

LIGHT



Mastery of new materials has transformed the quality of life throughout history. Bronze and iron, basic to the rise of our civilization, have distinct historical epochs named after them. Steel, aluminum, plastics and a host of other materials accelerated progress in more recent eras, and semiconductors – most notably silicon – are at the heart of the computer revolution.

Research with increasingly sophisticated instrumentation has been essential to progress in materials science. Developing theoretical models to increase our fund of materials knowledge requires probing such fundamental properties of matter as atomic, electronic and spin interactions and their interrelationships. It's a



quest that continues at Brookhaven National Laboratory in New York State, engaging NJIT Physics Department members Professor Trevor Tyson, Associate Professor Andrei Sirenko and Associate Professor Tao Zhou. At Brookhaven, the National Synchrotron Light Source (NSLS) is central to their work.

The two NSLS accelerator rings produce intense beams of “synchrotron light” over a broad range of energies and at frequencies which, in general, are invisible to the human eye. One ring is dedicated to research in the x-ray region of the electromagnetic spectrum and the other to the ultraviolet and infrared regions.

Synchrotron light and appropriate end-user instrumentation can illuminate a great deal about the atomic structure, dynamics, and magnetic and electrical properties of materials, as well as other key characteristics. Tyson, Sirenko and Zhou have designed and installed new and more capable instrumentation on each ring at the NSLS. Tyson has also supervised the installation of an advanced system for materials research at NJIT.

These efforts could lead to breakthroughs in theoretical modeling for high-temperature superconductivity, and for electronic and optical applications involving ferroelectric phenomena as well as combined ferroelectric and ferromagnetic systems. They could promote development of alternatives to

fossil fuels for producing electric power – including materials for innovative battery, hydrogen and solar technologies.

“Materials science has entered a fascinating era in which new microscopy and imaging technologies give direct evidence that atomic structures predicted by theory do, indeed, exist,” says Donald H. Sebastian, NJIT’s senior vice president for research and development. “Our researchers are creating the next generation of instrumentation that now probes the atom itself – with the prospect of creating a technology base leading to advanced materials with the power to revolutionize every field of application imaginable. We are truly fortunate to have faculty members like Trevor, Andrei and Tao, who are quite literally at ‘the edge in knowledge’ of this fast-evolving field.”

ENHANCING A REGIONAL RESOURCE

The three NJIT faculty members are helping to enhance Brookhaven’s capabilities as a regional resource serving investigators from universities, industry and government. With a \$530,000 grant from the National Science Foundation (NSF), Sirenko and Zhou have recently added a spectroscopic ellipsometer to one of the NSLS infrared beamlines, or research stations. NJIT also manages access to the new instrument for all researchers. A growing number of requests for “beamtime”

Associate Professor Andrei Sirenko at Brookhaven with the far-infrared ellipsometer that he developed with Associate Professor Tao Zhou for the National Synchrotron Light Source.

are coming from other U.S. universities and foreign institutions.

Spectroscopic ellipsometry is a powerful technique for materials research in fields ranging from semiconductor physics to biology. It is non-destructive and does not require physical contact with a sample. Analysis of how reflected light is polarized facilitates investigation of materials down to a single atomic layer, providing information about structure, chemical composition, electrical conductivity and other properties.

NJIT’s technical and managerial responsibilities at Brookhaven underscore the university’s standing in the scientific community. “No single university can build and maintain a facility like the NSLS,” Zhou says. “But we can individually make contributions needed to take full advantage of its capabilities.”

For their own research, Sirenko and Zhou plan to study materials that include multiferroics and superconducting films. Better understanding of multiferroics – in which unique electric and magnetic properties co-exist – could lead to data-storage devices with speeds and capacities not possible at present. The potential of superconductivity, especially



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if it can be sustained at or near room temperature, ranges from the transmission of electricity with virtually no resistance to wide deployment of magnetic levitation trains capable of operating above 300 miles per hour.

“Adding state-of-the-art instrumentation to the NSLS is very significant for the future of science and engineering in the U.S.,” Sirenko says. “We’re all part of an effort that encourages the spirit of cooperative research most likely to produce important results.”

SHEDDING LIGHT ON INVISIBILITY

As Sirenko explains, the far-infrared ellipsometer that he and Zhou have developed for the NSLS provides greater capabilities for observing the difference between electrical and magnetic effects. The equations that James Clerk Maxwell formulated in the 1860s prove that electricity and magnetism are coupled in nature. However, while materials researchers have an increasing need to distinguish between magnetic and electrical phenomena, they have found it very challenging to do so for many experiments.

With the help of the new ellipsometer, it will be possible to study magneto-electric effects in optics and advance understanding of the mutual interaction between electrical and magnetic optical excitations. One potential goal is to identify new materials that allow full control of how they propagate light, which

might even make it possible to bend light around objects in a way that renders them “invisible.” This could lead to the ultimate stealth technology. Although still in the realm of science fiction, Sirenko speculates that the ability to manipulate light in an appropriate manner could make the spacecraft “cloaking device” envisioned by the creators of *Star Trek* a reality, at least in the far-infrared spectral range.

A DECADE AT THE X-RAY RING

Over the past decade, NJIT has had a major role in operating and upgrading the NSLS x-ray ring, where the university jointly operates two beamlines for scattering and spectroscopic studies under a program organized by Tyson. In addition to serving on the panel that reviews research proposals for the NSLS, he is a member of panels that oversee funding, operations and development of new light sources at other national synchrotron facilities.

With more than a hundred publications, Tyson is one of the most highly cited researchers in the physical sciences at NJIT. Starting with an NSF Faculty Early Career Award, his work has been substantially funded by the NSF and the U.S. Department of Energy. Awards for his synchrotron-based research have totaled over \$4 million, including more than \$2 million for unique instrumentation.

Tyson’s group developed one of the first high-resolution x-ray emission spectrometers

NSLS AT BROOKHAVEN

A UNIQUE LIGHT IN NEW YORK

The National Synchrotron Light Source (NSLS) is located at Brookhaven National Laboratory in Upton, New York, within the greater area of the Town of Brookhaven on Long Island. Established in 1947, it is staffed by some 3,000 scientists, engineers, and other personnel. Brookhaven each year hosts thousands of guest investigators, including researchers from NJIT. Discoveries at the facility have won six Nobel Prizes.

The Brookhaven laboratory was originally dedicated to nuclear research. The scope of work has expanded greatly, and today the lab operates under the auspices of the U.S. Department of Energy. The NSLS, commissioned in 1982, is one of the most extensively used research facilities in the world. In addition to materials science, investigators from universities, government and industry pursue a wide range of other studies in chemistry, the biological and environmental sciences, and medicine.

The two NSLS rings accelerate electrons to produce beams of “synchrotron light” at specific frequencies. The x-ray ring is 170 meters (557 feet) in circumference with approximately 60 beamlines, or experimental stations. NJIT belongs to Participating Research Teams that jointly operate two of the x-ray beamlines. An additional 25 beamlines are available at the vacuum ultraviolet ring, which produces mostly ultraviolet, visible and infrared light. This ring is 51 meters (167 feet) in circumference. Now under construction at Brookhaven, the NSLS-II facility will produce x-rays more than 10,000 times brighter than the current NSLS, offering capabilities vital for further pioneering research.

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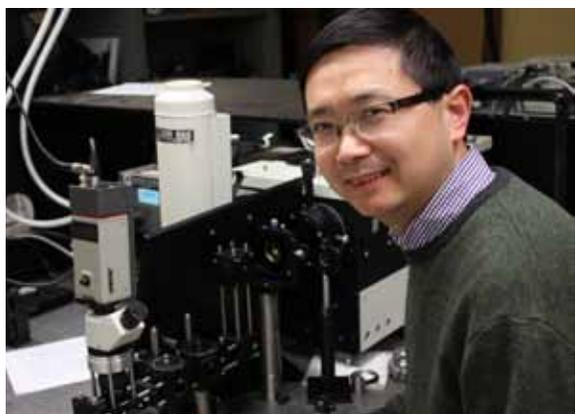


PHOTO: JOHN MICALÈ

Associate Professor Tao Zhou

in the U.S. and a compact system for routine measurements. These instruments enable accurate determination of electronic structure and valence as well as direct measurement of magnetic properties. The innovative concepts and methodology stemming from this effort have provided key support for the proposal to build a beamline at the new NSLS-II synchrotron ring dedicated to x-ray emission studies. They have also led to the development of instrumentation at other facilities – at Argonne National Laboratory’s Advanced Photon Source, for example, where researchers are evaluating materials that could be used to produce better batteries.

The high-resolution spectrometer is a potent tool for research that includes investigating the characteristics of transition metal oxides. Studying these materials could yield insights into new types of superconductors containing iron, active metal sites in protein molecules, nanoscale carbon and boron nanotubes and nanoribbons, as well as more efficient energy storage in batteries.

INTERNATIONAL INTEREST

Three new types of detectors with unequaled counting rates are also being developed under Tyson’s guidance. Lack of this capability has impeded synchrotron research around the globe, since no commercial system can deal with the high levels of radiation that can be produced. The detectors have already had a positive impact on research in the emerging field of x-ray holography.

Investigators will have access to the new detectors at ten NSLS x-ray beamlines, and researchers worldwide are expressing interest in collaborative use of the equipment. Envisioning even greater experimental utility, the innovative detectors are a key component of the proposal put forward by Tyson and an international group of scientists for a high-pressure, high-magnetic-field beamline.

Additionally, in collaboration with a commercial manufacturer, Tyson and his colleagues are helping to develop high-magnetic-field systems specially designed to operate in the steel enclosures at synchrotron facilities. Incorporating permanent magnets as well as superconducting magnet technology, the systems provide control of the magnitude and direction of magnetic fields and offer enhanced capabilities for x-ray experiments. Subjecting samples to both high pressure and strong magnetic fields makes it possible to study states of matter that produce novel physical properties, among them superconductivity.

WIDE-RANGING RESEARCH

The capabilities of the NSLS x-ray ring are invaluable for the efforts of NJIT investigators and other researchers in fields such as chemistry, biology, geology and physics. For example, NJIT Professor Lisa Axe, Civil and Environmental Engineering, has conducted x-ray studies of heavy metals found in dredged sediments, and Assistant Professor Xianquin Wang, Chemical Engineering, has researched catalytic control of the atmospheric pollutant sulfur dioxide.

The NSLS equipment is also available to NJIT undergraduate and graduate students. Under Tyson’s supervision, ten NJIT PhD candidates have completed their dissertations. These graduates are now teaching at U.S. universities, designing x-ray systems for medical use, developing novel materials for the electronics industry, and applying innovative x-ray techniques to the study of materials under high pressure in the earth’s interior.

ON THE NJIT CAMPUS

NSF funding of more than \$280,000 that Tyson has received is also moving materials research forward on the NJIT campus. Awarded under the American Recovery and Reinvestment Act of 2009, the grant has allowed acquisition of a sophisticated system for studying materials critical to innovative energy technologies – such as more efficient batteries and photoelectric solar cells.

In addition, the system will be a significant educational resource for NJIT students. It will be especially important for those enrolled in the master’s program in materials and energy efficiency that NJIT is developing.

Newark-area high school students will benefit, too, particularly those from groups underrepresented in scientific and technological fields. For more than five years, Tyson has engaged young men and women in summer programs focused on materials research. The goal is to increase the students’ scientific literacy and motivate them to consider careers in science, engineering and technology.

Participants learn basic chemistry, electronics, physics and computer programming through hands-on experiments with materials that are potential high-temperature superconductors and storage media for hydrogen transportation fuel. The experience includes trips to the NSLS to measure the spectra of samples that the students have prepared.

“It is serious materials research tailored to the level of their abilities,” Tyson says. “These young people come to NJIT and learn what

science can accomplish in the real world, and what education at the college level can mean in their lives.” ■

Author: Dean L. Maskevich is editor of NJIT Magazine.

Below: Leading NSLS investigator Professor Trevor Tyson (far right) and student researchers working with the physical properties measurement system recently installed at NJIT. From left are PhD candidates Tian Yu and Tao Wu, and post-doctoral student Peng Gao.

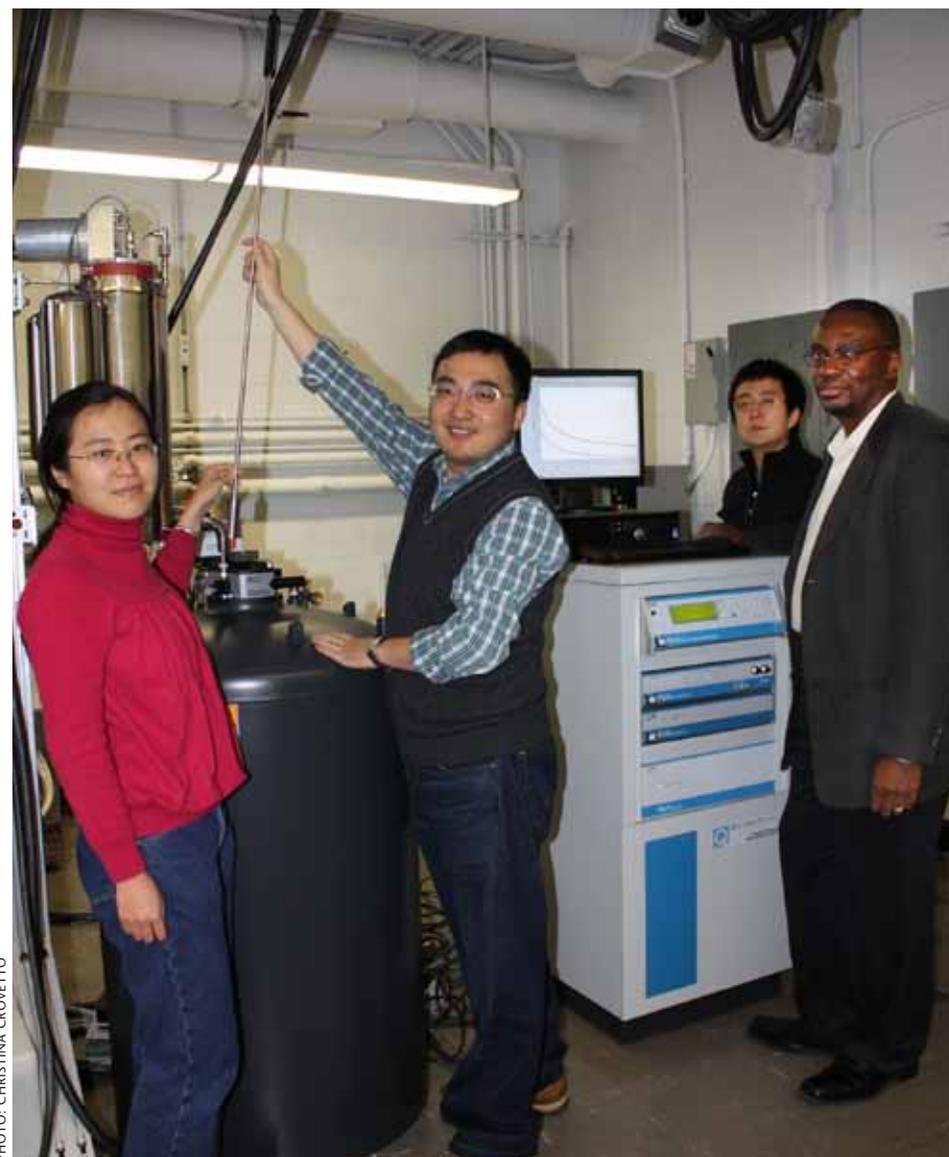


PHOTO: CHRISTINA GROVETTO

NJIT SCIENCE

ALTERNATIVE ENERGY INSIGHTS AT NJIT

The new physical properties measurement system at NJIT will be a valuable tool for developing materials vital to cutting our consumption of fossil fuels. The system can be used to analyze and optimize materials for fuel cells, new types of batteries, solar generation of hydrogen from water, hydrogen storage, and other leading-edge technologies. It will also be integral to educational initiatives such as a new MS program focused on materials and energy efficiency, and a program that promotes careers in science and technology among Newark-area high school students.

The instrumentation's capabilities include determining the thermal-transport, heat-capacity and electron-transport properties of materials. Optical investigation via light pipes and fiber optic cables facilitates the study of photovoltaic systems and materials for the photo-electrochemical production of hydrogen.

Measurements over a temperature range of 2 K to 400 K (-457°F to 260°F) are possible. The availability of strong magnetic fields enables investigation of particle spin and thermal properties. An integrated system for recovering the liquid helium needed makes operation cost-effective and allows continuous availability to students and researchers.

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