the phospholipid coating prevents leakage and provides both a steady signal over time and cell viability after the measurement. The ease of fabricating several independent devices also allowed the team to make simultaneous measurements on the same cell or at multiple sites on a cell monolayer. With the potential for attaining dimensions as small as 5 nm, these devices could become a useful new tool in electrophysiology.

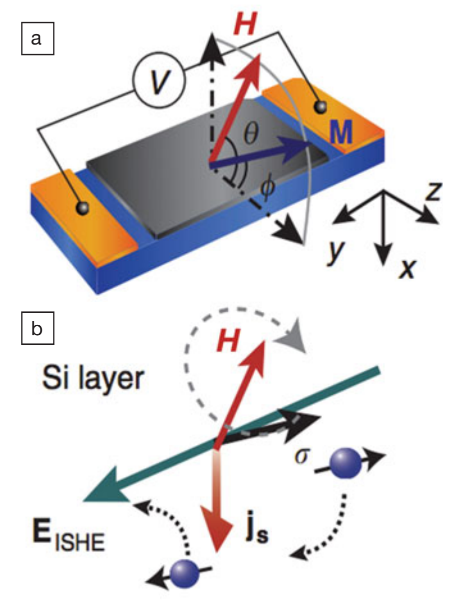
Tobias Lockwood

Inverse spin Hall effect observed in silicon

Designers of next-generation electronics are trying to take advantage of both the electron's charge and spin. The success of spintronic devices therefore hinges on the ability to convert between spin and charge currents. The direct spin Hall effect is typically used to probe spin-orbit coupling in these materials, but the technique cannot be applied to semiconductors with long spin lifetimes, such as indirect bandgap silicon. Researchers Kazuya Ando and Eiji Saitoh at Tohoku University in Sendai, Japan, have turned their attention to the inverse spin Hall effect (ISHE), which makes use of the high resistivity of semiconductors to detect tiny spin currents. Ando and Saitoh show that it is possible to study spin-orbit interactions using ISHE in otherwise unmeasurable systems.

As reported in the January 17 issue of the online journal *Nature Communications* (DOI: 10.1038/ncomms1640), the researchers first deposited a thin-film heterostructure of $Ni_{81}Fe_{19}$/B-doped Si onto a silicon-on-insulator substrate and laid down ohmic AuPd contacts to detect the in-plane Hall voltage. They then measured the voltage across the AuPd contacts with a magnetic field applied at 0° and 180° normal to the plane of the sample. They found that the Hall voltage depends on the direction of the magnetic field around the ferromagnetic resonance edge, which is indicative of the ISHE effect.

The researchers next measured the voltage dependence on the angle of the out-of-plane magnetic field. This revealed that a spin current is injected into the Si layer and that it precesses around an axis parallel to the applied magnetic field (see figure). Using the Landau–Lifshitz–Gilbert equation, Ando and Saitoh were able to demonstrate dynamical spin injection in *p*-type silicon at room temperature and unambiguously extract the ISHE contribution from the silicon layer. This technique can be used to explore the spin Hall effect in silicon with different dopants and doping levels, according to the researchers.



(a) Schematic of the $Ni_{81}Fe_{19}$/Si sample in spintronics study; (b) the precession of spins in the silicon layer measured by the inverse spin Hall effect (ISHE). *H* is applied oblique to the film plane; **M** denotes the static component of the magnetization; θ and φ show the magnetic field angle and magnetization angle, respectively; and $\mathbf{j}_s$ is the spin current. Reproduced with permission from *Nat. Commun.,* DOI: 10.1038/ncomms1640. © 2012 Macmillan Publishers Ltd.

Moreover, the researchers said that their technique can be applied to understand other materials with weak spin-orbit interactions. This makes it particularly useful for spin-current detection in semiconducting systems and opens many new areas for spintronics research.

Steven Spurgeon

Particle-free silver ink prints small, high-performance electronics

University of Illinois at Urbana-Champaign (UIUC) materials scientists have developed a reactive silver ink for printing high-performance electronics on ubiquitous, low-cost materials such as flexible plastic, paper, or fabric substrates. Jennifer Lewis, the Hans Thurnauer Professor of Materials Science and Engineering and director of the Frederick Seitz Materials Research Laboratory, and graduate student S. Brett Walker described the new ink in the January 25 issue of the *Journal of the American Chemical Society* (DOI: 10.1021/ja209267c; p. 1419).

Most conductive inks rely on tiny metal particles suspended in a solvent. The new ink is formed from a transparent solution of silver acetate and ammonia through a modified Tollens' process. The silver remains dissolved in the solution until it is printed, and the liquid evaporates, yielding conductive features. The ink is composed of 22 wt% silver, comparable to other silver-precursor-based inks.

"It dries and reacts quickly, which allows us to immediately deposit silver as

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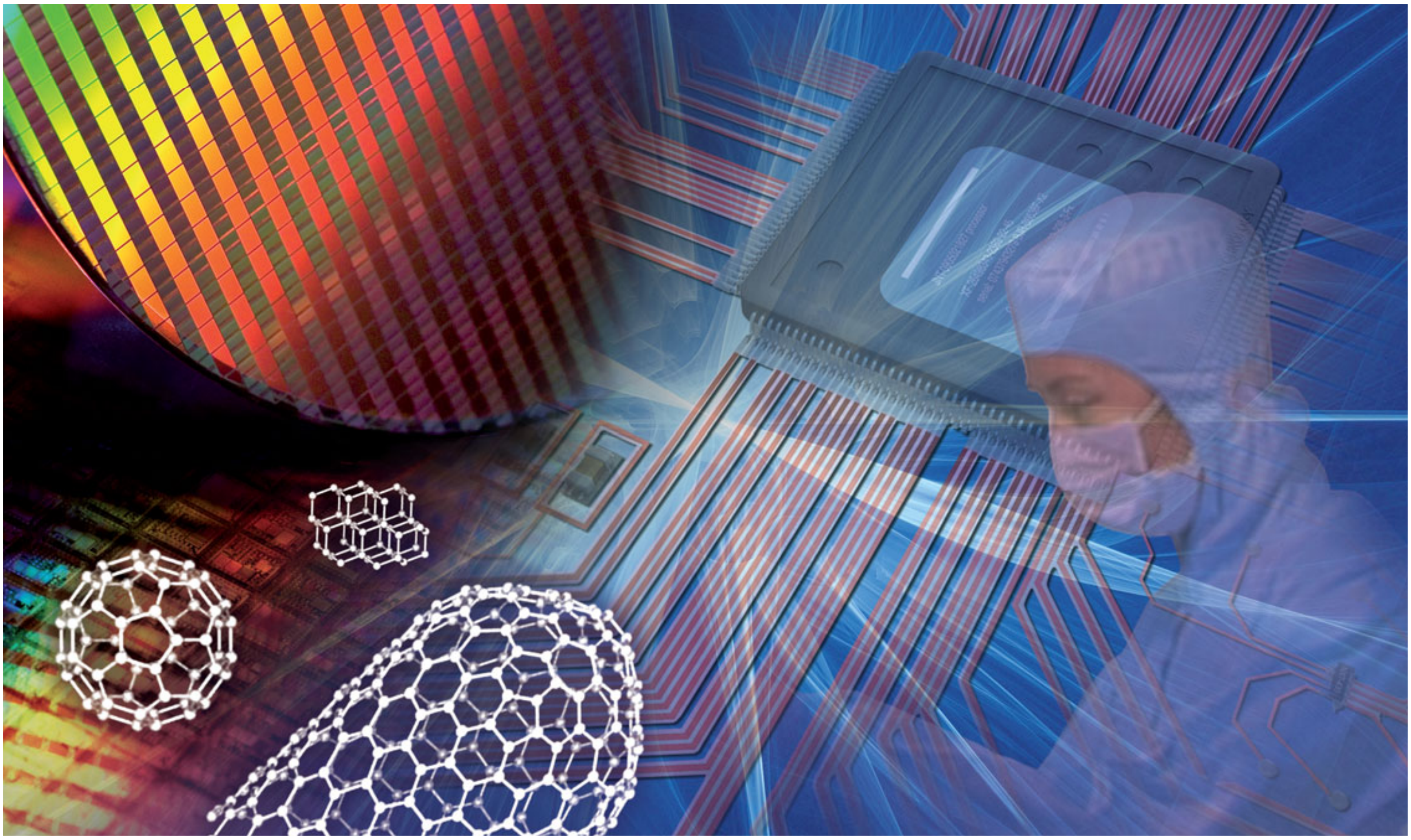


Reactive silver ink is airbrushed onto a thin, stretchy plastic film to make a flexible silver electrode. *Photo by S. Brett Walker*

we print," Walker said.

The reactive ink has several advantages over particle-based inks. It is much faster to make: a batch takes minutes to mix, according to Walker, whereas particle-based inks take several hours and multiple steps to prepare. The ink is also stable for several weeks.

The reactive silver ink can print through 100-nm nozzles, an order of magnitude smaller than for particle-based inks, an important feature for printed microelectronics. Moreover, the ink's low viscosity makes it suitable for inkjet printing, direct ink writing, or airbrush spraying over large, conformal areas.

"For printed electronics applications, you need to be able to store the ink for several months because silver is expensive," Walker said. "Since silver particles don't actually form until the ink exits the nozzle and the ammonia evaporates, our ink remains stable for very long periods. For fine-scale nozzle printing, that's a rarity."

The reactive silver ink boasts yet one more key advantage: a low processing temperature. Metallic inks typically need to be heated to achieve bulk conductivity through a process called annealing. The annealing temperatures for many particle-based inks are too high for many inexpensive plastics or paper. By contrast, the reactive silver ink exhibits an electrical conductivity approaching that of bulk silver upon annealing at 90°C.

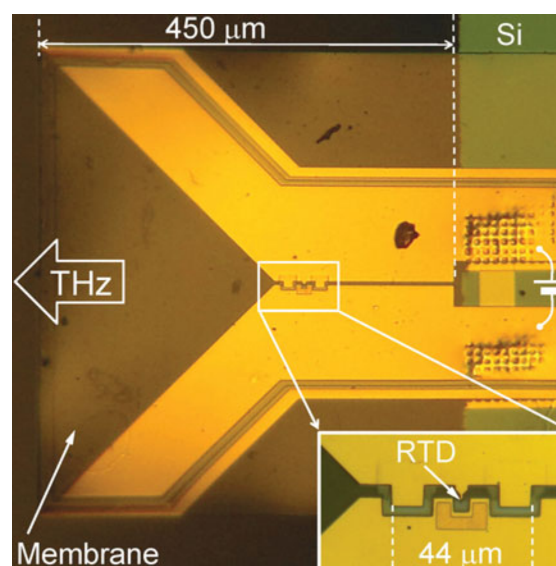
"We are now focused on patterning large-area transparent conductive surfaces using this reactive ink," said Lewis, who is also affiliated with the Beckman Institute for Advanced Science and Technology, the Micro and Nanotechnology Lab, and the Department of Chemical and Biomolecular Engineering at UIUC.

Terahertz transmitter sets frequency record

A terahertz transmitter developed at the Technical University (TU) of Darmstadt, Germany, has set a new frequency record, 1.111 THz, for microelectronic devices. The innovative device is also minuscule and operates at room temperature, which could lead to its paving the way for new applications in, for example, nondestructive testing or medical diagnostics.

As reported in the December 8, 2011 advanced online issue of *Applied Physics Letters* (DOI: 10.1063/1.3667191), a team of physicists and engineers led by Michael Feiginov at the TU Darmstadt's Institute for Microwave Technology and Photonics developed a resonance tunnel diode (RTD) for generating terahertz electromagnetic radiation. The RTD terahertz transmitter occupies less than a square millimeter in area and can be produced using mostly conventional semiconductor-device fabrication technologies.

The heart of their RTD is a dual-barrier structure, within which a quantum well (QW) is embedded. The QW is a very thin layer of indium-gallium arsenide semiconductor sandwiched between a pair of ultrathin barrier layers of aluminum-arsenide semiconductor. Each of these layers is one nanometer to a few nanometers thick. Due to a quantum-mechanical effect, this dual-barrier structure ensures that electromagnetic waves generated within a terahertz oscillator will be repeatedly amplified, rather than attenuated, which means that the oscillator will emit continuous-wave electromagnetic radiation at terahertz frequencies. The group of TU Darmstadt researchers collaborated with ACST GmbH, Germany, a fabricator of microelectronic circuit components, in producing their diode. Other authors of the article are C. Sydlo and P. Meissner of TU Darmstadt and O. Cojocari of TU Darmstadt and ACST GmbH. □



Terahertz transmitter; RTD stands for resonance tunnel diode. *Image: Michael Feiginov/TU Darmstadt.* Reproduced with permission from *Appl. Phys. Lett.* (2011), DOI: 10.1063/1.3667191. © 2011 American Institute of Physics.

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