COLLEGE OF ENGINEERING

Momentum!

Spring 2014

Exploring Materials Science

Oregon State
UNIVERSITY

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College of Engineering faculty and staff gathered at Reser Stadium for the 2013 Fall Awards Breakfast.

Materials matter

Understanding how materials behave at all scales — from the atomic level to massive infrastructure — is essential to engineers in all disciplines. Done correctly, materials science research requires interdisciplinary collaboration that ignores traditional academic boundaries and allows researchers the freedom to explore ideas from multiple perspectives.

In this issue, we introduce you to a variety of research projects that represent what's going on at Oregon State in materials science. These stories represent just the tip of the iceberg in this exciting field.

- John Conley is applying a thin-film synthesis technique called atomic layer deposition to create cutting-edge technologies in medicine, next-generation electronics, neuromorphic computing, and more.
- Brady Gibbons and David Cann are partnering with HP to find lead-free alternatives to PZT, the current state-of-the-art piezoelectric material. These materials are critically important in environmentally benign manufacturing.
- Two of our newer faculty members, Líney Árnadóttir and Joe Baio, are studying surface reactions at the atomic level, with implications for reversing osteoporosis and converting CO_2 to an endless source of clean energy.
- Pallavi Dhagat and Albrecht Jander are investigating a technology called spintronics, which has the potential to replace conventional semiconductor electronics and make way for smaller and more robust data storage devices.
- Armin Stuedlein, David Trejo, and Jason Ideker are developing new construction techniques and more resilient building materials that will mitigate future bridge and building failures in the event of earthquakes or other natural disasters.
- While at Oregon State, Randy Hoffman ('02 Electrical Engineering) demonstrated in his master's thesis an entirely new application for oxide materials. His invention of transparent thin-film transistors revolutionized electronic displays. He is now a senior engineer at HP.

Our responsibility is not only to educate the next generation of engineers, but to expand the body of knowledge we pass on. Research informs and improves teaching. By engaging our undergraduate and graduate students in research, we give them a deeper set of abilities — to think about real problems critically and creatively, to apply methodologies systematically, and to communicate discoveries effectively.

I hope these articles intrigue you, and that they will inspire you to remain engaged with the College of Engineering. Let us know next time you plan to be on campus — we would love to have the opportunity to give you a tour of our laboratories.

Go Beavs!

Scott A. Ashford, Ph.D.
Kearney Professor and Dean
Oregon State University
College of Engineering

Thin film, fat potential

By Marie Oliver

Professor John Conley and Ph.D. student Dustin Austin prepare to introduce a silicon wafer into an atomic layer deposition chamber for synthesizing a nanolaminate dielectric film.

Professor John Conley has no problem finding materials science research projects to keep him excited and engaged in his work. His challenge is to choose among the numerous, diverse projects that call for attention.

Conley came to Oregon State after extensive industry and national lab experience with Dynamics Research Corp., the Jet Propulsion Laboratory, and Sharp Laboratories of America. He is now an Oregon Nanoscience and Microtechnologies Institute (ONAMI) Signature Faculty Fellow with the School of Electrical Engineering and Computer Science and the Materials Science graduate program and the co-director of the Materials Synthesis and Characterization Facility (MASC) at Oregon State.

Conley's signature area is a thin-film synthesis technique called atomic layer deposition (ALD). At present, he is contributing his expertise in ALD to at least seven collaborative projects, including (but not limited to) an artificial pancreas for Type 1 diabetics; MIM (metal-insulator-metal) structures with applicability to high-speed electronics, high-density capacitors, and neuromorphic computing; and improved coatings for aerogels, dental braces, and prosthetics.

Atomic layering 101

Atomic layer deposition is a process used to create thin films. It was invented in the 1960s, but experienced a resurgence in the late 1990s because of its potential for enabling the fabrication of ever-smaller, higher-density microelectronic devices.

ALD sequentially introduces vaporous chemicals — called precursors — in a meticulous and well-organized fashion. The precursors react one at a time and the film builds up in layers, allowing scientists precise control over thickness and composition at the atomic level. The technique enables scientists to uniformly coat uneven surfaces. "So if you need to coat a really narrow trench with highly conformal film, this is really the only technique that can do that," said Conley.

The use of specific precursors is determined by the desired application, and Conley has helped develop several of them. "We've developed several materials using this technique and improved the electrical properties for emerging electronic devices," he said. "Although my main focus is materials development and electronic device applications, I'm also interested in other applications of ALD."

And the number of potential applications for ALD is mind-boggling.

Artificial pancreas

Any way you look at it, living with Type 1 diabetes is not easy. In contrast to Type 2 diabetes, which is acquired and can be controlled with diet and exercise, Type 1 diabetics are born with an inability to properly regulate insulin. In the absence of medical intervention, the condition is life threatening.

Current state-of-the-art technology allows Type 1 diabetics to wear a complex system that monitors glucose and delivers insulin and glucagon. Unfortunately, the system requires four devices to be inserted into the abdomen, which is a lot to keep track of and can be uncomfortable for the wearer. These devices include two sensors (both to monitor glucose) and two pumps (one for insulin, one for glucagon).

A couple of years ago, Pacific Diabetes Technologies approached Conley because they wanted to improve the current technology by using flexible electronics to build an "artificial pancreas." They had heard about Conley's work through one of his former graduate students who had consulted for the company.

Conley's eyes light up when he relates this first conversation. "It sounded like a really neat project, much closer to everyday experience than a lot of the stuff I do — and kind of a stretch for me, outside of my usual area." He invited Greg Herman from the School of Chemical, Biological, and Environmental Engineering onto the research project, because of Herman's industry experience with flexible electronics.

The research team designed and built a single device that mimics an organic pancreas. "We're building these devices on flexible substrates that can bend around a narrow radius and still work," said Conley. "The device has multiple sensing locations that monitor glucose and will be designed to work with a dual chamber pump that delivers the correct hormone as needed. It will require only one insertion point in the patient instead of four, and presumably should be much more comfortable."

The artificial pancreas is almost ready for prime time. "They're getting ready to do animal studies on the devices we've made here at Oregon State, so it's really exciting," said Conley.

In addition to Pacific Diabetes Technologies, funding for the project comes from the Small Business Innovation Research Program at the National Institutes of Health, the Leona M. and Harry B. Helmsley Charitable Trust, and ONAMI.

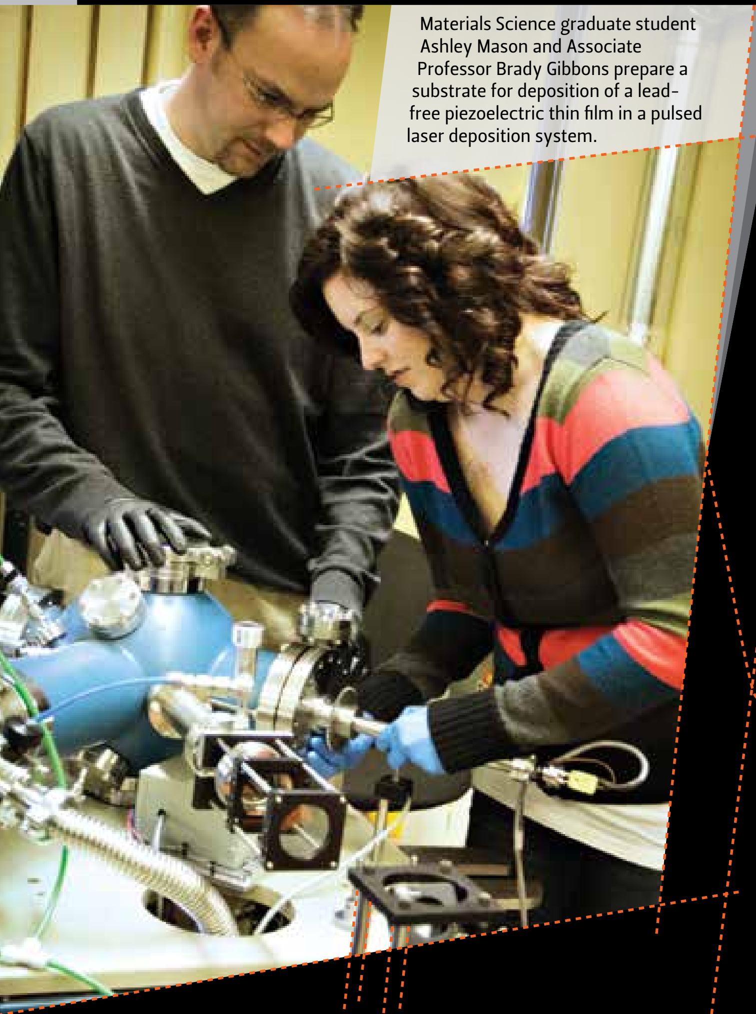
And so much more!

Conventional microelectronic technology is beginning to approach fundamental limits, and Conley is participating in several interdisciplinary projects that are breaking new ground in the world of electronics. Devices based on quantum mechanical tunneling, in which an electron can instantly appear on the other side of a barrier, may provide a path to ultrafast applications. Conley's group is improving the performance of MIM tunnel diodes by using the ALD technique to deposit a nanolaminate insulator tunnel barrier that is engineered for precise control of charge flow and will help to reduce power usage and heat buildup.

Another project of this type involves the creation of a new type of solid-state memory called RRAM (resistive random access memory) that may replace flash memory for ultradense storage and has implications for neuromorphic computing.

Along different lines, he is working closely with John Simonsen in the College of Forestry to develop an ALD coating for aerogels that will enable wood scientists to develop organic/inorganic composites with improved properties and stability.

Conley's other projects — too many to mention here — are no less impressive. He is a new brand of engineer, crossing traditional research boundaries to apply his specialized knowledge in the development of a host of unique and innovative materials. **M!**



Materials Science graduate student Ashley Mason and Associate Professor Brady Gibbons prepare a substrate for deposition of a lead-free piezoelectric thin film in a pulsed laser deposition system.

The hunt for a lead-free future

By Gregg Kleiner

Professor David Cann's research group *(from left)*: Sunny Triamnak, David Cann, Nitish Kumar, Troy Ansell, Eric Patterson, Noon Prasertpalichat, Jason Nikkel, and Ton Raensthon.

Six years ago, mechanical engineering professors David Cann and Brady Gibbons had just arrived at Oregon State University and were giving a tour of their labs in Dearborn Hall to a few visiting Hewlett-Packard executives. Among the execs was Tim Weber ('86 B.S., '88 M.S., '91 Ph.D., Mechanical Engineering), an HP vice president who was serving on the Industrial Advisory Board for the School of Mechanical, Industrial, and Manufacturing Engineering.

Cann and Gibbons, both with doctorates from Penn State and deep expertise in piezoelectricity, demonstrated their lab equipment and talked about their research capabilities in piezoelectric materials. Piezoelectric materials are certain ceramics and other materials capable of generating an electrical impulse in response to applied mechanical stress. They also exhibit the reverse effect by generating mechanical stress in response to an applied electrical field.

Piezoelectric materials are found in many products, including inkjet printers (where electric impulses can precisely control the amount of ink mechanically ejected from a print head), fuel injectors in automobiles (designed to distribute precise amounts of fuel at exact times to boost mileage), medical ultrasound equipment (in which electrical impulses launch acoustic waves that travel through tissue and amniotic fluid to attain images), sonar devices used by the Navy, and the ignition systems in push-start propane grills (where that physical clicking sound causes the piezoelectric material to emit a tiny spark to ignite the fuel).

Lead zirconate titanate (PZT) is the current state-of-the-art piezoelectric material. Although PZT has excellent piezoelectric characteristics, it is more than 60 percent lead by weight, and the toxicity and negative environmental impacts of lead make the material undesirable, even in small quantities. The European Union and Turkey have banned most lead-based materials by adopting the Restriction of Hazardous Substances (RoHS) Directive, which restricts the use of certain hazardous substances in electrical and electronic equipment. Japan, China, and South Korea are implementing equivalent restrictions. Although the U.S. does not have similar regulations, companies like HP want to comply with the RoHS to maintain access to European and Asian markets.

Another downside to PZT is that the material slowly loses its piezoelectric properties over time because it exhibits "fatigue" when subjected to multiple cycles of electrical inputs or mechanical stress, which lowers the efficiency of the device containing the material (automobile fuel injectors, for example). Because of the lead-based material's susceptibility to fatigue, designers must engineer around it, which complicates projects and adds costs.

The HP executives on the lab tour were impressed by Cann and Gibbons' research program and told them that HP might be interested in Oregon State's capability, because piezoelectric materials are used in inkjet print heads of some commercial, high-throughput printers. They invited Cann and Gibbons to give a tutorial on piezoelectricity at the company's Corvallis campus, and the professors happily complied. But afterward, months went by without a peep from HP. The pair figured that any opportunity for collaboration was probably lost.

"Then one day, about six months later, an email came in out of the blue," Cann said. "They wanted to start a project." HP offered initial funding to support the company's existing piezoelectric materials projects, but the collaboration grew into a five-year venture focused on helping develop lead-free piezoelectric materials.

Although finding a lead-free alternative that works as well as PZT has been a challenge, after more than five years of research, Cann and Gibbons have come up with several materials that work well.

In addition to discovering several proprietary lead-free materials, the project has generated one secured patent and five pending patents, a third party interested in commercializing the technology, and a recent investment of $75,000 from the OSU Venture Fund to fast-track commercialization.

"Other highlights of this project include a solid suite of intellectual property and two great Ph.D. students who have helped put OSU on the map globally for lead-free research," Gibbons said. "OSU is now known as a center for this kind of research, and much of that is thanks to the long-term industry support from HP."

Cann and Gibbons both agree that the level of industry support for their research — approximately $650,000 over five years, with some of that matched by the Oregon Metals Initiative — was invaluable in making their hunt for lead-free, fatigue-free materials successful.

"Industry support at this level over so many years just doesn't happen very often," Cann said. "HP has been incredible."

Gibbons and Cann are now actively seeking industry partners who can help them take the proprietary materials to market, and HP is interested in licensing some of the technology.

"This is a similar situation to what lead solder underwent twenty years ago when researchers had to develop a lead-free alternative," Cann says. "That was a 20-year effort, but today many electronics manufacturers use solder that is 100 percent lead-free. In a few years, we hope to see that lead has been replaced in all piezoelectric materials." M!

Top: Assistant Professor Líney Árnadóttir describes the interaction between an adsorbed molecule and a surface defect site to first-year graduate student Lynza C. Halberstadt. Bottom: Undergraduate student Malayla Gessford and Assistant Professor Joe Baio examine a sample of nanoparticles that self-assembled by biomineralization proteins.

On the surface

By Thuy T. Tran

What if the greenhouse gas, CO_2, could be converted to an endless source of clean energy? What if osteoporosis could be reversed through artificial biomineralization?

These are the types of questions that interest researchers Líney Árnadóttir and Joe Baio. To answer them, these two new faculty members in the School of Chemical, Biological, and Environmental Engineering are probing fundamental realities on the surface of things.

Fundamental science is critical in the long developmental pathway toward innovative products and services, because it creates the knowledge from which applied research is drawn. “Fundamental research is a million steps away from a viable product in the industry, but everything begins with solving fundamental physics problems,” said Baio.

Árnadóttir and Baio hope that their research ultimately will lead to technologies that improve the environment and human health.

In search of clean energy

Árnadóttir uniquely combines theoretical chemistry and experimental surface science to study catalytic surface reactions. Catalysts are substances that speed up reactions by providing an alternative pathway — one requiring lower-than-normal activation energy. “The catalysts themselves are generally nonuniform powders or pellets, but they work at the atomic interaction level,” said Árnadóttir.

In catalysts, the action happens at the steps, kinks, and defect sites. When an atom sits in the bulk of a material, it is surrounded by neighboring atoms in all three dimensions in a regular, repeated symmetry — a pattern that varies with the crystal structure of a particular material. For an atom sitting at the surface, life is a little more interesting, because its neighbors above are missing. At a step, the atoms above and on one side are missing. At kinks, even more neighbors are missing. Steps and kinks (see diagram) are among the surface anomalies generally referred to as defect sites.

Árnadóttir specifically studies the role of these defect sites on metal catalysts and the effect of co-adsorbed molecules. Her studies help to narrow the scope of usable materials for particular applications. Most of the bulk in any given catalyst is inactive and the work is done by relatively few atoms at the surface. Understanding which sites are active and the reaction mechanisms for each particular material helps scientists design better, more efficient catalysts.

“Catalysts come into play at some point in every industrial chemical process in the modern world today, from making fuel, to pharmaceutical products, to plastics,” she said. “Understanding how they work, and designing more reactive, selective, and effective catalysts, will help industry save materials and pollute less.”

Árnadóttir uses x-ray phoelectron spectroscopy (XPS), a surface-specific technique in which scientists irradiate a chosen material with x-rays under ultra-high vacuum conditions and measure the resulting kinetic energy of the electrons that escape from the first few nanometers of the surface region. XPS data reveal the elemental composition of the surface, including the support material and any catalyst nanoparticles.

To narrow down the unlimited experimental possibilities, Árnadóttir uses density functional theory, an approximation of the Schrödinger equation that is fundamental to quantum mechanics, to calculate interactions between electrons.

Once she has collected the data, she looks first at catalytic reactions from a theoretical perspective. “With theory, how a reaction takes place can be mapped out exactly. So rather than starting with a random metal, theory tells you which one is most likely to work,” she said. She then examines the system experimentally. Through the iterative process of comparing experimental and theoretical data, she hopes to reach a deeper understanding of catalytic reaction mechanisms.

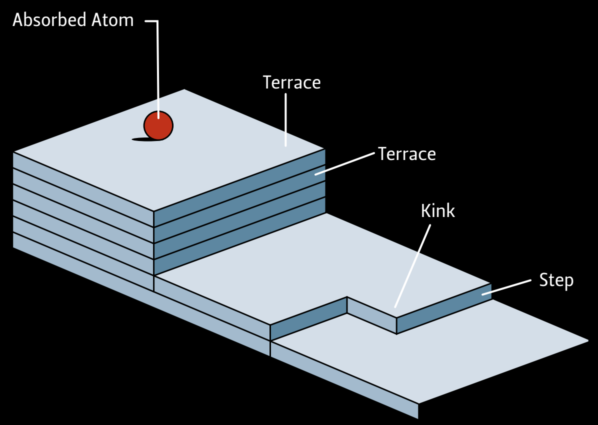
“In the short term, I’d really like to explain the role of alkali metals in activating reactions,” said Árnadóttir. “Ultimately, I would like to find the catalyst that would change the industry — not only to remove atmospheric CO_2, but to make something beneficial out of it.”

Improving human health

Baio also looks at surfaces, but of a different kind. He develops complementary analytical methods to solve protein structures on biomaterial surfaces. One of his interests is the molecular mechanism that drives biomineralization, the process by which organisms produce mineralized tissue, such as bones and teeth.

Baio’s research could help solve diverse industrial, manufacturing, and medical problems, such as why cargo ship hulls foul, why stents fail, and why catheters malfunction. Although his research projects are diverse, they all have one idea in common: solving the structure involved when a protein interacts with a surface.

“Solving the structure at the atomic and molecular levels leads to understanding the interaction mechanism and ultimately arriving at solutions to the macro-scale problems,” he said.



The main components of human tooth enamel are statherin (a protein) and hydroxyapatite (a mineral). “Statherin is what regulates the enamel growth on teeth, but no one understands how it binds to and controls the growth of hydroxyapatite,” said Baio. “Your teeth don’t continue to grow. There’s an on-and-off control mechanism that’s perfect — evolutionarily perfect.”

The protein-mineral interaction involves specific contacts between atoms on the hydroxyapatite surface and key side chains on the statherin protein. Solving the detailed three-dimensional structure at the binding sites is key to understanding the mechanism of biomineralization.

Baio combines a suite of surface analytical techniques, including near-edge x-ray absorption fine structure (NEXAFS) spectroscopy, time-of-flight secondary ion mass spectroscopy (ToF-SIMS), and element labeling, to build the puzzle pieces one-by-one and eventually interlock them to form the complete picture of biomineralization.

“From NEXAFS, we can determine the tilt angle of the entire protein with respect to the mineral surface,” said Baio. “ToF-SIMS, element labeling, and vibrational spectroscopy give us not only three-dimensional pictures of the different amino acids that make up the protein, but also the tilt and twist angles within the protein that help us connect the amino acids together.”

Baio’s interests are in a small but growing research field.

“For about 100 years now, physicists have been getting very good at creating different techniques to look at surfaces, but they are generally looking at very simple molecules or thin films on surfaces,” said Baio. “Even my background was in material processing for thin films. Then, I realized that biological questions are tougher, and a little bit more interesting.”

GPS (Global Positioning System) technology, which provides innumerable applications around the world today, originated from the idea of using atomic clocks to test Einstein’s century-old general theory of relativity. Similarly, the big “what if?” questions will one day be answered by scientific research into fundamentals like those explored by Árnadóttir, Baio, and others who probe the surface of things. M!

A new spin on magnetic materials

By Abby P. Metzger

Associate Professor Pallavi Dhagat places a magnetic tunnel junction sample, intended for MRAM applications, in a ferromagnetic resonance spectrometer.

The same phenomenon that keeps pins your family photos stuck to the fridge also now pins your "selfies" safely on your Facebook page: magnetism. In fact, magnetic recording remains the most inexpensive and widespread technology for data storage, and is found everywhere, from Facebook's vast server farms to your personal laptop hard drive and your Nordstrom credit card.

Pallavi Dhagat and Albrecht Jander, associate professors of electrical and computer engineering, are exploiting the unique properties of magnetism in numerous ways, ushering in new applications for information storage, energy-harvesting devices, and other technologies. They are specifically investigating a technology called spintronics, which has the potential to replace conventional semiconductor electronics and make way for smaller and more robust data storage devices.

This magnetic moment

As the name implies, spintronics relies on electronic spin rather than charge to acquire, store, and transmit information. In addition to its static properties — its charge and mass — the electron also has a dynamic property called spin that gives it a magnetic moment. In combination with the right materials and an electrical current, this magnetic moment enables researchers to record data.

Albert Fert and Peter Grünberg discovered the first practical spintronic effects in 1980s, and within 10 years it was in use in computer disk drives. Fert and Grünberg won a Nobel Prize for Physics in 2007 for their discovery.

"It's very rare that a basic discovery makes it into an application that quickly," said Dhagat. "That made a huge impact on the hard disk-drive industry. Being able to read information with greater sensitivity meant that you could make things smaller."

Byte by byte

By the mid-20th century, magnetic-core memory boards were the predominant form of computer memory. Jander displays one of these relics in his office; it is the size of a briefcase and contains 512,000 tiny magnetic beads strung on wires, each representing a single byte of memory. That's 64 kilobytes — enough to store this article.

Today, a 64-megabyte spintronics-based chip is about the size of a kernel of corn and has 1,000 times the capacity of those old memory boards. But to meet the needs of tomorrow's devices, it needs to be smaller yet.

Jander and Dhagat are investigating a spintronic device called Magnetic Random Access Memory (MRAM). Like their core-memory predecessors, bytes of information are stored in tiny magnets. High-tech photolithography is used to create multiple magnetic layers and electron spin reduces the energy required to write data.

MRAM has the potential to combine the speed of processor memory with the nonvolatility of flash memory, so data are retained even when the device is turned off. This contrasts to volatile forms of memory like DRAM, where files are gone if power is lost before the user saves.

In fact, MRAM is so robust, it can be used in the high-radiation environment of outer space. In a study conducted at the Oregon State Radiation Center, Jander and Dhagat have demonstrated that neither the electrical nor the magnetic properties of MRAM were affected as a result of exposure to gamma and neutron radiation.

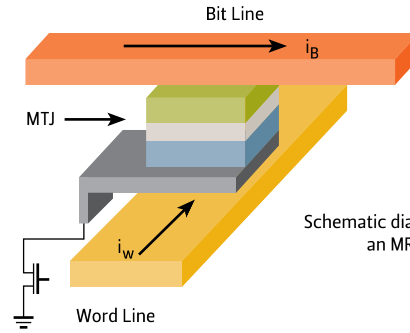
Even though it promises to combine nonvolatility, speed, scalability, and radiation tolerance, MRAM still has its challenges. With the current technology, it would take 100 of the 64-megabit chips to make up a typical 6-gigabyte memory board — too big and expensive to put into a laptop computer — so Jander and Dhagat are investigating materials that will help them achieve the necessary reduction without losing integrity.

"We're trying to pack more and more into smaller and smaller devices, and if you make something so small, it becomes volatile," said Jander. "The last thing we need is a forgetful computer."

Small devices require extremely precise design and composition. "The holy grail is making these things with lower currents, obviously because that means a lot of power savings," said Dhagat. "So how can you get lower current devices to operate while they are so small? You have to understand the details of the physics of the interfaces, at the edges of the device. You have to understand the quality and thickness of the film and the composition of that film. Those are some of the questions we are trying to address."

Beyond electronics

Faster, more robust memory chips in cell phones, computers, planes, and spacecraft represent just one application of spintronics. Dhagat and Jander are also taking the principles of magnetism into energy-harvesting systems. The technology is a close cousin of thermoelectrics — devices that create voltage due to a temperature gradient.



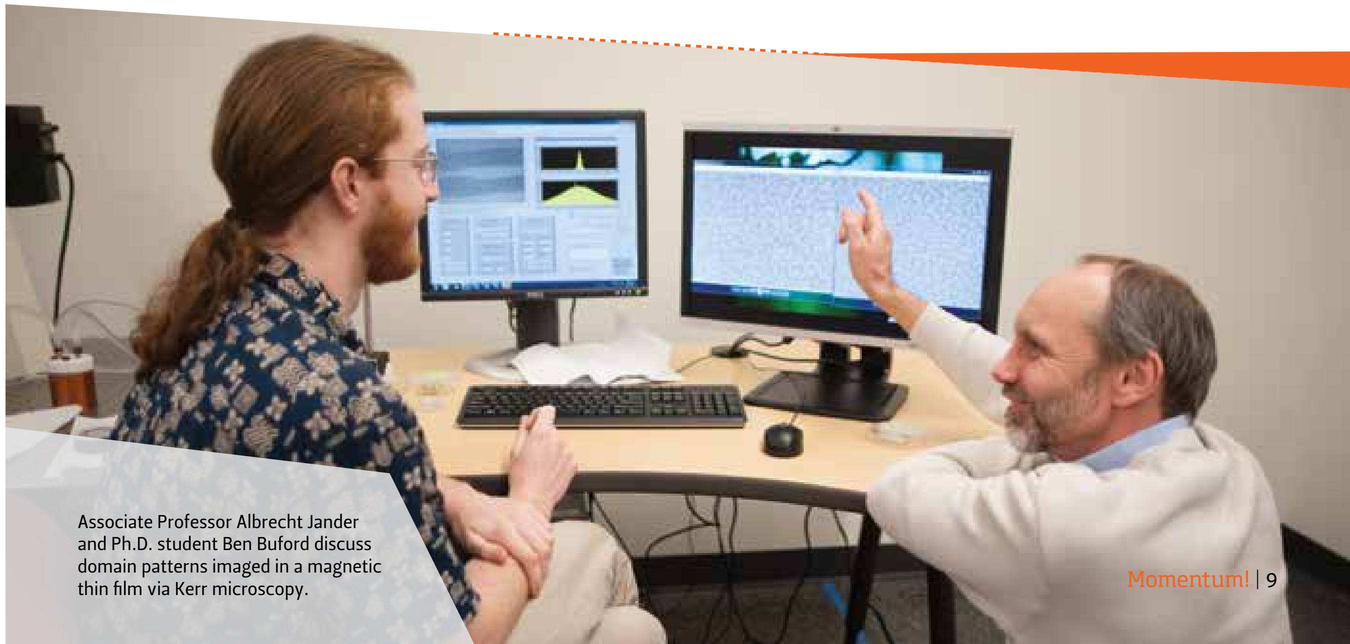
Schematic diagram of an MRAM cell.

Imagine a byzantine layer of semiconductors between two ceramic plates. When you connect it to current, heat moves from the cold side to the hot side, much like a refrigerator. Dhagat and Jander envision a surface film that exploits spintronics to achieve the same thermoelectric effect: the interaction between heat and spin-polarized electrons in magnetic materials produces an electric current.

The two researchers are collaborating with colleagues in Japan at the Fukuoka Institute of Technology to investigate new materials that can accentuate this effect and generate a useful amount of power. The current material is called yttrium iron garnet (YIG), a synthetic mineral that has the properties of spin yet can maintain a temperature differential necessary to generate power. Adding new materials to YIG could enhance its energy production potential.

Both researchers cautioned that real-life applications are far off, but theoretically you could recover energy from any surface that is hot on one side and cold on the other, such as a window. You could also harvest lost exhaust heat from your car, a clothes dryer, or a power station to amplify the energy output.

Applications of magnetic materials have made a remarkable leap in the last few decades. The physics of magnetism remain unchanged, but Dhagat and Jander are putting a new spin on an old phenomenon. **M!**



Associate Professor Albrecht Jander and Ph.D. student Ben Buford discuss domain patterns imaged in a magnetic thin film via Kerr microscopy.

Graduate students Rachel Fischer and Andrew Strahler look on as Assistant Professor Armin Stuedlein places an instrumented loading rod within a device used to measure the strength and stiffness of soil.

Assistant Professor Jason Ideker and Oregon BEST Postdoctoral Fellow Tengfei Fu inspect a concrete specimen taken from the Scientemp freeze-thaw chamber.

Professor David Trejo and graduate student Tim Link inspect a bridge column containing high strength steel subjected to seismic cyclic loads.

Engineering bridges to span centuries

By Warren Volkmann

The 6.7 temblor that struck Northridge, Calif., 20 years ago caused an estimated $20 billion in damages during 20 seconds of shaking. Although it was a strong quake, the world has seen much worse, and it was a wake-up call to civil engineers. Collapsed overpasses and pancaked buildings stood as mute, deadly testimony to the fact that the modern construction techniques used at the time were no match for the forces of nature.

"The Northridge earthquake was particularly important," said Armin Stuedlein, assistant professor at Oregon State University's School of Civil and Construction Engineering. "It began to open our eyes to the possible effects of design flaws."

Stuedlein, Professor David Trejo, and Assistant Professor Jason Ideker are working in their separate specialties to advance civil engineering to ensure that 21st-century bridges and buildings have the resilience to last well into the 22nd century. They are researching new construction techniques and more resilient building materials that will reduce the risk of future bridge and building failures.

In simplest terms, Stuedlein is researching bridge supports below the ground, Trejo is focused on the reinforcing steel inside columns and beams above ground, and Ideker is working to develop durable, crack-resistent concrete for bridge decking — the roadway itself.

The right foundation

The disastrous 9.0 quake and tsunami that struck the northern coast of Japan in 2011 added a sense of urgency to Stuedlein's and Trejo's research projects. The coast of Oregon and Washington are due for a similar disaster.

"There is a roughly 40 percent chance that we will have an extremely significant earthquake like Japan within the next 50 years," Stuedlein said. "It will have a magnitude of 8.5 to 9.0. The Northridge quake lasted only 10 to 20 seconds. Ours will last for three to five minutes. There will be many cycles of horizontal loading. I want to understand how the horizontal forces are transferred to the subsurface."

During severe earthquakes, even bridges that don't break apart can fail if they lose their bearing. To develop stronger, more resilient foundations. Stuedlein and his research team will be constructing four test shafts, three feet wide and 60 feet deep, on campus property just west of the O.H. Hinsdale Wave Research Laboratory. Into those holes, Stuedlein and his team will drop steel reinforcing cages, some made with typical steel and some made with high-strength steel. They will then pour in concrete, creating the equivalent of a bridge support that can withstand a lateral loading of 300,000 pounds (the weight of about 125 cars).

The resilience and stabilizing effect of the drill casing — the metal cylinder that lines the shaft to prevent the walls from collapsing during drilling — is often ignored, so Stuedlein's team will be paying particular attention to that aspect of the project.

"The casing can be an effective way to transfer lateral loads into soils that are stronger at depth. If leaving the casing means we can reduce the amount of reinforcing steel used, that would be very cost effective, and would reduce the potential for defects associated with concreting difficulties," he said. "That's where my research connects with David Trejo's work."

The right materials

Concrete and steel form an excellent construction partnership because they have complementary strengths. Concrete is strong and resists compression, but it crumbles when flexed. Steel is much more flexible, so reinforcing concrete with steel bars combines the strengths of both. However, in many cases there is so much reinforcing steel in bridge supports that it becomes difficult to place the reinforcing bars. If the concrete fails to flow around the steel bars, air pockets can form and weaken the structure.

Trejo advocates using high-strength steel because it would require less to do the same job and leave more space for the concrete to flow.

"The reason high-strength steels are not used already is because we don't understand them well," Trejo explained. "We don't understand how they perform in concrete. Our research, and Professor Stuedlein's research, is assessing whether high-strength steels can and should be used in bridge structures." Early results are promising.

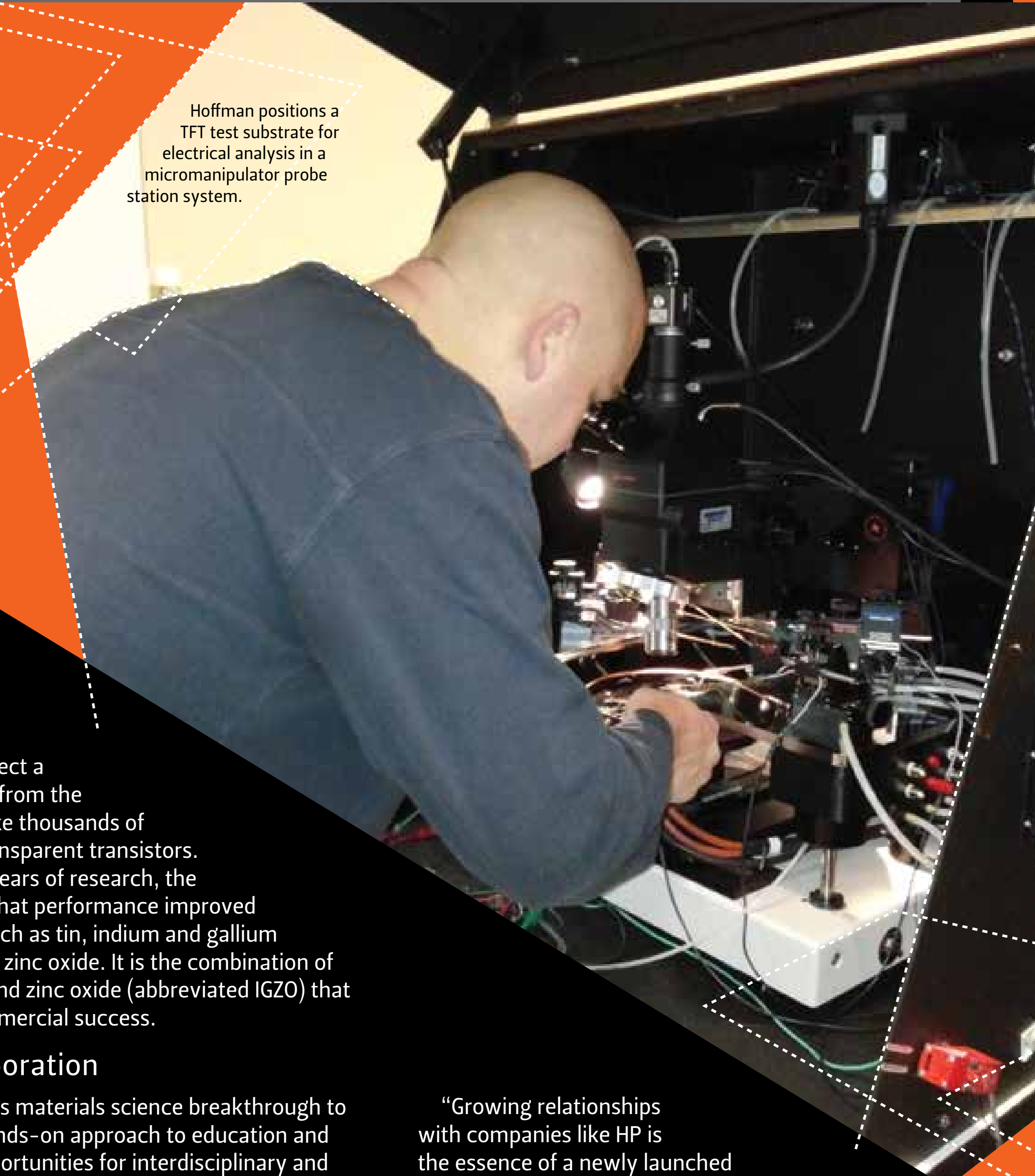
For now: rapid repair

Ideker is concerned with the daily strains of expansion and contraction that continually cause cracks in bridge decking. These cracks allow air, water, and road salt to invade the concrete and weaken it. His research characterizes early-age volume changes in rapid-repair materials, which has enabled civil and construction engineers to ensure the long-term durability of those materials.

"When a catastrophic event occurs, rapid-repair materials can be used to get critical infrastructure back into service again," he said. **M!**

Oregon State invention sparks a new industry

By Warren Volkmann



Hoffman positions a TFT test substrate for electrical analysis in a micromanipulator probe station system.

It is not often that a recent graduate publishes a master's thesis and lights the match on a new industry, but in 2003 Randy Hoffman ('02 Electrical Engineering) did just that. In *Applied Physics Letters*, Hoffman announced the creation of transparent thin-film transistors.

"Randy didn't just create a transparent transistor," said John Wager, Hoffman's graduate studies professor. "He captured a whole class of materials."

Hoffman started his master's work in Wager's lab in the fall of 2000. "Wager's group was just beginning to look at transparent semiconductors as a new area of research," he said. "I was the first person in the lab focused primarily on that research area."

Hoffman's discovery prompted a mutually beneficial research relationship between Oregon State University and HP, including a technology license agreement. "We structured the license broadly, with reasonable terms, to build a long-term relationship with HP that expanded the focus from solely commercialization to include research and student engagement," said Brian Wall, Oregon State University's director of the Office for Commercialization and Corporate Development. Wall worked with Wager and Hoffman early in the development to identify, protect, and license the intellectual property to HP. As research progressed, the relationship has expanded, always with an eye to continuing a win-win collaboration.

Technology on the verge

Upon Hoffman's announcement, the invention of transparent transistors drew immediate international attention. Hoffman's paper has been cited more than 1,000 times in technical journals.

Futurists heralded the transparent transistor as the key that would unlock flexible displays, web browsing on paper-like displays, and even wearable computers. Hoffman and Wager were more circumspect, avoiding lofty prognostications.

"This is a significant new advance in basic electronics and materials science," Wager said back then. "There's no doubt it will open the door to some interesting new products and businesses, but we're not sure what all they might be. It's a little bit like lasers when they were first developed in the 1960s. No one was quite sure what they could be used for. Later on, lasers became the foundation of dozens of products and multi-billion dollar industries. Right now, we're just beginning to think about what you could do with a transistor you can see through."

Ten years later, it is clear that Hoffman and Wager need not have worried about the future of transparent thin-film transistors. Hoffman has seen his transparent transistor technology combined with organic light-emitting diodes (OLEDs) in 55-inch flat-screen televisions sold by LG, and the research team is excited about the imminent adoption of transparent transistor technology for liquid crystal display (LCD) applications in the $100 billion market for large and small flat screens.

"For the past 10 years, everyone has known that amorphous silicon transistors would have to be replaced in future LCDs," Wager said. "Until a few years ago, most people in the display industry thought that they would be replaced by low-temperature polycrystalline silicon transistors. But now it looks like the winner will be our technology. It is a lot cheaper. Also, it turns out that about 100 times less current flows in our transistors when they are turned off. That could extend battery life for cell phones, tablets, and laptops from hours to days."

Also, because transparent thin-film transistors enable a faster refresh rate, they are useful in high-resolution tablets like the iPad.

"They can be made smaller than a conventional transistor, and this is important because a transistor must be used in each pixel of a high-resolution display," said Hoffman.

Winning combination

Hoffman's first transparent transistors were made with a nearly invisible layer of zinc oxide (just 0.1 microns thick). To get an idea of the scale, the amount of zinc oxide used to protect a beachgoer's nose from the hot sun could make thousands of Hoffman's first transparent transistors.

In subsequent years of research, the team discovered that performance improved when elements such as tin, indium and gallium were added to the zinc oxide. It is the combination of indium, gallium, and zinc oxide (abbreviated IGZO) that has achieved commercial success.

Valued collaboration

Hoffman credits his materials science breakthrough to Oregon State's hands-on approach to education and the numerous opportunities for interdisciplinary and industry collaboration.

"The initial interest focused on the transparency of the transistors," Hoffman explained. "That was cool, but not yet a value-adder. What did add value was that they are a higher performance material that could be adopted without a lot of manufacturing expense."

Through a decade of work at HP, Hoffman has continued to collaborate with Wager's group. He also has been a liaison between the Departments of Chemistry and Physics and HP's Advanced Materials Lab on behalf of several projects.

HP has continued to fund investigations into transparent electronics, hunting for the killer application that — like the laser — will lead to new, multi-billion dollar industries.

"Growing relationships with companies like HP is the essence of a newly launched initiative called the OSU Advantage," Wall said. "Company connections to OSU student talent, research capabilities, and commercialization opportunities are becoming an integrated component of Oregon State's culture, and Randy is a great example of the impact these relationships can offer."

Hoffman agrees. "It is one of HP's most successful university collaborations," he said. "The relationship with OSU is highly valued by HP both in Corvallis and worldwide." **M!**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