

Advancing Battery Technology

A multibillion dollar market awaits long-lived rechargeable batteries, but none of the half-dozen or so new battery technologies under development has yet achieved commercial success, even those that have reached their technical goals. This may soon change, however, as several companies begin mass marketing their newest products.

For the most part, conventional lead-acid batteries still power today's electric automobiles, and consumer products still operate on conventional alkaline batteries.

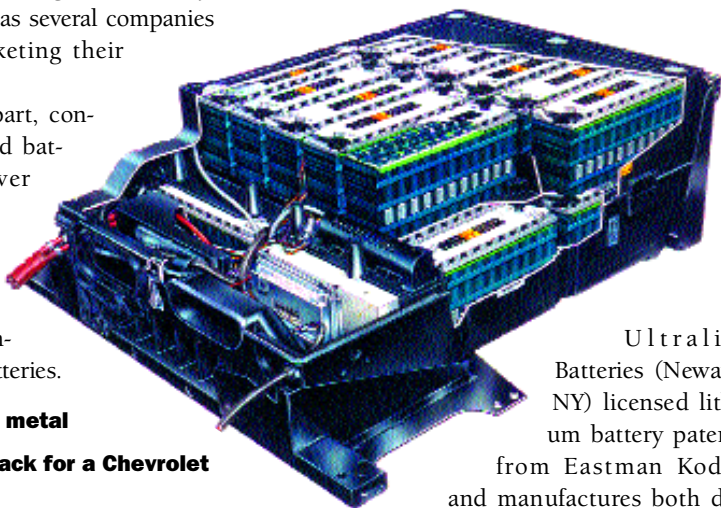
GM Ovonic nickel metal hydride battery pack for a Chevrolet S-10 pickup.

Duracell and EverReady recently introduced new and improved AA and AAA alkaline batteries for high-tech products such as cell phones, but the improvements are technically insignificant.

The U.S. Advanced Battery Consortium (USABC), created by General Motors, Ford, and Chrysler, has received the lion's share of the Department of Energy's funding for lithium-polymer battery research. Since 1993 USABC has awarded about \$60 million (half coming from the Department of Energy) to 3M and its partners to develop a lithium-polymer battery capable of powering a car for at least 300 miles. General Motors also has backed lithium battery R&D by Valence Technology (Henderson, NV), a start-up company that licensed basic patents for lithium-polymer batteries from Bellcore (which developed the first workable lithium-polymer batteries). With both 3M and Valence, the auto companies retained the market rights for using the technology they developed.

Valence is targeting the booming demand for rechargeable batteries in portable computers. The company, however, suffered a major setback when its first attempt at mass production of lithium-polymer batteries

failed and it had to rebuild the automated production line. Valence has spent more than \$150 million in battery R&D, and it has accumulated a portfolio of more than 170 battery-related patents.



Ultralife Batteries (Newark, NY) licensed lithium battery patents from Eastman Kodak and manufactures both disposable and rechargeable lithium batteries. Volume manufacturing of a 9-V lithium battery has stalled because of production-line problems. The company also is starting to make an advanced, solid-state, lithium-ion rechargeable battery; and it manufactures magnesium-silver chloride batteries that are activated by seawater and operate at any depth and water temperature, according to Ultralife.

Commercial production of lithium-polymer batteries for portable computers is planned for later this year by Lithium Technology at its plant in Plymouth Meeting, Pennsylvania. The company has a NASA research grant to develop a battery using its fiber-web composite technology to power an astronaut's space suit. Another start-up, Redox Technology (Houston, TX), is developing lithium-polymer batteries for both the consumer and automobile markets. Its first product is a lightweight back-up battery for cars and portable equipment. Nissan has introduced an electric car, the Altra EV, to the U.S. market that will become available in two years. The Altra is powered by a lithium battery developed jointly with Sony.

Nickel metal hydride (NiMH) batteries have reached the acceptance stage by auto-

motive manufacturers. Ovonic Battery Co., a subsidiary of Energy Conversion Devices (Troy, MI), is supplying NiMH batteries manufactured by GM Ovonic, a joint venture, for GM's electric cars and trucks.


A Solectria Corp. Force electric sedan powered by Ovonic NiMH batteries recently won the American Tour de Sol race. It ran 225 miles on a single charge. Last year, a Solectria Sunrise EV traveled nonstop from Boston to New York City at normal highway speeds. EV Global Motors, headed by Lee Iacocca, the former Chrysler CEO, has signed an agreement with Ovonic. Sanoh Industrial Co. (Koga, Japan) has set up a joint venture with Ovonic to manufacture NiMH batteries for use in two- and three-wheel vehicles. Ovonic also has a joint venture in Russia to manufacture NiMH batteries and battery materials for electric vehicles.

NiMH batteries also have found acceptance in the consumer market. According to Ovonic, NiMH batteries have captured about 30 percent of the market for rechargeable batteries for electric and electronic devices. The NiMH batteries store twice as much energy as nickel-cadmium-alkaline or lead-acid batteries.

Ovonic, the originator of NiMH technology, continues to improve NiMH batteries. The company has received an \$8.2 million research grant under the Advanced Technology Program (ATP) of the National Institute of Standards and Technology to replace expensive titanium-zirconium alloys currently used in NiMH batteries with thin-film magnesium alloys.

Zinc-air batteries are finding their way into the automotive market as well. Electric Fuel Corp. (New York, NY) successfully field-tested its zinc-air batteries in delivery vans operated by the German postal service; and a car with a 150-kW.h zinc-air battery traveled 272 miles from London to Paris on a single charge. The zinc-air battery was conceived at the Lawrence Livermore National Laboratory by John F. Cooper. Electric Fuel plans to market disposable zinc-air batteries for cell phones that have triple the talking time of those powered by rechargeable batteries, according to the company.

Energy Research Corp. (Danbury, CT) has licensed its nickel-zinc battery technology to a Chinese group that plans to use the batteries in electric cars, bicycles, scooters, and recreational vehicles. Some research work continues on sodium-sulfur batteries, but the need to maintain a high operating temperature has blocked their acceptance.

The rechargeable battery market is still in flux, and it is not clear which technologies will win out. NiMH and lithium-polymer batteries are poised to begin volume sales, which will substantially bring down their cost. Making refinements in battery technology, however, will undoubtedly keep researchers busy for many years. 

Microvalves on the Move

Microvalves etched in silicon appear ready to replace the bulky electro-mechanical valves now used to control the flow of gases or liquids. Microvalves, one of the first practical applications of MEMS (microelectromechanical systems) technology to reach the marketplace, are fabricated with the same silicon-etching equipment used to make integrated circuits. As a result, the controlling electronics can be integrated with the valve on a single silicon chip in a single manufacturing operation.

Redwood Microsystems (Menlo Park, CA), which pioneered the application of MEMS

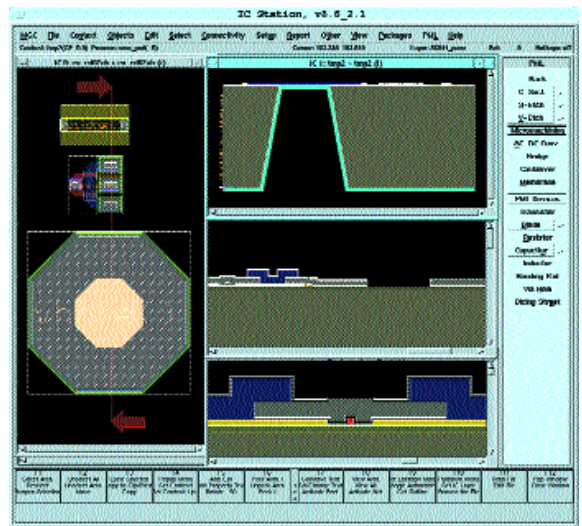
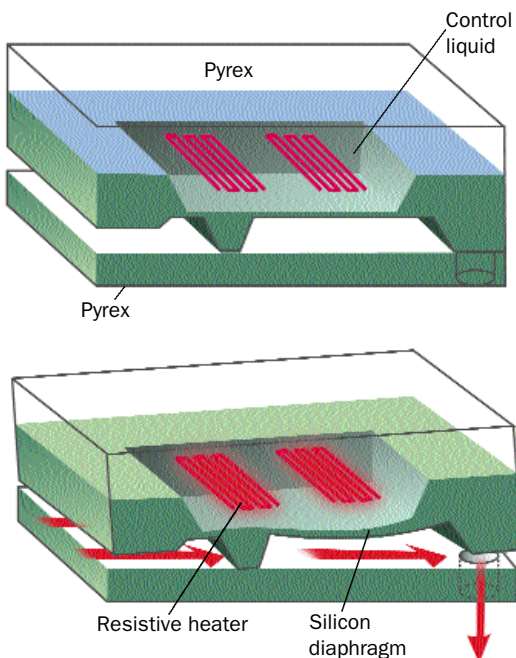
technology to valves, has developed a 6 mm × 6 mm × 2 mm silicon microvalve, called the Fluistor, that can control gas flow rates from microliters per minute to liters per minute. The operating principle of the microvalve is simple: a silicon membrane flexes in and out as inert fluid in a sealed cavity is heated by an electric current.

A line of silicon-based gas-pressure regulators that operate at a variety of ranges from 0 to 5 psi up to 0 to 100 psi is marketed by Redwood. These regulators and Redwood's flow controllers are well suited for low-flow applications in which high precision is vital, such as analytical instrumentation, environmental monitoring devices, and process control. Micromachined sensors are integrated with the valve to continuously monitor gas temperature and pressure.


Redwood has redesigned its patented microvalve to make it compatible with most process gases and liquids; and its new MEMS-Flow product line of pressure regulators, mass-flow controllers, and gas panels is designed for high-purity semiconductor fabrication. MEMS-Flow components have no moving mechanical parts, eliminating a troublesome source of contamination in silicon chip manufacturing. Off-the-shelf microvalve products are also finding a growing market in laboratories and pilot plants.

Some unexpected consumer products also are being outfitted with microvalves. BCAM International (Melville, NY) has developed a silicon microvalve for use in self-adjusting shoes, seats, and mattresses. The microvalve, about 1 cm in size, has a flexible silicon flap 100 μm long that bends to open and close air flow. Control and sensing components are etched on the silicon chip. Reebok has

When power is applied, the control liquid expands, forcing the stiff silicon diaphragm down, and supplying a counter-clockwise moment around the off-center fulcrum, raising the right-hand end.



This Mentor Graphics kit can provide fabrication-ready MEMS designs for nonspecialists.


licensed BCAM's microvalves for use in shoes; Textron has the license for seating; and Sealy has an option for adjustable beds. BCAM says the microvalve can also be used in medical inhalation devices to deliver precise doses. 

Kit for MEMS

Interested in designing your own MEMS products? Or making micromachined devices? You can get started with the \$50,000 MEMS engineering kits put together for designers "who don't push polygons" by Mentor Graphics (Wilsonville, OR), a major developer of electronic design-automation systems, and Memscap (Grenoble, France), a developer of MEMS technology with close ties to silicon foundries, which fabricate silicon devices.

The kits provide users with libraries of proven MEMS components from silicon foundries along with all the necessary tools to create fabrication-ready designs. The entire design process is automated so that designers who are not MEMS specialists can combine sensors and mechanical or optical actuators with integrated circuits in a single silicon chip.

MEMS technology is seen as potentially having as profound an effect on manufactured products as the microchip. Industry experts predict that MEMS will be the next major growth technology. MEMS devices are already used as microaccelerometers (see p. 46), and in fluid-flow controllers, cam-

orders, and display systems. Applications under development include motion detectors in virtual-reality headsets, optical-data storage, avionics, optoelectronic communication systems, and near-field optical-probe microscopy. 


Bow-Tie Resonance

Deliberately making a laser resonant cavity asymmetric can produce highly directional beams 1,000 times more powerful than those emitted from symmetric lasing cavities. Lucent Technologies' Bell Labs, working with researchers at Yale University and the Max Planck Institute of Physics in Stuttgart, Germany, recently demonstrated that light pulses inside an egg-shaped microlaser cavity travel in a bow-tie pattern until they are emitted primarily in four narrow directions. Each primary beam delivered 10 mW.

The advance was made with a modified quantum-cascade (QC), infrared microdisk laser that had been invented by Bell Labs in 1991. Scientists there believe that the technique can also be applied to conventional laser diodes. If that proves true, the use of certain types of asymmetric resonant cavities may hasten the development of highly efficient, low-cost blue laser diodes (see *The Industrial Physicist*, 9/97, p. 16, and 3/98, p. 19).

The concept of asymmetric resonant cavities was initially proposed in 1991 by Jens Nockel of the Max Planck Institute and A. Douglas Stone, professor of applied physics at Yale. Both collaborated, along with Evgenii Narimanov of Yale, with the Bell Labs team, which included Federico Capasso, Claire Gmachl, Deborah Sivco, Alfred Cho, and Jerome Faist (now at the Université de Neuchâtel, Switzerland).

The experimental lasers were fabricated by distorting a disk from circular symmetry to a shape with a cross section that is elongated in one direction and squeezed in the perpendicular direction (in effect, an egg shape). When the amount of deformation is small, the resulting cavity produces chaotic resonances. At higher specific deformations, the cavity generates a bow-tie mode of lasing and emits beams in specific directions. The bow-tie resonance results in lower thresholds for

lasing and substantially reduces the amount of input current required for high output. 

Shallow Wafer Defects

Semiconductor fabricators focus great effort on detecting flaws in large-scale integrated circuits after the devices have been produced (see *The Industrial Physicist*, 6/98, pp. 11-14). Some flaws, however, are not the result of circuit fabrication; they are caused by defects in the silicon wafer itself.

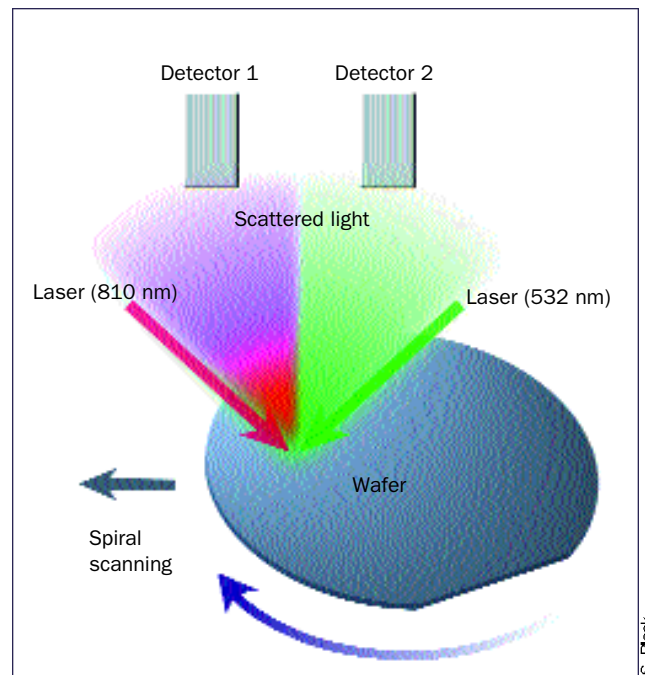
Several techniques are used in the industry to monitor wafer defects (see *The Industrial Physicist*, 6/97, pp. 28-30). Some methods destroy the wafer. Others, such as scanning infrared microscopy (SIRM), take advantage of silicon's transparency to near-infrared radiation to detect flaws inside a wafer without damaging it. Although the confocal version of SIRM can obtain good depth resolution from light backscattered by defects, it cannot be used to image the area immediately below the surface of a wafer, because reflection from the surface wipes out the backscattered light from just below the surface.

Flaws on or just below the surface of the wafer are of particular concern because that is the area used for making integrated circuits. A new technique developed by Hitachi, Ltd., in Japan may open a faster, nondestructive way to measure a wide variety of near-surface wafer defects. Called the optical shallow-defect analyzer (OSDA), the system measures the backscatter from two laser beams of different wavelengths to determine the size and depth of defects in a silicon wafer, as well as surface particles and flaws.

Both of the wavelengths used in the OSDA are absorbed by silicon, but their absorption coefficients differ. The travel distance is about 1 μm for the 532-nm radiation and about 10 μm for the 810-nm radiation. The OSDA uses two different wavelengths because a single scan with one wavelength

cannot distinguish between a large, deep defect and a small defect much closer to the surface. The intensity of the backscattered light depends on both the size and the depth of a defect.

Defects in the top 0- to 0.5- μm layer backscatter light from both the 532-nm and 810-nm beams, which provides information for calculating the depth and size of these defects. Depth resolution is $\pm 0.1 \mu\text{m}$, and defects as small as 0.02 μm can be measured. Defects from 0.5 to 5 μm below the surface backscatter light only from the 810-nm beam. These deeper defects can be counted and their horizontal positions can be plotted, but their size and precise depths cannot be deter-



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mined. In addition, the OSDA can detect surface particles as small as 0.05 μm and polishing damage.

Kazuo Takeda and Hidetsugu Ishida at Hitachi's Central Research Laboratory (Tokyo, Japan), and Atsushi Hiraiwa at the company's Semiconductor and Integrated

Circuit Division, recently reported using the OSDA to measure grown-in defects in wafers made by the Czochralski (CZ) process. Their data support previous findings that the size and density of defects in CZ wafers depend on the initial concentrations of oxygen in the growing process, which involves pulling a small seed crystal through molten material.

The researchers also found that a slow pulling rate greatly decreases defect density.

Applications of the OSDA, according to Hitachi, include monitoring wafer production, evaluating shipped wafers, and determining the effects of various processes such as polishing, cleaning, oxidation, dry etching, and ion implantation on wafer surfaces.

The OSDA system can measure defects in epitaxial and silicon-on-insulator wafers as well as in CZ wafers.

An automated, clean-room OSDA system for determining the depth and relative size of defects on and in the surface layer of a silicon wafer is marketed by Hitachi Scientific Instruments, Nissei Sangyo America Ltd. (Mountain View, CA). The system can handle wafers ranging in size from 4 to 8 in. According to Hitachi, the measurement time for an 8-in. wafer is 80 min with 100% sampling and 30 min with 25% sampling.

— Update —

Several schools in addition to the University of Southern California offer programs to physics graduates who want to combine business courses with science in their master's degree studies (see *The Industrial Physicist*, 6/98, p. 17).

The University of Texas at Austin offers a master's of science degree in science and technology commercialization (MSSTC) through its IC2 Institute, a nontraditional center for research on the enterprise system. The course is designed for working professionals and is available in Washington, D.C., and other locations, including overseas. IC2 claims that MSSTC was the first professional master's degree program to combine science, technology, and business. It also operates the Austin Technology Incubator, which has graduated 42 companies.

Georgia Institute of Technology's DuPree School of Management offers an executive master's program in the management of technology for technical professionals pursuing careers in high-tech companies. The course is given in seven two-week resident sessions over 20 months. DuPree also offers a course in entrepreneurship for engineers and science graduates with at least five years of work experience. This is more focused on technology than traditional MBA programs.

Other universities also offer business-oriented master's degree programs for physics graduates, and future Updates will report on them. Readers are invited to send information and comments about physics-business master's degrees to tip@aip.org. 