occur. *I–V* measurements show a linear relationship across the grain boundary in the nonevaporated bicrystal, while the cobalt-evaporated sample displays distinctly nonlinear *I–V* characteristics. Since the grain boundaries were shown to be highly coherent, only the presence of cobalt can account for the potential barrier that developed. The researchers attributed this phenomena to the formation of additional interface states at a lower level in a bandgap generated by the solution of cobalt ions at the grain boundary.

TIM PALUCKA

## Adding HCl during Chemical Vapor Deposition Produces Controlled Growth of 6H-SiC on On-Axis 6H-SiC(0001) Substrates

Researchers from the Department of Chemical Engineering at Kansas State University and the Department of Mechanical Engineering at Wichita State University have found a reliable epitaxial-growth method for 6H-SiC on 6H-SiC substrates. As reported in the August issue of *Electrochemical and Solid-State Letters*, they achieved this process by adding HCl as a reaction gas during the growth procedure.

Traditionally, chemical vapor deposition (CVD) processes are used to grow various polytypes of SiC. Two methods for the growth of 6H-SiC(0001) polytype are available. The first is on-axis homoepitaxial growth of 6H-Si between 1700°C and 1800°C, and the second is off-axis homoepitaxial, step-controlled growth of 6H-SiC between 1400°C and 1500°C. Both methods are sound, except that slight variations may result in the formation of 3C-SiC. These defects are caused by substrate imperfections, which in turn induce triangular stacking faults.

The researchers suggest a method that can grow reliable 6H-Si films without the 3C-SiC defect. The substrates used were on-axis Si-face *n*-type 6H-SiC(0001), ultrasonically degreased, etched, and rinsed. The gases used for deposition were $SiH_4$, $C_2H_4$ (as source), and HCl. The ratio of HCl/Si was kept at 50. The 6H-SiC film was grown on-axis at a reaction temperature of 1475°C.

The researchers said that the benefits of HCl addition are twofold: Not only does HCl act as a pregrowth etch that provides stepped surfaces, it also continuously etches away 3C-SiC nucleation sites so that defects cannot develop. The conclusion from this work is that 6H-SiC films may be deposited reliably (i.e., defect-free) on on-axis substrates at a lower temperature—1475°C, as compared with 1700–1800°C for conventional deposition.

JUNE LAU

## Gecko Foot Hair Research Feeds Adhesive Development

In a study on the adhesive nature of the microscopic hairs between the toes of Tokay geckos (native to Southeast Asia) that enable the reptiles to cling to surfaces, biologists at the University of California—Berkeley and Lewis and Clark College have determined that van der Waals forces may account for the adhesion, though they have not ruled out the possibility of water adsorption or other types of water interaction. Robert J. Full, head of the Poly-PEDAL (Performance, Energetics, Dynamics, Animal Locomotion) Laboratory at UC—Berkeley; Kellar Autumn, assistant professor of biology at Lewis and Clark and a former postdoctoral student in Full's laboratory; and their colleagues have measured the forces that these hairs, called setae, exert on a surface in order to prepare a synthetic adhesive that is both dry and self-cleaning.

The key seems to be the hundreds to thousands of tiny pads at the tip of each hair. These pads, called spatulae, measure only about $10^{-5}$ in. across. Yet, they come so close to the surface that weak interactions between molecules in the pad and molecules in the surface become significant.

In order to measure the forces involved when one hair sticks to a surface, engineer Thomas Kenny of Stanford University micromachined a device to measure the forces involved in attaching the hair to a surface. The dual-axis piezoresistive cantilever was fabricated on a single-crystalline silicon wafer. As they reported in the June 8 issue of *Nature*, with the microelectromechanical system (MEMS) tool, the researchers showed how the gecko engages the surface by pushing in and pulling slightly downward, achieving 600 times greater sticking power than friction alone could achieve.

Engineer Ron Fearing of UC—Berkeley employed a 4.7-mm aluminum bonding wire with a 25-µm nominal diameter to measure the forces when detaching. Using Fearing's device, the research team showed that pulling away is not enough to disengage. The strength of attachment is so strong that a single gecko hair could bend the aluminum wire. If the hair is levered upward at a 30° angle, however, the spatulae at the end of the hair easily detach.

They estimated the van der Waals force for a spatula to be ~0.4 µN. As the number of spatulae per seta varied from 100 to 1000, the researchers estimated the setal force to be in a range from 40 µN to 400 µN.

Though the setae work extremely well in adhering to a smooth surface such as glass, Autumn said that in the natural world, waxy coatings on leaves may hinder adhesion by resisting the intermolecular interactions. Therefore, while geckos may not need more than 10% of their setae to stick to glass, they may need to use more of them to walk on vegetation.

The researchers have ruled out the most common methods used by animals to stick to a surface. Full, Autumn, and their colleagues calculated that suction is much less effective than the measured sticking force of a gecko's foot. Geckos can also cling to a wall in a vacuum. The researchers found no evidence that geckos use a glue: The foot has no glue glands, and no glue residue is left on the surface. The hairs do not interlock with the surface, as with Velcro, and friction is unlikely because friction cannot explain the animals' ability to walk on the ceiling. Electrostatic attraction was ruled out by other researchers.

Autumn and Full report, too, that the gecko hairs are self-cleaning, unlike any other known adhesive.

"We clogged their hairs with microspheres, and five steps later they were clean," Full said. "We don't know why, but it's amazing."

Full and Autumn said that their next goal is to find a way to study individual spatulae and measure their attractive force. Eventually, the researchers want to develop an artificial dry adhesive. Since the hairs and spatulae work so well, Fearing and Kenny have launched an effort to make artificial hairs that use the same sticking technique and could make a strong-yet-dry adhesive.

## Self-Assembling Peptides Arise as Possible Biomaterial for Generating Nerve Cells

Researchers Todd C. Holmes, assistant professor of biology at New York University, and Shuguang Zhang, research scientist at the Massachusetts Institute of Technology, have made a self-assembling, peptide-based scaffold that supports living nerve cells. They said that this is the first peptide-based biomaterial of its kind that can be designed at the molecular level.

As reported in the June 6 issue of *The Proceedings of the National Academy of Sciences* (PNAS), peptides of arginine-alanine-aspartate (RAD) 16 scaffolds self-assemble into thin, wavy films containing a network of individual, interwoven fibers ~10–20 nm in diameter. The researchers have grown neurons on these scaffolds, in which the fibers communicate with each other and establish functional synapses.

Holmes said, "The nervous system actually produces factors that prevent regrowth and repair. That's what makes this newly discovered biomaterial so exciting. It supports nerve-cell attachment, neurite outgrowth, and the establishment of new functional connections between nerve cells that allow the nerve cells to communicate with each other. These are important considerations for the design of new materials for repairing the damaged nervous system."

Unlike other synthetic materials, these peptides are completely biological, composed of amino acids. And unlike parts of animal cells such as collagen that can be extracted as a basis for growing cells but may also carry and pass viruses to the attached growing cells, the peptides do not evoke an immune response or inflammation in living animals.

According to the researchers, while synthetic scaffolds have been used to grow skin, liver tissue, and cartilage, little progress has been made on developing biomaterials for the generation of nerve cells.

### With Shrinking Size, Smart Materials Lose their Effectiveness

Piezoelectric ceramics are commonly used in pressure sensors, microphones, and accelerometers. Deposited as thin films, the material can be used to form sensors and actuators in microelectromechanical system (MEMS) devices, elements in ultrasonic motors, and switching capacitors for integrated circuitry. While thin films have much better mechanical properties than the bulk ceramics—for example, films are far less brittle—Nancy Sottos and her research team at the University of Illinois at Urbana-Champaign have found that other physical and electrical properties change in undesirable ways, such as decreases in both piezoelectric response and dielectric constant.

As reported in the April 15 issue of the *Journal of Applied Physics*, Sottos, a professor of theoretical and applied mechanics, and graduate research assistant Lei Lian obtained lead-zirconate-titanate thin films that ranged in thickness from 0.5 μm to 2.0 μm. To record the films' displacements, Sottos and Lian developed a high-resolution, laser Doppler heterodyne interferometric technique.

Sottos said, "The properties of piezoelectric films are critical to the quality and the reliability of MEMS devices. To optimize the performance of thin-film structures, we must first understand the factors that influence those properties."

For their experiments, the measurement scheme is based on the Doppler shift. First, the beam from an argon laser strikes a 40-MHz acousto-optic modulator, which produces two beams and sends them along different arms of the interferometer. One beam then bounces off the sample, while the other beam serves as a reference. When the two beams are recombined, the researchers accurately extract the displacement signal from the Doppler shift riding on top of the 40-MHz carrier. The experiments show that as the films become thinner and thinner, their piezoelectric response and dielectric constant decrease. For instance, for films with (111) preferred orientation, as the thickness drops from 2.0 to 0.5 μm, the dielectric constant drops ~67% and the $d_{33}$ piezoelectric coefficient drops ~73%.

Significant stresses build up in piezoelectric thin-film structures during the fabrication process, Sottos said. "Changes in the residual-stress state might be one major cause for the change in properties with film thickness that we observed. By applying a mechanical stress—to relieve some of the residual stress—the response of the film can be greatly enhanced." □

Materials Research Society

## Call for Nominees

### Outstanding Young Investigator Award, 2001

The award recognizes outstanding, interdisciplinary scientific work in materials research by a young scientist or engineer. The award recipient must also show exceptional promise as a developing leader in the materials area.

The award consists of a $3,000 cash prize, a presentation trophy bearing a brief citation, and a certificate. Reasonable travel expenses to attend the Spring Meeting at which the award is presented and the meeting registration fees will be reimbursed.

**The deadline for submission of nominations is October 1, 2000.**

For guidelines and application forms, contact—

Sue Novosel, Materials Research Society
506 Keystone Drive, Warrendale, PA 15086, USA
e-mail: novosel@mrs.org or access the MRS web site at **www.mrs.org**.