New Directions

Volume 12 | Issue 4 Article 12

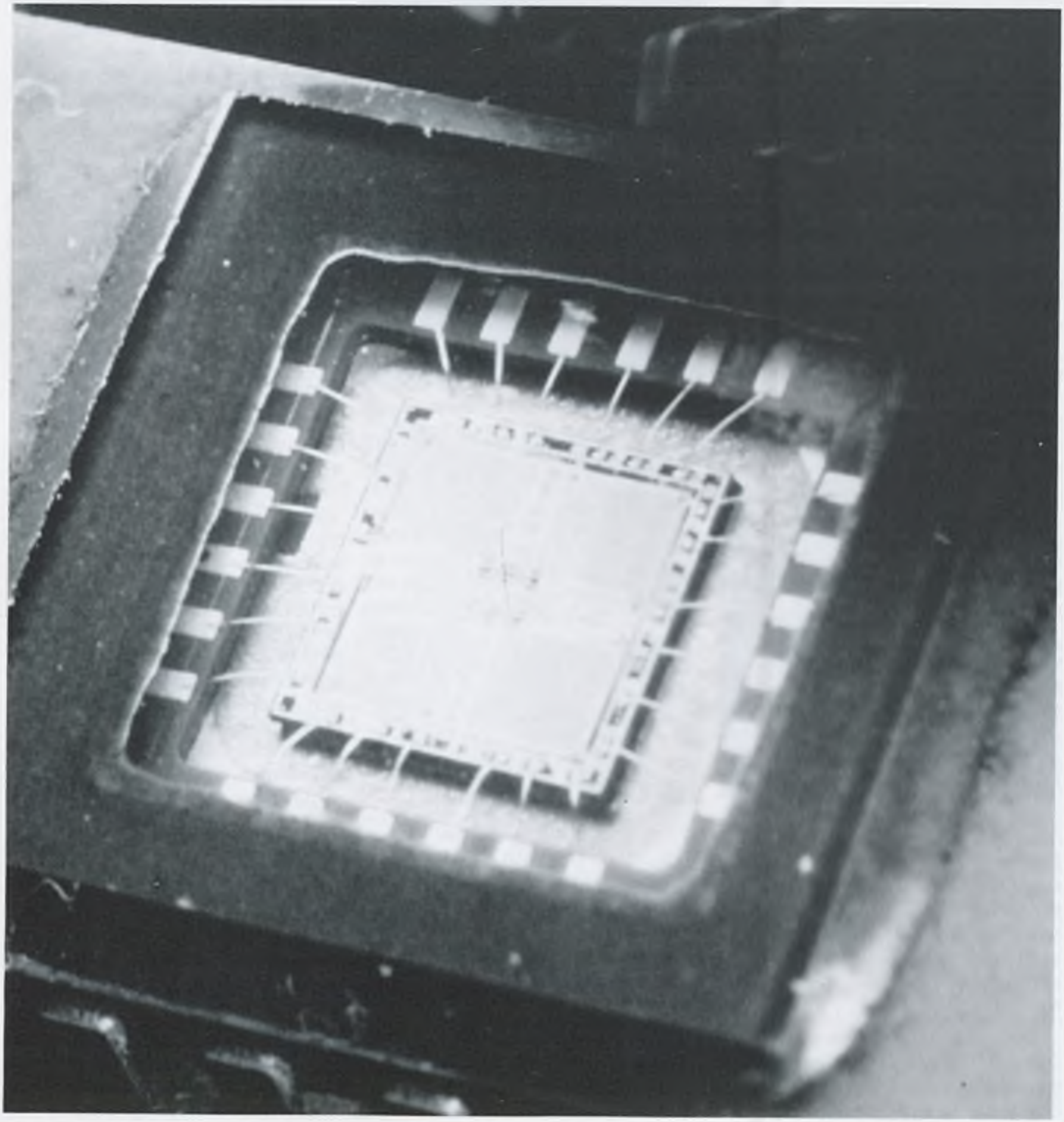
10-1-1985

Microelectronics Research At Howard: Working on the Edge of Technology

Harriet Jackson Scarupa

Recommended Citation

Scarupa, Harriet Jackson (1985) "Microelectronics Research At Howard: Working on the Edge of Technology," *New Directions*: Vol. 12: Iss. 4, Article 12.
Available at: https://dh.howard.edu/newdirections/vol12/iss4/12



Microelectronics Research At Howard:

Working on the Edge Of Technology

By Harriet Jackson Scarupa

If you use lousy materials, you'll end up with a lousy product. That's something any cook or carpenter or tailor—or solid state electronics engineer—understands.

Howard University's Rockwell Solid State Electronics Laboratory is embarked on a technological quest to grow, understand and process new, sophisticated, high-quality electronic materials destined for the gadgets of the future.

Already, of course, electronic gadgets have transformed our lives. Consider such taken-for-granted products as the hand-held calculator, digital watch, burglar alarm, hearing aid, solid-state stereo, video cassette recorder and the all-pervasive computer. Responsible for the electronic devices that make these familiar products work are so-called miracle chips, flat, quarter-inch squares of silicon on which scores of circuit lines have been etched by a computer-controlled beam of electrons. An electronic device made from a typical silicon chip is about 50 times smaller than a human hair. Because of this tiny scale, miracle chip technology is also known as *microelectronics*.

Electronics is a specialized study of electricity concerned with the behavior and effect of electrons, i.e., of negatively charged particles found outside the nucleus of an atom. Microelectronics is the branch of electronics that deals with the behavior and effect of electrons in miniature circuits and components. Why miniaturize? Because in the world of electronics, smaller means faster. Why is this? Because the electrical impulses that run through a miniature device have a much smaller distance to travel than they would in a larger one.

Electronically, silicon is classified as a semiconductor, a crystalline, solid material which has properties that lie somewhere between that of a metal (which conducts great amounts of electricity) and an insulator, such as glass (which conducts very little electricity.) By adding various impurities to semiconductors they can be made to look and act like conductors at times and like insulators at other times.

Silicon has been—and is—considered the workhorse of the semiconductor industry as any visitor to Santa Clara County in California (aka Silicon Valley) could attest. But as we know, and as the Japanese and Soviets know as well, technology does not stand still. And so, spurred on by the needs and wants of the defense community, the telecommunications industry and the consumer products market, the race is on to develop faster, more efficient and more sensitive semiconductor devices to put into a new generation of electronic products. And that means looking beyond silicon.

It's not that silicon is considered a "lousy" material with which to power this new generation of electronic products. After all, it is abundant in the Earth's crust; it is easily refined into a high-purity form; and it is relatively cheap to process into devices. It's just that because nature is the way it is, the electrical properties of silicon can satisfy only some of the seemingly unquenchable thirsts of modern technology. Or as one of Howard's microelectronics researchers puts it, "Silicon is like the Volkswagen of the industry. It's rugged; it can take a licking. But it's not the Cadillac. So we always have to look for the Cadillac."

A silicon-based device can't handle the super speeds necessary for the operation of a new generation of supercomputers very well, for instance. A silicon-based device can't emit light which means you couldn't use it for the likes of a semi-conductor laser, part of the "Star Wars" hardware coveted by the military. A silicon-based device can't operate very well at microwave frequencies so there would be problems if you wanted to put it in an antenna to receive satellite signals at these frequencies. Because of such limitations, researchers have begun to study other electronic materials which could serve not so much as a substitute for silicon but as supplements to it.

And that's where Howard's microelectronics effort, or more precisely, its semiconductor research program, comes in. The program involves growing and characterizing two promising semiconductor compounds, gallium arsenide and silicon carbide, fabricating electronic devices from these compounds and then testing the devices electrically to see how they work and if they don't work trying to figure out why. [A compound is a pure substance that is composed of two or more elements. Gallium arsenide is formed by gallium and arsenic; silicon carbide, by silicon and carbon.]

Headquarters for this research are six laboratories of various sizes which are housed in the School of Engineering and are known collectively as the Rockwell Solid State Electronics Laboratory.

The laboratory was dedicated in 1977 with initial funding from Rockwell International Corp., manufacturer of the space shuttle, and now boasts some $4 million in advanced, space-age-looking equipment, including a molecular beam epitaxy machine, ion milling machine, low pressure/high pressure vapor deposition reactor, Auger mass spectrometer, network analyzer and Yag and dye lasers.

Since 1980, the research of the laboratory has been supported by $1,888,957 in grants and contracts from the National Aeronautics and Space Administration, the Solar Energy Research Institute, the Jet Propulsion Laboratory, the Air Force Office of Scientific Research, the National Science Foundation, Lawrence Livermore Laboratories, the Naval Research Laboratories and the Federal Systems Division of International Business Machines Corp.

Leading the laboratory's 15-member research team are three young assistant professors in the Department of Electrical Engineering who were recently featured in an *Ebony* article appropriately entitled, "The Future-Makers." They are Gary L. Harris, Keith H. Jackson and Michael G. Spencer.

"We're working at the first level of technology—right down at the materials level," explains Harris in discussing the major thrust of the work he and his two colleagues are doing. "I like to draw an analogy with a plane. A plane uses a certain amount of fuel and the reason it uses a lot of fuel is based on the fact that the plane is made of aluminum. Aluminum has some weight to it but it needs that weight in order to maintain the mechanical properties of the plane so that it will be sturdy.

"Well, eventually you could think of a material that would be just as strong as aluminum but would weigh much less. Then the efficiency of the use of fuel would go up tremendously because you wouldn't have to carry the weight of the plane itself. That's the kind of thing we're trying to do with semiconductors. We try to look for applications of materials and then develop materials systems that will meet future needs."

Spurred on by the needs and wants of the defense community, the telecommunications industry and the consumer products market, the race is on to develop faster, more efficient and more sensitive semiconductor devices to put into a new generation of electronic products.

How does the Howard laboratory actually go about this? What is involved when you grow and characterize these two advanced semiconductor materials and make and test devices fabricated from them? Many of the details of such research are unintelligible to the layman, but visiting the laboratory and talking at length with its three principal investigators can help one understand something of the broad scope and significance of the undertaking.

You grow tulips. You grow tomatoes. You grow turnips. But how do you "grow" semiconductors? Researchers at Howard's Rockwell Solid State Electronics Laboratory do it through three complicated processes: molecular beam epitaxy, vapor phase epitaxy and liquid phase epitaxy. Consider the case of gallium arsenide. A substrate of this material (purchased from a commercial vendor) constitutes the "seed" for the growth process. This substrate looks like a shiny, flat, steel-grey wafer, is 2 inches in diameter and about the thickness of 10 sheets of thin paper, and is in the form of a single crystal.

To "grow" this crystal, the Howard researchers have to build layers on top of layers on it, layers of atoms which will determine the resistance of the crystal to electricity. Sometimes this means adding various controlled impurities (e.g., boron, phosphorus or nitrogen) to the crystal in order to modify its electrical properties.

Molecular beam epitaxy is the crystal growth process that seems to make the researchers the most excited. In this process a gallium arsenide substrate is heated on a hot plate inside the laboratory's molecular beam epitaxy machine and is then hit with multiple molecular beams of different intensity and chemistry.

The machine, which bears a hefty $750,000 price tag, is a fanciful-looking bit of technological hardware featuring all sorts of nobs and dials and hoses and chambers and curious round window-looking structures. The atmosphere inside the machine is a vacuum which is as good as that found in outer space, the researchers explain. This allows them to have far better control of any impurities in the material they are growing than they could under more ordinary conditions.

"We're trying to get a controllable form of the crystal so we can always duplicate it and know how it's going to come out," says Spencer. "Once you have good control of the single crystal then you can get a good device. That's what technology's about. It's about control."

"What's exciting about molecular beam epitaxy," he adds, "is that it's a growth system that makes it possible to controllably grow layers that are of the atomic dimension. That was impossible to do until recently. By atomic layer control I mean we actually can controllably lay down one layer of atoms of a particular type and then lay another layer of atoms of a different type. We can actually modify a structure's physical dimension. That's a startling capability!

"We can actually manipulate the very atoms of the crystal on the scale that the crystal is growing, which means we can control the crystal itself. That's a staggering capability! Staggering!!" Being able to do this, acknowledges his colleague Jackson, "is a bit like playing God—in a lightweight way."

After the layers of gallium arsenide or silicon carbide are grown, they must be characterized. That is, they have to be closely examined to see if they are, in fact, pure or if some errant atom has somehow gotten into the material or if it is defective for some other reason. "It's analogous to diamond cutting," explains Jackson. "When you cut a diamond you want to see what kind of flaws it has, how many imperfections it has. In the case of a diamond, imperfections sometimes add value. In the case of semiconductors, they are always the kiss of death."

The laboratory does three basic types of characterization: physical, electrical and chemical. "The electrical resistance of a semiconductor material is affected by small changes in purity and content, and to be able to measure these changes is a science in itself," observes Spencer. "We use some very sophisticated techniques to try to measure the small amounts of impurities that are introduced into a crystal."

The Howard research program involves growing and characterizing two promising semiconductor compounds, gallium arsenide and silicon carbide, fabricating electronic devices from these compounds and testing the devices electrically to see how they work, and if they don't work trying to figure out why.

Some of these techniques seem relatively simple, such as examining a crystal with an electron microscope. Other techniques, such as Auger electronic spectroscopy and photoluminescence, do not. In photoluminescence, for example, a laser is beamed on a crystal to excite states or levels inside. Because these excited levels radiate at a characteristic wavelength, studying these wavelengths can be used to identify impurities.

Why bother with all this? "The more understanding you have of the properties of the crystal," Spencer reiterates, "the more you'll be able to control the performance of the ultimate device you can make from it." Or as Harris puts it in his down-to-earth style, "If the material is lousy, the device will be lousy. So that's why we need all these characterization techniques."

Once the crystal has been grown and characterized, it is ready to be fabricated into an actual electronic device. To do this, researchers take the layers of gallium arsenide or silicon carbide and use delicate, precision instruments and high-powered microscopes to map out special electronic patterns on the surface of the materials.

This process is called lithography (as in the worlds of art and printing) and it must be done in a "clean room" (which is also true of the growth process.) Such a room is as spotless and dustless as possible, where the air is continuously filtered and the researchers must wear coats, gloves and head and shoe coverings as if they were members of an operating room team. Why take so many precautions? It doesn't seem so enigmatic when you consider the fact that a typical microelectronic device is so small that one dust particle could wipe it out.

With the electronic patterns now etched and/or deposited on the surface of the crystal's layers, the crystal has been transformed into a series of devices. This material is then cut into smaller pieces containing one or more devices and these pieces are connected to the "outside world" by attaching a thin gold wire to them. This is done through a process called thermocompressional bonding using a machine that resembles an elaborate sewing machine connected to a microscope.

The predominant devices currently being fabricated by the laboratory are high speed diodes and high speed microwave transistors. It is now gearing up to make a third type of device: high performance solar cells. To the naked eye the electronic devices made in the laboratory don't look like much of anything, but when you examine

Research associate James Griffin working with electron beam evaporator.

Michael Spencer at the control panel of the molecular beam epitaxy machine.

Michael Spencer checking a part of the molecular beam epitaxy machine.

one under a microscope you see a pleasing, intricate pattern of circuits that brings to mind the design of a Navaho rug.

The researchers test the performance of these devices using a machine called a network analyzer. It measures how well the devices control the flow of electrons and how fast the devices operate, "reporting" its answers via a detailed computer printout. "You can test a device without actually putting it into a system," explains Spencer. "For instance, you don't have to put a high speed microwave transistor into a satellite-to-satellite communication system to see if it works. You can find out by using the network analyzer."

Because the laboratory starts out its work at the level of the crystal and takes it through the fabrication and testing of a device, its researchers often speak of the laboratory's "vertical integration." And they consider this one of the laboratory's greatest strengths. "Some laboratories get locked into one stage," remarks Harris. "They can only grow materials or they can only fabricate the device or they can only measure the electrical properties of the materials, whatever. We're not locked in and that gives us maximum flexibility and allows us to explore a range of new possibilities".

The broader focus of the laboratory also seems to match the working styles and preferences of the laboratory's three principal investigators. Each has a research specialty. (Jackson, for instance, is the expert of Auger electronic spectroscopy, a chemical characterization technique.) But they also seem to enjoy wearing different hats.

The three have presented papers describing some of their research efforts at a variety of national and inter-

Graduate student Andre Cropper using microscope to examine lithography pattern on a crystal.

national scientific meetings and have published their findings in such publications as the *Journal of the Electrochemical Society, Journal of Applied Physics, International Journal of Mass Spectrometry, Journal of Electronic Materials* and the *IEEE Transactions on Electronic Devices.* Most of these articles are totally baffling to the layman. A typical title: "The Study of High Purity and Semi-Insulating $Ga_xAl_{1-x}As$ $(x \sim 0.4)$ for GaAs Heterostructure Mesfet Devices Grown by LPE." Suffice it to say that such an article represents but another link in the chain of understanding electronic materials and their processing.

Question: Will the seemingly arcane research being undertaken and reported by the Howard investigators make any difference in the lives of Aunt Sarah and Uncle Joe and you and me?

"Research is sometimes once removed from the ordinary person," answers Spencer. "The fact that we understand more about gallium arsenide may help industry make a better device which may put a better product on the market. But sometimes the product will not get to the ordinary consumer. A lot of these products go to the defense community. Some go to the communications community which does involve the ordinary consumer..."

"I don't want to be flip," he adds. "Gallium arsenide devices could be used in calculators or video discs, home computers, watches, solar energy systems, automobile controls...in an infinite variety of things where silicon does not meet the performance requirements either in terms of speed, temperature, stability or optical interactions. If silicon doesn't meet those requirements, then gallium arsenide or silicon carbide could be a potential candidate."

The truth of the matter is that the three Howard researchers don't seem overly concerned with questions about what can be done with the materials the laboratory is growing and processing and the technology it is developing. "I don't think on a day-to-day basis about that," acknowledges Jackson. "I don't think you can approach a problem from that point of view. Our question is not so much 'what can you do with this?' as 'what can you do with this *if*?'"

The field of microelectronics is ripe with intriguing ifs. And that's one of the reasons those working in the field find it so challenging.

The field of microelectronics is ripe with intriguing ifs. And that's one of the reasons those working in the field find it so challenging. Spencer, who last February received a prestigious Young Investigator Award from the National Science Foundation, pauses to dwell on some of these challenges. "The challenges in microelectronics are really the joys," he says. "How do you make devices very small? How do you develop theories and models to understand them? And as you make them smaller, the techniques of characterizing them become more difficult. The things you're looking for that are causing the device to go wrong are more difficult to see. The technology of making contact with the outside world has to be rethought.

Research associate Konji Fekade operating deep ultra-violet mask aligner used for lithography.

"And then with this new flexibility that molecular beam epitaxy provides, people have to be innovative enough to take advantage of it. Now it's possible to make new classes of devices instead of the traditional ones, devices that will operate on principles that are different from those that are functioning now. They'll probably be quantum devices and these devices will probably be hybrids of optical and high speed devices..."

His voice trails off as if exhausted by contemplating the sheer wonder of future possibilities. "There's not a whole lot of certainty about the exact way the technology is going," he adds. "But it's very exciting to be involved in it. It's very exciting to be involved in exploring these new possibilities." □