

# Semiconducting the Future

Microelectronic devices group explores new materials for future computer chips and high-power transistors

As computer-chip makers struggle to build faster microprocessors, they must continually shrink the transistors at the heart of those chips in order to cram in more power. In the not-too-distant future, they'll reach a point where the devices can't get any smaller, a threshold that could end a half-century of steady increases in computing power. But Jesus del Alamo looks at that looming limit and sees opportunity.

"We work on extreme devices, I tell my students," says del Alamo, associate director of the Microsystems Technology Laboratories. "I'm interested in electronic devices at the extremes of operation."

He's talking about devices that work at very high power and voltage levels, as well as those that are very, very small. In about 15 years, manufacturers won't be able to make the silicon devices that currently rule the chip world any smaller. Once the features get down to about 20 nanometers in thickness, any further shrinkage will cause electrons to jump from one place to another, short-circuiting the devices.

Del Alamo's group may have one solution: building microprocessors out of so-called exotic semiconductor materials such as indium gallium arsenide (InGaAs). Because of its different crystalline structure, electrons flow more quickly through InGaAs than through silicon. The result is faster performance in circuits of a given size.

Engineers have long used InGaAs for applications such as infrared spectroscopy and millimeter-wave communications. Now del Alamo and postdoc Dae-Hyun Kim have built a 60-nanometer transistor that can carry two and a half times as much current as a 65-nanometer silicon transistor—today's state of the art. This suggests that even when transistors can't get smaller, new materials can still improve the devices' performance by working faster. "By the time we reach 20 nanometers, silicon is expected not to work at all, and this material is expected to work very well," del Alamo says.

It will still take a lot of work to develop InGaAs into a viable alternative to silicon. For one thing, while negatively charged electrons flow easily through the material, their positively charged counterparts, "holes," move at a much slower pace. Microprocessors need both to control the flow of power through a device; otherwise, heat becomes a problem. Del Alamo believes that by manipulating the mechanical strain on the material, he will be able to change the crystalline structure to promote better movement of holes. The material will also require new device designs and manufacturing technology. He

hopes that in about 12 years, he'll have developed InGaAs technology to the point where industry could step in and start refining manufacturing processes.

He doesn't know for sure that InGaAs will eventually become the basis for computer chips, but he's hopeful. "It's a bit far-fetched," he admits. "It's a non-silicon material" in an industry that is built on silicon. "But it has a lot to offer."

Another material he's investigating is gallium nitride (GaN), a compound semiconductor used to make certain types of LEDs. It could also make transistors that could handle more power and voltage than today's devices. Such transistors would be useful as automobiles' electrical systems move from 12-volt to 42-volt setups that can handle all the new electronics expected in future cars. They would allow for high-efficiency, high-power cell-phone transmitters that could transmit at higher frequencies, where more bandwidth is available. They'd also be useful in wireless large-area networks, plasma televisions, and military weapons systems.

The problem with GaN is that it easily develops microscopic cracks that render it useless. Del Alamo's group has found that a layer of aluminum gallium nitride, placed on the devices to trap electrons, induces mechanical strain on the GaN, which then stretches until it can't carry electrons efficiently. In addition, high voltages cause mechanical strain, and the two stresses together destroy the device. Del Alamo says this new understanding of the problem suggests possible solutions, such as using thinner barrier layers with less aluminum and altering the electrical field to eliminate voltage peaks.

Housed in Building 39, del Alamo's group consists of eight members, including grad students, postdocs, and a visiting professor. It receives funding from Intel, as well as through the Microelectronics Advanced Research Corporation, a research consortium formed by the semiconductor industry.

Suman Datta, a researcher in Intel's Advanced Transistor and Nanotechnology Group, collaborates with del Alamo and calls the results coming out of his lab "very impressive." He agrees with del Alamo that there's a lot of work to be done to make an InGaAs device that is practical and compatible with silicon manufacturing processes. "This kind of research needs to be encouraged and pursued, but the challenges that come with it [must be] identified and addressed at the same time," Datta says.

## IN BRIEF

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### MAJOR PROJECTS

Indium gallium arsenide transistors  
Gallium nitride transistors  
Silicon interconnects for millimeter-wave systems