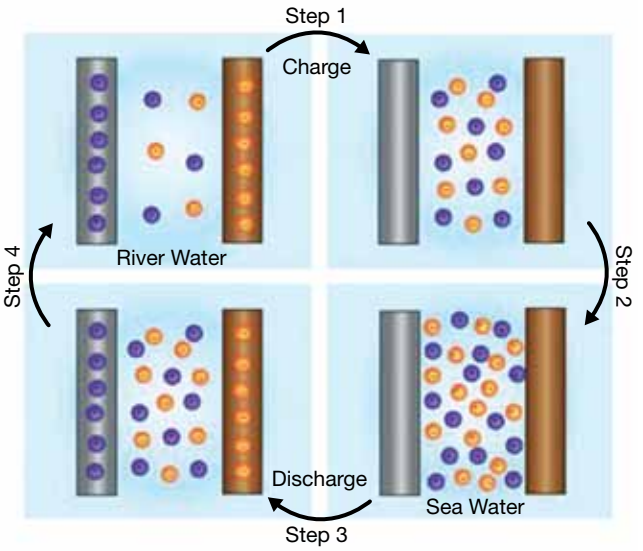
Update

ENERGY

Salinity Difference Generates Electricity

A new battery developed by scientists from Stanford Univ., Penn State Univ., and the Univ. of Milan capitalizes on the difference in salinity at the point where freshwater rivers flow into oceans.

The mixing of seawater and fresh river water produces an enormous amount of entropic energy, but extracting it and converting it into a form of useful energy has been challenging. The researchers, led by Stanford associate professor of materials science and engineering Yi Cui, have dubbed their device the mixing entropy battery, and have successfully extracted the entropic energy and stored it as electrochemical energy.



▲ A battery in its discharged state has two electrodes immersed in fresh water. Purple and orange dots represent positively and negatively charged ions, respectively. In Step 1, a small electric current is applied to charge the battery, pulling ions out of the electrodes and into the water. Then in Step 2, the freshwater is purged and replaced with seawater, creating an abundance of charged ions in the salt water. In Step 3, electricity is drawn from the battery for use, draining the battery of its stored energy, and the ions return to the electrodes. Finally, in Step 4, seawater is discharged and replaced with river water, and the cycle repeats. Image courtesy of Yi Cui.

The reduction of free energy due to the mixing of saltwater and freshwater is estimated at 2.2 kJ/L of freshwater. A previous attempt to harvest the free energy used activated carbon electrodes, but that approach had intrinsic technical challenges, such as high sensitivity to impurities and dissolved oxygen. The new mixing entropy battery overcomes these challenges by storing the extracted chemical energy inside the electrode material's bulk crystal structure.

The battery uses a reversible electrochemical system in which the salts in the electrolyte are the reactants and two electrodes store ions. An anionic electrode interacts selectively with Cl^- ions, and a cationic electrode selectively interacts with Na^+ ions.

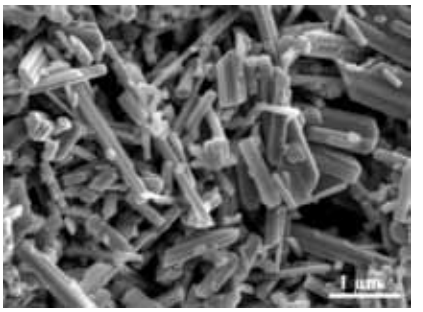
The positive electrode is made from nanorods of manganese dioxide. With roughly 100 times the available surface area of other materials, the nanorods make it possible for the sodium ions to move in and out of the electrode with ease, speeding up the process. One of Cui's concerns is finding a suitable material for the negative electrode. Silver was used in the experimental device, but silver is too expensive to be practical.

The electrodes in their discharged states (*i.e.,* the electrode materials contain the respective ions incorporated in their structures) are first submerged in river water of low ionic strength. The battery is then charged by removing the Na^+ and Cl^- ions from the respective electrodes. The dilute electrolyte is exchanged for a concentrated solution of seawater, which produces an increase in the potential difference between the electrodes. The battery discharges at this higher potential difference, as the anions and cations are reincorporated into their respective electrodes.

The scientists tested their device in water samples from local natural sources — seawater from the Pacific Ocean off the California coast, and freshwater from Donner Lake, high in the Sierra Nevada. They observed no decrease in cycling performance, nor any electrode degradation, self-discharge, or other detrimental phenomena. The battery achieved energy extraction and conversion efficiencies of up to 74% in these tests, but Cui thinks that with simple modifications the efficiency can be increased to 85%.

The researchers have determined that a power plant operating with 50 m^3/s of freshwater flow could produce up to 100 MW of power — enough to provide electricity for about 100,000 households.

Cui points out that the energy can be easily harvested at low temperatures and is completely renewable, since the ultimate source is the solar energy that powers the water cycle. In addition, he notes that "the water for this method does not have to be extremely clean." Storm runoff and



▲ Manganese dioxide nanorods create the positive electrode of a new entropic energy battery. The nanorods' large surface area allows for increased interaction with sodium ions. Image courtesy of Yi Cui.

gray water might be useable, as well as perhaps treated sewage water. "I think we need to study using sewage water. If we can use sewage water, this will sell really well," he says.

Moving forward, the team plans to modify the system to operate on a smaller scale using solar energy to distill water.

Two-Particle Systems have Power-Generating Abilities

Scientists at the U.S. Dept. of Energy's (DOE) Brookhaven National Laboratory (BNL) have taken a step in the engineering of ever-smaller electronic devices by assembling nanoscale pairings of particles that show promise as miniaturized power sources.

The researchers link light-absorbing colloidal quantum dots to carbon-based fullerene nanoparticles. The tiny two-particle systems can convert light to electricity in a precisely controlled way. Brookhaven physical chemist Mircea Cotlet, who led the research, notes that this is the first demonstration of a hybrid inorganic/organic dimeric material that acts as an electron donor-bridge-acceptor system for converting light to electrical current.

Organic donor-bridge-acceptor systems have a wide range of charge transport mechanisms, and their charge-transfer properties can be controlled by varying their chemistry. In addition, by varying the length of the linker molecules and the size of the quantum dots, the scientists can control the rate and magnitude of fluctuations in light-induced electron transfer at the level of the individual dimer.

"This control makes these dimers promising power-generating units for molecular electronics or more efficient photovoltaic solar cells," says Cotlet.

Quantum dots have recently been combined with electron-accepting materials, including fullerenes, in the hope that the light-absorbing and size-dependent emission properties of quantum dots would boost the efficiency of such devices. So far, however, the power conversion rates of these systems have remained low.

The precision fabrication method developed by the BNL researchers allows them to carefully control particle size and interparticle distance so that they can explore conditions for light-induced electron transfer between individual quantum dots and electron-accepting fullerenes at the single-molecule level.

The interaction of the particles could lead to the components combining in many ways if assembled by solution-based methods. To avoid these interactions, the entire assembly process takes place on a surface and in a stepwise fashion. The surface-based assembly also achieves controlled, one-to-one nanoparticle pairing.

Quantum dots absorb and emit light at different frequencies according to their size. The team varied the size of the quantum dots, as well as the length of the bridge molecules connecting the nanoparticles, to identify the optimal architectural arrangement for the particles. For each arrangement, they measured the electron transfer rate using single molecule spectroscopy.

"This method removes ensemble averaging and reveals a system's heterogeneity — for example, fluctuating electron transfer rates — which is something that conventional spectroscopic methods cannot always do," Cotlet explains.

Reducing quantum dot size and the length of the linker molecules led to enhancements in the electron transfer rate and suppression of electron transfer fluctuations. "This suppression of electron transfer fluctuations in dimers with smaller quantum dot size leads to a stable charge generation rate, which can have a positive impact on the application of these dimers in molecular electronics, including potentially in miniature and large-area photovoltaics," says Cotlet.

"Studying the charge separation and recombination processes in these simplified and well-controlled dimer structures helps us to understand the more complicated photon-to-electron conversion processes in large-area solar cells, and will eventually enable us to improve their photovoltaic efficiency," adds BNL materials scientist Zhihua Xu.

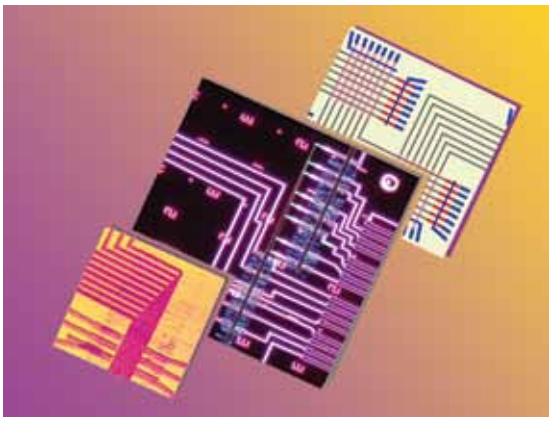
NANOTECHNOLOGY

Reprogrammable Nanowire Circuit Could Enable Nanowire Computers

A team led by Harvard Univ. chemistry professor Charles Lieber and Shamik Das, principal engineer of The MITRE Corp.'s Nanosystems Group, has built a reprogrammable circuit out of nanowire transistors. When connected, such circuits could create the first scalable nanowire computer capable of running inside microscopic, implantable biosensors and ultra-low-power environmental or structural sensors.

Lieber notes that the practicality of nanowires for extended computing systems had traditionally been doubted, explaining, "There had been little progress in terms of increasing the complexity of circuits." Still, nanowires can shrink the scale of computing systems to a degree that traditional semiconductor materials cannot.

In order for a circuit to operate correctly, the nanowires ideally would be virtually identical. However, it had not been possible to reproduce these structures reliably. Now, the researchers have developed a method of producing nearly identi-



◀ The graphic depicts the design for the programmable nanowire-based nanoprocessor circuit tile (top right), an optical micrograph of the functioning tile (center), and an atomic force microscope image of microwires crossing nanowires to form the programmable nanotransistors on the tile (bottom left). Image courtesy of J. Ellenbogen, J. Klemic, and S. Das, The MITRE Corp.

cal nanowires in bulk that enabled them to prototype a programmable nanowire circuit that can be scaled up by design.

They employ a bottom-up approach to create the nanowire circuits. Unlike the top-down etching technique for making traditional chips, the bottom-up method allows the nanowire circuits to be deposited onto various surfaces, such as plastics. Also, these circuits ultimately can be made more compact than traditional top-down semiconductor circuits.

The team first deposits lines of nanowires composed of a germanium core sheathed in a silicon shell on a substrate, and crosses them with lines of metal electrodes to create a grid. The points at which the nanowires and electrodes intersect behave as transistors that can be turned on and off independently, and that maintain their state regardless of whether the power is on. This ability is important for low-power sensors that might need to collect data only sporadically and also need to conserve power. In addition, applying a high enough voltage to the electrodes can change the threshold voltage of each transistor, making the circuit completely programmable.

Das explains that these circuits could be made ten times more power-efficient than circuits made of traditional materials. One reason for this, he says, is that the nanowire's electrical properties do not allow electric current to leak, unlike traditional transistors. In addition, the circuit design uses capacitive connections instead of resistive ones, which are less efficient.

So far, the researchers have made a single tile composed of 496 transistors in an area of 960 mm^2. The tile can be wired to other tiles so that the transistors, in aggregate, could act as complex logic gates for processing or memory.

"Because of their very small size and very low power requirements, these new nanoprocessor circuits are building blocks that can control and enable an entirely new class of much smaller, lighter-weight electronic sensors and consumer electronics," says Das.

Lieber says that his group still needs to demonstrate thousands of transistors on a single tile — more than the 496 transistors achieved so far. They will also work toward scaling up to multiple tiles. Realistically, Lieber says, manufacturing of these circuits is still several years down the road.

BIOTECHNOLOGY

Carbon Nanotubes Create a Synthetic Neural Synapse

Synthetic brains may someday no longer be an element of science fiction, thanks in part to engineers at the Univ. of Southern California (USC). Combining circuit design with nanotechnology to address the complex problem of capturing brain function, electrical engineering professors Alice Parker and Chongwu Zhou built a carbon nanotube circuit that reproduces the function of a synapse — the junction in the brain that permits a neuron to pass an electrical or chemical signal to another cell. The carbon nanotubes act as metallic conductors or semiconductors, as they do in electronic circuits, and the input and output waveforms to and from the synapse resemble biological waveforms in shape and relative amplitudes and durations.

The USC team chose single-walled carbon nanotubes because they avoid most of the scaling limits of traditional silicon transistors. The carbon nanotubes can also be configured into 3-D arrangements, a capability that the researchers believe will be critical when implementing the circuit in larger portions of the cortex. And, the carbon nanotubes do not provoke an immune response in biological tissue, making them attractive for use as neural prostheses.

Parker summarizes the question her group seeks to answer: "How can we build structures out of these circuits that mimic the neuron, and eventually the function of the brain, which has 100 billion neurons and 10,000 synapses?" The brain's 100 billion neurons perform complex nonlinear computations on a quadrillion synaptic inputs.

In tests of the fabricated nanotube-transistor synapse, the amplitude of the action potential (*i.e.,* an event in which the electrical membrane potential of a neuron rapidly rises and falls) was –10 V and the resulting post-synaptic potential (PSP; a change in the membrane potential of the postsynaptic terminal of a neural synapse) was about –0.2 V, while the action potential duration was 3 ms and the PSP duration was 10 ms. The researchers note that the ratios between the corresponding amplitudes and time periods of the action potential and PSP are analo-

gous to biological ratios found in the human brain.

The engineers also varied the resistor values to test for changes in synaptic strength. The results of that test demonstrated that the synaptic strength did indeed change — a key neural behavior that is typically observed in biological neurons and is believed to play a role in learning.

Although the initial synapse has been fabricated, Parker notes that the construction of a full artificial brain is decades away. The next step is reproducing brain plasticity in the circuits, because the human brain continuously produces new neurons and adapts throughout life. Parker believes that a prosthetic brain could eventually lead researchers to methods of healing traumatic brain injuries.

▲ The polymer coating (light blue) is shed as the particle approaches a tumor, exposing positive charges. Those charges enable the particle to be absorbed through the tumor cell membrane. Image courtesy of Stephen Morton.

Cloaked Nanoparticles Target a Variety of Tumor Cells

Chemical engineers at the Massachusetts Institute of Technology (MIT) have designed a new type of drug-delivery nanoparticle that they say could target nearly any type of tumor and carry virtually any type of drug.

The new nanoparticles, developed by a team led by chemical engineering professor Paula Hammond, exploit a trait shared by almost all tumors: They are more acidic than healthy tissues. Tumor cells grow and divide much more rapidly than normal cells, and their accelerated metabolic activity requires a large amount of oxygen, which increases their acidity. The tissue becomes more and more acidic as the tumor grows.

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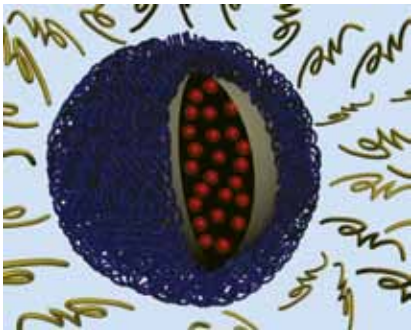


▲ The outer layer of this nanoparticle breaks apart and falls off (the gold squiggles) in an acidic environment, exposing a positively charged layer that penetrates a tumor cell membrane. Image courtesy of Stephen Morton.

Similar to most other drug-delivery nanoparticles, the new particles are cloaked in a polymer layer that prevents them from degrading in the bloodstream. Unlike previous nanoparticles, after the MIT-designed nanoparticles enter the slightly more acidic environment surrounding a tumor, their outer layer falls off, revealing another layer that is able to penetrate individual tumor cells.

Most drug-delivery nanoparticles are coated with molecules that bind specifically to proteins found on the surface of specific cancer cells, and therefore target a specific type of tumor. Hammond points out that it can sometimes be challenging to find the right molecule to target — it needs to be present on the cancer cells of a particular tumor, but not on healthy cells. In addition, a target that is effective for one type of cancer might not work for another.

Hammond explains that the new nanoparticles are built using a layer-to-layer assembly technique, and each layer can be tailored to perform a specific function. The outer layer, composed of polyethylene glycol (PEG), cloaks the particles so that upon injection into the body they target only tumor cells and do not destroy healthy tissue. This PEG layer breaks down in the tumor's acidic environment, exposing a positively charged middle layer. The positive charge allows the particles to penetrate the negatively charged cell membrane and enter the cell. The innermost layer of the particle can be a polymer that carries the cancer drug, a quantum dot that could be used for imaging, or virtually anything else that needs to be delivered into the body.

The new nanoparticles are the first to be successfully tested in living animals. The researchers report that their particles can survive in the bloodstream for up to 24 h, accumulate at tumor sites, and enter tumor cells. They plan to further develop the particles and test their ability to deliver drugs in animals. They expect it to take five to ten years before human clinical trials could begin.

Hammond's team is also working on nanoparticles that can perform multiple tasks — for example, with an outer PEG layer carrying a drug that would prime the tumor cells to be susceptible to another drug carried in the particle's core.

Patch Helps Heart Tissue to Heal Itself

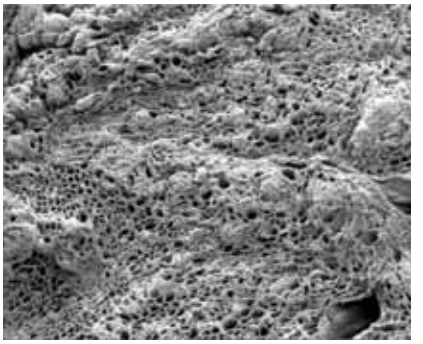
A novel cell therapy to treat myocardial infarction (*i.e.,* heart damage that follows a heart attack) has been developed by engineers at Columbia Univ. The researchers, led by biomedical engineering professor Gordana Vunjak-Novakovic, successfully combined human stem cells conditioned during *in vitro* culture to maximize their ability to improve blood flow to the infarcted tissue using a biological composite scaffold designed to deliver these cells to the damaged heart. The scaffold keeps the cells within the infarct bed — in contrast to the massive cell loss associated with infusion of cells alone — and enhances cell survival and function in the infarct bed, where most of the cells would have died because of the obstruction of blood supply.

"This platform is very adaptable, and we believe it could be readily extended to the delivery of other types of human stem cells we are interested in to rebuild the heart muscle and further our research of the mechanisms underlying heart repair," says Vunjak-Novakovic.

To build the platform, the engineers removed the cells of a human heart muscle (the myocardium), leaving a protein scaffold with its composition, architecture and mechanical properties intact. They filled the scaffold with human stem cells and then applied it as a patch to damaged heart tissue. The patch promoted the growth of new blood vessels and released proteins that stimulated the native tissue to repair itself.

The team also used the controllable platform to identify the signaling mechanisms involved in the repair process and the role of cells and scaffold design in heart repair.

Vunjak-Novakovic explains that the approach they developed aims to "instruct" cells to form human tissue by providing them with the right environment. "The cells are the real tissue engineers — we only design their environments so they can do their work. Because these environments need to mimic the native developmental milieu, progress in the field is driven by the interdisciplinary



▲ A biological composite scaffold composed of human heart muscle cells and human stem cells is used as a heart patch to promote vascularization after a heart attack. Image courtesy of Gordana Vunjak-Novakovic.

work of bioengineers, stem cell biologists, and clinicians. By enabling regeneration and replacement of our damaged tissues, we can help people live longer and better," she says.

The researchers are investigating the formation of a contractile cardiac patch using human stem cells that can give rise to both the muscle and vascular network of the heart muscle. They are also studying how the cells within such a cardiac patch, when implanted on infarcted heart tissue, develop their ability to generate mechanical force and electrical conduction, and how these functions can be modulated by *in vitro* culture.

"Ultimately, we envision this system as a possible point-of-care approach, with components produced and assembled in the operating room to most-effectively target signaling mechanisms involved in the repair process of someone's damaged heart," says Vunjak-Novakovic.

INSTRUMENTATION

Sensor Detects and Identifies Bacterial Infections Quickly

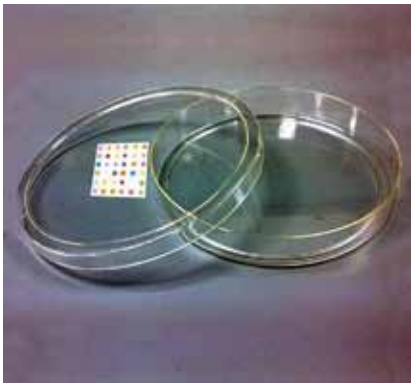
Doctors may soon have a new, faster tool for detecting bacterial infections. Scientists at the Univ. of Illinois at Urbana-Champaign have devised a quick, simple method that uses a low-cost array of printed pigments as a chemical sensor to identify bacteria by their aroma.

Blood-borne bacterial infections are traditionally identified through blood cultures. The process is more automated than it was when it was developed a century ago, but the basic approach remains the same. First, blood samples are incubated in vials for 24–48 h, at which point a carbon dioxide sensor in the vials will signal the presence of bacteria. If bacteria are detected, the task remains to identify the species and strain of bacteria in the vial — which can take up to another 24 h.

Chemistry professor Kenneth Suslick, who led the research, says that this clinical process takes too long. "In 72 hours, they may have diagnosed the problem, but the patient may already have died of sepsis," he notes.

Bacteria emit a complex mixture of chemicals as byproducts of their metabolism, and the resulting odor can be used to identify the species of the bacteria. Each species produces its own blend of gases, and even individual strains within the same species have their own aromatic fingerprint.

Suslick, an expert in chemical sensing, has already developed sensors that can detect and identify poisonous gases, toxins, and explosives in the air (*CEP,* Dec. 2010, pp. 6–7, and Oct. 2009, p. 9). "Our approach to this problem has been to think of bacteria as simply micron-sized chemical factories. Our technology is now well-proven for detecting and distinguishing among different chemical odorants, so applying it to bacteria was not much of a stretch," he says.

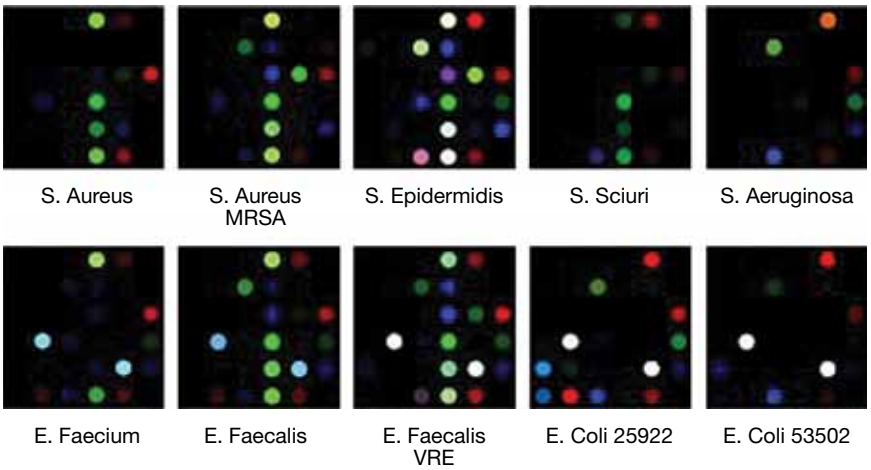


▲ A colorimetric sensor array is placed in a Petri dish for culturing bacteria, and is scanned with an ordinary flatbed photo scanner kept inside a lab incubator. The dots change color as they react with gases the bacteria produce, identifying specific strains by their aromatic "fingerprints." Image courtesy of K. S. Suslick.

The new device is an array of 36 cross-reactive pigment dots that change color when they detect chemicals in the air. The researchers tested the device on blood samples in Petri dishes containing a standard growth gel. They attached an array to the inside of the lid of each dish and then inverted the dishes onto a flatbed scanner. At 30-min intervals, they scanned the arrays and recorded the color changes in each dot. The pattern of color change over time is different for each bacterium.

"It is like time-lapse photography. You are not looking just at a single frame, you are looking at the motion of the frames over time," Suslick explains.

In a few hours, rather than days, the array can identify a particular species and strain of bacteria. In addi-



▲ Color changes in the sensor array show what kinds of bacteria are growing, and even whether they are resistant to antibiotics. Image courtesy of K. S. Suslick.

tion, it can recognize antibiotic resistance, a factor that can affect the course of treatment. Currently, the device can identify 10 of the most common disease-causing bacteria with 98.8% accuracy. The team believes that the array could eventually be used to diagnose a much wider variety of bacterial infections.

Medical researchers at other institutions have already performed studies using Suslick's arrays to diagnose sinus infections and to screen for lung cancer, evidence of the chemical-sensing array's broad sensitivity.

"We don't have an upper limit. We haven't found any bacteria that we cannot detect and distinguish from other bacteria. We picked out a sampling of human pathogenic bacteria as a starting point," Suslick says.

Going forward, the scientists are working on integrating the arrays with vials of liquid growth medium, which is a faster culturing agent and more common in clinical practice than Petri dishes. The team has also improved the pigments to be more stable, more sensitive, and easier to print.

Suslick is commercializing the array technology for clinical use through iSense, a company he co-founded.

Trace Gas Detector Chirps at Terahertz Frequencies

Researchers at the National Institute of Standards and Technology (NIST) have developed a trace gas detector that can detect and identify a small quantity of a particular molecule — such as a whiff of formaldehyde or a hint of acetone — in a vast sea of others. Such sensors can be used in medical tests, air pollution detectors, and bomb sniffers. According to its developers, the device is hundreds of times faster and more sensitive than other similar technologies, and it may be portable, economical, and fast enough to be used virtually anywhere.

Trace gas detection is used widely in industry to measure contaminants and ensure quality in manufacturing. The presence of a trace amount of a particular gas can indicate that a problem exists nearby, but many sensors are only able to detect one type of gas, and some require a long time to analyze the sample. The NIST sensor overcomes these difficulties.

"This new sensor can simultaneously detect many different trace gases at very fast rates and with high sensitivity. It is also built from off-the-shelf technology that you can carry in your hands. We feel it has great commercial potential," says research chemist Kevin Douglass.

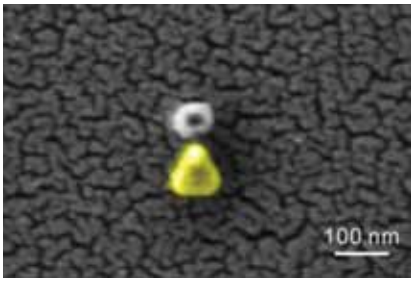
The new sensor uses radiation at terahertz frequencies — between the infrared and microwave regions of the spectrum — which causes the gas molecules to rotate. Initially, the molecules rotate in phase but at rates unique to each gas. The sensor identifies the molecules as they gradually fall out of phase.

The use of terahertz frequencies enables the sensor to identify and quantify nearly all possible gas molecules virtually instantly. Previously, it was necessary to expose a gas sample to a wide range of terahertz frequencies — slowly, one after another. Because no technology existed that could step through the entire frequency band quickly and easily, the NIST team had to teach its off-the-shelf equipment to "chirp."

"The sensor sends a quick series of waves that run the range from low frequency to high, sort of like the chirp of a bird call. No other terahertz sensor can do this, which is why ours works so fast. Teaching it to chirp in a repeatable way has been one of our team's main innovations, along with the mathematical analysis tools that help it figure out what gas you're looking at," says Douglass.

Palladium Nanoparticles are Key to Antenna-Enhanced Gas Sensing

Researchers at the U.S. Dept. of Energy (DOE)'s Lawrence Berkeley National Laboratory (Berkeley Lab) and the Univ. of Stuttgart in Germany have reported the first experimental demonstration of antenna-enhanced gas sensing at the single paticle level. By placing a palladium



▲ A palladium nanoparticle with a gold antenna, as shown in this scanning electron microscopy image, enhances plasmonic sensing. Image courtesy of Alivisatos group.

nanoparticle on the focusing tip of a gold nanoantenna, they were able to clearly detect changes in the palladium's optical properties upon exposure to hydrogen. This, they say, is an important step toward being able to observe a single catalytic process in a nanoreactor or to optically detect low concentrations of biochemical agents and gases.

"We have demonstrated resonant antenna-enhanced single-particle hydrogen sensing in the visible region, and presented a fabrication approach to the positioning of a single palladium nanoparticle in the nanofocus of a gold nanoantenna. Our concept provides a general blueprint for amplifying plasmonic sensing signals at the single-particle level, and should pave the road for the optical observation of chemical reactions and catalytic activities in nanoreactors, and for local biosensing," says Berkeley Lab's director and research leader Paul Alivisatos.

Plasmonics — the confinement of electromagnetic waves in dimensions smaller than half the wavelength of the incident photons in free space — is one of the hottest new technology fields today. Typically, plasmonics takes place at the interface between metallic nanostructures — usually gold — and a dielectric — usually air.

Plasmons are electronic surface waves generated when electromagnetic waves are confined in these metallic nanostructures. The matching of the oscillation frequencies of the plasmons and the incident electromagnetic waves is a phenomenon known as localized surface plasmon resonance (LSPR), which can concentrate the electromagnetic field into a volume less than a few hundred cubic nanometers. Any object brought into this locally confined field — referred to as the nanofocus — will influence the LSPR in a way that can be detected using dark-field microscopy.

"Nanofocusing has immediate implications for plasmonic sensing. Metallic nanostructures with sharp corners and edges that form a pointed tip are especially favorable for plasmonic sensing because the field strengths of the electromagnetic waves are so strongly enhanced over such an extremely small sensing volume," says Laura Na Liu, a member of Alivaisatos' research group who is now at Rice Univ.

Plasmonic sensing is a promising alternative for the detection of flammable gases such as hydrogen. Conventional sensors that require electrical measurements pose safety concerns because of the potential threat from sparking. Hydrogen, for example, can ignite or explode in concentrations of only 4%.

Palladium was initially considered a prime candidate for the plasmonic sensing of hydrogen because it readily and rapidly absorbs hydrogen, which alters its electrical and diectric properties. However, the LSPRs of palladium nanoparticles yield broad spectral profiles that make detecting changes extremely difficult.

"In our resonant antenna-enhanced scheme, we use double electron-beam lithography in combination with a double lift-off procedure to precisely position a single palladium nanoparticle in the nanofocus of a gold nanoantenna. The strongly enhanced gold-particle plasmon near-fields can sense the change in the dielectric function of the proximal palladium nanoparticle as it absorbs or releases hydrogen. Light scattered by the system is collected by a dark-field microscope with attached spectrometer and the LSPR change is read out in real time," says Liu.

The team found that the antenna enhancement effect could be controlled by changing the distance between the palladium nanoparticle and the gold antenna, and by changing the shape of the antenna.

"By amplifying sensing signals at the single-particle level, we eliminate the statistical and average characteristics inherent to ensemble measurement. Moreover, our antenna-enhanced plasmonic sensing technique comprises a noninvasive scheme that is biocompatible and can be used in aqueous environments, making it applicable to a variety of physical and biochemical materials," Liu adds.

She says that by replacing the palladium nanoparticle with other nanocatalysts, such as ruthenium, platinum, or magnesium, the antenna-enhanced plasmonic sensing scheme could be used to monitor for the presence of numerous other important gases, including carbon dioxide and nitrous oxides.

The technique also shows promise as an alternative to the fluorescent detection of catalysis, which requires identifying appropriate fluorophores, as well as for the observation of individual chemical or biological events.

"We believe this approach can serve as a bridge between plasmonics and biochemistry. Plasmonic sensing offers a unique tool for optically probing biochemical processes that are optically inactive in nature. In addition, since plasmonic nanostructures made from gold or silver do not bleach or blink, they allow for continuous observation, an essential capability for *in situ* monitoring of biochemical behavior," Liu explains. CEP

CHEM ECONOMICS

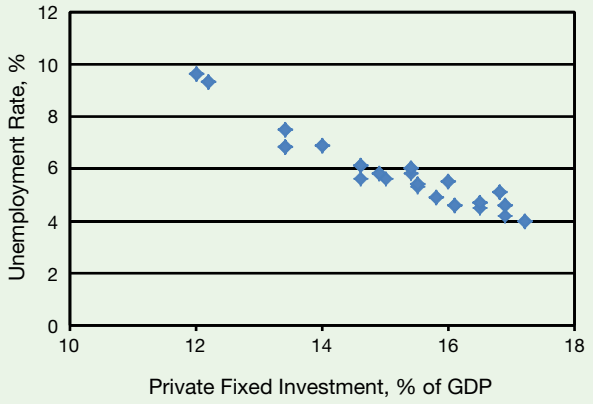
The Relationship Between Private Investment and Unemployment

When I started my career nearly four decades ago, an experienced chemical engineer offered the following advice: "An average engineer can design something complicated, but a great engineer designs things to be simple." That stuck with me all my life (as did his suggestion to save 7% of my salary every year without exception), and this advice applies to economics as well.

An anonymous author once wrote that "Economics is the painful elaboration of the obvious." In the spirit of simplicity, I will suggest a good rule of thumb that explains the dynamics of the labor market and unemployment.

Savings and investment are intertwined. As savings are converted into investments, the money will be spent on business expansion — new equipment and buildings, new employees, etc. — and will flow back into the economy. As it flows back into the economy, these monies will be used to buy the goods and services that investment brings. In turn, this will bring about more employment, profits, and savings — a virtuous circle.

Increased investment leads to increased employment and lower unemployment. The accompanying chart illustrates this relationship, showing the share of the U.S. economy consisting of private fixed investment in business equipment and software as well as business structures and residential structures for the 1989–2010 period. There is a near-perfect inverse relationship between investments and the unemployment rate that makes intuitive sense. Whenever the share of private fixed investment falls, the unemployment rate rises. Whenever the share of private fixed investment rises, the unemployment rate falls. This is consistent with the virtuous circle and the fact that private investment is the primary creator of jobs.



▲ The unemployment rate is inversely proportional to the share of private fixed investment in the gross domestic product (GDP).

Based on econometric analysis of the data, my rough rule of thumb is this: From a constant figure of 21.0, subtract the share of private fixed investment; the result is the unemployment rate.

Here's how it works. As a result of the collapse of the housing market and subsequent cutbacks in business investment during the Great Recession, the unemployment rate reached high levels. A recovery has emerged, and in 2011 and 2012 private fixed investment is expected to expand at a rate roughly twice that of the overall economy. As a result, the share of private fixed investment will expand to 12.3% in 2011 and to 12.6% in 2012. Using our rough rule of thumb, as the virtuous circle engages, the unemployment rate should average 8.7% (21.0 – 12.3) in 2011 and 8.4% (21.0 – 12.6) in 2012. This is roughly in line with economists' expectations.

Let's call this "Swift's Law #38." I hope that I made my former mentor proud.

— T. Kevin Swift
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Eyeglasses and Contact Lenses

- Chemistry contributes 27% of the value of the materials in eyeglasses and contact lenses.
- Polycarbonate lenses, which combine high impact strength and transparency, are made from bisphenol A and phosgene.
- Specialty coatings can be applied that absorb UV light, reduce light reflection, and prevent scratches.
- Hydrophilic soft contact lenses are made from flexible polymer hydrogels (*i.e.*, etafilcon A and lotrafilcon) that absorb water and enable more oxygen to reach the cornea.
- Gas-permeable contact lenses are made from polymethylmethacrylate (PMMA).
- Contact lenses are packaged in a sterile saline (NaCl) solution.

During 2011, the International Year of Chemistry, Chem Economics will look at some of the impacts of chemistry and chemical engineering on modern living. For more information on the benefits of chemistry, visit ACC's website, www.americanchemistry.com.