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FOCUS on MATERIALS

MATERIALS RESEARCH INSTITUTE BULLETIN SUMMER 2013

BIOINSPIRATION, BIOMIMETICS, AND BIOREPLICATION

Focus on Materials is a bulletin of the Materials Research Institute at Penn State University. Visit our web site at **www.mri.psu.edu**

Carlo Pantano, *Distinguished Professor of Materials Science and Engineering, Director of the Materials Research Institute*
N-317
Millennium Science Complex
University Park, PA 16802
(814) 863-8407
cgp1@psu.edu

Robert Cornwall, *Managing Director of the Materials Research Institute*
N-319
Millennium Science Complex
University Park, PA 16802
(814) 863-8735
rgc5@psu.edu

Walt Mills, *editor/writer*
N-336
Millennium Science Complex
University Park, PA 16802
(814) 865-0285
wem12@psu.edu

guest contributor:
Graduate student Kaitlin Haas

Mark Passmore, *graphic design*
Passmore Design
(814) 353-8853
passmoredesign@comcast.net

Message from the Director

Nature is the grand experimentalist, and bioinspiration looks at nature's successful experiments and attempts to apply their solutions to present-day human problems.

This issue of *Focus on Materials* looks at several Penn State faculty members who are taking inspiration from the plant and animal world, as well as the human body, to create new materials and improved devices based on replicating nature's elegant solutions to mimic their unique functionality. These researchers are looking to solve real-world problems aimed at sustainable energy, clean water, chemical pollution, tissue engineering, and disease targeting and treatment, to name but a few of their concerns.

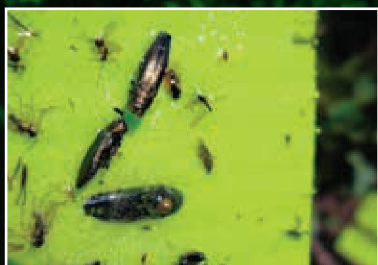
Over the past decade or so, journal articles, patents, and grants involving biomimicry and bioinspiration have grown more than seven-fold, according to a study commissioned by San Diego Zoo Global in 2010. In my own research, I have been collaborating with Akhlesh Lakhtakia and Raul Martin-Palma since 2008 to enhance the direct bioreplication of natural nanostructures with a unique method based on evaporation of a chalcogenide glass. The remarkable nano and microscale features of nature become even more apparent and functional through their direct replication in the otherwise nano/micro-structureLESS glass. Whether it is the structural color of butterfly wings or the self-cleaning microstructure of the lotus leaf, nature has learned tricks we can put to use to make life simpler, safer, or more beautiful. Lakhtakia and Martin-Palma are the editors of the new book, *Engineered Biomimicry*, mentioned later in this issue. And in a different kind of 'bioreplication,' Professor Yang and Professor Wang lead groups who are developing polymers, gels and related materials to direct nature's own machinery to 'regenerate' damaged tissue and organs in humans. I am certain you will enjoy reading about this stimulating research.

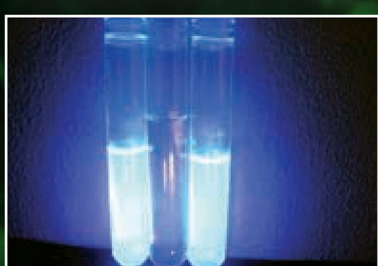
Finally, I encourage you to take note of our annual Materials Day event, which will be held October 15 & 16 on Penn State's University Park campus. This year we are featuring three outstanding invited speakers from industry who will be discussing innovation in materials from the industry perspective. Our Keynote-Reception at the Nittany Lion Inn on Tuesday evening, October 15, is themed toward meeting with our graduate students and post-docs. We look forward to seeing you there in October.

Sincerely,
Carlo Pantano
Director of the Materials Research Institute and Distinguished Professor of Materials Science and Engineering

To access the materials expertise at Penn State, please visit our Materials Research Institute website at **www.mri.psu.edu** or the Office of Technology Management website at **http://www.research.psu.edu/offices/otm**

CONTENTS





IN THIS ISSUE:

BIOINSPIRATION, BIOMIMETICS, AND BIOREPLICATION

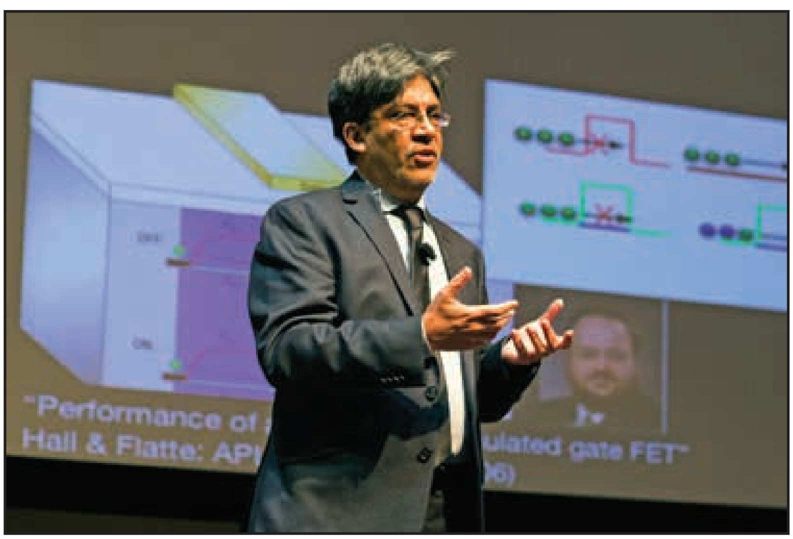
DEPARTMENTS

FEATURE ARTICLES

Cover credit: W. Federle, H. Bohn, and Ulrike Bauer

Snapshots are brief summaries of significant materials-related breakthroughs by MRI researchers. More information is available by visiting the links at the end of each summary.

SUPERFAST TRANSISTORS USE THE SPIN OF ATOMS TO COMPUTE



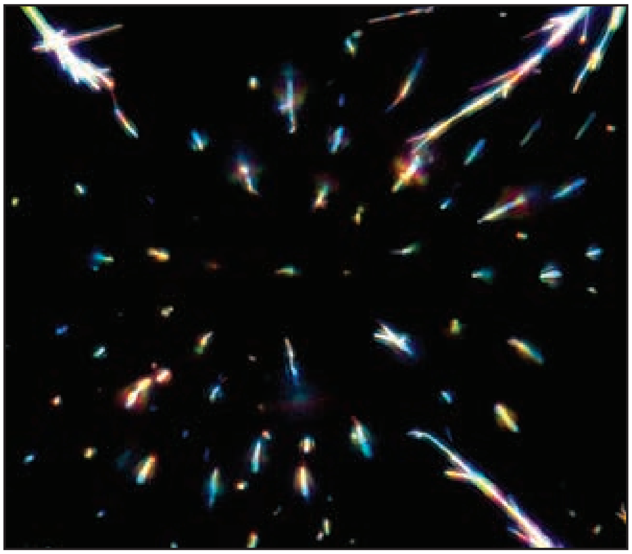
Nitin Samarth discusses spintronics at the 2013 Taylor Lectures.
Credit: Tom Harrington, Materials Science and Engineering, Penn State

Spintronics is a portmanteau word combining spin and electronics. Electrons in a magnetic field have two types of spin, called spin-up and spin-down, which can be equated with the on/off of binary logic – the basis for computing and memory storage. By developing new materials and technologies that take advantage of the spin state of electrons, computers could be made significantly faster and more compact.

Topological insulators are materials that theoretically can control the spin of electrons. They have the unusual property of being insulators – poor conductors of electrons – in the interior of bulk materials, but good conductors on the surface. Nitin Samarth and colleagues are using molecular beam epitaxy to build up 3D semiconductor crystals of topological insulators one atomic layer at a time. Surface science techniques reveal that surface electrons in these crystals are inherently of a particular spin. "The big challenge is how to exploit this spin polarization for information technology."

Nitin Samarth is the George A. and Margaret M. Downsbrough Department Head of the Department of Physics at Penn State. Read more about his research at http://www.mri.psu.edu/news/.

SOUND WAVES CREATE GRIDS OF NANOWIRES



Close up of a three-dimensional nanowire spark pattern.
Credit: Tony Jun Huang, Penn State

Using a piezoelectric substrate, a team of researchers led by Tony Jun Huang, associate professor of engineering science and mechanics, creates standing acoustic waves that can position metallic nanowires into precise patterns that can then be transferred to rigid or flexible substrates. This technique can create nanowire patterns smaller than those easily made using photolithography and on substrates that might not be compatible with conventional lithography.

Potential devices made using this technique include sensors, optoelectronics, and nanoscale circuits. "We really think our technique can be extremely powerful," Huang said. "We can tune the pattern to the configuration we want and then transfer the nanowires (to other substrates) using a polymer stamp." This research appeared in the journal *ACS Nano*

Adapted from Penn State Live A'ndrea Elyse Messer.
To learn more visit http://www.mri.psu.edu/news/

HIGH ENERGY DENSITY FLEXIBLE GLASS CAPACITORS

In a recent issue of a new publication, *Energy Technology*, researchers at Penn State, Strategic Polymer Science, and Nippon Electric Glass report on the latest advances using ultrathin glass to store energy at high electric fields and for high-temperature applications, such as electric vehicle power electronics, wind turbine generators, grid-tied photovoltaics, aerospace, and geothermal exploration and drilling.

Lead author Mohan Prasad Manoharan, post-doc in engineering science and mechanics, evaluated energy density and power density of 10 micron-thick alkali-free aluminosilicate glass compared with commercial polymer film capacitors typically used in hybrid-electric and plug-in electric vehicles. Polypropylene capacitors require a separate cooling system in order to operate in these vehicles, as well as requiring extra material as a safety factor. Glass can provide a less bulky and simpler (no extra cooling) system at potentially low cost. Recent advances include identifying a high-temperature polymer coating that improved self-healing properties allowing for graceful failure of the capacitor over time, and energy density improvements of 33 percent over un-coated glass.

Postdoctoral researcher Mohan Manoharan unspools a ribbon of 10-micron-thick flexible glass for energy storage.
Credit: Walt Mills, Penn State

For further information, contact Michael Lanagan, professor of engineering science and mechanics, at mxl46@psu.edu and visit http://www.mri.psu.edu/news/.

NANOPARTICLE PRODUCES HYDROGEN FROM WATER

A nanoparticle made of nickel and phosphorus has been found to trigger a chemical reaction that generates hydrogen from water at a rate comparable to much more costly platinum. Nanoparticle catalysts from earth-abundant elements open the door to cheaper and cleaner energy.

In the laboratory of Raymond Schaak, professor of chemistry at Penn State, researchers created quasi-spherical nanoparticles with many flat, exposed edges to catalyze reactions that triggered chemical reactions with a high degree of efficiency. The particles were tested in the lab of Nathan S. Lewis at the California Institute of Technology, and the results were published in the journal of the *American Chemical Society*.

Read the full story by Katrina Voss at http://www.mri.psu.edu/news/. Raymond Schaak can be reached at res20@psu.edu.

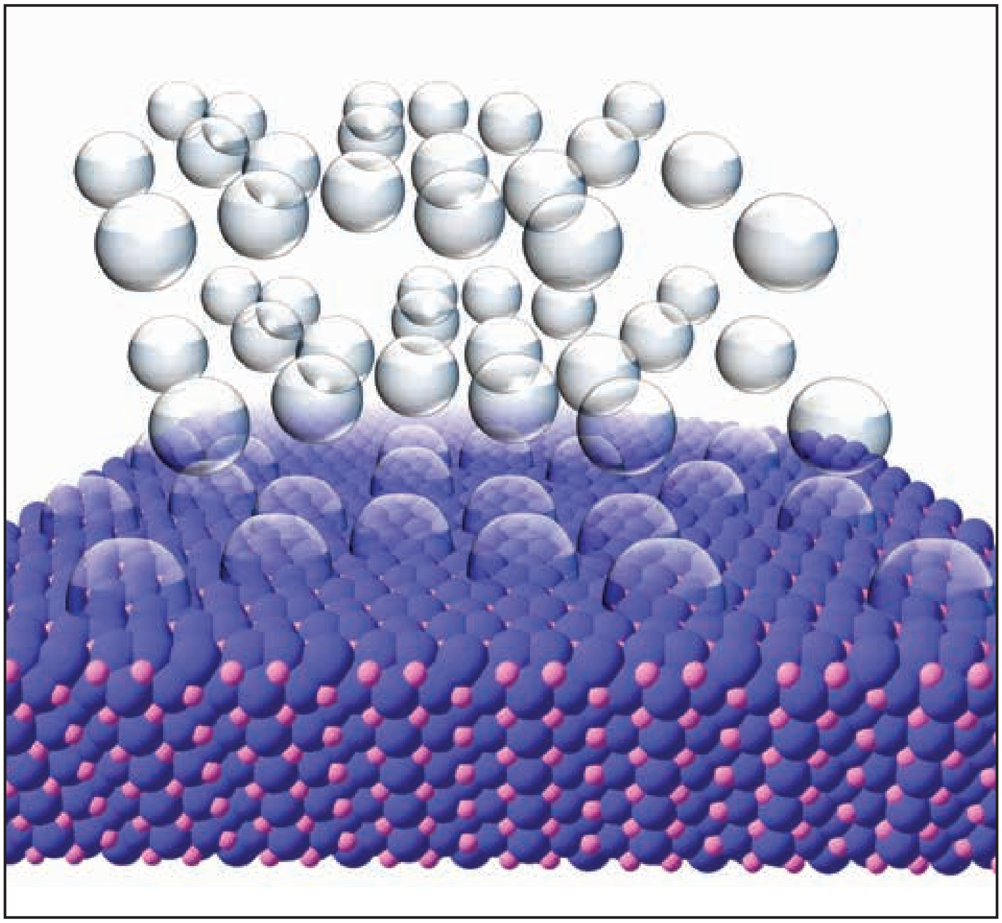


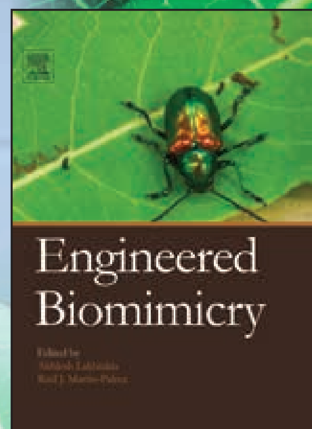
Image showing hydrogen gas bubbling off of the surface of a nickel phosphide crystal. A team led by Raymond Schaak of Penn State University is studying nanoparticles made from nickel phosphide as a means to create cleaner energy technologies.

Credit: Eric Popczun, Penn State University

Three closely related ideas with different names make up one of the fastest growing fields in science and engineering. The first term, ***bioinspiration***, is a million years old. Our earliest ancestors must have looked into the sky and dreamed of flying like birds.

BIOINSPIRATION, BIOMIMETICS, AND BIOREPLICATION

Myths from earliest civilizations tell of strapping on artificial wings and trying to soar. Leonardo's flying machines and submarines were inspired by birds and sea creatures 600 years ago. But these were only taking a function from nature and crudely trying to replicate that function in a machine. Nature has done it, so it must be possible. Yet we recall what happened to Icarus when he flew too near the sun.



Akhlesh Lakhtakia, co-editor of Engineered Biomimicry

Recent faculty hires, such as those introduced in the following articles, will

Nature is not an efficient engineer, but nature can inspire engineering solutions for a host of energy and environmental concerns. Nature is wasteful, taking millions of years and tens of thousands of mistakes to arrive at a solution. Engineers strive for efficiency and look for the shortest time and fewest number of steps to improve performance. Engineers have not been used to looking to nature for solutions, but that is changing. Now scientists and engineers have the tools to examine and replicate structures at the scale in which nature often finds solutions – the micro and nanoscale.

Biomimetics is a convenient term for a realm we have only recently begun exploring. The famous example of biomimicry is the invention of Velcro by Swiss engineer George de Mestral in 1948, based on the tiny hooks of the burdock burr. The question for biomimicry is - once the function of the natural phenomenon has been recognized, can the mechanism be replicated? De Mestral's bioinspiration was just the beginning; it took him years and some clever engineering to bring his inspiration to fruition.

Another famous example of biomimicry is one of the 19th century's greatest engineering feats, London's Crystal Palace, built to house The Great Exhibition of 1851. The Palace's architect, Sir Joseph Paxton, based his modular design of the 19-acre iron-and-glass exhibition hall on the giant Amazon waterlilies that he grew in his greenhouse. These fragile plants can support the balanced weight of a small adult due to their web-like vein structure. The Crystal Palace was a brilliant bioinspired design, but it required the invention and manufacturing of cast plate glass three years earlier to make its construction possible.

In a recently published book, *Engineered Biomimicry*, edited by Penn State professor of engineering science and mechanics Akhlesh Lakhtakia and his colleague Raúl Martín-Palma from the Universidad Autonoma de Madrid in Spain, the editors define the third term,

A field test in Hungary in 2012 by a Penn State team shows that insects similar to the emerald ash borer can be attracted by artificial replicas. Testing will continue in Pennsylvania this year. Inset – the iridescent color of the female emerald ash borer is replicated here. *Credit: Michael Domingue, Penn State*

help lead Penn State into a new regime in which, as some proponents say,
"biology is the future of engineering."

bioreplication, as "the direct replication of a structure found in natural organisms, and thereby aims at copying one or more functionalities." Examples include replicating the compound eyes of insects to gather light and the wings of butterflies to reproduce their color.

Lakhtakia and Martín-Palma have used bioreplication as a tool to help control the spread of the emerald ash borer, an invasive insect devastating the ash forests of the Northeast. By making a cheap replica of the female ash borer using some clever fabrication techniques to reproduce the insects' iridescent green color, the pair, with help from other Penn State researchers, has demonstrated the ability of the replicas to attract male ash borers into traps, where they can be tracked and controlled using other methods.

Biomimetics is an exceptionally new field of engineering, but one that is beginning to take shape at Penn State and a few other universities.

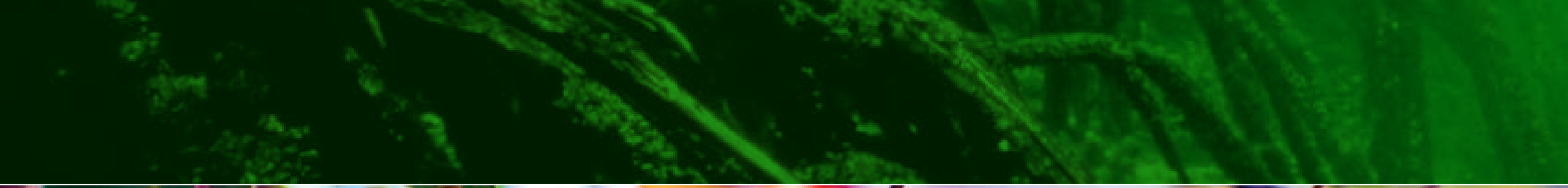
It is a highly multidisciplinary field, which makes it a good fit for the diverse engineering, science, and medical disciplines available within Penn State's interdisciplinary institutes and the Penn State College of Medicine. Recent faculty hires, such as those introduced in the following articles, will help lead Penn State into a new regime in which, as some proponents say, "biology is the future of engineering."

Akhlesh Lakhtakia is the Charles Godfrey Binder (Endowed) Professor in Engineering Science and Mechanics at Penn State. Contact him at axl4@psu.edu.

An ant climbs up the side of the leaf of a carnivorous plant and when it reaches the lip slides helplessly down into the plant and is eaten. A beetle in a southern Africa desert climbs to the top of a dune and unfurls its wings to catch miniscule drops of fog. The drops gather on small water-loving (hydrophilic) bumps on its back, and then roll down water-hating (hydrophobic) troughs into its mouth. This is in one of the driest climates on Earth. In a very wet place, the shorelines of Florida's Everglades, mangrove trees thrive in salty and brackish water, filtering the salt from their roots and delivering fresh water to the trunk and leaves.

INSPIRATION at the Intersection between Disciplines

Credit: U.S. National Oceanic and Atmospheric Administration



Pitcher plants, the inspiration for a new omniphobic surface   *Credit: istockphoto*

These are only a glimpse into nature's many complex engineering solutions to environmental challenges. Tak-Sing Wong, a new assistant professor in mechanical engineering at Penn State, believes that some of the biggest problems the world is facing can be solved with a little help from nature-inspired engineering at the nano- and microscale.

SLIPS – Improving on nature

Most of us are familiar with the self-cleaning lotus effect. The lotus grows in muddy ponds but shows no trace of grime. Water beads up on the lotus leaf's waxy hydrophobic surface, maximizing the contact angle between the water and leaf. Microscopic bumps on the leaf's surface further maximize contact angle. And finally, a layer of air trapped between the bumps acts as a cushion to keep the water from wetting the surface. As the beads of water roll off the leaf, they clean the plant of dirt and microbes. The lotus effect has been reproduced and commercialized in products such as self-cleaning paints and anti-stain clothing.

Most developments of synthetic liquid-repellant surfaces are based on the lotus effect. However, it was another Asian plant that inspired Tak-Sing Wong and colleagues. As a post-doctoral researcher at Harvard, Wong was part of a team in the lab of Joanna Aizenberg that developed a new type of material based on the slick surface of the Southeast Asian pitcher plant. The slippery quality of the plant's rim is due to a thin layer of water that is captured and held on the surface microstructure after rain. Because water doesn't mix with the oily coating on the feet of ants that helps them to climb, the ants slide on the surface of the water layer into the plant interior where they are eaten.

The bio-inspired invention, called slippery liquid-infused porous surfaces, or SLIPS, won the inventors a 2012 R&D 100 Award. Both the Harvard group and Wong's group at Penn State continue to develop the technology. And because there is so much left to develop, so many pathways to pursue, Wong expects SLIPS research to be one of the major focuses of his lab for the next several years.

In both the pitcher plant and SLIPS, the coating of water does not run off even if the surface is turned upside down. The reason? It's the microstructure, Wong explains. "At large scale, water is dominated by gravity. But if you have the same water, and reduce it to very small sizes, other forces come into play, surface forces."

Take a glass of water, he says, turn it upside down, and the water spills out – that's gravity. But if you cover the glass with cardboard, and make a hole in the cardboard as large as one millimeter, the water will stay in the glass held by surface tension. The microscale structure of the pitcher plant is on the order of 20 microns, but in SLIPS, the pores are even smaller, in the nanometer range. At this size scale, even more exotic molecular forces come into play. "We can use forces that oppose gravity," Wong remarks.

How does SLIPS improve on nature? The pitcher plant repels oil, and the lotus leaf repels water, but SLIPS can repel both oil and water. The term is omniphobic. But it goes beyond that. The SLIPS nanopores are infused with a special chemical called perfluorinated fluid, which is immiscible (unmixable) with almost anything except itself. "This is a highly fluorinated chemical that is immiscible to water, oils, alcohols, ketones, blood, and most other chemicals you can find," Wong says. "It doesn't really dissolve in chemicals except those like itself that are highly fluorinated."

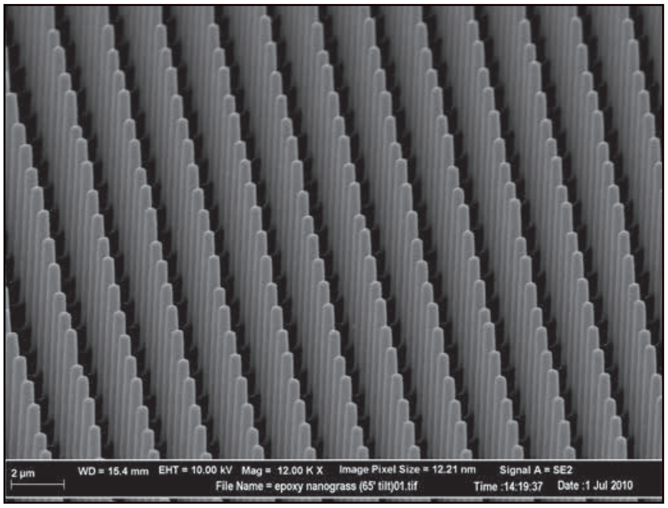
SLIPS saves energy, combats disease

A coating this slippery could have many possible uses. Think of a medical implant or catheter with a coating of SLIPS that biofilms can't stick to. That could help reduce hospital acquired infections like MRSA. Biofouling also applies to the marine creatures that attach to ships' hulls. Currently, marine vessels use a toxic metallic coating to get rid of barnacles. The coating pollutes harbors and kills other sea creatures. SLIPS could be developed as a bio-safe coating that would save fuel by reducing drag in the water.

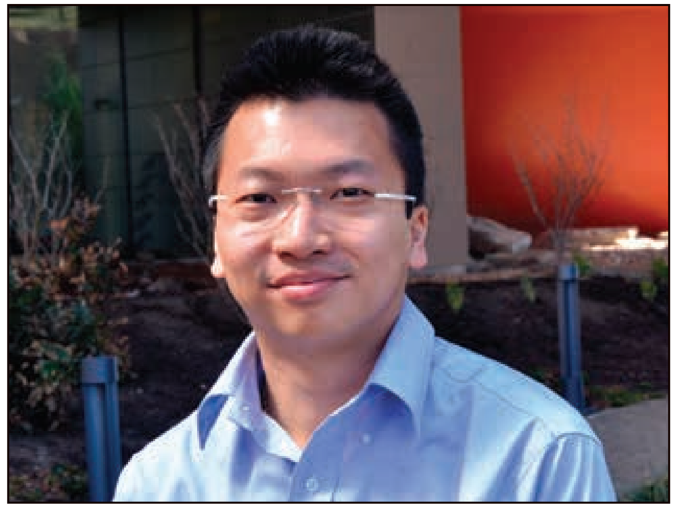
Another energy saver might be to use SLIPS as a coating in oil pipelines. Current pipelines require powerful pumps to force crude oil against the friction of the metal surface. A SLIPS coating would lower the energy needed to push the oil and possibly require fewer pumping stations. A not insignificant amount of energy is used defrosting refrigerators and freezers. With a coating of SLIPS, ice would not stick to the freezer walls. Solar panels are often located in dry dusty or desert areas where blowing sand can cover a panel and reduce efficiency. It would be beneficial to coat solar panels with a nonstick surface that could keep the dust from adhering.

The goal for SLIPS and the other materials under investigation at many other labs is a robust, scalable, and low-cost surface that can repel any fluid, self-heal upon damage, allow for smart/switchable control of wettability, and operate under a wide range of environmental conditions. SLIPS has come closest

A SLIPS coating on a glass substrate. The coating is structured with regular arrays of nanoposts.
Credit: Tak-Sing Wong



A nanopatterned array of epoxy nanoposts compose the SLIPS surface. *Credit: Wong lab*



Tak-Sing Wong is a new assistant professor of mechanical engineering and PI in the Laboratory for Nature Inspired Engineering

to achieving many of those goals, but a great deal of work remains.

A simple diagnostic tool for developing countries

Many millions of people in the developing world live without the resources we take for granted. Wong's research is inspired by nature, but the real inspiration may be trying to provide those individuals with clean drinking water and access to affordable healthcare. The lack of electricity and the cost and complexity of most methods for diagnosing diseases are barriers to improving lives in third world countries. "If we could develop a simple diagnostic method that could help them, it would be wonderful," says Wong.

One simple phenomenon of nature is leading him toward a possible solution. It's called the coffee ring phenomenon, and you can see it when a cup of coffee or tea makes a round spot on the counter. "If you look at the mechanism of the coffee ring, there is something we can learn that can help us make some interesting diagnostic devices," he predicts.

Typical microfluidic systems for diagnosing diseases begin with whole blood. The blood is separated into red blood cells, white blood cells, platelets, and proteins. The procedure can be complicated for minimally trained practitioners and some reagents require refrigeration. In the coffee ring phenomenon, just by evaporation, and without the need for refrigeration, the particles will separate based on size.

There is some complex science behind this, Wong admits. "It's the merging of fluid mechanics and how fluid dynamics interacts with particles of different sizes, different adhesion properties, that interact to form different patterns. If we can couple the patterns with diseases, in terms of science this is a very rich area."

The diagnosis might require a special surface for the blood to evaporate on, and a library of patterns, but after that it might only require snapping a photo with a cell phone and sending it off for analysis, or even creating a built-in cell phone app. More than 34 million people around the world are infected with HIV/AIDS, for instance, but only a small percentage of them have ever been diagnosed. A device this simple could be a game changer for the third world, he believes.

The making of a scientist

For scientists and engineers, there is often a defining event that led them into their careers. If we are interested in encouraging students to pursue STEM professions, as indeed we should be, the stories of how they made the choice are of interest. For Tak-Sing Wong, the path he chose was marked by a series of small epiphanies.

"I really got interested in science in general in the latter part of my high school career," he recalls. "In his lecture, my high school physics teacher explained Newton's first, second, and third law. I saw for the first time how the physical world can be quantitatively described with equations."

Later, in college, there was a professor – Wen J. Li – working in MEMS and microtechnology who showed his students a series of beautiful images of the microscale world. One of the images showed an ant holding a gear. "I was amazed how humans could machine things at such a small scale." The professor went on to explain that the physics of the microscale and nanoscale world are different from the macro world. Those experiences, and one further event, were what sparked his interest in science and engineering, and especially in research.

The other defining epiphany came about in his freshman year at university. He was given the opportunity to come to the United States and spend a week at Bell Labs, where he was able to talk with some of their top researchers. "I asked one of the researchers 'How can I become one of you guys in the future?'" The scientist told him to first get a Ph.D. at a university in the U.S., and then he could have choices. He took the advice and after earning his undergraduate degree at The Chinese University of Hong Kong entered the Ph.D. program at UCLA where he worked in the laboratory of Prof. Chih-Ming Ho, a notable expert in MEMS and bio-nanotechnology. Ho's philosophy of doing research and mentoring future leaders in his lab greatly influenced Wong's interest in becoming a mentor himself.

The next nudge on his path came when he got to Harvard for post-doctoral training. Working with some of the world's top experts in the world of biomimicry and bioinspired engineering was an eye-opening experience. Under the direction of Prof. Joanna Aizenberg, he was free to pursue ideas in many different areas. His co-workers in the group included physicists, chemists, biologists, bioengineers, materials scientists, and microbiologists. "I think those two-and-a-half years at Harvard broadened my research perspective. Doing good research shouldn't be focused on one discipline. A lot of new things happen at the intersection between disciplines. That's been my whole scientific philosophy up to this point," he sums up.

Future plans

In many parts of the world, water is the most precious commodity. Although water is everywhere, 97 percent is in the form of non-potable salt water. Wong is interested in examples of natural solutions to desalinization, such as the mangrove tree, and with finding ways to extract water from air, such as the desert beetle or the needles of cactus plant. "I like this research area, because the developing world cannot afford desalinization plants. Something that is simple and cheap could ultimately benefit everyone on Earth," he says.

"Right now we are in an exciting time. We have techniques that allow us to make micro and nanoscale devices. We have instruments that allow us to see the nanoscale world at extremely high resolution. We are in a time when we can uncover some of nature's secrets and translate those concepts to our human world. That's what I'm trying to do here at Penn State, and I think we have the great resources here to allow me to accomplish these goals."

Tak-Sing Wong is an assistant professor of mechanical engineering in the Department of Mechanical and Nuclear Engineering. He leads the Laboratory for Nature Inspired Engineering at Penn State. Wong is also the co-editor of a special issue of the MRS Bulletin (May 2013) devoted to Interfacial Materials with Special Wettability. He can be reached at tswong@psu.edu.

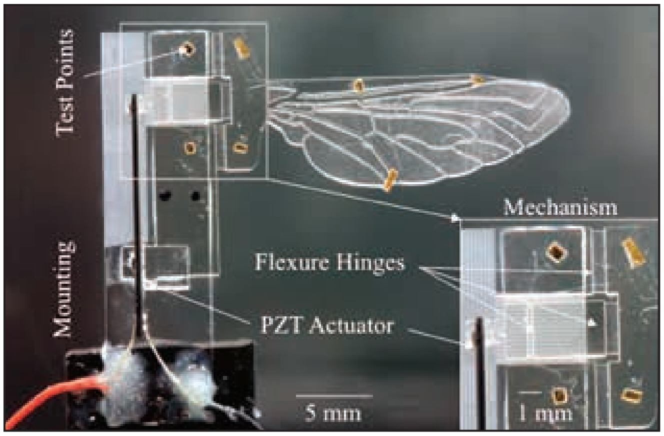
The Sound of One Wing Flapping

In 1997, DARPA, the Defense Department's futuristic research program, launched a micro air vehicle (MAV) program with a goal of developing the technologies to enable a self-powered flying machine with dimensions of 6 inches or less for reconnaissance and surveillance purposes. As time went on, DARPA shrank the package into a nano air vehicle (NAV), with dimensions less than 15 centimeters and a weight less than 20 grams, for both indoor and outdoor maneuvering capabilities. This could be thought of as hummingbird size. At Penn State, faculty in electrical and mechanical engineering and their graduate students have spent the past two years working at an even smaller scale, called the pico air vehicle (PAV), based on insect flight.

At that size scale, everything is changed and all of the problems of fabrication, stabilization, power, and control have to be answered anew. The one thing that is already known for sure is that nature has solved the problems many times before, with dragon flies, bumble bees, and the humble house fly. In the process of creating the technologies to develop a PAV, interesting and difficult scientific questions will be answered.

Srinivas Tadigadapa, an expert in the field of microelectromechanical systems, or MEMS, and Christopher Rahn a mechanical engineer with expertise in modeling, design, and control, both faculty at Penn State, call their pico air vehicle the LionFly – a name coined by their graduate student Kiron Mateti. Although it has yet to get off the ground under its own power, the Lion Fly project has made a number of contributions to the field of bio-inspired miniaturized flight.

"Chris and I worked for 4 ½ years on this project that was funded by the Air Force Office of Scientific Research. The idea was very simple. My group was working on micromachined PZT-based actuators, along with Prof. Rahn. We call them T-beam actuators" Tadigadapa recalled.



Photograph of the LionFly prototype and zoomed inset of the hinges and PZT actuator. *Credit: Tadigadapa/Rahn labs*

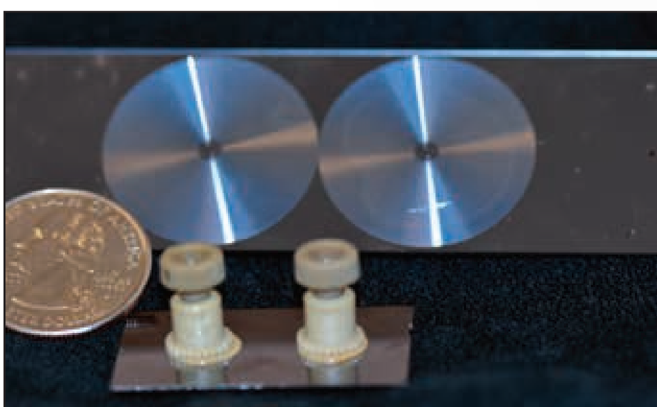
Made from a single piece of lead zirconate titanate (PZT), a ceramic piezoelectric material, the T-beam actuator is capable of flexing in two directions, similar to the flexing of the muscles of an insect wing. "We finished with these actuators, and we got so many degrees of freedom with them, that we wondered what we could do with them," said Tadigadapa. "And the idea came to use them to actuate the wings of a nano air vehicle based on a dragon fly or butterfly."

Because of Tadigadapa's experience in nano and micro fabrication, the engineers decided to try to put together the entire wing using photolithography, using photoresist as the material to build the wing and a piezoelectric actuator as the motor. This departed from other flapping wing NAVs, which run on electromechanical motors. They set themselves a lateral size limit of 5 centimeters, including wings and actuator. Then they began research.

They needed a large flapping motion in the wing for straight flight. They also needed rotation, which gives insects and birds lift. Without lift, the LionFly would not be able to rise or hover. Because of the difficulty in assembling joints at the microscale, they wanted the wing to be made all in one piece and all from one material. This required some creative thinking.

They came up with the idea of making what is known as a compliant mechanism, which is a design in which they make the material thinner where they want the wing to flex and thicker where they want the wing to be rigid. By using the same fabrication methods as in microelectronics, it would become possible to produce many wings simply and accurately at the same time.

Tadigadapa continued: "Our student, Kiron, took a picture of a diptera (housefly-like) wing under a microscope, and then translated the image into a photolithography mask pattern. We wanted the design to be both light and rigid. The wings of a



A chip-based chromatography column with radically redesigned compression seals. *Credit: Penn State*

Srinivas Tadigadapa

housefly or fruit fly are amazing really. At the same time they are very rigid, and very small and thin."

They settled on a type of photoresist called SU-8, a negative photoresist. When exposed to ultraviolet light, the photoresist hardens and does not wash away in the solvent. On the thin parts of the wing, they shone a 310 nm wavelength ultraviolet light through the mask. That wavelength only penetrates a short distance into the surface. They placed a second mask over the photoresist and shone a 365 nm light, which penetrates completely through the resist to the bottom. The unexposed material washes away in the solvent, leaving a wing with a thick and thin pattern on the scale of an insect. "We were able to use a single material and a little bit of clever lithography and wavelength ideas and go on to make the device. The hinge part of the wing, although it is very thin, about as thick as kitchen foil, has still not broken after one million cycles."

The PZT actuator is the mechanism that flaps the wing. When an electric field is applied from a battery, the piezoelectric actuator moves a small amount, but not enough to get the kind of wing movement they need. For that they had to create a mechanism to amplify the actuator motion. They used a mechanical joint concept, translated it into polymer push-pull mechanism, and attached that to the actuator and the wing. This resulted in a movement of from 120 to 150 degrees from the top of the wing stroke to the bottom. "We've gotten from just a flapper to a rotational flapper that produces lift," Tadigadapa explained. Still to solve are the weight of the battery, which is a large problem for NAVs and PAVs. Also to be worked out are the aerodynamics of micromachine flight, something nature has solved, but which will require some ingenious engineering. "Between the two of us, we've brought this quite a long way," he said.

Srinivas Tadigadapa is professor of electrical engineering at Penn State and leader of the Micro and Nanoscale Devices Group. Contact him at sat10@psu.edu. Christopher Rahn is professor of mechanical engineering at Penn State. Contact him at cdrahn@psu.edu

A MEMS Race Track for Chromatography

David Gaddes, graduate student in bioengineering, works on chip-based chromatography in the Tadigadapa lab.

In a seed project funded by MRI and the Huck Institutes, Srinivas Tadigadapa in electrical engineering and Frank Dorman in biochemistry and molecular biology are developing a MEMS approach to chromatography, a project that many groups have worked on without much success. In fact, says Tadigadapa, a miniaturized chromatography device in silicon was one of the first concepts in the MEMS field three decades ago.

Chromatography is a simple concept that is used commercially to analyze liquids and gases. The idea is that if you pass a mixture of chemicals through a column with some kind of functionalized coating on the surface, as the molecules flow through, they will be attracted to varying degrees to the coating and be slowed down. This sticking coefficient is different for different molecules. With a long enough column, the molecules will start to come out of the column at different times, which can be measured by a mass spectrometer.

The commercial systems work pretty well, but for continuous monitoring of chemicals and pollutants such as soot in the environment, it would be useful to have a cheap miniaturized version that could be made by standard MEMS techniques.

"For a long time, I was under the impression that since chip-based chromatography had been done by a lot of people for a long time that there must not be much I could add to this area. I was totally wrong," Tadigadapa remarked.

Making the micro-columns on a chip was easy enough, but connecting the macroscopic world to the millimeter-thick chip at the inlet and outlet was a difficult problem. The standard solution was to drill a hole on opposite edges of the chip and push the tube carrying the gas or liquid into the chip and then glue it in with an epoxy.

Different groups worked on different aspects of the system, some focusing on the column designs and functionalization, others on integrating all the components of a chromatography system including detectors onto the chip. "What we learned is that by focusing on a chip-scale integration approach, one gets bogged down in overall performance by the least effective component that doesn't work very well. Overall, people are looking at the field and saying the commercial big machines still work better than chip-scale chromatography columns," he explained.

Tadigadapa and Dorman decided to reinvent the system. They didn't think they could start by designing all the components on one chip, so they focused on the column and the connections, and left out the mass spectrometer detector. They had ideas on how they could incorporate the chip-based sensors at a later point, but for now they would connect the microchip to a regular mass spectrometer.

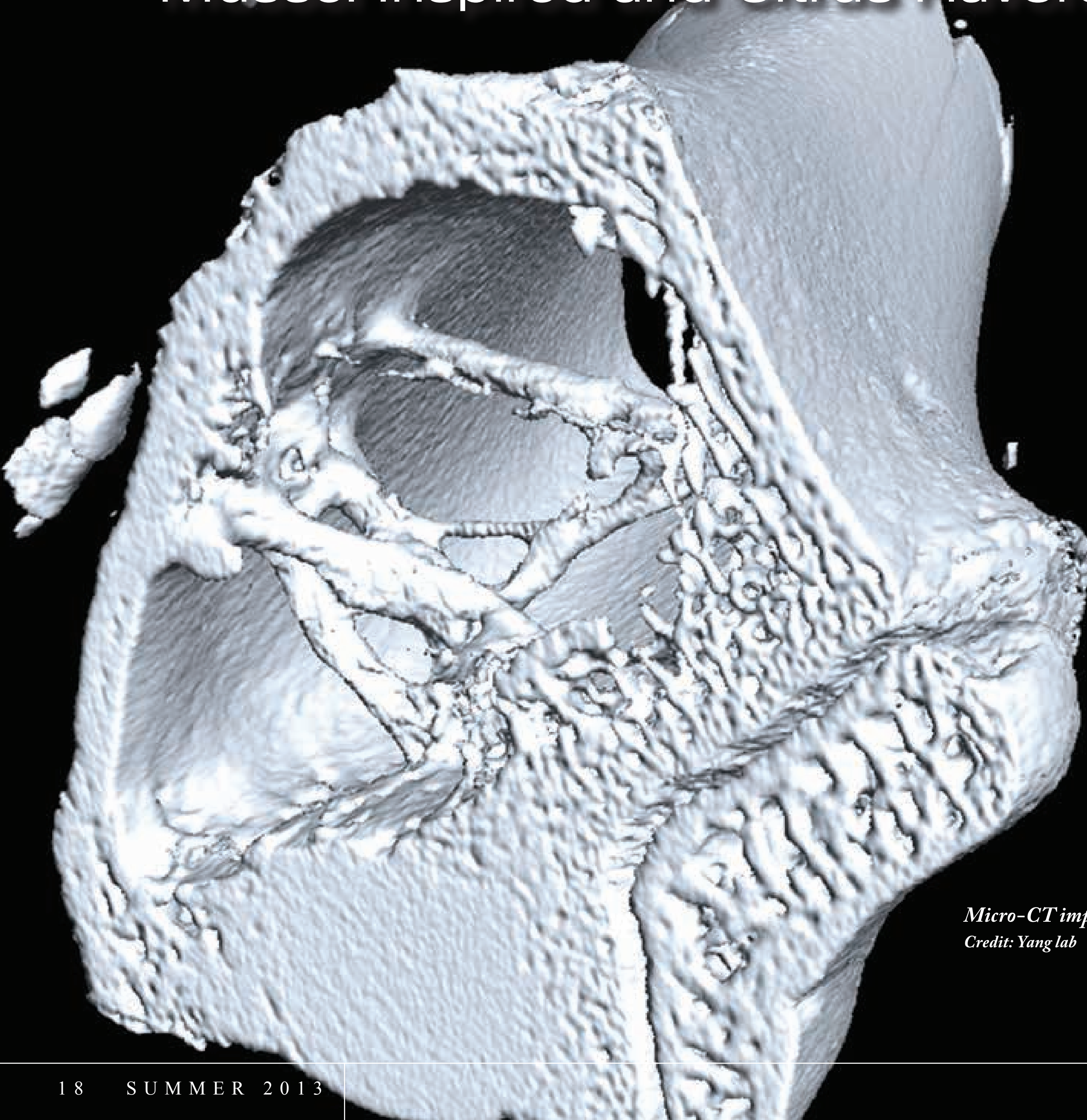
In their new design, they moved the inlet and outlet ports off the edge and into the center of one side of the chip. This allowed them to make an exact connection and replace the epoxy with a compression seal. They also changed the column design from square spiral to Archimedean spiral, in fact, to a double spiral in the shape of an "S", so that both the inlet and outlet were at the center of the spirals. Where the first spiral begins is the inlet and where the second spiral ends is the outlet. With this new configuration, they can run multiple columns side by side, adding to the efficiency of the throughput at small scale.

A further benefit of the new port design was that by not having to use epoxy to make connections, they can now do high-temperature separations up to 400° C or higher. In addition, because of the small size of the device, the time and energy required to heat and cool the device is reduced to a few minutes.

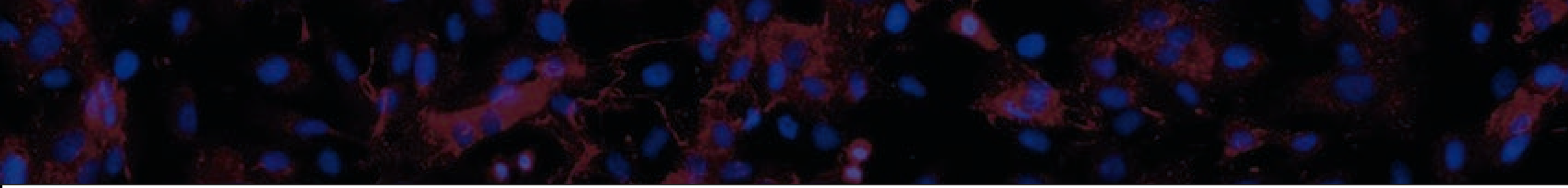
"The two-meter columns we have already produced are giving us such good data, and the 10-meter columns will be even better. Already we are comparable to a 10-meter commercial column, and this has drawn a great deal of interest from industry." Tadigadapa said. This recent work has been undertaken by his graduate student David Gaddes.

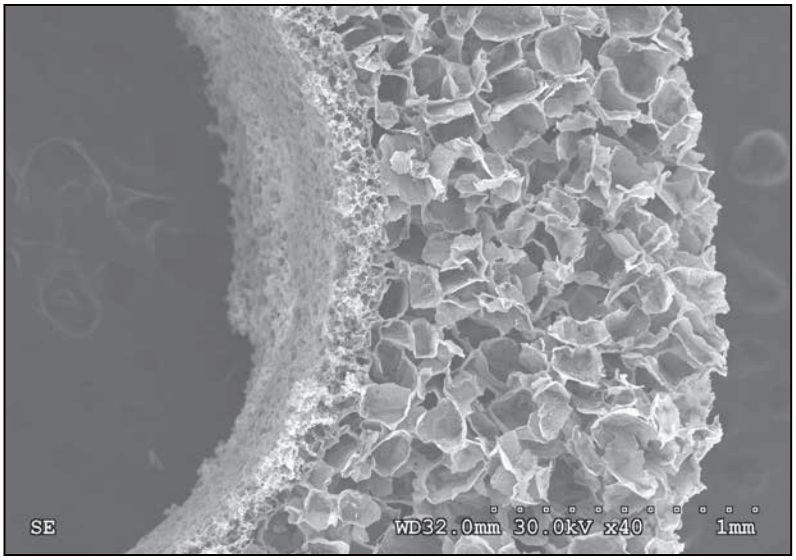
POLYMERS in the Body–

Mussel Inspired and Citrus Flavored

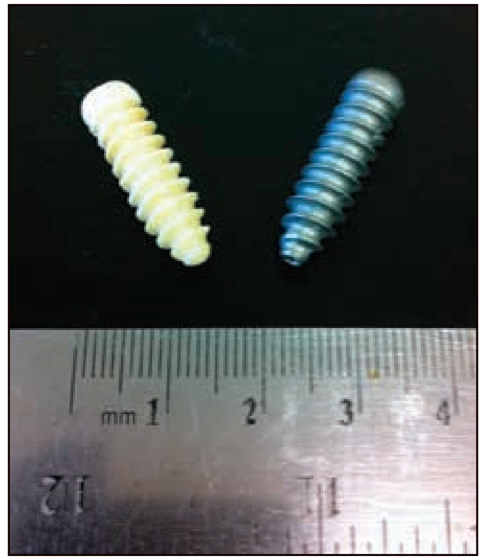


Micro-CT implants in bone
Credit: Yang lab





A blood vessel scaffold infused with a small percentage of the body's natural citric acid *Credit: Yang lab*



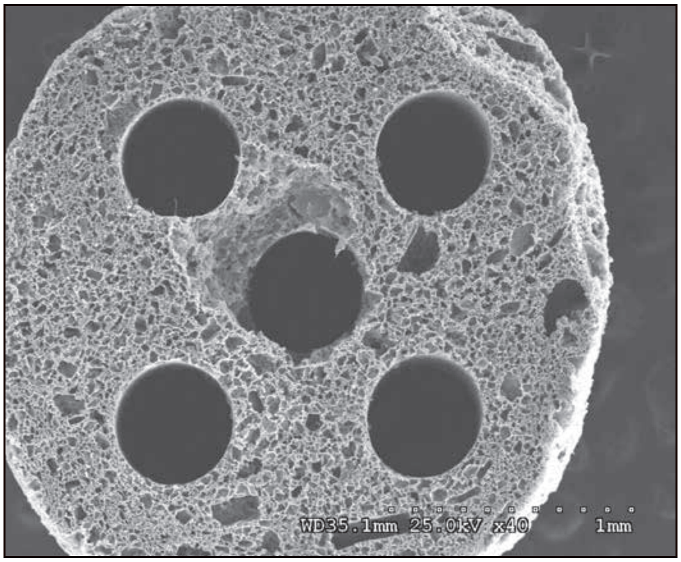
Biodegradable hard polymer bone screws release citric acid to promote healing.
Credit: Yang lab

Jian Yang,associate professor of bioengineering, is leader of the Transformative Biomaterials and Biotechnology Lab at Penn State.

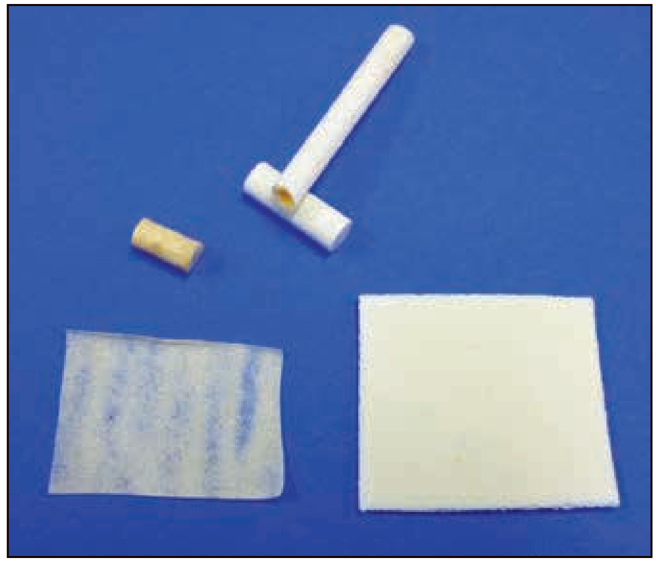
Implant biomaterials cover a wide range of materials and devices that are inserted into our bodies. It is a field that may be unique in the number of disciplines it crosses, from materials science to mechanical engineering, biology to pharmacology to clinical medicine to chemistry to electrical engineering. And the list goes on. For Jian Yang, a polymer scientist working in biomaterials, collaboration across multiple disciplines is critical for the diverse projects underway in his Transformative Biomaterials and Biotechnology Lab in Penn State's Millennium Science Complex.

A common thread in all the projects undertaken in Yang's research group – and there are currently eight research projects underway – is a common material called citrate, a metabolite in the body that is involved in the Krebs Cycle, the process by which a majority of our food-derived energy is created. Citrate is a form of citric acid found in high concentrations in citrus fruit that is critical for bone health. "Everything in my lab comes from citric acid," Yang remarks. "Any polymer we make has one monomer of citric acid and some other monomer, such as amino acid or polyethylene glycol."

Like any good scientist trying to heal the human body, Yang's first priority is safety. His materials, although novel, are all biocompatible and disappear harmlessly from the body over time. Citrate, for example, has been approved by the Food and Drug Administration to be used in many biomedical devices. Yang studied the citric molecule as a post-doctoral scholar at Northwestern University, though



A soft plastic five-channel nerve conduit is currently being tested at the University of Hong Kong's school of medicine. *Credit: Yang lab*



Various types of scaffolding for nerve and tissue regeneration *Credit: Yang lab*

at that time they were working with only a single citric-based polymer. Since then, Yang has developed a methodology for producing various polymers based on citric acid for a variety of biomedical applications.

The applications – A bioinspired glue

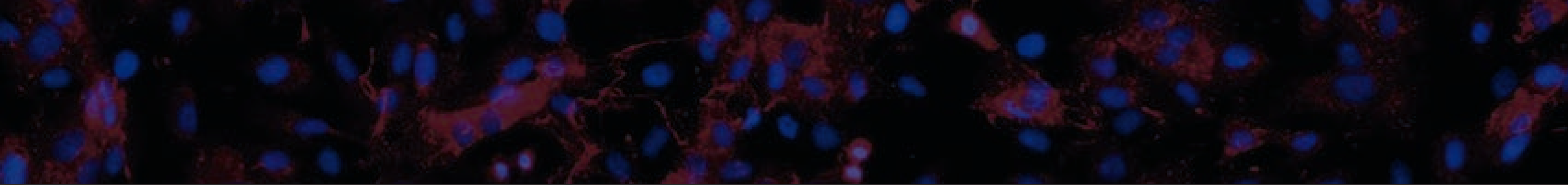
The eight projects in Yang's lab mentioned previously attempt to solve a variety of problems facing healthcare practitioners. One of the most interesting of these is a new way to close wounds without sutures. Current glues used frequently in hospital settings are either too weak, do not work in wet conditions, or have toxic decomposition products. Inspired by the natural glue that allows mussels to cling to rocks even under the continuous pounding of waves, Yang's team recently developed a new family of adhesives that can close wounds both on the skin and within the body under wet conditions.

Mussels, like those we eat steamed or in seafood stews, make a protein with a unique chemical structure called mussel adhesive protein. By copying the chemical structure of the protein, Yang's team has developed a one-step synthesis process to create a citrate-based injectable bioadhesive for surgical uses. "Our one-step chemistry approach is very powerful and very simple," he says. "Other glues you look at are very complicated." His adhesive has controlled biodegradability, is non-toxic, has elastic properties, and is 2.5 to 8-fold more adhesive than fibrin glue, the current gold standard. The glue, which is currently being optimized to increase its adhesion strength, could have wide impact for surgery in which tissue adhesives are used.

"In animal studies, we make incisions in the back of rats, then inject some of our liquid formulation into the wound and use our fingers to clamp the wound. Within a short time the wound is closed. After seven days the wound is healed and the adhesive has decomposed," Yang explains. His bioglue research was published in the journal Biomaterials in August 2012. Since then he has been contacted by companies interested in other uses for the glue, but he is considering the option of translating his research into a spin-off company of his own, along with one of his students.

Biodegradable bone screws

A second project in his lab involves biodegradable materials for orthopedic surgery. Recent trends in bone repair call for materials that remain in the body only long enough for the bone to heal, and then decompose. Metal screws and plates often



cause inflammation and can require a second surgery over time. Normal bone consists of organic collagen and inorganic minerals, with about 5 percent citric molecules on the mineral surfaces. Citric molecules have never previously been included in any biomaterials design, Yang says. But his group has found that citric molecules play an important role in bone development. By making orthopedic fixation devices–screws and plates–from biomaterials incorporating citrate, the polymer devices can release citric molecules into the healing bone, simulating normal bone.

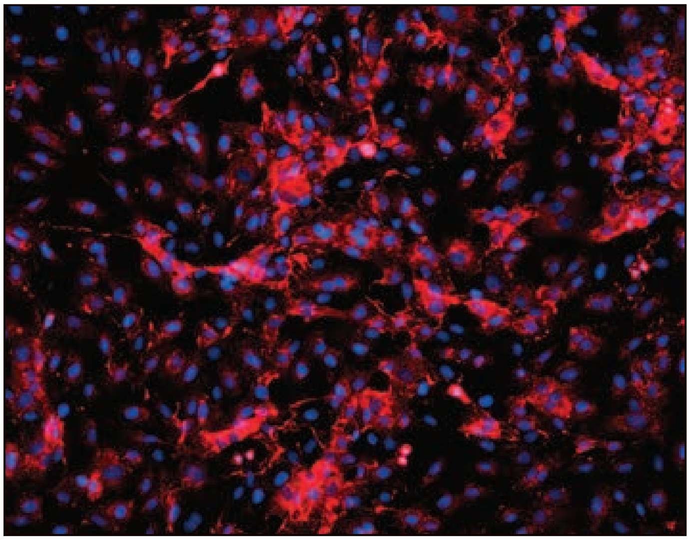
Polymer chemistry is playing an important role in biomedical engineering, and Yang's Ph.D. training in polymer chemistry, which he undertook at the Chinese Academy of Sciences, and his years of post-doctoral work in biomaterials and tissue engineering have guided his independent research program, both at the University of Texas-Arlington and at Penn State, where he is associate professor in the Department of Bioengineering. "I feel that my skill set allows me to talk with biologists and physicians and we have common grounds for communication," he attests.

Along with hard polymers, such as the bone screws, Yang also develops soft polymers for soft tissue regeneration such as nerve conduits to guide regenerating nerves. The plastic biodegradable nerve guide is currently being tested in rats at the University of Hong Kong's school of medicine, with encouraging results. All of the implants are, of course, citric based.

The first naturally fluorescing polymer

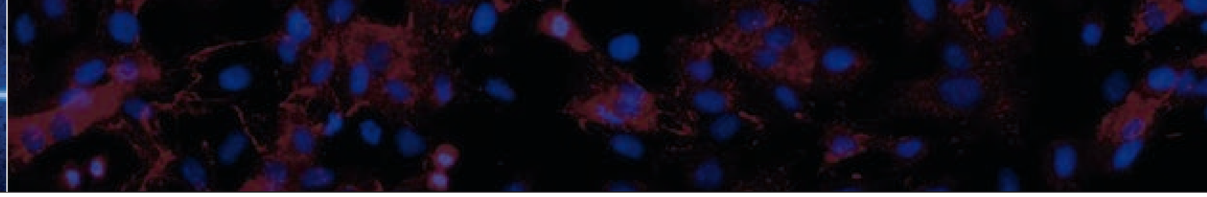
The discovery of the first naturally fluorescing polymer came about by accident. The story goes like this: One day in 2009, one of Yang's students was crossing campus carrying a tube of a newly synthesized polymer with a unique structure incorporating amino acid. The glass tube was the kind used in nuclear magnetic resonance studies, and the student was crossing between buildings to study the chemical structure under NMR. Under the bright Texas sky, the student noticed the polymer solution was emitting color. When he returned, he mentioned to his adviser what he had seen.

"When he told me, I realized it was a brand new polymer structure that could make the material fluoresce without incorporating toxic dyes or quantum dots, as is usually the case. With this new phenomenon, we can now make biocompatible and biodegradable materials that fluoresce under a wide range of wavelengths, from UV to near infrared, the colors changing depending on the source of light."



Biodegradable photoluminescent polymer nanoparticles accumulate in cells. *Credit: Yang lab*

Naturally fluorescing polymer nanoparticles in solution *Credit: Yang lab*



Biocompatible and biodegradable polymer materials will fluoresce under a wide range of wavelengths, from UV to near infrared.
Credit: Yang lab

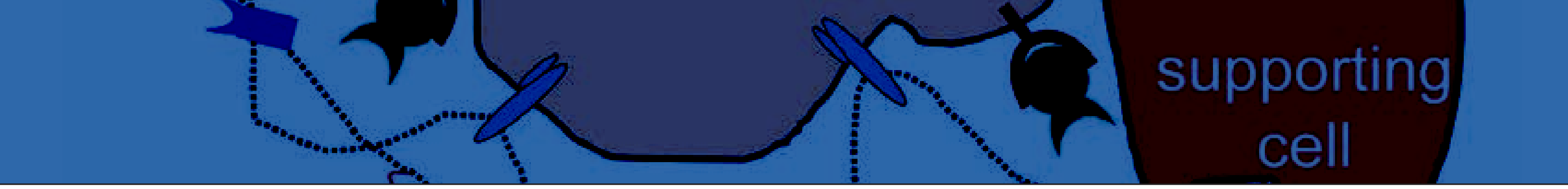
With this discovery, a new research program was born, with support from the National Institutes of Health, the National Science Foundation, and Texas cancer research funding. His continued funding from NSF will enable Yang to understand exactly how the photoluminescence comes about. The material has potential for bioimaging, drug delivery, and the detection of cancerous cells during surgery.

Collaborating across disciplines

With his methodology to develop different types of citric-based polymer for different applications, Yang is reaching out across campus and to Penn State's College of Medicine to expand his collaborations into new areas. Because he would like his biomaterials to be electrically conducting, he is talking to Qing Wang in Materials Science and Engineering who is an expert in electrically conducting polymers. With biologist Yingwei Mao, he is beginning a new program to use Yang's material to deliver drugs to treat mental disease, such as schizophrenia. He recently began a collaboration with Dr. April Armstrong, director of shoulder and elbow surgery at Hershey Medical Center, to possibly use some of his material in shoulder surgery. In the Center for Neural Engineering, he is working on his biodegradable nerve conduits with colleagues such as Francesco Costanzo and Bruce Gluckman. "It's like regenerating your own nerves without any foreign materials remaining in the body," he says of his plastic nerve guides.

"Biomaterials is a tool," he concludes. "My program is unique because I have focused on one thing, the citric-based materials. This is a niche people haven't studied very much. I'm working on a unique material."

Jian Yang is an associate professor of bioengineering and leader of the Transformative Biomaterials and Biotechnology Lab at Penn State. He can be contacted at jxy30@psu.edu.



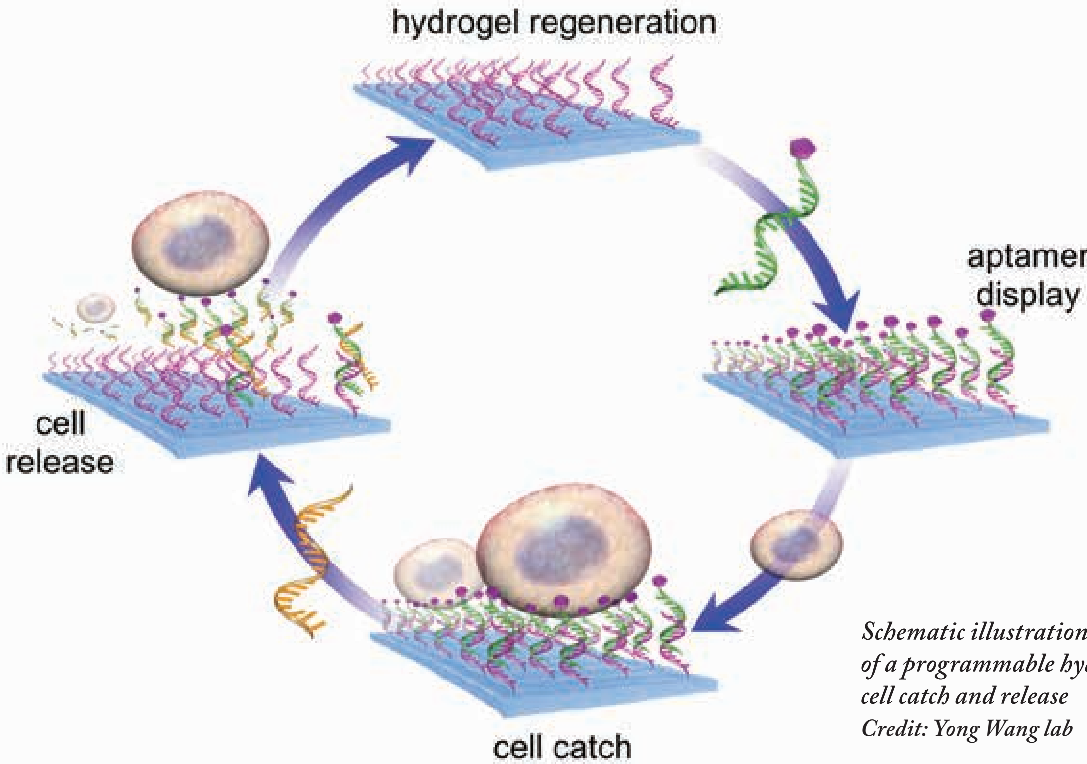
BIO-INSPIRED Body Parts

In recent years, the prospect of growing artificial tissue either outside or within the body has created a new biomedical field called regenerative medicine and tissue engineering. It is a research area that crosses a number of physical and life science and engineering disciplines, among them chemical engineering, bioengineering, biology, chemistry, materials science, and medicine. The goal, according to a National Science Foundation report, "The Emergence of Tissue Engineering as a Research Field," is to make "living replacement parts for the human body."

Whether or not our tissue can recover from disease or injury is determined by the microenvironment of cells. This microenvironment is called the extracellular matrix. The extracellular matrix is the part of the tissue that lies outside the cells, acts as a framework to support the cells, and guides the cells in the way they grow and function as they become bones, organs, or skin. Made up primarily of fibrous glycosaminoglycans and proteins such as collagen, the extracellular matrix also facilitates signaling between cells and stores growth factors to promote healing.

Yong Wang, an associate professor of bioengineering who came to Penn State in January 2013 from the University of Connecticut, is developing unique methods to make artificial extracellular matrix in the lab. Using polymer hydrogels that mimic the structure of tissue, along with nucleic acid, a biologically

Yong Wang is an associate professor of bioengineering and leader of the Biomolecular and Biomimetic Engineering Lab at Penn State.



Schematic illustration of the use of a programmable hydrogel for cell catch and release
Credit: Yong Wang lab

functional molecule, he is trying to bring life to artificial tissue.

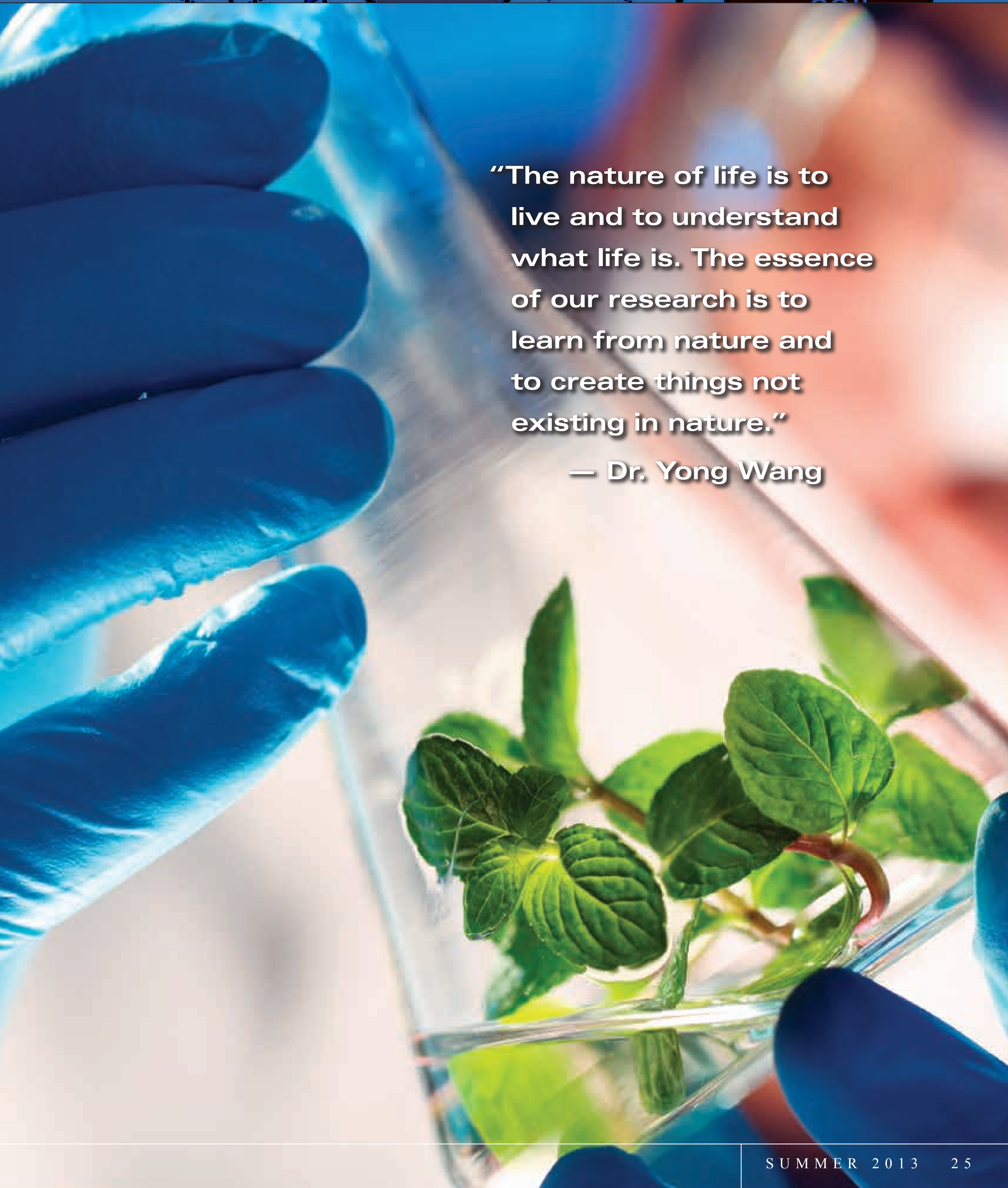
"People like to use hydrogel because the structure and mechanical properties are really similar to tissue," Wang said during a two-day visit to campus as he prepared to move his family from Connecticut to State College this summer. "But hydrogels themselves are not enough, because most of them have no biological function or lack critical functions. Therefore the second component in our system is nucleic acid, and more specifically nucleic acid aptamers."

Cells need to communicate with their surrounding environment and do so with receptors on the cell surface. The nucleic acid aptamers are engineered to recognize cell receptors and a variety of other biomolecules. By adding the aptamers to the hydrogel, which is a network of polymers that is 90 percent water, the hydrogel can communicate with the cells.

In the past, the vast majority of people trying to make this type of biomimetic system have tried to chemically incorporate peptides into hydrogel to make extracellular matrix. Peptides are chains of amino acids that make up protein, and in nature, protein makes up collagen, and parts of collagen can communicate with cells. "This approach has two major issues. On one hand, most peptides do not bind to cell receptors or soluble signaling molecules with high strength. On the other hand, though some of them may bind to their targets strongly, the strong binding cannot be reversed when needed," Wang explained. His lab has developed a method to allow the aptamer to be incorporated to the hydrogel until a trigger changes the aptamer and it releases signaling molecules or cells from the hydrogel without damage. The hydrogel can then be reused.

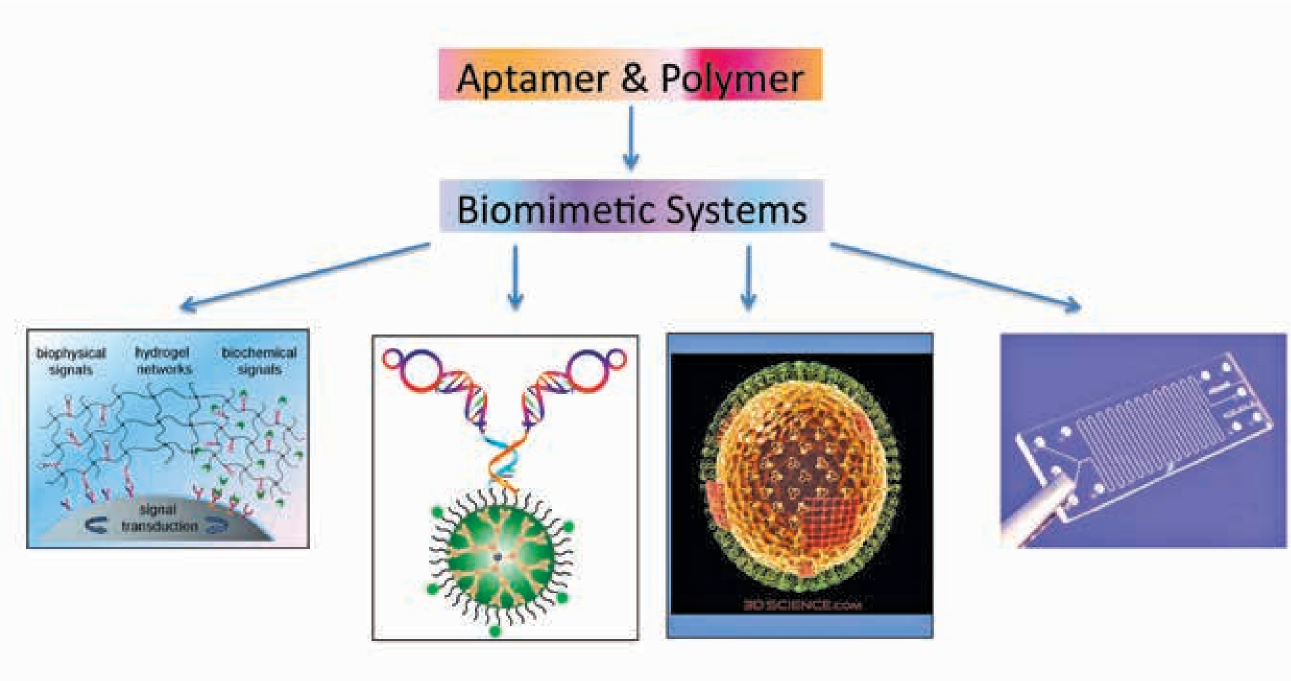
Programmable tissue-like constructs for the aging body

As we age, our bodies take longer to recover from injury to tissue and bone. At some point, a broken bone may not heal at all. Wang can help speed the healing of tissue and bone by incorporating individual types of proteins called growth factors. Growth factors added to artificial tissue hydrogel can



"The nature of life is to live and to understand what life is. The essence of our research is to learn from nature and to create things not existing in nature."

— Dr. Yong Wang

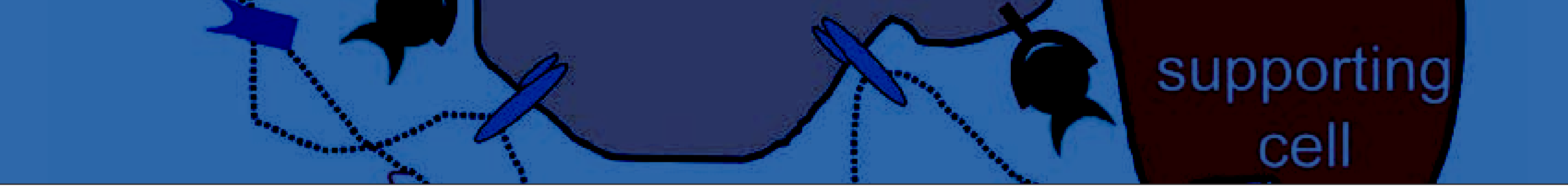


stimulate cells to grow and differentiate. It can be used virtually anywhere in the body – soft tissue or hard tissue, internal organs, skin or bone. "We make a tool that can be applied to many types of disease," Wang said. "At the moment our target is the growth of blood vessels, called angiogenesis. The growth of blood vessels is important to the recovery of any type of tissue."

Currently, most drugs are made of small molecules, but in the near future the treatment of disease using medicines may involve large biomolecules, particularly protein drugs. The first of these drugs – human insulin - was developed 30 years ago. Highly specific protein drugs have since been used to reduce blood clots or alternatively to increase blood clotting in hemophilia, help in wound healing, inhibit cancer cell growth in certain types of leukemia, and reduce inflammation in arthritis, among numerous other functions. But delivering larger biomolecules to the body has been a huge challenge, according to Wang. The method of delivery, stability of the drug, rapid clearance from the body, and the body's own immune response have all caused failure of the active drug to act on cell membrane or to be taken up into the cell.

Using polymers or polymer matrix to deliver protein drugs has been one method attempted to safely and effectively deliver large biomolecules. In the past, however, the problems with this method included the denaturation (deactivation) of the protein in the polymerization process and the inability to control the delivery amount dynamically. This is an area where Wang's approach could be useful. "Based on our method," he said, "there is no denaturing at all. When you load the drugs into the delivery vehicle, it will be active. Moreover, we can regulate the release rate, frequency, and duration of multiple protein drugs."

Asked how difficult it is to prepare his aptamer-hydrogel system, he replied "It is not difficult at all. Anyone can do it – in my lab." The difficulty is that many labs do not have the cross-disciplinary expertise in materials and biomolecular engineering in which Wang was trained. "My students think this is simple, but I tell them, that is only because you are being trained in my lab. For somebody else, it is not." But simple is a relative term. It took Wang and his students seven years to get to the point where his material was successful enough to move from the laboratory to animal studies. He is now working with a vascular specialist and an orthopedic surgeon at the University of Connecticut Health Center to begin testing his material.



Making artificial antibodies for cancer therapy

More than 20 real antibodies have been approved by the Federal Drug Administration for treating cancer and other diseases. Antibodies are y-shaped proteins that the immune system uses to identify and sometimes bind with and neutralize viruses or bacteria. Real antibodies are produced by injecting an antigen into certain animals thereby producing antibodies that can be removed from the animal blood and purified. Real antibodies can be easily denatured and lose potency. Wang is using his polymer-aptamer material to create more stable and effective artificial antibodies that are also capable of delivering anticancer drugs. Their antibodies would be designed to only recognize cancer cell receptors.

"In the past five or six years, my lab has taken on the development of a polyvalent artificial antibody. Polyvalent means that instead of one or two arms to attach to a cell, there are three or five or ten arms. We could even put on more than ten, but we have to determine the best amount. When you attach to a cancer cell, you want to bind very tightly," Wang said.

For applications such as healing bone fractures, their needs to be a lot of hydrogel material. But for artificial antibodies, he needs to shrink the system to the nanoscale, less than 100 nm. In order to see how many arms are attached to his antibody, his students are frequent visitors to the Materials Characterization Laboratory in the Millennium Science Complex to use the high-end microscopy instruments. His own lab is a mixture of simple chemistry equipment, some characterization tools, and a thermocycler adapted from biology to chemistry.

Artificial blood vessel surface

Bio-inspiration is based on what nature does well, and that includes cancer's ability to metastasize and invade other organs through the circulation system. Wang and his students are developing a system to capture circulating cancer cells in the same way that cancer cells interact with the surface of blood vessels. They want to mimic what nature does in the body for the purpose of cancer diagnostics in a clinical setting.

Wang explains: "What we want to do is, for instance, we think this person may have cancer, so we take 10mL of their blood and run it through our artificial vessel surface. Only circulating tumor cells will be captured by the surface. If the person has received therapy, the number of captured cells will indicate if the therapy is working or not."

Capturing circulating cancer cells is not an easy task in itself. A milliliter of blood may contain 10 or fewer cancer cells compared to many billions of normal cells. Once captured, the cancer cells need to be released without damage for downstream characterization, a process known as "catch and release." Wang uses aptamer-functionalized hydrogel similar to his artificial tissue with a nondestructive release mechanism using triggering molecules or restriction endonucleases, enzymes that are typically used to cleave DNA in molecular cloning.

Wang's artificial blood vessel surface could be coated on a microfluidic device to nondestructively capture and release rare circulating cancer cells and used in a doctor's office or at the patient's bedside.

All of Wang's research has been supported by the National Science Foundation, with five active NSF grants currently in progress. In the future, as results come back from animal testing, he will be seeking NIH funding to translate his seven-year materials system projects into clinical applications. His tissue-like polymer hydrogels with functionalized aptamers were inspired by nature, but now may go a step beyond what even nature can do to repair damaged tissue, deliver anti-cancer drugs, and diagnose cancer at its earliest stages.

Yong Wang is an associate professor of bioengineering. He leads the Biomolecular and Biomimetic Engineering Lab at Penn State, which has six Ph.D. students including Mark Battig, Niancao Chen, Xiaolong Zhang, Shihui Li, Yike Huang, and Erin Richards. These students are currently playing essential roles leading these projects. Yong Wang can be contacted at yxwbio@engr.psu.edu.

Celebrating 150 Years of Graduate Education at Penn State

This year marks the 150th anniversary of graduate education at Penn State. The accompanying article by Penn State graduate student Kaitlin Haas was written for this issue of *Focus on Materials*.

Science under EXTREME Conditions

By Kaitlin Haas, graduate student

A list of people that work with extreme temperatures might include: blacksmiths, glassblowers, iron smelters, and...organic chemists? I never thought that, as a chemist, I would be running reactions at 1300 K (~1200° C) and producing predictable results. The vast majority of solvents used in chemistry degrade well below 600 K (~325° C), and running chemical reactions at high temperatures invites a product that chemists lovingly refer to as "tar." Conventional organic chemical wisdom says that using extreme temperatures and expecting tractable results is a fool's errand. Well, call me a fool, because this is exactly what I find myself doing in the laboratory of Professor Benjamin Lear.

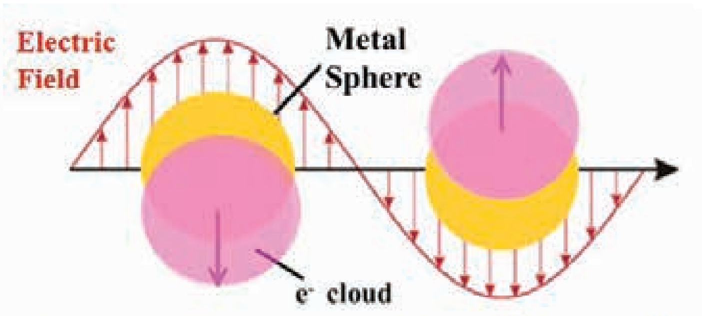


Figure 1: The electric field (light) excites electrons on the nanoparticle surface. The energy is transferred to the nanoparticle. This energy causes the nanoparticle to vibrate, which results in heating.

My research focuses on using the photothermal effect to generate temperature gradients of thousands of degrees on the nanometer scale. You experience this phenomenon every time you sit on a hot leather car seat or step barefoot onto pavement that has been in the sun. In my research, the role of the pavement, sun, and bare feet are filled by gold nanoparticles, lasers, and chemical transformations. Nanoparticles are chosen because they are strong light absorbers due to their surface plasmon: a collective oscillation of electrons at the nanoparticle surface. These electrons may be excited by light with a frequency equal to the frequency of the surface plasmon. The excited electrons transfer their energy to the nanoparticle phonons, producing the heat that can then dissipate away from the nanoparticle and into the surrounding environment. The heat produced is highly localized, which makes nanoparticles good candidates for providing strong localized heat on the nanoscale while maintaining desired bulk properties.

The plasmonic approach to heating has already been used in cancer therapy and high temperature organic reactions. It has also been used to accomplish physical transformations in the solid state, such as selective defect healing. However, few studies have focused on gaining a fundamental understanding how the properties of nanoparticles influence the effectiveness of the heat. This limits the usefulness of the spatial control over the heat produced. It's kind of like employing a stove to heat a kettle of water, but you have never used a stove before. My research aims to provide this understanding of how nanoscale heating can be efficiently used in the present applications and may possibly create new applications. To do this, we need to study the effects that different nanoparticle parameters (size, shape, composition, etc) and environments (surfactants, solvents, etc) have on the ability of these nanoparticles to generate and diffuse chemically relevant heat.

In order to understand the parameters that control the efficacy of plasmonic heating, I employ a model system of solid films of polypropylene carbonate (PPC) containing heptane thiol-protected gold nanoparticles (AuNP). These films were cast onto glass slides and the dry film was exposed to a laser. Exposure to the laser results in elevated temperatures, decomposition of the polymer, and subsequent evaporation of the monomer. This whole process results in a loss of material, which can be used to follow the reaction. From initial experiments using this approach, I was able to estimate the kinetics and temperatures achieved. I found that temperatures between 800 and 1300 K were reached in order to accomplish the amount of polymer degradation

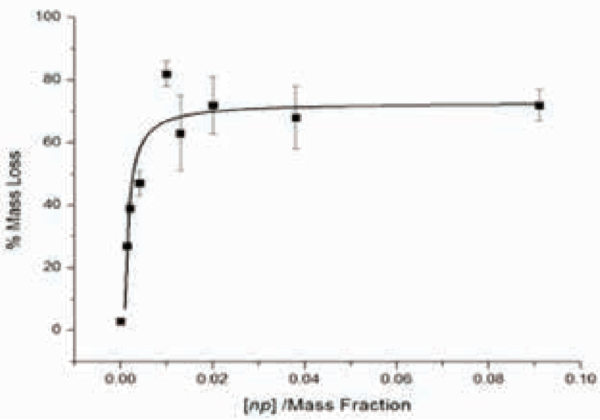


Figure 2: Change in the % mass loss of polymer *versus* mass fraction (concentration) of gold nanoparticles

observed. However, it is important to remember that this heat is highly localized (10-20 nm from the nanoparticle surface), allowing for the bulk to remain unaffected. In fact, despite these extreme localized temperatures, the polymer films are comfortable to handle with bare hands immediately following exposure to light – a result that is quite useful while carrying out these experiments!

Once I established this as a working model system, I had an easy way to both qualitatively and quantitatively measure the effects that various nanoparticle parameters, such as concentration and size, will have on the ability of the nanoparticle to accomplish polymer degradation. My first study focused on nanoparticle concentration. It was expected that a more concentrated sample (more heat sources) would best drive the reaction to completion and a less concentrated sample (fewer heat sources) would not. However, it was determined that a less concentrated sample was the most efficient driver of decomposition (Figure 2).

This result was rather surprising at first, but is easily explained. At low AuNP concentration, the optical density of the film is small enough that the entire thickness of the film experiences significant fluence of photons. By increasing the AuNP concentration, I am not merely increasing the number of hot spots, but also the optical density. Eventually, the optical density will be large enough that the front portion of the film functions to shield the back portion of the film. In this regime, the reaction volume (the portion of the film exposed to significant laser irradiation) decreases as AuNP concentration, while the sources of heat within the shrinking illuminated volume continue to increase linearly with AuNP concentration. These two effects cancel out to give an absorbed energy that is independent of AuNP concentration. Thus, I observe an overall decrease in efficiency at high loadings of nanoparticles.

Further research of other nanoparticle parameters, such as size and surfactant, will increase our understanding and control of plasmonic heating. This will aid in our ability to harness the photothermal effect of nanoparticles to drive chemical transformations far beyond what is accessible in traditional chemical approaches. In addition, these studies will contribute to current applications in medicine and materials, while providing an opportunity for new applications.

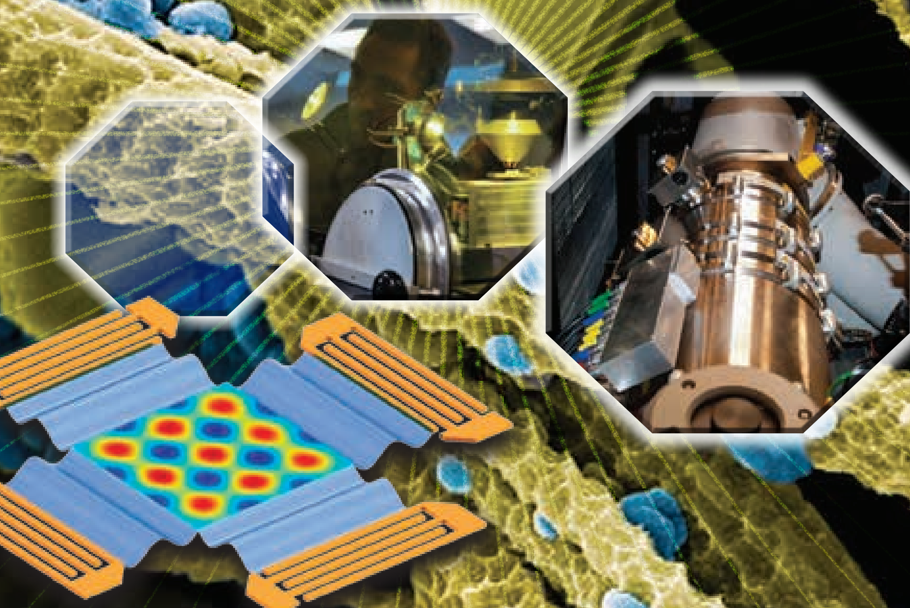
If you had asked me 15 years ago where I thought I would be today, I would have told you that after being a star college soccer player and attending medical school, I would then become the first female president of the United States and make the world a better place. I knew these were lofty goals, but I also knew I wanted to make a difference in people's lives. While I did follow my dreams of playing Division I soccer as an undergraduate, my plans for helping people have taken a different path than the one I laid out for myself as a ten year old. Today, I create the fundamental understanding of nanomaterials upon which new medicine and materials will be based.

Kaitlin Haas is a graduate student in Penn State's Department of Chemistry and the winner of the 2013 Rustum and Della Roy Innovation in Materials Research Award. Contact Kaitlin at kwh5231@psu.edu.

Materials Day 2013

OCTOBER 15 & 16

Materials for Emerging Technologies



THEME: Advanced materials are fundamental to the technologies of the future, enabling economic progress, energy security, national defense, and human health and well-being. Join the Penn State materials community this October for Materials Day to find out the latest progress in designing, synthesizing, and testing new materials and devices from Penn State students, faculty researchers, and distinguished industry leaders.

WHY ATTEND: Materials Day 2013 will kick-off with tours of the Millennium Science Complex at 11 a.m. on Tuesday, October 15. Beginning at 1 p.m., attendees can choose among seven tutorial sessions led by active faculty researchers and Ph.D.-level research staff across a wide range of topics. Interactions with students and faculty will continue at a meet-the-graduate-students themed reception in the Nittany Lion Inn from 5-7 p.m., highlighted by the keynote address at 5:30 p.m. by an industry leader.

On Wednesday, October 16, the venue will shift to the HUB auditorium, a short walk from the Millennium Science Complex, for invited presentations from two distinguished industry leaders and research presentations by two of Penn State's active faculty researchers. Faculty, Ph.D. researchers, and graduate students will be on hand at an afternoon poster session to discuss Penn State's latest research accomplishments.

TABLETOPS: A limited number of industry tabletops are available for the Tuesday evening reception. For additional details and registration, go to www.mri.psu.edu/events/materials_day.

Additional sponsorship opportunities are available for industry. Please contact Dave Fecko at dlf5023@psu.edu or (814) 865-6691.

For details and registration, go to www.mri.psu.edu/events/materials_day

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