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INSIDE

What's New About Atomic Layer Deposition *—by Adam Gruen*

If you've ever painted a model, figurine, or anything miniscule, you know how exasperating it can be to place just the right amount of paint at the right spot with smooth and continuous coverage. At the microscopic level, it's impossible—even the finest paintbrush and a magnifying glass won't help you.

Confronted with the need to paint microscopic, sub-micron-sized objects, engineers long ago resorted to deposition (by intimate dipping or submerging an object in a chemical bath). However, as miniaturization improved, even deposition failed. Engineers switched to releasing a precise amount of gas at a precise temperature in a vacuum chamber over time to cover a target surface with a thin film. This process, called chemical vapor deposition (CVD), reached limits. A new generation of semiconductor and memory storage devices, with complex three-dimensional topologies, demands even finer layering techniques.

The next-generation process is called atomic layer deposition (ALD), a variant of CVD that was first conceptualized in the late 1970s. Without ALD, advancement in semiconductor and data storage devices and other nanoscale machines needing physical buffers on the atomic scale would come to a grinding halt. MDA has an interest in making sure that ALD is affordable and reliable.

Genus, Inc. (Sunnyvale, CA), was in the business of making CVD equipment and services. As a direct result of MDA funding beginning in 1998, Genus developed ALD equipment that layers metallic oxides and nitrides upon target substrates with improved precision and conformity. In the summer of 2002, the company introduced an ALD product line of equipment and related services called StrataGem. Today, more than half of its $50 million per year revenue derives from the ALD process and the company is a recognized leader in the field with international customers including Infineon Technologies, Samsung Electronics, Seagate, and Western Digital.

MDA first awarded a Phase I SBIR contract to Genus in 1998 for ultra-thin (less than 100 Angstrom) barrier materials to advance copper interconnect technology used in integrated circuitry. The Phase I program successfully demonstrated the development of a process and tool capable of controlling atomic level reactions. MDA quickly followed this up in 1999 with Phase II SBIR funding and awarded a new SBIR Phase I contract to test similar processes for integrating new high-K dielectric materials in devices such as advanced gate insulators based on complementary metal-oxide semiconductor technology.

Sheer Genus. *The Genus StrataGem ALD System brings chemical precursors to a surface one at a time instead of running a deposition process continuously.*

At the conclusion of these early studies by the end of 2001, there was no doubt about it: Genus' ALD technique

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FROM THE EDITOR

GETTING REAL

Working for the Technology Applications program in the mid-1990s, I wrote about a small Minnesota company called NVE and its lofty goal of creating a new memory technology called magnetic random access memory (MRAM). MRAM has been called the ideal memory because it combines the best attributes of existing memories: the speed of static RAM, the density of dynamic RAM, and the nonvolatility (the ability to store data permanently) of hard disks.

A good portion of the company's MRAM research back then was being funded by the MDA's predecessor, the Ballistic Missile Defense Organization. This made NVE eligible for commercialization assistance provided by the Technology Applications program. We helped refine their business strategies and expand their contact network through a Technology Applications Review, our unique business panel forum. Further, we helped spread the word about the company's technology through various newsletter articles and special reports.

Well, I'm pleased to report that—some 10 years later—the MRAM technology may finally be getting real. According to NVE, Cypress Semiconductor, a global player in the semiconductor manufacturing market, has made working MRAM using NVE intellectual property. Ralph Schmitt, Cypress Semiconductor's executive vice president of sales and marketing, recently said "we feel very confident that we are close to having a production-ready product."

NVE also reports that under a technology exchange agreement, it has rights to Cypress Semiconductor's MRAM designs, rights to modify such designs, and rights to have MRAM manufactured at Cypress Semiconductor's foundry. Motorola, another licensee, has said it expects to begin MRAM production by late 2004. If Motorola's production devices contain NVE's intellectual property, NVE expects to receive royalties.

I'm hopeful the MRAM technology will be a big winner in the marketplace, enabling a new generation of Dick Tracy-like cell phones and instant-on computers where programs load and execute immediately. Furthermore, it could dramatically simplify computer architecture by eliminating the many data paths needed to move information between fast memory, dense memory, and nonvolatile memory.

Striking a Chord With Our Readers

Readers' opinions struck a perfect chord with our opinions of marketing misconceptions often encountered by high-tech researchers ("Marketing Misconceptions Jeopardize Commercial Success," Spring 2004).

One response came from the president of a business consulting firm, who commented "Right on the mark!" Another response came from the general manager of a composites company. He said our article reminded him of some marketing advice he received several years ago: "Salesmen can live without engineers, but

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TECHNICAL MISCONCEPTIONS JEOPARDIZE COMMERCIAL SUCCESS

—by Tim Bennett, Joel Price, and Patrick Hartary

Turning technical know-how into entrepreneurial success is the goal of many MDA-funded researchers. But such commercialization efforts can be sabotaged by the researchers' own technical misconceptions, hindering the adoption of innovations into real-world applications.

Through its business assistance programs for MDA-funded researchers, the National Technology Transfer Center-Washington Operations (NTTC-WO) has identified three common technical misconceptions, which are briefly described below.

Misconception #1: "This product can be inexpensively developed."

Lack of knowledge and experience with the complete product development cycle often leads new technical entrepreneurs to make false statements such as "This product can be inexpensively developed." Although renderings and concept models can be rather easily produced, significantly more cash will be required to develop a functioning prototype. Even more monies are needed for market study focus groups, industrial and engineering designs, regulatory testing, and alpha and beta prototype production to meet specific application requirements.

Potential product manufacturers will desire up-front cash, and rarely contribute development dollars on the promise of future business. Investors and strategic partners want to see products that are far along in the development process. Often, a start-up company developing the simplest technical product requires about $2 million and two to three years to reach the market.

To better position the company and its technology in the early negotiation process, it pays to have the product demonstration version as close as possible to its final state. Spending some extra time and a few thousand dollars working with outside sources to refine the envisioned product will always be a valuable use of resources. It is during this initial phase that potential "show stoppers" can be identified, before even more serious expenditures are incurred.

Misconception #2: "I know what customers want."

New entrepreneurs often claim to "know what their customers want." As a result, they may add many features that are either possible or assumed to be of value to the user. Additional "bells and whistles" affect manufacturing costs, product reliability, and user friendliness, leading to lower profit margins or market penetration at a higher price point.

Knowing that market "pull" drastically increases the probability of a product's success, entrepreneurs must first speak with the targeted customers and distributors to determine their essential needs. Understanding the nuances within a target market base and its distribution chain will help the product designers and developers incorporate the desired features and capabilities. Remember that up-front marketing efforts are critical to all successful product introductions.

Misconception #3: "Cost is not an issue to our customers."

Another popular misconception among new entrepreneurs is that "my technology is so much better, cost will not be an important factor."

Consider the battle between Beta and VHS video players back in the late '70s and early '80s. Sony's Beta video offered a much higher quality picture than the VHS, but it was also more expensive. As it turned out, the general consumer was content with the VHS picture quality and lower price-point combination. VHS manufacturers went on to dominate the market and displace the competing Beta technology.

Cost is always an important factor, even if you are defending a nation or ridding a horrible disease from the world. Most importantly, a company's technology and products must always present to the customer a clear value proposition. Educate yourself about the price points of current competition. Even if your technology is superior, the market will immediately compare it to current alternatives. Always ask how a superior product can be offered at a comparable price—a better value proposition.

In the Spring 2004 issue, we presented four marketing misconceptions that could hinder MDA-funded researchers' commercialization efforts. In the Fall 2004 issue, look for our last installment in this series of articles: business misconceptions.

GELS ARE BEST SHAKEN, NOT STIRRED

All shook up. *Resodyn's equipment uses sonic energy instead of rotors or blades to mix materials.*

James Bond believes martinis are better shaken, not stirred. As it turns out, shaking instead of stirring also can produce better gels.

With MDA SBIR funding, Resodyn Corporation (Butte, MT) is building industrial mixers that offer significant performance improvements in gel manufacturing. The mixers use sound instead of rotors to shake gels, improving quality, speed, and safety. They should find use in the pharmaceutical, processed-food, and chemical industries as well as in propellant manufacturing.

The company's technology works by inducing low-frequency resonant sonic (LFRS) energy in a fluid, resulting in an increased rate of energy dissipation per unit mass of the fluid and allowing rapid and efficient dispersion of solids, gases, and immiscible liquids. Resodyn's technology—essentially a vessel with no moving parts inside—runs at approximately 50 to 100 hertz. A proprietary, patent-pending drive system on the outside of the vessel serves as the resonant mechanical driver that radiates an acoustic-energy field that mixes the vessel contents. "You end up in essence causing an earthquake within that material," said Lawrence Farrar, Resodyn's president. "In other words, you are able to fluidize materials as is caused by an earthquake situation. High-G loads are put on that material."

As to safety, Resodyn's method of mixing materials does not require the cleaning of rotors or mixer blades, meaning less handling of potentially hazardous equipment or material by workers. In addition to safety, the technology brings speed. Mixing time can be trimmed from more than an hour to just a few minutes. And compared with conventional propeller-driven mixing, Resodyn's technology brings the benefit of greater density by reducing the potential for gas bubbles, which can degrade the overall quality of the material being mixed.

MDA funded Resodyn's technology through a $2.16 million contract to develop a 1-gallon bench-scale machine, with the greater goal of creating a production-scale unit that can handle as much as 50 gallons. The MDA contract focuses on high-density metallized gel propellants for a divert and attitude control system in the Theater High Altitude Area Defense (THAAD) program. Loading gels with metallized nanomaterials increases the burnable surface area within a propellant and generates a higher specific thrust. Gel propellants also are considered safer than liquid propellants because they do not have the same tendency to leak.

Dow Corning already is using a Resodyn industrial machine to mix viscous materials at an extremely pasty 100 million centipoises in five minutes, compared with conventional methods that might take as long as an hour and a half. (The viscosity of water is 1 centipoise. The higher the number, the more viscous the material.) Resodyn makes only the machines, not the gels, and the company expects to fill more orders in coming months, including one from the U.S. Army.

Resodyn officials estimate their market size at hundreds of millions of dollars since many industries have very specific mixing needs for the substances they produce. The pharmaceutical industry, for example, mixes materials that might include fungi, E. coli, or mammalian cells. Conventional mixing methods involving propellers would require running equipment at high speeds to produce the desired high degree of gas-liquid mass transport (the movement of gas into a liquid during the mixing process). But the high speeds of the propellers can destroy cells being mixed. Resodyn's technology, however, could produce good gas-liquid mass transport with little or no cell damage. The company's technology also should work especially well in mixing fumed silica—a fluffy, light material that is difficult to mix.

Resodyn continues to focus on the challenges of market acceptance for its technology as well as assessing market opportunities. But the 28-person company is preparing for growth and is adding about 15 employees, including biologists, mechanical engineers, and chemical engineers.

—S. Tillett

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MAGNETIC MATERIAL ADVANCES ACTUATOR TECHNOLOGY

Piezoelectric materials respond quickly to applied voltages, but only produce very small displacements. Now there's a new material whose fast response times and large displacements could lead to more advanced actuator technology.

Ferromagnetic shape memory alloys (FSMAs) are a new class of active materials whose shape can be altered using magnetic fields. With MDA SBIR funding, Midé Technology Corporation (Medford, MA) has found that a nickel-based FSMA is particularly well-suited for latching valve applications in which high speed and large displacement are required. Other commercial possibilities include hydraulic valves, optical switches, and electromechanical relays.

In a Phase I SBIR contract, the company experimented with nickel-manganese-gallium (NiMnGa), which in recent years has shown significant potential as an actuator material. Applying a magnetic field to NiMnGa changes the magnetization vector of the crystals in the material to a new orientation. When the crystals are reoriented, the material becomes physically strained (i.e., it deforms due to an applied force). Midé's early experiments proved that under the influence of a magnetic field NiMnGa could be strained up to 6 percent at a frequency of 500 hertz. Although faster, piezoelectric actuators are limited to strains of up to 0.15 hertz. Other shape memory alloys can achieve 6 percent, but only at speeds much slower than NiMnGa.

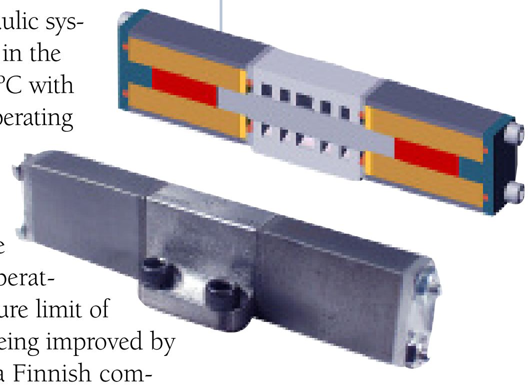
MDA's interest in NiMnGa FSMA lies in the material's ability to operate at cryogenic temperatures and its potential for use in ground-based optical correction systems. Under a Phase II SBIR contract, Midé built and tested a prototype hydraulic latching valve system using the new material. The company replaced the electromagnetic coils of a commercial valve system with two NiMnGa extensional actuators, which shuttle the valve spool between open and closed positions. An opposing actuator is used to move the spool into the desired position as well as to reset the opposing actuator. Maximum valve actuation frequency is 185 hertz in a 2,000-psi hydraulic test bed. The size of the complete system, including the two actuators, valve body, and spool, is 0.75 x 0.75 x 3.5 inches.

A key advantage to the NiMnGa FSMAs is that it offers a no-power-hold capability. For example, if a latching valve is actuated to be in the "open" position, it isn't necessary to continuously supply power to keep it in that position. The valve stays open without electrical power, thereby reducing the need to supply power, and eliminating the danger of "closing" the valve during power disruptions. The no-power-hold capability would also work well in an optical switch application. Because the material provides considerable strain, the size of optical switches could be significantly reduced.

One impediment to the commercialization of NiMnGa FSMA material is its limited operating temperature range, currently -50°C to 32°C. Typical hydraulic systems operate in the region of 60°C with maximum operating temperatures of 80°C to 90°C. However, the maximum operating temperature limit of NiMnGa is being improved by Adaptamat, a Finnish company that produces the new material. Adaptamat says that temperature limits of new batches have already been increased to 50°C.

Founded in 1989, Midé specializes in developing, producing, and marketing high-performance actuators, software, and smart (active) materials systems for the aerospace, automotive, and manufacturing industries. The company is open to inquiries regarding high-speed, large-flow-rate applications for its NiMnGa FSMA latching valve device.

—P. Hartary



Magnetic valve. *A latching value based on a ferromagnetic shape memory alloy material offers large displacements and fast response times.*

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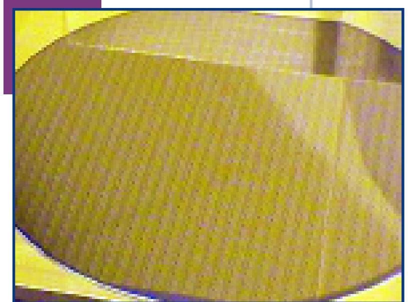
FAST OUT OF THE GATE



Rad CMOS. *A Schottky Barrier CMOS wafer promises more speed and power and reduces the effects of a radiation strike.*

A transistor with a shorter gate length operates faster with less power consumption. Conventional integrated circuit architecture based on doped silicon technology can't be pushed much further; engineers need a new paradigm to reduce gate length. Enter: Schottky Barrier CMOS (SB-CMOS).

Spinnaker Semiconductor, Inc. (Eden Prarie, MN), has patented and demonstrated a breakthrough short channel complimentary metal oxide semiconductor (CMOS) transistor architecture at a gate length of 25 nanometers. State-of-the-art gate length is 50 nanometers; the shorter distance promises an eightfold improvement in speed and power of circuitry. In addition, SB-CMOS technology enables improvements in the manufacture of other metal components and dramatically reduces the effects of a radiation strike or other charged particle effects.

Spinnaker worked in partnership with MIT Lincoln Labs and with SBIR funding provided by the U.S. Air Force and MDA. MDA was sufficiently intrigued by the radiation tolerance promise of SB-CMOS that, in 2002, it awarded the company a Phase II SBIR contract based on a U.S. Air Force Phase I SBIR contract completed in 2001. Spinnaker had proven that Schottky Barrier PMOS and NMOS devices could be created and manufactured. Working with commercial partner BAE Systems North America, the company intends to prototype actual SB-CMOS–based circuitry.

Whenever a metal comes into contact with a semiconductor, the contact point is called a Schottky contact. Examples of Schottky contacts include gold on gallium arsenide, or platinum silicide on silicon. The junction between the two materials creates an energy barrier—measured in electron volts—called a Schottky Barrier.

Energy barriers are the key to how transistors work. The energy barrier allows an electron to pass from a source to a drain across a channel. Two transistors working in tandem can switch a bit from zero to one (or vice versa) in less than ten picoseconds. This delay in switching, called an intrinsic gate delay, can be lessened by shortening the distance the electrons travel. Additionally, a SB-CMOS device creates a larger barrier with less channel doping than traditional doped silicon MOS devices.

Another advantage SB-CMOS technology offers is manufacturability by removing the step of ion implantation into silicon wafers. Ion implantation causes damage to a silicon lattice, which needs rapid thermal annealing on the order of 1000°C to heal. This is called a "spike anneal"—literally, a quick broiling—and would damage other materials that can only survive up to 800°C. Metal silicides, on the other hand, can be manufactured at relatively lower temperatures of about 450°C. In sum, by using metal silicides for the contact points, SB-CMOS permits innovation in other parts of the circuitry or gate stack where engineers would like to substitute hafnium oxide or zirconium oxide for the current nitrided silicon dioxide.

Yet another advantage of SB-CMOS technology is that it is relatively impervious to radiation and energetic particle strikes. Single event upsets (SEUs), such as iron ions flying through space, wreak havoc on a densely packed integrated circuit. SEUs are random and have the unfortunate effect of causing bit errors. Shielding chips is possible, but shielding adds weight. Designing circuits to be radiation hardened is equally possible, but designers pay a penalty in speed and performance.

Finally, the use of Schottky Barrier technology promises to eliminate parasitic bipolar action, an unwanted effect that exists in the use of all silicon CMOS circuitry. If a silicon CMOS circuit is designed without parasitic bipolar action in mind, it can literally short circuit itself. SB-CMOS will reduce by a factor of 4 to 5 bit errors caused by this effect.

Spinnaker Semiconductor has no manufacturing capability. The company instead hopes to license its SB-CMOS technology to existing semiconductor manufacturer and welcomes inquiries about the technology and its performance characteristics.

—A. Gruen

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NEW MEMS APPROACH REDUCES ASSEMBLY COST AND MORE

Sophia Wireless, Inc. (Chantilly, VA), is using a new micromachining approach to build integrated circuits, delivering a product that could offer size, weight, and cost benefits to the radar and aviation markets.

The company has turned its attention specifically to using monolithic microwave integrated circuits (MMICs; pronounced "mimics") and combining them with other active components such as diodes and transistors, as well as passive components such as resistors and capacitors, to create integrated solutions for millimeter-wave applications. Sophia's technology can be found in point-to-point radios, satellite communications equipment, and radar systems.

MMICs serve as great amplifiers and frequency-conversion devices, or frequency multipliers, but they lack some parts that would allow them to operate as transceivers—or devices for both sending and receiving signals. Those missing parts, generally referred to as resonant passive devices, include such components as filters, diplexers, resonators, and couplers—larger-scale devices that are typically difficult to include on a MMIC and that require very low-loss propagation of signals. And since MMICs conventionally are optimized for small size and low cost, putting such resonant passive devices on the gallium arsenide (GaAs) area of a MMIC would be an inefficient use of space. So a transceiver that involves a MMIC typically comprises a MMIC plus resonant passive devices that are not integrated into the MMIC.

Sophia's focus, however, is on integrating those devices. The company has a patent on a process that uses silicon and micromachining techniques for microelectromechanical systems (MEMS) to make the low-loss resonant passive structures. The silicon-MEMS approach also is good at providing a substrate and a sort of second-level packaging for the MMIC, integrating the usual MMIC pieces with the resonant passive components to form integrated transceivers.

The micromachining approach ultimately can produce smaller and lighter products that require less human intervention in the production process. Sophia's technique eliminates the need for circuit boards and housing, making for circuits that are about one-fifth (or even one-tenth) the weight of competing circuit assemblies. And when it comes to size, Sophia researchers claim their product is about one-third the size of competing circuits comprising MMICs with resonant passive components.

Another key benefit of the approach is fewer manufacturing steps. A MEMS approach (involving nonmoving parts and using micromachining surface-mount techniques) eliminates hand-tuning and hand-assembly. Eliminating these steps also should help drive down cost, according to Sophia officials.

The benefits should appeal to makers of electronic equipment such as radars, sensors, and communications devices in which size and weight are issues—as in aircraft or satellites. Sophia executives expect their technology to be a good fit for equipment that runs on frequencies of 8 gigahertz or higher.

Makes cents. *Sophia's micromachining-based process for building monolithic microwave integrated circuits eliminates assembly steps, helping drive down costs.*

MDA predecessor BMDO originally funded Sophia's work to develop a novel interconnection and assembly system for MMICs, with the technology holding potential to reduce assembly cost while improving interconnect performance in hardware such as microwave systems, wireless telecommunications, and radars. The company, previously known as Virginia Millimeter Wave, Inc., received Phase I and Phase II SBIR awards for the project.

The company continues to look for contracts that will generate revenue to help increase capacity and spur true commercialization of its technology.

—*S. Tillett*

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FIBER LASER SHEDS LIGHT ON MICROSURGERY

A new fiber laser technology will give surgeons the green light to perform microsurgery. Literally.

Go for the green. *An optically pumped fiber laser emits a 2712 nm beam of continuous wave output.*

Spire Corporation (Bedford, MA), with assistance from both MDA and NIH, has demonstrated a 1.2 watt continuous-wave-output fiber laser operating at the 2712-nanometer wavelength that can be run at room temperature without water cooling. As a fringe benefit, the fiber laser emits bright green light sufficient to locally illuminate a target. The laser might one day become part of a portable laser device that a doctor could transport for on-the-spot microsurgery.

MDA awarded Spire Corporation a Phase I contract in 2002 to investigate the potential for using a specialized erbium-doped fluoride glass fiber called ZBLAN to run a diode-pumped laser at high power levels in the mid-infrared frequency range. An output of 1.2 watts is not useful as a laser weapon but it might be scaled effectively to the point that it could help identify and track targets. MDA has an interest in finding low-cost approaches to improving laser output. While lasers can be expensive, the attractive aspect of using 970- to 980-nanometer laser pump diodes are that they are commercially available and relatively inexpensive.

"Our ultimate goal is to have a portable laser device that a doctor can put into a car or take into an office."

—Dr. Kurt J. Linden
Engineer
Spire Corporation

Spire engineers believe that as laser surgery becomes more generally available at a lower cost, professionals will find new uses for the higher power output. Generally speaking, 1.2 watts is considered "high" power in the microsurgery industry. However, the laser can be tuned down to 150 milliwatts to perform microsurgery. Tissue consists of mostly water which has a strong absorption peak close to the 2712-nanometer operating wavelength of the laser. In sum, a beam doesn't penetrate deeply and this minimizes peripheral damage.

Erbium-yttrium-aluminum-garnet (Er:YAG) lasers are most commonly used in medical applications today, but they have a drawback: they are pulse lasers, not continuous wave. Erbium-ZBLAN provides continuous wave output. The advantage of using continuous wave lasers in microsurgery is basically a smoother cut and faster incision and excisement. It is the difference between sawing a piece of wood with a hand saw versus a high powered buzz saw.

Another drawback in today's laser surgery is the need for illumination. Typically, for applications such as retinal surgery, surgeons need a second source of illumination. That introduces another level of complexity into the procedure. A laser that provides its own light would be a benefit and would simplify insertion and extraction. Additionally, the flouride fiber is flexible, permitting guided insertion into difficult spaces. This could be useful for shaping materials on the micro- or nano-scale as well.

"Our ultimate goal," said Spire engineer Dr. Kurt J. Linden, "is to have a portable laser device that a doctor can put into a car or take into an office." This would enable home or site visits to perform microsurgery or even use by field hospitals or emergency response personnel.

Finding a commercial partner may be the key to making the fiber laser technology a success. Spire Corporation has expertise in biomedical optoelectronics but will need to collaborate with a company that is in the business of manufacturing specialized medical laser equipment.

—A. Gruen

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"The competitor to be feared is one who never bothers about you at all, but goes on making his own business better all the time."

—Henry Ford

MIRROR TECHNOLOGY GETS THE HARD SHELL

Mirror manufacturers reduce the weight of bulky optics using a technique called lightweighting, or machining pockets of material out of the backs. But the optics' support structures—often called webs—become progressively weaker as more material is removed. This makes the lightweighted optics much more difficult and costly to manufacture, and optical qualities can be compromised.

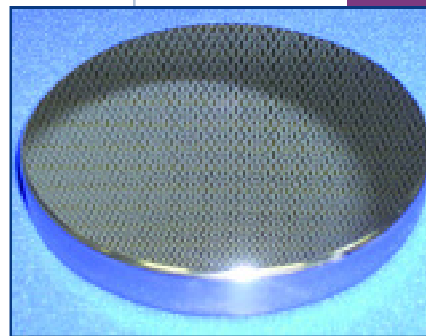
Schafer Corporation (Albuquerque, NM) has developed a new lightweighting technique that solves this problem. Rather than cutting out material from a solid, the company uses a proprietary chemical-vapor deposition process to grow a silicon mirror core from a foam substrate. The core is encapsulated with a continuous hardened shell, significantly improving the mirror's structurally efficiency and thermal performance while reducing its cost and weight. Schafer is using the technique to create low-cost Silicon Lightweight Mirrors (SLMS™) for aerospace and industrial applications.

The company is able to tune the foam's properties at a cellular level. For example, it can vary the foam's pore size, and ligament size and thickness. Tailoring these characteristics results in many structural efficiency benefits over machined webs, including increased stiffness, increased first-mode frequency, fully distributed load paths under the mirror surface, easier metrology mounting, and more graceful failures.

SLMS are far less costly than other mirror systems. While mirrors made of lightweighted glass, beryllium, and silicon carbide sell for $2.5 to $3 million per square meter, SLMS cost between $1.5 to $2 million per square meter—a cost reduction of up to 64 percent. Modified to weigh 5 to 10 kilograms per square meter (kg/m^2), SLMS are significantly lighter than silicon carbide, beryllium, and glass mirror systems at 10 kg/m^2, 10 kg/m^2, and 12 to 15 kg/m^2, respectively.

SLMS are polished at room temperature, but they can be used at cryogenic temperatures (down to 25 K) without cryo-nulling. Glass and beryllium technology requires expensive cryo-nulling where an optic is polished at room temperature and tested, put in a cryo-chamber and tested again, and then repolished at room temperature to correct distortions caused by cooling. Additionally, for most applications, SLMS are dimensionally stable and do not require active cooling. Active cooling for SLMS is required for submillimeter and far-infrared measurements, and Schafer is currently building an actively cooled SLMS for NASA.

With an interest in space imaging and surveillance, MDA funded Schafer through Phase I and II SBIR contracts to develop the SLMS lightweighting technique. In a 2002 Phase I SBIR project, the company demonstrated that it could produce identical spherical SLMS to be used as primary mirrors for the Air Force Research Laboratory's Deployable Optical Telescope System. In two 2003 Phase II SBIR projects, Schafer is using the SLMS technique to develop a lightweight telescope and a combined optical telescope and radio-frequency antenna. NASA also has contributed a significant amount of SBIR funding to develop low-temperature SLMS.



Light, yet strong. *A high structural-efficiency mirror is made of pure beta-silicon carbide foam and encapsulated by a polished pure silicon facesheet. It is suited for extreme ultraviolet to far-infrared applications.*

Schafer says SLMS can provide a lightweight, low-cost solution for optical instruments used in aerospace and space environments. Possible commercial and military applications include scientific instruments, high-energy lasers, imaging, laser scanning, fast beam steering, and laser communications. The company is currently manufacturing a 60-cm diameter SLMS for NASA. Since larger mirrors have a much broader range of applications, the company plans to scale up this technique to produce 1.5-meter diameter mirrors within the next year.

To win more business, the company has created an ISO9001/2000 Quality Assurance Plan and expects to be ISO9001 certified by 2005. It seeks contacts with large aerospace companies and Federally funded laboratories in particular, but also welcomes inquiries from others interested in potential SLMS applications.

—P. Hartary

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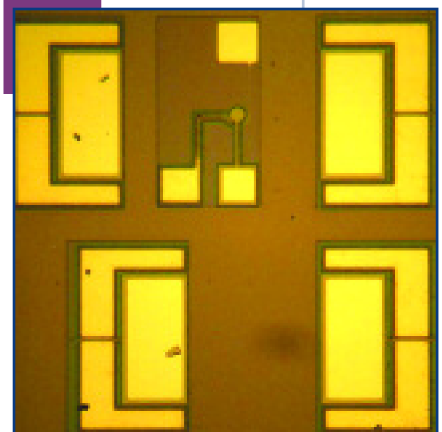
SIMPLE CHIP BRINGS COST ADVANTAGES FOR TELECOM, NETWORKING

The makers of chip-based devices such as telecommunications equipment or computer buses face a constant question: How can we inexpensively convert high-density signals from optical format to an electronic digital format?



Cheaper chip. *Produced in mass quantities, Opel's thyristor-based device will cost about the same as conventional silicon circuits. This should make the device attractive for use in communications and satellite equipment as well as in other hardware requiring optical-electronic interfaces.*

The answer might lie in an MDA-funded thyristor-based photoreceiver, which can act as an affordable bridge between optical and digital, ultimately helping drive down the cost of communications and networking equipment. The new photoreceiver, developed by Opel, Inc. (Mansfield, CT), addresses cost issues by requiring less human intervention and fewer components in the manufacturing process.

The photoreceiver, which also can operate as a transceiver to send as well as receive signals, is not yet available as a commercial product, but Opel is working to close a financing deal that would allow it to produce the device in high volume. The budding technology should draw interest from the communications, satellite, and optical data industries as well as from the computer networking market or any other business sector that requires optical-electronic interfaces.

With most optical-electronic interfaces today, digital components operate using silicon technology while optical components operate using indium-phosphide (InP) or gallium-arsenide (GaAs) technology. Opel is proposing its technology, based on GaAs, to serve as a monolithic optical-to-electronic bridge that could be produced in high volume, bringing down costs to the same level as conventional silicon circuits.

Since the company's approach combines optical and electronic components from the same epitaxial process, it provides components that are inherently compatible and that can be produced using the integrated circuit process but with fewer assembly steps needed. Geoff Taylor, one of the founders of Opel, said his company's photoreceiver, which includes a GaAs laser, requires only four components. Competing conventional devices might include as many as 50 components. The inclusion of a thyristor helps keep the device simple by serving as a switch and replacing the amplifier chain found in competing devices. The thyristor provides digital signal detection for the device by being switched on (by light) and off (through the restoring force of transistors).

As the thyristor switches on and off, it generates a voltage—performing not only the optical-to-electrical conversion but also producing gain. Conventional approaches that rely on diodes, which are passive, don't produce such gain and have to separate the sensing function from the gain function, which consumes more power. In a conventional receiver, the amplifier chain needed to produce gain requires more power than Opel's four-component combination, Taylor said.

He also said that the operating speed of Opel's product is limited only by the switching time of the thyristor, which could exceed 100 gigabits per second. The speed puts the device on par with competing technology. The monolithic device that Opel has created also has a smaller footprint than conventional competing devices, allowing manufacturers to add more components and, therefore, more functionality to their end products. The monolithic approach to producing the photoreceivers also eliminates steps in the production process that could drive up cost and increase the chance of human error.

MDA funded the technology for its potential in high-speed, high-bandwidth communications involving optical and electronic processing. The technology could wind up in applications ranging from computer buses to analog-to-digital converters to optical data links and optical memories.

The University of Connecticut holds patents on this technology and has granted Opel an exclusive license. The company continues to search for potential customers and new markets.

—S. Tillett

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POLYMER ULTRACAPACITORS TAKE CHARGE

It conducts like copper but can be grown like plastic. It's called nanoporous ordered conducting polymer, and it can be useful either for energy storage or as a battery.

With MDA SBIR funding, Fractal Systems, Inc. (Safety Harbor, FL), developed a unique method for producing and ordering the internal morphology of conductive polymers as well as the composition of the matter itself. Eager to use this polymer as an electrode, Fractal is working in partnership with Evans Capacitor Company to create a prototype ultracapacitor. It will have an order of magnitude more energy density than conventional carbon-based capacitors, and perform two to three times better at less cost than a ruthenium-dioxide capacitor. The relative ease of manufacture of polymer ultracapacitors spells good news for any industry interested in electrical power storage and discharge including automotive and consumer electronics applications.

High power density and high energy density are always important requirements for military systems sensitive to weight limitations. MDA awarded SBIR contracts to Fractal in 2001 and 2002 to assess the characteristics of, and develop techniques for growing, the nanoporous conducting polymer for use in capacitors.

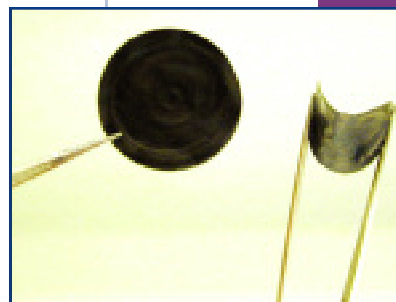
Chemists grow thin films of specialized polymers using electrochemical synthesis of commercially available monomers and reagents. Fractal chemists experimented with various configurations of polythiophenes, polyanilines, polypyrroles, and other copolymers and settled on those with the best combination of voltage and energy density. They use a proprietary preparation technique to settle thin coatings throughout a carbon paper to achieve desired nanoporosity.

There are advantages to using conducting polymers for capacitance and not all of these are related to price and performance. First of all, polymers are simple to manufacture and can be produced in sheets and films. Since a polymer can be coated on a substrate, the mix can be used as an electrode. This is simpler than the process used to make a batch of carbon paste to manufacture one carbon pellet at a time. In theory, a sheet of polymer/substrate one-foot square could supply 144 one-inch-diameter electrodes simultaneously.

Secondly, an inexpensive carbon-based capacitor uses sulfuric acid in its electrolyte and outgasses carbon monoxide as it breaks down. For some applications that is not a significant problem, but it is an environmental effect that does not scale well. In contrast, a conducting-polymer-based capacitor uses an organic electrolyte such as lithium tetrafluoroborate and can operate in water with no acids involved.

Price and performance ultimately will determine when and where conducting polymer is used, however. A conducting-polymer-based capacitor has more than 10 times the energy density and approximately 500 times the power density of a carbon-based capacitor, but it cannot compete on price alone. Polymer compares favorably to existing ruthenium-dioxide-based capacitors on both price and power/energy density.

Since a high power, high energy density capacitor can be used in tandem with a battery (or in some cases act as a battery), one possible commercial market is the automotive and transportation industry. Typical applications would include cold-start support, use with regenerative braking, and preheating catalytic converters. Locomotives and industrial equipment demanding short bursts of peak electrical load would also benefit. Almost any equipment needing an uninterruptible power supply would be able to take advantage of powerful capacitors.



Battery of the future. *Flexible polymer ultracapacitors will provide higher power and energy density at less cost than ruthenium-dioxide.*

At the conclusion of its Phase II SBIR funding in 2004, Fractal Systems and Evans Capacitor intend to make the polymer ultracapacitor commercially available either by licensing it or by direct manufacture and sales. The market for ultracapacitors is in its infancy—currently, limited to weapon fuzing and medical implantable devices—but promises to expand in direct proportion to the demand for more power, and less waste and weight in batteries. Interested parties should contact Fractal Systems directly.

—A. Gruen

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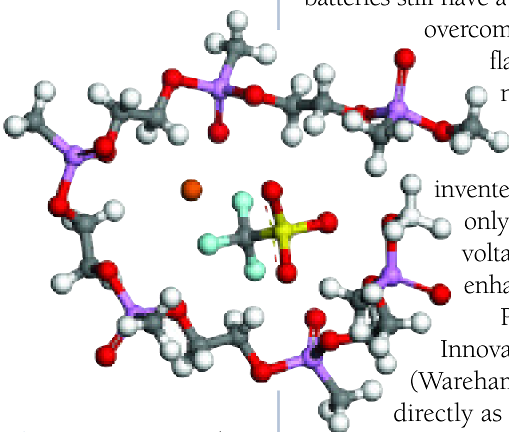
SAFETY FIRST: IMPROVED POLYMER ELECTROLYTE RETARDS FLAME



Polymer magic. *A polymer chain containing phosphorus makes a highly conductive, flame retarding electrolyte for use in batteries.*

Powerful and lightweight, rechargeable lithium-polymer batteries still have a problem to overcome: they are flammable. A new class of polymer recently invented may not only improve voltage but also enhance safety. Phoenix Innovation, Inc. (Wareham, MA), directly as a result of work performed under MDA SBIR contracts, has patented a polyphosphonate electrolyte that offers higher conductivity than traditional polyethylene oxide electrolyte used in lithium-polymer batteries. As an important bonus, company chemists discovered that the same element that improved conductivity also retarded flammability. The combination of higher power density and lower risk is of huge interest to the mobile power and electric vehicle industry.

"This would not have happened had it not been for MDA funding," said Dr. Brian G. Dixon, Phoenix president and co-founder. "We wouldn't have anything to talk about." In 2001, MDA awarded a Phase I SBIR contract to the company to investigate methods for producing highly conductive polymer electrolyte and immediately followed up with a Phase II SBIR contract to focus more on actual production techniques of liquid polymer electrolyte in a pouch battery. Phoenix is working closely with several other corporations on development and commercialization of the technology.

"This would not have happened had it not been for MDA funding."

—Dr. Brian G. Dixon
President
Phoenix Innovation

Originally, Phoenix wanted to focus on making a solid high-voltage polymer electrolyte. Solid electrolyte offers the prospect of a lighter weight battery because in principle it would not need a containment vessel. However, liquid has an order of magnitude higher ionic conductivity than solid. In other words, it is much easier and more effective to charge and recharge through a liquid electrolyte than a solid when dealing with lithium-polymer batteries. So in pursuing their discovery, company chemists decided to focus in on the safety and power density aspects and were less concerned about the liquid versus solid issue. The technology does have potential to transition to solid and Phoenix intends to work towards that objective.

Phosphorus is the key to the equation. Phoenix chemists found that if the "backbone" of a polymer chain contained phosphorus moieties, the electrolyte retained excellent properties of high voltage stability and flame retardance. Traditional polymer electrolytes can be made more stable and flame retardant, but only by including additives that compromise performance and add weight.

The result is higher power density with low risk. Phoenix chemists estimate that in the same volume as a traditional 3-volt cell, the improved polymer electrolyte could push a battery voltage up to somewhere between 4.5 and 4.8 volts. According to Dixon, the limiting factor is not the electrolyte but rather the cathode. Phoenix has developed what it feels is a superior anode technology, and is currently working with a company with compatible cathode technology.

Making lithium-polymer batteries is not an easy task. There is a transition process in which the lessons learned in the laboratory, where batteries are carefully handcrafted one at a time, have to be translated into high-volume mass production. Because Phoenix is a small company, it is most actively exploring the possibility of either licensing its patents or partnering on a formal basis with a larger firm. However, it is also open to the possibility of growing into a larger company as the lithium battery market evolves, and towards that end recently advertised for experienced managers and engineers with production expertise.

—A. Gruen

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MATERIAL ACTS LIKE BUILT-IN INSPECTION SYSTEM

Our skin is embedded with sensors—nerves—to help us figure out when we're being touched or damaged. Soon, structures such as car chassis and airplane wings might also include a skinlike network of sensors to help owners and operators monitor structural wear and tear.

The sensor technology, called "SMART Layer®," is being developed by Acellent Technologies, Inc. (Sunnyvale, CA). MDA funded Acellent to marry the company's SMART Layer technology with composites to create "intelligent composites," which could help monitor structural health of missiles and space assets.

Acellent's technology, which consists of a thin dielectric film embedded with a network of sensors, monitors structures for misuse, damage, impact, or fatigue. "What we have developed is a built-in inspection system that uses an array of sensors," said Amrita Kumar, Acellent's director of technology and projects. SMART Layer could be used in the testing process, to determine faults of a planned structure before final production, or it could be used to monitor the ongoing health of an existing structure, according to Kumar.

The SMART Layer technology should give users the advantage of more precise location monitoring of structural health. The SMART Layer, which works in conjunction with the company's SMART Suitcase™ diagnostics hardware and a software application for analyzing structural health, actually can detect and measure damage in the area covered by the sensors. Competing technologies that use strain gauges or fiber optics can provide only point measurements. Moreover, systems using strain gauges and fiber optics monitor passively, generating output only when changes occur within the structure. Acellent's Smart Layer works passively, too, but it also can actively excite a structure upon command to assess structural health. Since SMART Layer can be embedded within a structure, it also monitors internal changes that competing surface-mounted sensors have difficulty detecting.

Applied as a single sheet or layer to a piece of structure during assembly, the sensor network can be installed in less time than it would take to surface-mount sensors. Acellent envisions that the SMART Layer system can be used in a wide range of applications, from the monitoring of small hot spots or critical areas on aircraft structures to the monitoring of entire motorcase structures used in missiles and rockets.

The technology should appeal to makers of aircraft, spacecraft, automobiles, and industrial equipment. Acellent already is working on pilot projects with the Boeing Company, NASA, BMW, ATK-Thiokol, and an offshore petroleum concern.

Despite its high aspirations, the company is only beginning its commercialization phase for the technology, and most projects with SMART Layer so far are pilot projects. Kumar said she hopes SMART Layer will be available as part of a real commercial product within the next year or two. Acellent continues to work on miniaturizing its technology and adding wireless capability. The company, which intends to license SMART Layer as well as manufacture it, also continues to look for potential customers and partners for other pilot projects.

—S. Tillett

Health monitoring. *SMART layer strips are embedded into a rocket motor to monitor its structural health. The technology also can be applied to aircraft, automobiles, and industrial equipment.*

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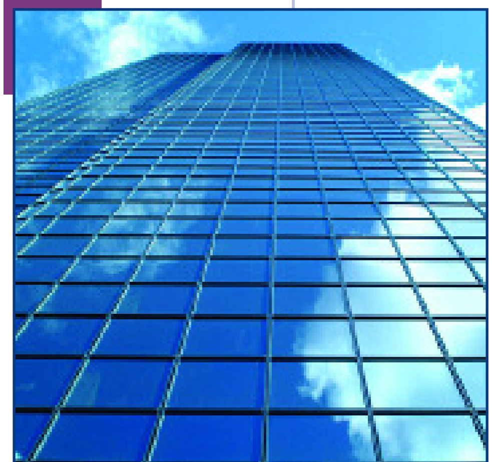
> *"Somewhere, something incredible is waiting to be known."*
>
> —Carl Sagan

A SMART APPROACH TO CONTROLLING NOISE AND VIBRATION

Glass for buildings, cars, and eyeglasses already can react to light to become darker as needed. Soon, glass and other structures will be able to react to sound and vibration, too, allowing buildings to better withstand tremors and creating quieter environments for working and living.



Courtesy of FreeFoto.com

Sound solution. *QRDC's SmartSkin technology should lead to windows that do a better job of dissipating noise and vibration, creating quieter work environments.*

MDA-funded QRDC, Inc. (Minneapolis, MN), is developing a technology that creates a "smart" design for windows and other materials, allowing noise and vibration to be dissipated easily. The technology also promises reduced weight as well as lower cost and should find application in everyday products such as automobile windshields, residential windows, and even furniture and walls.

QRDC was funded by MDA predecessor BMDO to develop an energy-based vibration-control system for load-bearing skin surfaces. The company calls the technology "SmartSkin." BMDO funding came through Phase I and II SBIR awards.

QRDC's sister company, SmartSkin, Inc., will concentrate on commercializing the technology while QRDC remains focused on research and development. Already the two companies have been working with a manufacturer of office and residential windows to apply the technology in a real-world test, and QRDC officials hope the manufacturer will offer SmartSkin technology as part of a commercial product in 2004.

QRDC's technology comes in two forms: passive and active. The passive form of the technology is actually a design process that involves laboratory modeling and analysis of structures such as windows and frames. The passive process focuses on building new structures whose inherent design helps dissipate noise and vibration without the need for actuators or other moving parts. The active version of the technology focuses on embedding moving components such as piezoelectric actuators or shape-memory alloys into structures such as walls to change stiffness or contours, which will reduce noise and vibration. The company initially is pursuing its passive technology because no power source is needed, making it appropriate for use in unwired structures such as windows.

Addressing the problem of vibration and noise—whether it's the sound of a barking dog, a skyscraper's movement from the wind, or an explosion—means treating such disturbances almost as if they were electrical energy. "Once you inject energy in a structure, in this case a surface, its propagation has to do with the stiffness discontinuity, very much like current in electrical systems. The current finds its way to the least resistance," said Dr. Daryoush Allaei, chief executive officer of QRDC. "So if you create a stiffness discontinuity, you can control that propagation throughout the surface and, therefore, its effective noise radiation. So that's how we do it passively—by simply changing a few design criteria and having a few attachments that create what I call a 'vibration valve'—valves in a sense that they change the control or flow of vibration energy."

QRDC's approach competes with the conventional approach of adding layers of material to a window or a structure to soundproof it. But QRDC's passive approach, since it addresses design elements rather than adding material, does not add weight. Moreover, the technology can improve upon the typical window's sound transmission class (STC) rating of 28, raising the rating to as high as 38. And while raising that STC, the technology brings practically no added cost—other than initial design costs—to the product being made. By comparison, conventional methods of boosting the STC would increase the retail price of the window by 30 percent to 60 percent.

QRDC expects that its window partner will offer a commercial product using SmartSkin technology in 2004. QRDC continues work on an Army project to develop acoustically intelligent surfaces for shelters. The company also plans to develop acoustically intelligent furniture, such as chairs and equipment racks, that could reduce the noise in a working environment by as much as 15 decibels.

Continued on page 16

What's New About . . . from page 1

was going to be a manufacturing reality. Products sold today have Genus ALD films—for example, sensor devices known as thin-film reader heads for 80 megabit-per-square-inch compact discs. Using state-of-the-art precision pneumatic valves and a unique design for transporting chemical precursors from tank to substrate, Genus had invented a film process module that could layer metal oxides and nitrides on targets with high aspect ratios.

What's a high aspect ratio and why is it important? Simply put, the topologies of semiconductors and thin-film reader head devices are getting denser as their feature size gets smaller and smaller. It's as if skyscrapers are being developed on what is recognized to be valuable and limited real estate. No alternative exists to uniformly coat these devices—to buffer the outside of the skyscrapers—to insure that they function efficiently.

Genus' ALD equipment differs from the traditional CVD process by bringing chemical precursors to a surface one at a time instead of running a deposition process continuously. Genus researchers use a unique chemistry of precursors that create a self-limiting, saturating surface layer. This is the microscopic equivalent of firing a volley of specialized paintballs at a wall and watching the paint rapidly spread out to provide a coat by itself. By quickly changing the precursor (firing a different "color" of paintball, so to speak, in a process called cycling), Genus technicians can place a second layer or coat upon the first with exactly the same kind of self-limiting, saturating results. This enables growth of the film. The cycle time was about three seconds, requiring a purge between reactions to flush out the leftover portion of the first precursor before introducing the second.

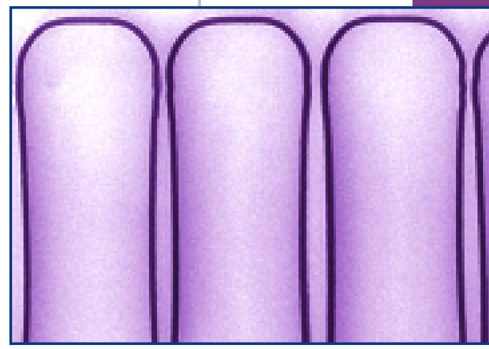
Now It's Rapid ALD, or "RAD"

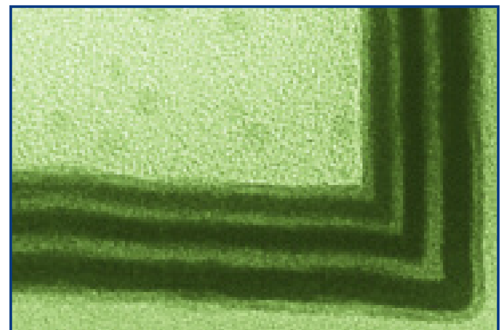
Sometime in 2003, a Genus engineer wondered: What if we speed up the ALD rate at which we cycle the precursors and decrease the exposure time and purge periods? How fast can the machines run and still get good results?

The resulting experiments showed that improved StrataGem equipment could deposit films ten times faster without sacrificing significant film performance. With less exposure time, the thickness of the film deposited per cycle was less than the maximum possible. However, the lower cycle time produced a higher rate of film deposition, up to 100 angstroms per minute. In short, by working with less precursor in each pulse, but a much higher pulse rate, Genus ends up depositing more film per unit of time—with no sacrifice of film uniformity, conformality, or stoichiometry. Manufacturing output can be improved at no additional cost.

Genus labels this latest improvement as Rapid Atomic Deposition (RAD). It promises to be an important enabling tool for the production of an expanding set of applications and devices needing high quality, thicker conformal coatings on high aspect ratio structures. The company has already filed patents on its RAD technology and hopes to introduce a new generation of StrataGem products and services starting in late 2004.

Until recently, the main anticipated applications for ALD were semiconductors with capacitors and gate stacks, and data storage with thin-film reader heads. RAD technology may become a critical enabling factor in the future development of nanoscale machines as well. Genus supplies flexible process modules that can be used both for research as well as manufacturing, and is interested in finding new applications for practically coating with metallic oxides and metal nitrides over the broadened range of thickness of 20 to 1,000 angstroms.





Tight fit. *A conformal nanolaminate film coating on 100-nm features (top) means superior performance. A close-up view of the nanolaminate film (bottom) shows metallic oxides layered in thicknesses ranging from 20 to 50 angstroms.*

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From the Editor . . . from page 2

engineers cannot live without salesmen."

The MDA Technology Applications program continues its discussion of common misconceptions facing high-tech researchers with its second article, which can be found on page 3 of this newsletter. As before, we hope the material in this article also resonates with our readers.

—Patrick Hartary
pat@nttc.edu

A Smart Approach . . . from page 14

The Defense Advanced Research Projects Agency funded QRDC's underlying technology, which is being applied in the mining industry to magnify vibrations instead of reduce them. BMDO funded application of the technology specifically for reduction of vibration and noise in skin-type materials.

QRDC continues to look for investors as well as partners that can help accelerate commercialization efforts.

—S. Tillett

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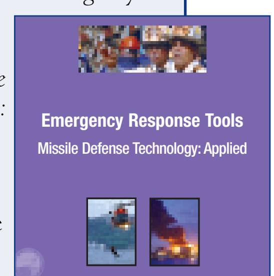

The MDA TA program has produced a special report that highlights MDA-funded technologies that hold potential for emergency response applications. The report, titled *Tools—Missile Defense Technology: Applied*, focuses on tools such as a water-purification product, protective materials, and technologies that can help detect hazardous substances. To receive a free copy of the report, call (703) 518-8800, ext. 239, or send e-mail to pgroves@nttc.edu. Please provide your name, company name, and telephone number, as well as your mail and e-mail addresses.