MAKING THE WORLD'S SMALLEST CONNECTIONS

Research Professor Reginald Farrow, Department of Physics, and the group he leads have discovered how to make the world's smallest probe for investigating the electrical properties of individual living cells. Larger electrical probes have been extremely important in understanding these properties, as indicated by the Nobel Prizes awarded to the inventors of two previous generations of probes.

Farrow's probes use carbon nanotubes that can be spaced a small fraction of a micrometer apart, allowing minute parts of a single cell to be studied with many nanoprobes. Furthermore, the larger probes restrict cell functions while the new nanoprobes do not. Besides increasing basic knowledge of cell physiology, these probes have practical applications such as testing the toxicity of drugs, since the distribution of electrical charges in a healthy cell changes markedly when it becomes distressed.

Carbon nanotubes are very strong, electrically conductive structures a single nanometer in diameter. That's one-billionth of a meter, or approximately ten hydrogen atoms in a row. Farrow's breakthrough is a controlled method for firmly bonding one of these submicroscopic, crystalline electrical wires to a specific location on a substrate. His method also introduces the option of simultaneously bonding an array of millions of nanotubes and efficiently manufacturing many devices at the same time.

The technical community has been quick to recognize Farrow's achievements, and he has brought substantial recognition to NJIT. For his success, Farrow has been honored with the 2012 NJIT Overseers Excellence in Research Prize and Medal.

Being able to position single carbon nanotubes that have specific properties opens the door to further significant advances. Other possibilities include an artificial pancreas, three-dimensional electronic circuits, and fuel cells with unparalleled energy density.

POWERFUL TECHNOLOGY

Farrow's cutting-edge work with nanotubes has already had a key role in advancing the development of a unique biofuel cell.

Research Professor Zafar Iqbal, Department of Chemistry and Environmental Science, had created a potentially more efficient alternative to conventional batteries that employs an enzyme to convert sugar into electrical energy. Iqbal's design incorporated positive and negative plates, an anode and cathode, in a configuration similar to that found in all fuel cells.

Farrow and his team connected one end of a nanotube electrically to a circuit and an enzyme to the other end. They also fabricated an array on a single plate with multiple nanoscale biofuel cells. Since each is so small, there is negligible internal resistance, which typically causes substantial energy loss. The power density is the highest ever achieved using the enzymes selected.

[continued]

Research Professor Reginald Farrow is the recipient of the 2012 NJIT Overseers Excellence in Research Prize and Medal.

"Imagine electrical circuits that have billions of highly efficient submicron-sized batteries powering individual components," Farrow says. "We've created new engineering that can scale down the AA batteries in a television remote to the molecular level. But it's engineering we can use to create power sources on a larger scale as well, devices that are much lighter and contain less toxic material than the typical battery." It's engineering that could also lead to minimally invasive physiological monitoring, targeted drug delivery, brain and spinal stimulation, and other medical applications using nanoscale devices powered by the body's own glucose and oxygen.

Farrow's work with carbon nanotubes has put his name on three patents as lead inventor. But in speaking about this success, Farrow emphasizes its cooperative, multidisciplinary character. Of the biofuel cell effort, he says that it was Iqbal who laid the groundwork with his expertise in converting chemical energy into electrical energy, and that in-depth knowledge of enzyme chemistry and electronics was required as well. He also cites the nanofabrication skills of Assistant Research Professor Alokik Kanwal, who came to NJIT as a postdoc in 2008. "When it comes to efforts like this, you really need lots of different expertise to make things work."

INSPIRED BY THE LASER

Farrow says that reading about the laser as a young teenager is what started him on the path to becoming a scientist. "I was fascinated by the laser. I also learned that it was created by physicists, and that physicists worked at a place called Bell Labs. So I decided that I was going to become a Bell Labs physicist."

Earning BS, MS and PhD degrees in physics, that's exactly what Farrow did.

For more than two decades at AT&T Bell Laboratories and the spinoff Agere Systems, Farrow worked in materials science. He applied his expertise mainly to electron microscopy and the challenges of fabricating increasingly complex integrated circuits with extremely small components. But he also had the goal of one day moving to the academic world as a researcher and teacher, a transition eventually facilitated by his friendship with NJIT Professor of Physics Gordon Thomas.

Farrow met Thomas, then a graduate teaching assistant, as an undergraduate at the University of Rochester. Many years later, it was Thomas who invited Farrow to join him at NJIT, which he did in 2004. Since then Farrow has supported his work with major government grants, including funding from the U.S. Defense Advanced Research Projects Agency and the U.S. Army's Armament Research, Development and Engineering Center. This support, and Farrow's dedication to fostering intellectual synergy among diverse disciplines, has produced intellectual property with a wealth of potential for new commercial technology and for NJIT.

In addition to his technical knowledge of microelectronics, Farrow came to NJIT with a strong personal interest in biophysics and experience connecting efforts by teams with wide-ranging abilities. Early on at the university, he collaborated with Thomas on a project which engaged the full scope of his professional background and interests. That effort produced the recently patented SmartShunt™, a unique device for monitoring cerebrospinal fluid pressure in individuals suffering from hydrocephalus or brain injury.

While contributing to the SmartShunt™ project, Farrow simultaneously investigated how to make things work in another area – and on a much smaller scale.

THE CELLULAR CONNECTION

Several years before joining the NJIT faculty, Farrow completed a major project at Bell Labs that involved the precise vertical alignment of minute integrated circuits and interconnection with micron-sized wires, thus increasing the density of circuit components and their operating efficiency. This work and his growing interest in the electrical properties of living cells led him to think about the potential – and far greater difficulties – of making electrical connections to cells without impairing their physiology.

At NJIT, Farrow was able to investigate ways to make this cellular connection. He determined that the most promising approach was to use carbon nanotubes. And

"WE'VE CREATED NEW ENGINEERING THAT CAN SCALE DOWN THE AA BATTERIES IN A TELEVISION REMOTE TO THE MOLECULAR LEVEL."

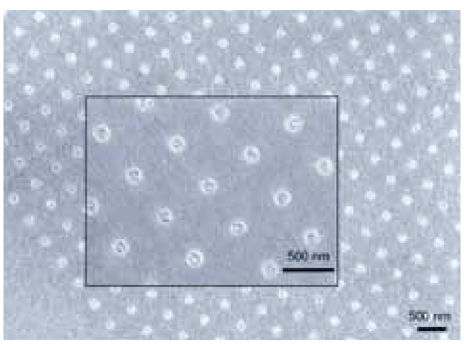
– Research Professor Reginald Farrow

each connection necessary would have to be made with just one nanotube.

Ever since the discovery of carbon nanotubes decades ago, researchers have tried to overcome a daunting obstacle to realizing their usefulness. These structures are so small that it is extremely difficult to manipulate them individually into a specific position or orientation. The applications envisioned by Farrow required precise positioning of single nanotubes with specific electrical properties.

The solution was electrophoresis, the electrically directed motion of particles in a fluid. Farrow refined the technique by guiding a team that included PhD students Amit Goyal '07 and Sheng Liu '08.

One day after running a test, Goyal came to Farrow with a scanning electron microscope image that showed a single nanotube oriented nearly vertically in the center of a much larger hole on a substrate. Their expectation was to see multiple nanotubes in each hole. It turned out that an electrical field forms around the holes under the right conditions and can be used to guide individual nanotubes to a metal at the bottom of the hole.



Scanning electron microscope image of carbon nanotubes deposited on metal inside windows approximately 100 nanometers in diameter in silicon nitride. The nanotubes were deposited using electrophoresis.

"Amit thought he might have done something wrong," Farrow recalls. "I told him he had done something wonderful, positioning an object one nanometer in diameter using a technology a hundred times easier than any other technique. Magic does happen in science at times."

EDUCATOR AND RESEARCHER

As gratifying as his research has been, Farrow says that another aspect of being at NJIT gives him even greater satisfaction. "The students," he says without hesitation.

"What we do at NJIT is transformational. We take students from every background and help them become professionals who can succeed in many, many fields. It doesn't happen with every student, but it does happen with most. Watching that transformation and being part of it has to be the most rewarding experience for anyone who's a professor."

It's Farrow's hope that the skills and knowledge NJIT students acquire will sustain U.S. leadership in science and technology, and that the necessary resources will be available. But he does acknowledge the international dynamic of scientific research and progress in the 21st century.

AWARD WINNERS

EXCELLENCE IN THE SEARCH FOR NEW KNOWLEDGE

Initiated in 2008, the NJIT Board of Overseers Excellence in Research Prize and Medal honors individuals who have been NJIT faculty members for at least five years and whose work has significantly advanced knowledge in their field of expertise as well as the reputation of the university.

In 2012, Research Professor Reginald Farrow joins the four other exceptional members of the NJIT community who have been awarded the NJIT Overseers Excellence in Research Prize and Medal since its inception:

2011 – Haim Grebel
Professor of Electrical and Computer Engineering

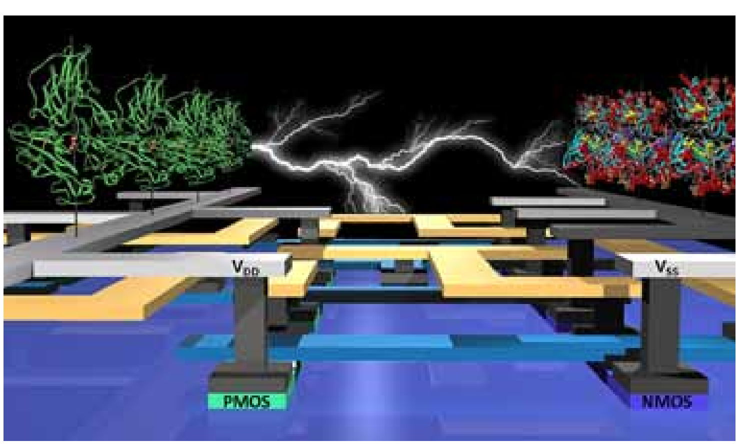
2010 – David B. Rothenberg
Professor of Humanities

2009 – Kamalesh K. Sirkar
Distinguished Professor of Chemical Engineering and Foundation Professor in Membrane Separations

2008 – Philip R. Goode
Distinguished Professor of Physics and Director of the Center for Solar-Terrestrial Research

"The search for answers to the questions we have about the world around us is happening in many places. The beauty of the human mind is that curiosity and creativity does not speak any one language." ■

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



Conceptual illustration showing how a series of nanoscale biofuel cells would power an integrated circuit. The power for each complementary metal oxide transistor in this latch circuit is supplied by a pair of enzymes (glucose oxidase on the right and laccase on the left). Each enzyme transfers electrons from the conversion of sugar and oxygen through a carbon nanotube, which is connected to the circuit. Since the power is generated very close to where it is needed, the device is highly efficient. The scale varies with the generation of the integrated circuit, but with the current state of the art spacing between the glucose oxidase and laccase could be less than 200 nanometers.