the healing of wounds. However, cancerous tumors can also perform angiogenesis, which allows cancer cells to grow and spread. With the unique ability to observe angiogenesis at the subcellular level, Argonne's scientists help to discover ways to inhibit the growth of blood vessels in cancerous tissues. "It's almost like having Superman for a doctor - using hard X-rays to find cures for problems far more severe than just broken bones," Srajer said.

In order to do these types of biological experiments, Argonne's scientists require a device that can detect the presence of small amounts of particular compounds in highly dilute solutions. By using the nanoprobe or other APS microprobes, researchers can study trace metal distributions in cells at ever finer spatial resolution. These high-resolution tools provide Argonne researchers with the capacity to study the cellular processes important in normal physiological function and in disease.

The different types of information revealed by X-ray optics also allow researchers at the APS to investigate material processes as they occur. These experiments, known as in situ studies, give scientists a deeper understanding of material properties than they can glean from disconnected structures. The real benefit of in situ studies comes from the ability to modify materials while they are being observed.

The basic scientific explorations carried out at the APS hold the potential to spawn a new generation of products and inventions that will improve our lives and stimulate the economy. In one in situ experiment, researchers exposed parallel layers of silicon to a small, well-defined stress, which caused a tiny displacement of the atoms in the material.

The mismatch created regions through which electrons could pass more

smoothly, like water pouring through a crack in a seal. Unlike visible light, the X-rays produced by the APS enabled the scientists to see the small displacements. This information, Maser said, could lead to the production of enhanced semiconductors for a new generation of microprocessors.

The combination of the world's finest X-ray tools and sophisticated imaging techniques has allowed scientists and engineers who use Argonne's research facilities to reach a deeper understanding of the small-scale processes and interactions that surround us. The new discoveries Argonne scientists make every day foster advances in basic knowledge and the development of breakthrough technologies that improve our health, our economy and our environment.

Provided by Argonne National Laboratory

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