

Science & Technology

REVIEW

October 2006

National Nuclear
Security Administration's
Lawrence Livermore
National Laboratory

Livermore Wins 7 R&D 100 *Awards*

Also in this issue:

- **Tiny Technologies for National Security**

About the Cover

Laboratory researchers captured seven R&D 100 awards in *R&D Magazine*'s annual competition for the top 100 industrial innovations worldwide. Highlights beginning on p. 4 describe the award-winning technologies: a pocket-sized explosives detector, a highly precise radiation detector, an airborne wide-area surveillance system, an improved wavelength converter for high-average-power lasers, data-mining software, an application to provide programming language interoperability, and an interferometer that improves the search for distant planets. Since 1978, Livermore researchers have received 113 R&D 100 awards. The R&D 100 logo on p. 1 is reprinted courtesy of *R&D Magazine*.



Cover design: Amy Henke

About the Review

Lawrence Livermore National Laboratory is operated by the University of California for the Department of Energy's National Nuclear Security Administration. At Livermore, we focus science and technology on ensuring our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published 10 times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

Please address any correspondence (including name and address changes) to *S&TR*, Mail Stop L-664, Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California 94551, or telephone (925) 423-3432. Our e-mail address is str-mail@llnl.gov. *S&TR* is available on the World Wide Web at www.llnl.gov/str.



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Contents

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2006 R&D 100 Award Highlights

- 3 Innovative Solutions Reap Rewards**
Commentary by George H. Miller
- 4 Surveillance on the Fly**
An airborne surveillance system can track up to 8,000 moving objects in an area the size of a small city.
- 6 A Detector Radioactive Particles Can't Evade**
An ultrahigh-resolution spectrometer can detect the minute thermal energy deposited by a single gamma ray or neutron.
- 8 Babel Speeds Communication among Programming Languages**
The Babel program allows software applications in different programming languages to communicate quickly.
- 10 A Gem of a Software Tool**
The data-mining software Sapphire allows scientists to analyze enormous data sets generated by diverse applications.
- 12 Interferometer Improves the Search for Planets**
With externally dispersed interferometry, astronomers can use an inexpensive, compact instrument to search for distant planets.
- 14 Efficiently Changing the Color of Laser Light**
Yttrium-calcium-oxyborate crystals provide an efficient, compact approach to wavelength conversion for high-average-power lasers.
- 16 Pocket-Sized Test Detects Trace Explosives**
A detection kit sensitive to more than 30 explosives provides an inexpensive, easy-to-use tool for security forces everywhere.

Features

- 18 Tailor-Made Microdevices Serve Big Needs**
The Center for Micro- and Nanotechnology develops tiny devices for national security.

Departments

- 2 The Laboratory in the News**
- 27 Patents and Awards**
- 29 Abstracts**

Spice's pigment may prevent Alzheimer's disease

Research conducted by Livermore chemist Krishnan Balasubramanian has revealed the characteristics of the spice pigment curcumin that give it the ability to prevent and even treat Alzheimer's disease. Curcumin, the yellow pigment in the east Indian root plant turmeric (*Curcuma longa*), can penetrate the blood-brain barrier, the natural mechanism that protects the brain from harmful substances. Plus curcumin can bind to and reduce amyloid plaque in brain cells, which in combination with oxidative stress and inflammation, causes Alzheimer's disease.

Brain chemistry is difficult to understand. Few agents can penetrate the blood-brain barrier and also act to prevent or cure diseases such as Alzheimer's. In addition, some of these preventive or curative agents are toxic. "The greatest challenge for medical researchers has been to find a treatment that can penetrate this protective barrier without doing more harm than good," says Balasubramanian.

The Livermore project builds on earlier research by Gregory Cole, a professor of neuro and brain chemistry at the University of California at Los Angeles. Balasubramanian used the Advanced Simulation and Computing Program's UV machine at Livermore to explore which properties give curcumin its dual characteristics. "By understanding the molecular mechanisms of curcumin's preventive and curative properties for Alzheimer's, we can discover other drugs with molecular similarity," says Balasubramanian. Results from his work appeared in the April 2006 edition of the *Journal of Agricultural and Food Chemistry*.

Contact: Krishnan Balasubramanian (925) 422-4984
(balasubramanian1@llnl.gov).

Hydrogen storage project gets hybrid vehicle

The Energy Conversion and Storage Group in Livermore's Energy and Environment Directorate began its second-generation hydrogen-storage research project when it received a Toyota Prius hybrid vehicle converted to run on hydrogen instead of gasoline.

The Prius was modified for hydrogen operation by Quantum Fuel Systems Technologies Worldwide of Irvine, California. Quantum delivered the Prius to Livermore with two room-temperature compressed hydrogen tanks rated at 34 million pascals (MPa). The tanks store a total of 1.8 kilograms of hydrogen, enough to travel about 145 kilometers before needing to refuel.

The goal of the current project is to modify the Prius so that it exceeds the Department of Energy's target driving range of more than 480 kilometers. To achieve this goal, the group will remove the ambient-temperature tanks and install a cryogenic-capable pressure vessel that can hold hydrogen as a compressed room-temperature gas, a cryogenic gas, or even a liquid. "Filling the tank with high-density liquid hydrogen cooled to -253°C may allow us to achieve a driving distance as far as 800 kilometers," says Laboratory technician Tim Ross.

In previous research, the Livermore group installed a 25-MPa cryogenic-capable hydrogen tank in a Ford Ranger pickup truck as part of a pilot project to demonstrate that a vehicle could be refueled with both liquid and ambient-temperature compressed hydrogen. The vessel used for the Ford Ranger held 135 liters of hydrogen, whereas the one for the Prius holds 150 liters in a much smaller package. The multifunctional tank consists of a pressure vessel insulated with many layers of plastic and enclosed within a vacuum vessel. The pressure vessel was custom fabricated by Structural Composites Industries of Pomona, California, and insulation was installed at Livermore. Because the tank can store different forms of hydrogen, drivers can choose the type of fuel that serves their needs on each trip. For example, a driver could use room-temperature hydrogen for running short errands and switch to liquid hydrogen for a long trip.

By testing the different types of fuel and storage options on a vehicle, the Livermore group can evaluate the effectiveness of the available options and help the nation transition to a clean and domestically produced fuel such as hydrogen.

Contact: Salvador Aceves (925) 422-0864 (aceves6@llnl.gov).



Innovative Solutions Reap Rewards

LAURENCE Livermore's continuing excellence in science and technology has its roots in a history of innovation. Our scientists, engineers, and technicians search for out-of-the-box solutions to achieve challenging mission goals and strengthen national security in an ever-changing world.

R&D Magazine honored the Laboratory with seven R&D 100 awards, the most of any organization this year, all for innovative solutions discovered in the process of achieving mission-related goals. This issue of *Science & Technology Review* highlights these seven technologies, beginning on p. 4. R&D 100 awards demonstrate that pursuing the goals of our mission leads to the development of technologically significant products and processes that can advance U.S. economic competitiveness. Livermore has won 113 R&D 100 awards to date, making us one of the top institutions overall.

This year's award-winning innovations are diverse, reflecting the Laboratory's breadth of expertise. Three awards are related to homeland security, two to high-performance computing, one to astrophysics, and one to laser science. Solutions are always tailored to the needs of the user. Some of these technologies are ingenious but simple. Although others are more costly and complex, they remain the optimal solution to the challenge at hand.

An easy-to-use explosives detector called E.L.I.T.E.TM is the size of a credit card and can be tucked in an airport screener's pocket until needed. The detector, which is licensed to a private firm, is sensitive to more than 30 explosives, making it one of the most effective explosives detection systems available. Another new homeland-security device is a high-precision gamma and neutron radiation detector called UltraSpec, which can distinguish threat sources of nuclear materials from legitimate sources, such as medical isotopes, and naturally occurring background radiation. UltraSpec helps government agencies ensure the safety of stored nuclear material at nuclear power plants, weapons stockpiles, and waste facilities. A third homeland-security application, called the Sonoma Persistent Surveillance System, offers the first integrated, broad-area motion imagery system for real-time surveillance at high resolution. Mounted on an airplane or other airborne

platform, Sonoma's sensors and software can track up to 8,000 moving objects in an area the size of a small city.

High-performance computing generates large, complex, multidimensional data sets that can be challenging to explore. A technology dubbed Sapphire applies ideas from data mining, video processing, statistics, and pattern recognition to help researchers better extract useful information. Sapphire was developed to solve a specific research problem and proved to be useful far beyond its original purpose. The second award in the computations field is for Babel, a program that allows software pieces written in different programming languages to seamlessly pass scientific data to each other. With Babel, scientists can inexpensively integrate almost any library or third-party tool into their scientific application.

With the externally dispersed interferometry (EDI) technique, astrophysicists can make precise measurements of the Doppler velocities of stars or sunlit targets. EDI has already been used to detect the planet around the star 51 Pegasi and to discover a new planet in the constellation Virgo. This latter planet is the farthest discovered with the Doppler effect using a telescope smaller than 1 meter in diameter.

Finally, Livermore laser scientists, together with a private company in Florida, developed an yttrium-calcium-oxyborate (YCOB) crystal to convert high-average-power laser light into light with half the incident wavelength. The YCOB converter crystal, developed for Livermore's Mercury laser, may also increase the efficiency of lasers used in manufacturing, basic physics research, and defense applications.

In 1997, when the Laboratory last won seven R&D 100 awards, homeland security was not yet part of the national consciousness or our mission. Four of the winners that year were for laser technologies that helped build the National Ignition Facility. One was our first R&D 100 Award for an advance made through the Accelerated Strategic Computing Initiative, the program that brought today's record-breaking supercomputers to Livermore. As this history demonstrates, the Laboratory's mission goals and challenges change, but the innovation never stops.

■ George H. Miller is director of Lawrence Livermore National Laboratory.

SURVEILLANCE ON THE FLY

CAMERAS mounted on an airplane or other airborne platform constantly monitor an area, feeding data to the ground for real-time analysis. This R&D 100 Award-winning technology, called the Sonoma Persistent Surveillance System, can provide continuous, real-time video imagery of an area the size of a small city with a resolution fine enough to track 8,000 moving objects in its field of view.

With Sonoma, a user can ascertain the pattern of movements, for example, of vehicles, both spatially and over time. This capability is essential for establishing connections between known and unknown targets, determining the time history of those connections, and identifying new targets. Sonoma was developed for nonproliferation applications by researchers in Livermore's Nonproliferation, Homeland and International Security Directorate.

But it can also provide real-time data to monitor traffic, enhance security at special events, and improve surveillance at borders and ports. Livermore physicist Deanna Pennington, who leads the development project, says, "If a Sonoma system had been used in the aftermath of the Katrina and Rita hurricanes, emergency responders would have had real-time information on roads, water levels, and traffic conditions, which perhaps would have saved lives."

End-to-End Systems Approach

The key technology developments that made Sonoma possible include novel sensor designs that can view a wide area at high resolution, real-time on-board data processing, automated data processing to absorb and analyze the resulting data stream, and high-performance visualization technology. Livermore's end-to-end systems



Boxes superimposed on a satellite image of Washington, DC, show the area coverage provided by a standard video camera, a high-definition television (HDTV) camera, a 22-megapixel sensor (Sonoma prototype 1), a 66-megapixel camera (prototype 2), and a 176-megapixel camera (prototype 3). The image in the lower right corner indicates the resolution provided by the Sonoma sensors.



The Sonoma development team (from left to right): Michael Newman, David Bloom, Charles Thompson, Deanna Pennington, Curtis Brown, Aaron Wegner, Laurence Flath, Robert Sawvel, and Michael Kartz. Not pictured: Allen House, Daniel Knight, John Marion, and Gary Stone.

Lawrence Livermore National Laboratory

approach to problem-solving and expertise in optics and advanced computing fostered the needed developments in sensor and data-processing technologies.

For the sensor, the Sonoma team designed a mosaic technique that optically stitches together images from multiple cameras to create a large-format sensor. The technique can be scaled to produce large-aperture arrays that image in both the visible and infrared spectra. It requires far less computing power than other stitching methods, so computer resources are available for other data-processing routines. Another advantage is that the sensor's commercially available cameras, lenses, and mounting hardware cost just one-tenth of those used in similar surveillance sensors.

The top figure on p. 4 compares the area coverage provided by various sensors superimposed on a satellite image of Washington, DC. The current Sonoma prototype, a 66-megapixel sensor, can cover the entire central urban area with an image resolution comparable to that shown in the lower right corner.

A 176-megapixel sensor (prototype 3) is under construction.

For surveillance data to be useful, an analyst must be able to see the information in real time. In other words, all data processing for one frame must be completed before the next frame is captured. With data being collected at two frames per second, the data generated exceed the bandwidth of commercially available communications links by a factor of 100 to 10,000. Compressing the data before transmitting them to a ground-based station would cause artifacts, or errors, that can lead to misinterpretations. To eliminate this problem, the Sonoma team developed a data-processing system for the airborne platform based on the graphics processors used in gaming applications.

The software and hardware for the onboard system work extremely fast. They collect and archive the video data, record an object's geospatial coordinates to freeze the background, and change the viewing perspective so that data collected at a 30- to 45-degree angle are displayed from the top down. All of these data are processed at a rate of two frames per second.

Freezing the Background

Raw imagery collected from a moving platform can be difficult to interpret because its perspective changes constantly as the platform moves. Removing this motion and registering an image's geospatial coordinates in the traditional manner require either data from multiple Global Positioning System (GPS) satellites or scene-based correlation algorithms, both of which are computationally intensive and time consuming.

The Livermore team solved this problem by combining a GPS/inertial measurement unit (IMU) with the sensor to improve tracking accuracy. The GPS/IMU and sensor operate through

a common boresight, and both are mounted on a gimbal, which allows them to rotate in three dimensions. The center of the image remains locked on target as the platform moves. Geospatial coordinates and elevation data are recorded into the header of each camera frame, so every pixel in every frame can be located accurately. Location data are then fed into a flat-earth model. Together, these operations subtract the motion of the platform so that moving objects can be easily separated from the background. Specialized software operates on graphics processing units rather than on standard computer processing units to speed the processing of visual data. (See *S&TR*, November 2005, pp. 19–20.)

The System at Work

Data processed on the airborne platform are handled in two ways. Full-resolution data on the regions around each moving object are transmitted to a ground-based station twice per second via a radio-frequency link. Full-resolution contextual background imagery is sent to the station once per minute, where it is combined with the moving object data for real-time display. The resulting reduction in data volume is equivalent to a compression of up to 100 million but without the artifacts.

The Sonoma team developed several visualization tools to give the ground-based analysts a range of options to manipulate the incoming data. Users can view data from all of the cameras in the sensor array or just one, panning over an area or zooming in and out. They also can alter the rate that imagery is played forward or backward, change the scale for an area of interest, or dynamically reset the magnification. Another visualization tool builds the merged, aggregate image file, using data from all of the cameras or only a subset.

Together, these components—the broad-area imager, onboard data acquisition and processing, a communications link, and a ground station to reconstruct and analyze the imagery in real time—make Sonoma a complete end-to-end system. Other sensor packages or custom image-processing techniques are available, but Sonoma is the only fully integrated system available. Says Pennington, "Our success with Sonoma is already changing how surveillance systems are designed, in terms of a system's architecture and the concepts of operation."

—Katie Walter

Key Words: electro-optical sensors, graphics processing unit, nonproliferation, R&D 100 Award, Sonoma Persistent Surveillance System, video imagery, visualization.

For further information contact Deanna Pennington (925) 423-9234 (pennington1@llnl.gov).

A DETECTOR RADIOACTIVE

AS part of its national security mission, Lawrence Livermore develops technologies to help government agencies prevent terrorists from smuggling nuclear materials into the country. One ongoing effort is to design radiation detectors that can distinguish threat sources from legitimate sources, such as medical isotopes, and naturally occurring radiation. (See *S&TR*, September 2004, pp. 4–11; May 2006, pp. 4–10.) Detectors intended for use by nonspecialists must be easy to operate and require minimal

maintenance. To be most effective, they also must detect both gamma and neutron energies.

That may sound like a lot to ask of one instrument, but the Ultrahigh-Resolution Gamma and Neutron Spectrometer (UltraSpec) delivers all of these features. UltraSpec is so sensitive that even the minute thermal energy deposited by a single gamma ray or neutron can be detected with high precision. With this capability, the detector can identify differences in composition that help reveal a material's origin, processing history, and likely intended use. In addition to its application as a counterterrorism technology, UltraSpec can be used to protect nuclear material stored at nuclear power plants, to evaluate weapon stockpiles, and to verify material composition.

UltraSpec was developed by a team of scientists and engineers from Livermore's Physics and Advanced Technologies and Engineering directorates working with VeriCold Technologies of Ismaning, Germany. The detector's design builds on a technology base established in three Laboratory Directed Research and Development projects. The UltraSpec team, which is led by Laboratory physicist Stephan Friedrich, received a 2006 R&D 100 Award for the detector's innovative design.



UltraSpec is an ultrahigh-resolution spectrometer that can be configured to detect either gamma rays or neutrons. The instrument operates at extremely low temperatures to reduce thermal noise, and its measurement precision is 10 times higher than conventional gamma and neutron spectrometers. Data-acquisition electronics provide spectra that are displayed on a laptop computer.



The UltraSpec development team (from left to right): Stephan Friedrich, Owen Drury, Jan Batteux, Simon Labov, and Thomas Niedermayr.

PARTICLES CAN'T EVADE

Analyzes All Signatures

UltraSpec uses an ultrasensitive thermometer to measure radiation energy. The thermometer is a superconducting sensor whose resistance changes rapidly with changes in temperature. Thus, when the detector absorbs a gamma ray or a neutron, the sensor precisely records the resulting increase in temperature. UltraSpec can operate as a gamma-ray or neutron spectrometer, depending on which radiation absorber is attached to the sensor. "To convert the spectrometer from one form to the other, a user simply opens the instrument and changes the sensor inside," says Friedrich.

Gamma-ray and neutron spectrometry is widely used to determine the isotopic composition of radioactive materials. During the decay process, radioactive isotopes emit characteristic energies that provide a "fingerprint" of a material's composition. Researchers use spectroscopic line intensities to determine the abundance and ratio of particular isotopes. With this information, they can then infer a material's age, origin, and processing history. The more precise a spectrometer is, the smaller the differences it can measure in isotopic composition and, thus, the more reliable it will be in identifying the source of an unknown material.

Most spectrometers are limited in the energy resolution and precision they can provide—a particular concern when analyzing complicated mixtures of radioactive elements. Some detectors cannot differentiate between legitimate and illicit sources of gamma rays. This capability is crucial when the threat source involves uranium or plutonium.

As a gamma-ray spectrometer, UltraSpec uses a tin-foil detector to achieve a measurement precision greater than 0.1 percent for gamma-ray energies of about 100 kiloelectronvolts—the energy most relevant for nuclear forensics. This precision is about 10 times better than that of conventional gamma-ray spectrometers using high-purity germanium crystals.

Configured as a neutron spectrometer, UltraSpec uses lithium fluoride crystals and achieves a precision of 1 percent for neutrons in the megaelectronvolt range. The neutron spectrometer can also measure the amount of light elements, such as oxygen, that may be bound to a nuclear element. Gamma-ray spectrometers cannot detect these elements because many light elements do not emit gamma rays.

In addition, as a neutron spectrometer, UltraSpec can detect a nuclear material even when it is covered with dense shielding. For example, if a threat source were placed behind a heavy metal such as lead, the metal could absorb some of the emitted gamma rays, thus making the signal too weak for a gamma-ray spectrometer to record.

Neutrons, however, can travel through heavy metals, providing a signal strong enough for UltraSpec to record.

Cool and Calm under Heat

As with all high-precision gamma-ray spectrometers, UltraSpec relies on extremely low operating temperatures to reduce the thermal motion, or noise, during operation. In the past, spectrometers have been cooled with liquefied gases such as liquid nitrogen or liquid helium. However, liquefied gases are expensive and difficult to handle, and cooling systems that use them require frequent maintenance. Mechanical refrigerators have been used in some detectors, but these systems have been susceptible to vibration, which precludes their use in high-precision measurement applications.

VeriCold Technologies has developed refrigerator technology that eliminates the vibration problem. The company's novel system uses a mechanical pulse-tube refrigerator to cool UltraSpec to its required operating temperature of about 0.1 kelvin.

Preserves the Evidence

Another advantage offered by UltraSpec is that the collected samples remain intact. Conventional mass spectrometers vaporize a sample and electromagnetically separate its elements based on the differences in their masses. The sample is therefore essentially destroyed, which prevents further analysis. In addition, traditional mass spectrometry, which must be performed by a trained specialist, may require several weeks to analyze a dilute sample with high precision. In contrast, UltraSpec does not chemically separate the elements, reducing analysis time from weeks to hours. And the cost to operate this fieldable detector is half that of conventional mass spectrometers.

UltraSpec's speedy analysis and automated operation make it a valuable technology for people working on the front lines of the nation's nonproliferation and counterterrorism efforts. With it, law-enforcement officers, airline and customs inspectors, and other security officials have a powerful tool to help keep the nation safe.

—Gabriele Rennie

Key Words: lithium fluoride, mechanical pulse-tube refrigerator, radiation detection, R&D 100 Award, Ultrahigh-Resolution Gamma and Neutron Spectrometer (UltraSpec).

For further information contact Stephan Friedrich (925) 423-1527 (friedrich1@llnl.gov).

BABEL SPEEDS COMMUNICATION

BABEL is the Hebrew name for the ancient city Babylon, where, according to the Bible, construction on an enormous tower ended in confusion because the people working on the project spoke different languages. In a similar manner, building a scientific application is often complicated by the many programming languages used. Making these codes communicate with each other can require expensive and labor-intensive programming.

A new Lawrence Livermore program called Babel makes sense of the confusion. Developed with funding from Livermore's Laboratory Directed Research and Development Program by a team of Livermore computer scientists, Babel earned a 2006 R&D 100 Award for being the world's most rapid means of communicating among many programming languages. With this application, applications in different languages can interoperate, allowing them to pass scientific data seamlessly and efficiently from one to another. The user community, which includes scientists from almost 20 fields, can combine programs with minimal loss in performance. What's more, Babel facilitates access to outstanding applications that were formerly too difficult or expensive to integrate manually.

Targeting Massively Parallel Supercomputers

Although Babel is a general-purpose tool, its primary market is high-performance, scientific software running on massively parallel supercomputers. "Scientific applications are becoming more complex, incorporating more types of physics, numerical methods, and visualization techniques," says Livermore computer scientist Thomas Epperly, who leads the Babel project. Computational scientists developing new applications face difficulties in combining software packages because different languages such as Python, C++, and Fortran are used to write them.

Epperly, a member of Livermore's Center for Applied Scientific Computing (CASC), explains that some combinations can be connected

with relative ease—for example, a C++ package that calls, or interoperates with, a C function. For other pairs, such as C++ and Fortran 95, developers must write "glue code" to connect the pieces. In the worst case, computational scientists may need to rewrite a particular library from scratch or not use the library at all.

The Babel toolkit reduces this manual programming burden by automatically generating the glue code. "Babel provides a consistent, semi-automated approach for coupling software pieces written in different programming languages," says Epperly.

The program manages all of the function calls between any combination of C, C++, Fortran 77, Fortran 90/95, Java, and Python, while hiding the complex operations from the user. Babel automatically determines the interoperability issues and then generates the software needed to translate data between the requested languages. From a programmer's viewpoint, calling between languages is seamless. Another advantage for the developer is the consistent interface used to set up these connections.

Working with Babel, scientists can integrate almost any library or third-party tool into a scientific application. Epperly says Babel ends the "programming language wars" because the best language for each component can be used. "Programmers can work in their favorite language," he says. "No one needs to be disenfranchised."



The Livermore-developed program called Babel allows software applications in different programming languages to communicate quickly. It is available at: www.llnl.gov/CASC/components.

AMONG PROGRAMMING LANGUAGES

Strong Support for Fortran

One of Babel's strongest features is its support for Fortran, a language that similar tools ignore. "Many programmers think Fortran is a dead language from the early days of computing," says Epperly. "Although largely ignored by mainstream computing, it is still very much alive in scientific and engineering computing." Babel currently supports Fortran 77 and 90/95 and will support Fortran 2003 in the near future. "The language-interoperability technologies available on the market address only a small subset of languages that don't include Fortran," says Epperly. "Those tools are useful for many operations, but they do not solve the general interoperability problem as more languages are mixed into a single application."

Babel supports the complex numbers and multidimensional arrays that are common in scientific applications. It also allows applications to transfer array data between languages without having to make copies of the data in the new language, which can significantly decrease performance.

In developing Babel, the Livermore team designed the Scientific Interface Definition Language (SIDL) to address the unique needs of parallel scientific computing. SIDL provides a road map for transferring data between languages.

Babel is used increasingly by researchers who are developing common standards for high-performance computing. Livermore is a member of the Common Component Architecture Forum, which includes national laboratories and academic institutions committed to defining a component standard for high-performance computing. Such a standard will promote interoperability between components developed by teams at different institutions. Epperly explains that community standard interfaces are valuable because they allow developers to choose between several software libraries without having to modify existing code. In addition, ancillary tools will work with all of the code libraries that meet the community standard.

Babel is available at no cost from the CASC Web site at www.llnl.gov/CASC/components and is downloaded on average about 90 times per month. Users also have access to online documentation, reports, and frequently asked questions. Babel's current customers are programmers at national laboratories and universities. These scientists are developing advanced applications in diverse disciplines including astronomy, biological and medical simulations, climate and weather modeling, climate feature extraction, computational chemistry,

data management, fusion and plasma physics modeling, multiscale materials science, nanophotonics, nuclear power plant simulations, performance measurement, and scientific visualization.

With Babel's help, the supercomputing world can readily support many different languages, all which can work together to facilitate scientific discovery.

—Arnie Heller

Key Words: Babel, Common Component Architecture Forum, Fortran, language interoperability, R&D 100 Award, Scientific Interface Definition Language (SIDL).

For further information contact
Thomas Epperly (925) 424-3159
(epperly2@llnl.gov).



The Babel development team (from left to right): James Leek, Thomas Epperly, Tamara Dahlgren, Scott Kohn, and Gary Kumfert.

A GEM OF A SOFTWARE TOOL

WITH the explosive growth of more powerful computers that process large amounts of data, researchers often find themselves confounded by data sets with trillions, even quadrillions of bytes of data. These sets are so large and complex that useful information is easily overlooked, and the potential benefits of increased data-gathering capabilities are only partially realized.

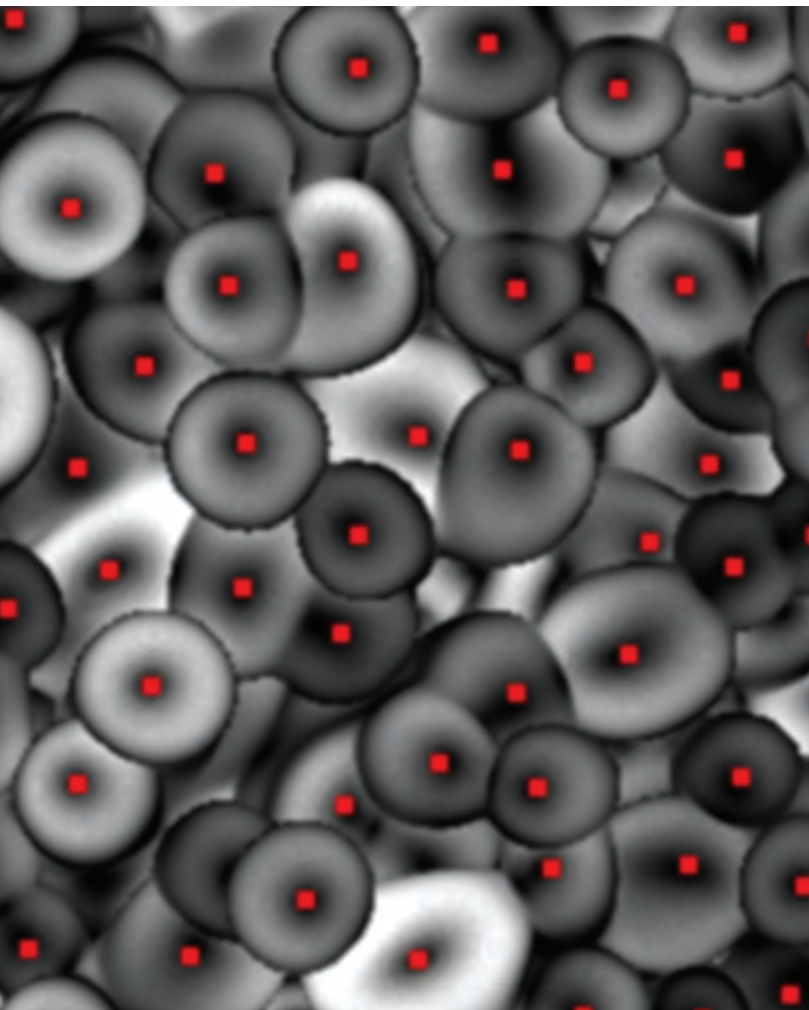
To address the problem of data overload, a team of scientists from Livermore's Computation Directorate developed a scientific data-mining tool called Sapphire. The team, led by computer scientist Chandrika Kamath, and funded in part by two Laboratory

Directed Research and Development projects, received a 2006 R&D 100 Award for this novel software. Sapphire provides an end-to-end approach that finds useful information in enormous data sets and offers a breadth of functionality. It is being used for a range of research applications, including astronomy, experimental physics, remote sensing, and computer simulations. According to Kamath, no other data-mining tool meets the analysis needs for such a diverse set of disciplines.

Sapphire Tackles Data, Start to Finish

Sapphire starts by preprocessing raw data—images, videos, points in space, or mesh data—and finds the user-defined objects of interest. It then extracts characteristics that represent these objects and uses them to identify patterns. Scientists look at the results to validate that the recognized patterns are the ones they need. “Most data-mining tools do not address the tedious and time-consuming task of preprocessing the raw data,” says Kamath. “They only perform pattern recognition. Sapphire can handle the entire spectrum of a problem.”

Sapphire's architecture also distinguishes it from other data-mining tools. Each task in the pipeline is considered a separate module and is packaged as one or more libraries. The Sapphire



Sapphire software was used to characterize and track bubbles and spikes in an 80-terabyte data set from a three-dimensional, high-fidelity simulation of Rayleigh–Taylor instability. This image shows the bubble counts (in red) highlighted on the magnitude of the x - y velocity at the bubble boundary.

Sapphire development team (from left to right): Cyrus Harrison, Chandrika Kamath, and Abel Gezahegne. Not pictured: Erick Cantú-Paz, Samson Cheung, and Nu Ai Tang.



software, written in C++, addresses computationally intensive tasks such as identifying objects and extracting features. Public domain software is used extensively in the modules that deal with more routine tasks such as reading, writing, and displaying data. Intermediate data extracted from raw images or meshes are stored in a database or other storage scheme that is either commercially available or in the public domain. Sapphire's modules can be connected directly with software code or through a scripting language such as Python. This packaging allows users to extract the information they need and combine tasks in the order that is appropriate for a particular application. Other modules can be easily added to enhance the software's functionality.

"From the start, we designed Sapphire to meet the diverse needs of scientific applications," says Kamath. "We used various technologies from the fields of data mining, machine learning, image and video processing, statistics, and pattern recognition to provide this end-to-end approach. Designing a flexible system was a key focus of our efforts."

In addition to its modular, extensible architecture, Sapphire can support several algorithms—the detailed sequence of operations for a given task—so users can experiment to find the best algorithms for each problem. The data-mining package has user-friendly interfaces, allowing users to fine-tune each algorithm to specific data sets. In addition, the software can process incrementally growing data sets. That way, users can explore a sample of data to determine the best approach for a problem. Once they select a method, they can apply Sapphire to the entire data set.



Bringing Data Overload under Control

Researchers have used Sapphire to analyze scientific data sets ranging in size from a few megabytes to tens of terabytes. "For example," says Kamath, "Sapphire was used to identify galaxies with a 'bent-double' shape. The researchers were originally faced with examining a million galaxy images by hand to visually identify these particular galaxies—a task that would be tedious, subjective, and error-prone." (See *S&TR*, September 2000, pp. 20–22.)

Another study used Sapphire to characterize bubbles and spikes in a high-fidelity simulation of Rayleigh–Taylor instability in a fluid mix problem. The massive amount of data (80 terabytes) was a major challenge, as was the difficulty of defining the bubbles and spikes that form as the fluids mixed. A quantitative task, such as counting the thousands of bubbles and spikes over time, did not lend itself well to manual or visual analyses. "The Sapphire team provided advanced bubble-tracking algorithms and a framework to analyze our simulations," says Livermore physicist Paul Miller. "The results were striking—revealing distinct regimes of fluid behavior. This perspective is helping us understand the development process of a complicated physical system."

To date, Sapphire has mainly been used in scientific research, but it could also be applied to commercial problems, for example, to detect credit card fraud or analyze documents and video images. "Data overload is also of great concern to national security organizations," says Kamath. "The common issue in all of these disciplines is how to make sense of large amounts of data—effectively and efficiently—without overlooking something of importance. We see Sapphire as unique among data-mining software packages in its ability to provide a complete solution to the analysis needs of a diverse set of applications."

—Ann Parker

Key Words: data-mining software, R&D 100 Award, Sapphire.

For further information contact Chandrika Kamath (925) 423-3768 (kamath2@llnl.gov).

INTERFEROMETER IMPROVES

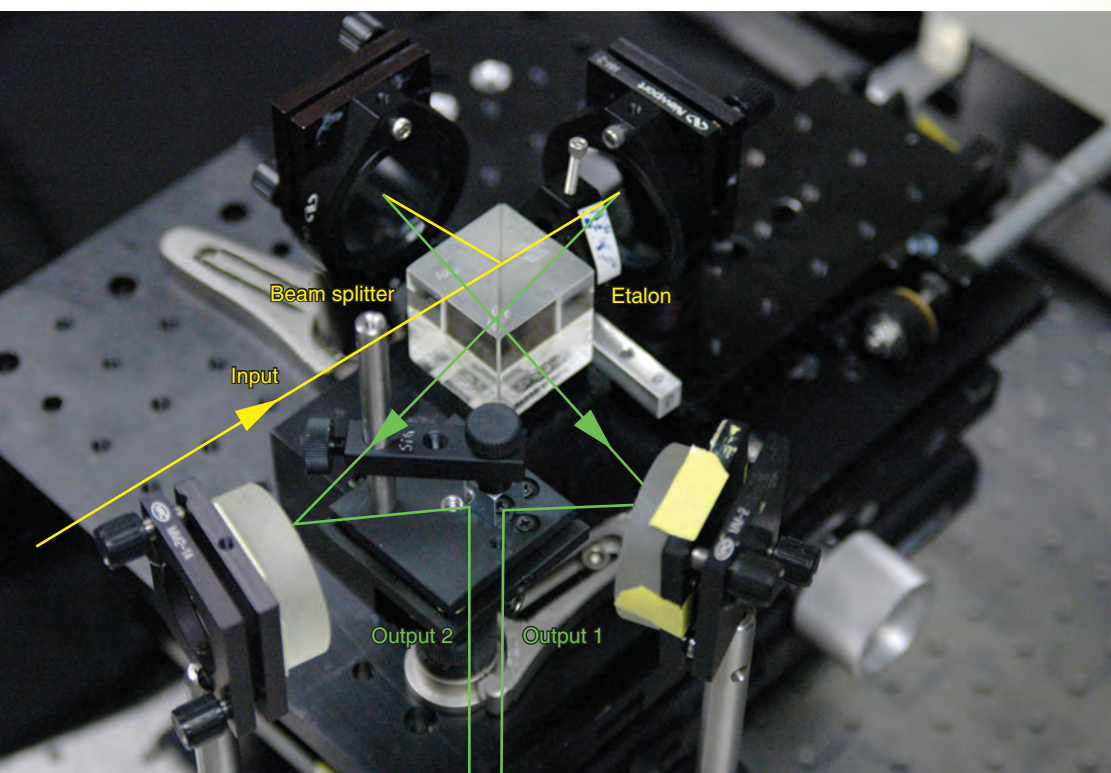
ASTRONOMERS engaged in the search for planets thrive on the occasional discovery of a new one. Spectroscopy allows them to measure small variations in the wavelength of the light received from a planet's host star. Extremely high resolution is needed to accurately record stellar spectra. Only a few observatories have the space or funding to field the multi-million-dollar, meters-long spectrographs required for this work. Observatories that do not have these resources measure stellar spectra with smaller, low-resolution spectrographs, which limit their ability to find new planets.

A new technique, called externally dispersed interferometry (EDI), allows more astronomers to join the search. Designed by Livermore physicist David Erskine in collaboration with Jerry Edelstein, an astronomer at the University of California (UC) at Berkeley's Space Sciences Laboratory, EDI achieves the high-

spectral resolution needed using a much smaller and less expensive instrument. The mathematical calculation and software written for the EDI system can also be used to boost the time resolution and stability of streak cameras that record high-speed phenomena. Two projects funded by Livermore's Laboratory Directed Research and Development Program contributed to the EDI design, and this year, Erskine and Edelstein won an R&D 100 Award for developing the system.

Boosting Resolution with an Interferometer

Spectroscopy relies on the Doppler effect to measure the motion of stars. The gravitational pull of a planet as it orbits a star causes a small back-and-forth wobble in the star's position and the



A laboratory-scale unit of the externally dispersed interferometry (EDI) system shows the path light takes as it enters the EDI device and is recorded by the spectrograph. The interferometer splits the light into two beams, which produce a moiré pattern that shifts in phase proportionally to changes in Doppler velocity. The etalon is a parallel plate of glass used to delay light.



Jerry Edelstein from the University of California at Berkeley's Space Sciences Laboratory.



Livermore's David Erskine.

THE SEARCH FOR PLANETS

observed wavelength of the light it emits. Called Doppler shifts, these small changes in wavelength can be measured by tracking the exact wavelength of absorption lines. These features in the stellar spectrum are like a fingerprint for the star. In conventional spectrometry, a diffraction grating disperses the spectrum across a detector, which records the absorption-line data. The pixel coordinate for each line represents its wavelength. Astronomers use these data to determine the reference star's velocity and infer the mass of the orbiting planet.

The challenge with spectrometry is obtaining the needed resolution. The width of an absorption line is equivalent to a frequency change of about 6,000 meters per second. But astronomers need to measure shifts in wavelength that are about 500 times smaller than an absorption line and about 200 times smaller than a single pixel. These subtle shifts can be dwarfed by distortions, such as air convection along the path of a star's light as it travels to Earth, or by a change in spectrograph temperature, which alters its position.

Unlike conventional spectroscopic methods, EDI boosts resolution by adding an interferometer to the measurement system. An interferometer divides the beams of light and then recombines them to force interference. Whether the interference is constructive or destructive depends on changes in wavelength so the interferometer can measure small shifts in Doppler velocity. In addition, interferometry allows scientists to process the data using mathematical equations based on only two signal paths. More complicated equations are needed to process results from a diffraction grating because it records thousands of paths.

Light entering an EDI system is split into two beams that travel separate paths. One beam travels about 1 centimeter farther than the other before the two are recombined in the output. This extra distance, called a delay, corresponds to 20,000 wavelengths of green light. Fringes—light or dark bands produced by the interference—appear in the output spectra. The moiré pattern created by these bands indicates a shift in phase that is proportional to the Doppler velocity. A Doppler wavelength shift of one part in 20,000 creates a corresponding shift in the moiré pattern of one whole fringe. As a result, EDI measurements are insensitive to spectrographic distortions. In addition, because EDI analyzes a wavelength before absorption lines are blurred by the diffraction grating, a low-resolution spectrograph coupled to an EDI system shifts the moiré pattern with the same accuracy provided by a high-resolution spectrograph.

Versatile and Affordable

A small EDI system built with commercially available optics costs about \$7,000. "Many laboratories already possess

a low-resolution spectrograph," says Erskine. "Adding an EDI system to an existing spectrograph is like putting on a pair of eyeglasses. It improves the system's performance severalfold and at minimal expense."

In one demonstration project, an EDI system used at UC's Lick Observatory on Mount Hamilton more than doubled the spectrographic resolution. Another demonstration improved a spectrograph's resolution by six times—far beyond the capability of the spectrograph without the EDI system.

Erskine is working with collaborators from UC Berkeley and Cornell University to design an EDI system that will operate with the Hale Telescope at the Palomar Observatory near San Diego, California. This three-year project, which is funded by the National Science Foundation, will search in the near-infrared region for planets orbiting low-temperature stars. The Gemini Observatory is also funding a study to develop a Doppler search instrument for use with the Gemini North Telescope on Mauna Kea, Hawaii.

In 2005, the EDI technique was licensed noncommercially to the University of Florida and was used with a telescope at Kitt Peak National Observatory in Arizona to discover a new planet. This planet, which lies in the Virgo constellation, is about 90 light years from Earth. It is the most distant planet to be discovered with the Doppler technique using a telescope mirror less than 1 meter in diameter.

In addition to astronomy, the EDI technique can be applied to streak cameras to improve the data obtained on high-speed phenomena, such as shock-wave experiments conducted at Livermore's National Ignition Facility. Other potential applications include technologies to improve meteorology, space surveillance, and national security.

Since 1995, astronomers have discovered about 160 planets near 3,000 stars using the high resolution available from large telescopes. With EDI, astronomers working with smaller telescopes can join the search for undiscovered planets. The added resolution could allow them to survey more than 100,000 stars in the coming decade.

—Gabriele Rennie

Key Words: externally dispersed interferometry (EDI), moiré pattern, R&D 100 Award, spectroscopy.

For further information contact David Erskine (925) 422-9545 (erskine1@llnl.gov).

EFFICIENTLY CHANGING THE

ONCE developed chiefly for physics research, high-energy, high-average-power lasers are now used in a diverse range of applications, such as high-speed manufacturing, demolition, and national defense technologies. These lasers operate in the infrared portion of the electromagnetic spectrum, producing light beams with wavelengths of about 1,000 nanometers. However, infrared light is not always the best color for every application. For example, ceramics and plastics are more efficiently machined with ultraviolet light, green light is better for cutting the copper metal used in electronic circuit boards, and the targets for high-energy-density physics experiments are often designed to require light at wavelengths other than infrared.

The color of laser light is changed with wavelength conversion crystals, but each type of crystal has performance drawbacks. Barium borate crystals have excellent thermal properties but cannot be grown to the sizes needed for some applications. Cesium lithium borate crystals can be grown to large apertures for large-beam-size lasers, but these crystals degrade rapidly when exposed to air. Potassium di-deuterium phosphate (DKDP) crystals are well suited for high-pulse-energy wavelength conversion, but their relatively poor thermal properties limit their performance on high-average-power systems.

A team of researchers from Lawrence Livermore and Crystal Photonics, Inc. (CPI), of Sanford, Florida, has developed a more efficient and compact converter crystal using yttrium calcium oxyborate (YCOB). The team, led by Livermore physicists Christopher Ebberts and Zhi Liao, received a 2006 R&D 100 Award for the YCOB innovation. This R&D 100 Award is the third for Ebberts, who works in the National Ignition Facility Programs Directorate. (See *S&TR*, September 1999, pp. 8–9; October 2003, pp. 14–15.)

Dealing with the Heat

The YCOB crystal is designed for Mercury, Livermore's large-aperture, high-average-power laser. Intended as a prototype of a fusion laser driver, Mercury has a high repetition rate (10 hertz), and its average power is about 0.5 kilowatt. In addition, it operates for hours at a time, which poses tough cooling challenges. Scientists are using the Mercury laser to probe the fundamental interactions of light and matter, and many of these experiments require the conversion of infrared light to green.

The most basic wavelength conversion process, known as second-harmonic generation, converts the input laser wavelength into light with half the incident wavelength. Thus, infrared light



The Livermore development team for the high-average-power wavelength converter: (first row, from left to right) Noel Peterson, Manuel Carrillo, Bob Kent, Kathleen Schaffers, Chris Ebberts, Kathy Allen, Zhi Liao, Camille Bibeau, Tony Ladrán, and Steve Mills; (back row) Rod Lanning, Stanley Oberhelman, Greg Rogowski, Everett Utterback, Andy Bayramian, Bruce Warner, Barry Freitas, Rob Campbell, Dave Van Lue, Steve Telford, and Nick Schenkel. Not pictured: Peter Thelin, Kathy Alviso, and Steve Payne.

COLOR OF LASER LIGHT

with a wavelength of 1,047 nanometers, when propagated through a crystal, is output as green light with half of the original wavelength (523.5 nanometers). When the speed of light for the two colors in the crystal is identical, 100 percent of the infrared light can be transformed to the second harmonic (green). However, as the crystal heats up, the speed differs, and the light will oscillate between green and infrared, which reduces the conversion efficiency. To eliminate this problem, Livermore researchers use four thin DKDP crystals as wavelength converters and individually cool each one with a sapphire plate.

The complexity of the DKDP converter led Livermore and CPI to explore the potential of YCOB crystals in a 1997 project funded by Livermore's Laboratory Directed Research and Development Program. Results from the initial project showed that YCOB was extremely insensitive to heating, but other crystals were more efficient at converting the wavelength of low-pulse-energy lasers. The team determined, however, that if YCOB crystals could be produced in large sizes, they held potential for use on high-pulse-energy, high-average-power lasers. In 2005, with funding from the Mercury project, the team began scaling the volume of YCOB.

Clear, Crack-Free Crystals

The 1997 project team grew 10-centimeter-long boules of YCOB crystal with 2.5-centimeter apertures, from which they cut high-optical-quality YCOB plates with volumes of 1 cubic centimeter. By June 2005, the team had improved the crystal's internal optical quality and had grown clear, crack-free crystals that

measure 7.5 centimeters in diameter and 24 centimeters in length, representing a 27-fold increase in volume. The converter plates cut from these large boules measure 5.5 by 8.5 centimeters with a thickness of 1.6 centimeters.

A single, side-cooled YCOB crystal has replaced the four-crystal assembly in Mercury. In a demonstration experiment, the new wavelength converter achieved 50-percent power conversion, using 450 watts of infrared light to generate a world-record 225 watts of green light. In this experiment, the laser operated for 30 minutes, performing 18,000 shots at 10 shots per second, without any degradation in performance from heating. The Livermore-CPI team is working to reduce the pulse length from 15 to 5 nanoseconds, which should increase the conversion efficiency to 80 percent.

"The thermal robustness of the single-plate YCOB wavelength converter allows for a more efficient laser system," says Ebbers. Replacing the four DKDP crystals and their sapphire cooling plates with one YCOB crystal also reduces the size of the system, which lowers the manufacturing cost. As a result, high-average-power lasers can be considered for diverse applications from exploring the interactions of light with matter to developing a suite of tools for homeland security and national defense. Other lasers, such as Livermore's solid-state heat capacity laser, could potentially take advantage of this converter as well.

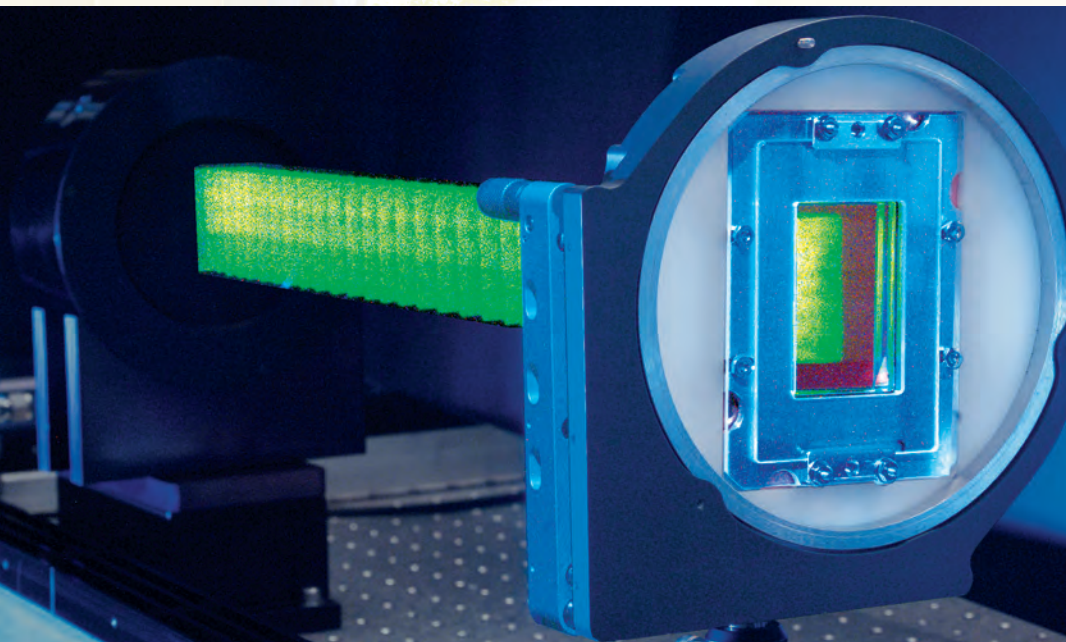
With its strong advantages over other crystals, the YCOB wavelength converter crystal promises a new era of laser research and laser systems with an easy route to green.

— Arnie Heller

Key Words: high-average-power laser, Mercury laser, potassium di-deuterium phosphate (DKDP) crystal, R&D 100 Award, wavelength conversion, yttrium-calcium-oxyborate (YCOB) crystal.

For further information contact
Christopher Ebbers (925) 423-9465
(ebbers1@llnl.gov).

Invisible infrared light with a wavelength of 1,047 nanometers enters the laser system from the right and interacts with the yttrium-calcium-oxyborate crystal in the center of the holder. The crystal shifts the infrared light to green light with a wavelength of 523.5 nanometers.



POCKET-SIZED TEST DETECTS

SECURITY forces throughout the world need detection tools that can quickly and accurately locate small amounts of explosives. Technology developed by Lawrence Livermore will provide emergency response, law-enforcement, and military personnel

with an easy-to-use explosives detector small enough to carry in a shirt pocket. This technology, called E.L.I.T.E.TM (Easy Livermore Inspection Test for Explosives), is inexpensive and requires minimal training for deployment.

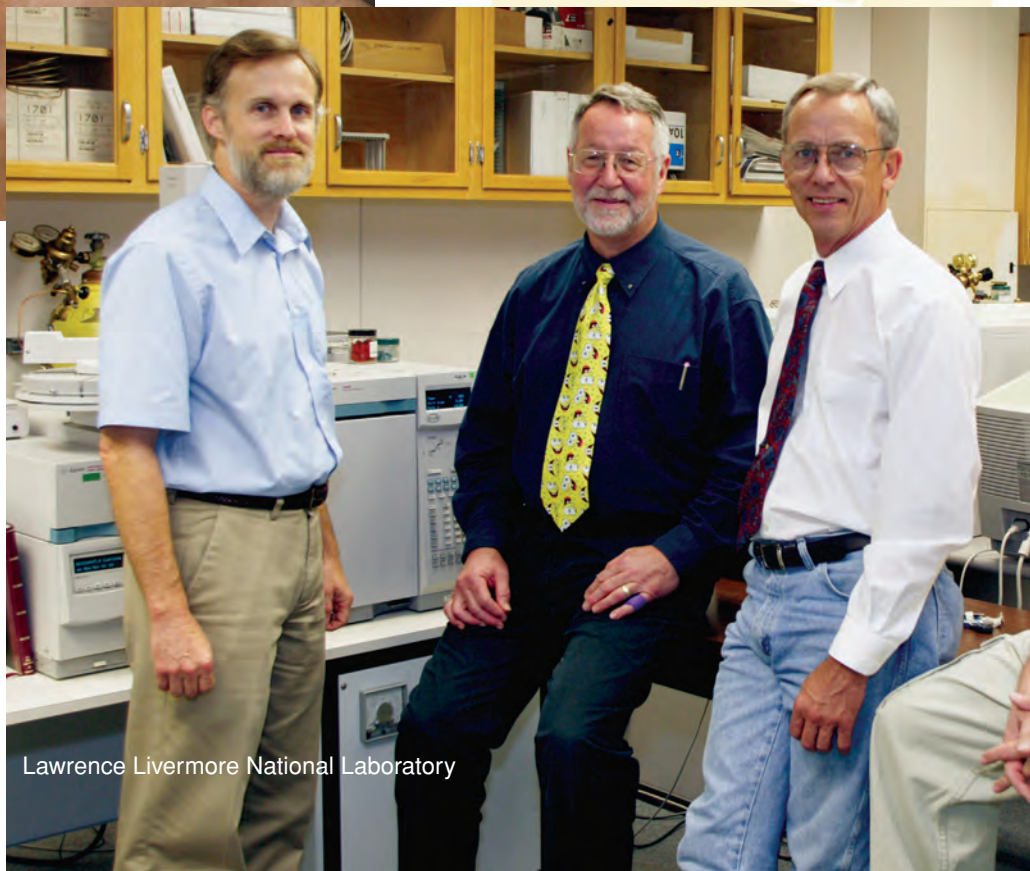
E.L.I.T.E. cards are particularly useful for screening vehicles, containers, and people for explosives residue. The 5- by 7.5-centimeter card weighs about an ounce, and test results are available immediately in the field. After a card has been used, it can be discarded without special handling.

The E.L.I.T.E. card technology was developed by a team of scientists and engineers from the Laboratory's Forensic Science Center (FSC) and Center for Energetic Materials. Led by FSC deputy director John Reynolds, the team won a 2006 R&D 100 Award for the new technology. The product, which also received a 2006 Excellence in Technology Transfer Award from the Federal Laboratory Consortium, is marketed by Field Forensics, Inc., of Florida. Since October 2005, when units became commercially available, Field Forensics has sold E.L.I.T.E. cards to many government agencies, including the Department of Homeland Security, New York State Police, Royal Canadian Mounted Police, and Queensland (Australia) Police.



The E.L.I.T.E.TM card is small enough to fit in a pocket, yet sensitive enough to detect trace amounts of up to 30 explosives.

Livermore members of the E.L.I.T.E.TM development team (from left to right): Randall Simpson, John Reynolds, J. Del Eckels, and Pete Nunes.



Lawrence Livermore National Laboratory

TRACE EXPLOSIVES

Inexpensive Cards with Built-in Simplicity

Each E.L.I.T.E. card is good for one test. To collect a sample, a user removes the swipe from the card, rubs it on a suspect area—a shoe, car door, or suitcase—and slides it back into the card. The user then ruptures two sealed ampoules that contain the developing chemicals. A few drops of the reagent flow onto the swipe through microchannels fabricated in the card's plastic case. Within a minute, an explosive trace, if present, will appear as a brightly colored spot on the white swipe.

The color and intensity of the spot indicate the type and concentration of the explosive found. Explosives generally show up as bright red or pink, so they are easy to distinguish from dirt and other stray substances. The chemical formulation used in E.L.I.T.E. cards can detect military and commercial explosives, such as C-4, Semtex, TNT, and derivatives, as well as inorganic explosives and propellants, such as ammonium nitrate and black powder. A used card requires no special handling and can be disposed of as regular waste.

The cost of detection technology is a critical issue for many security organizations, and E.L.I.T.E. delivers an affordable product. Cards cost \$10 to \$20 each; other commercially available screening systems can range from \$40 to \$7,500. But cost is not the only advantage. "We developed a reagent formulation with a dramatically improved shelf life," says Reynolds. "E.L.I.T.E. units have a much longer service life than comparable products." Similar screening products have an average shelf life of one year or less.

Once in service, these detection tools remain effective for one to four months. The E.L.I.T.E. reagents, however, have an indefinite shelf life and do not have to be replaced frequently.

The E.L.I.T.E. card also has lower detection limits than other screening products and can detect more than

30 types of explosives and propellants. In addition, reagents are self-contained in each card, so users are never exposed to these chemicals. Other detection technologies typically store reagents in separate bottles, and users must spray the formula onto a swipe or otherwise apply it by hand. This approach not only exposes users to chemicals but also can be difficult to use in inclement weather.

Reynolds notes that other explosives detection kits can be cumbersome or require users to follow complicated procedures. "The E.L.I.T.E. card solves this problem, too," he says. "Instructions are printed right on the card, so user error is largely eliminated. Plus the engineered design dispenses the proper amount of chemicals each time."

Potential to Save Lives

E.L.I.T.E. cards operate effectively in harsh environments, so the technology could be adapted for military use, such as to screen materials in combat zones. Other applications include border inspections, airport and transit security, and decontamination verification.

The cards' potential to stem terrorism is also clear. "Explosives will continue to be a terrorist's weapon of choice as long as they are available in a usable form," says Reynolds. "E.L.I.T.E. cards provide security personnel with a fast, effective method to detect explosives and deter their use. These sensitive, robust explosives detectors offer an enormous potential for saving the lives of civilians and military and law-enforcement personnel."

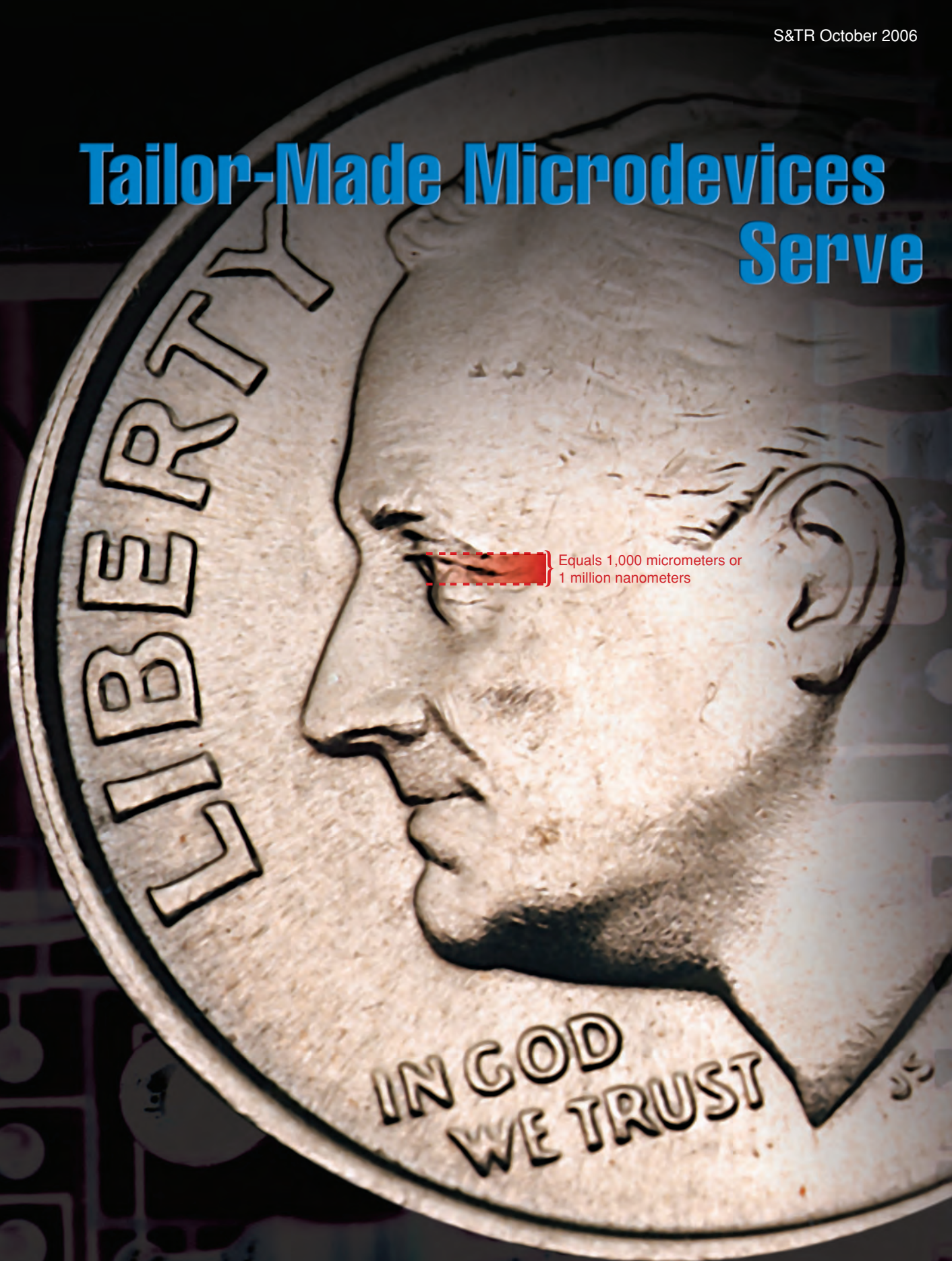
—Ann Parker

Key Words: Easy Livermore Inspection Test for Explosives (E.L.I.T.E.™) card, explosives testing, R&D 100 Award.

For further information contact John Reynolds (925) 422-6028 (reynolds3@llnl.gov).



Tailor-Made Microdevices Serve



Big Needs

Livermore engineers invent and fabricate micrometer- and nanometer-scale devices for national security.

AT one time or another, almost everyone wishes for a custom-made gadget to perform a specific task. Talented engineers often find a way to transform those ideas into workable devices. At Livermore's Center for Micro- and Nanotechnology (CMNT), fulfilling special requests has an added challenge because researchers must focus on the very tiny. "CMNT engineers, scientists, and technicians develop technologies with critical dimensions that are only a few nanometers to micrometers in size," says Mike Pocha, the center's chief engineer. "Much of the Laboratory's research for its national security missions requires unique devices not available commercially, so we invent and manufacture them here at Livermore."

The tailor-made components designed at CMNT range from highly integrated biomicrosystems for sensors and medical devices to photonic microsystems for high-speed signal and data acquisition, microelectromechanical systems (MEMS) for sensing and actuation, and micrometer and nanometer-scale energy systems for miniature power supplies. A measure of the center's success is the number of patents issued to its staff members. In the past two years, more than 20 percent of the Laboratory's patented technologies were developed at CMNT.

Originally called the Center for Microtechnology, the center was formed

in the 1980s as part of Livermore's Engineering Directorate. Its early efforts focused on high-speed diagnostics and radiation detectors for underground nuclear testing. CMNT researchers were among the first to combine micro-optical devices, such as laser diodes and guided-wave photonics, with microelectronics, increasing processing speeds by several

orders of magnitude compared with those of electronic devices.

In 2000, the center changed its name in recognition of the push for technologies with ever-smaller components. Most devices are designed to meet specific programmatic needs, such as targets for experiments on the National Ignition Facility (NIF). But the staff often finds that



At the Center for Micro- and Nanotechnology, researchers develop micrometer- and nanometer-size devices and systems in support of the Laboratory's national security missions. The critical dimensions of these technologies are much smaller than the highlighted area of the dime shown on p. 18.

a new tool has commercial applications as well. “For example, our engineers invented components for a MEMS-based contact stress sensor designed as a flight-test diagnostic,” says Pocha, who has worked at the center since it was formed. “We also adapted the stress sensor for biomedical research to measure the contact stress in, say, a knee joint or an artificial limb.” (See *S&TR*, April 2006, pp. 4–9.)

As with many of the center’s developments, the stress sensor resulted from the ingenuity of young researchers with a fresh approach for solving a complicated problem. CMNT director Anantha Krishnan says, “A large part of our strategy is hiring young engineers and scientists who bring in new ideas and skills to help achieve the long-range project and mission goals being pursued by senior researchers.”

Ring in the Light

For example, consider engineer John Heebner. Before he joined the Laboratory in 2003, Heebner completed his Ph.D.

dissertation on the use of microresonators to enhance optical propagation in waveguides. He now focuses on devising optical-based devices to replace traditional electronic components and systems, such as switches, transistors, oscilloscopes, and streak cameras.

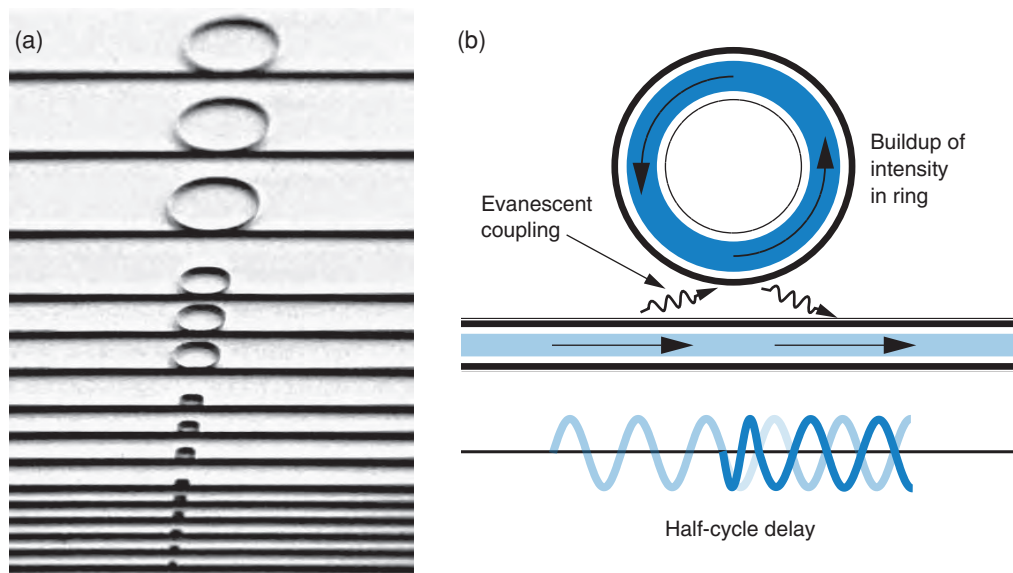
Optical or photonic systems rely on photons rather than electrons to carry signals. Photons transfer information 10 to 100 times faster than electrons while maintaining better signal integrity. Light is also more secure from interference. These characteristics make optical-based systems ideal for long-distance communications.

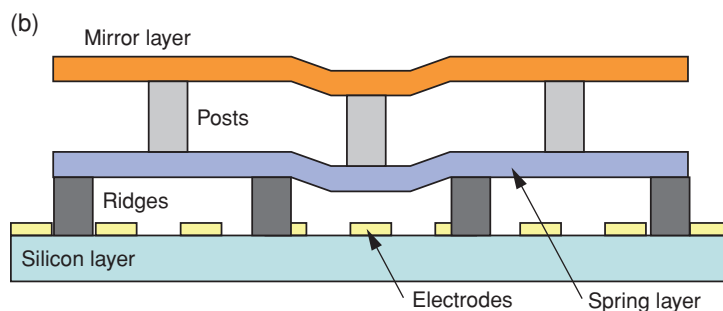
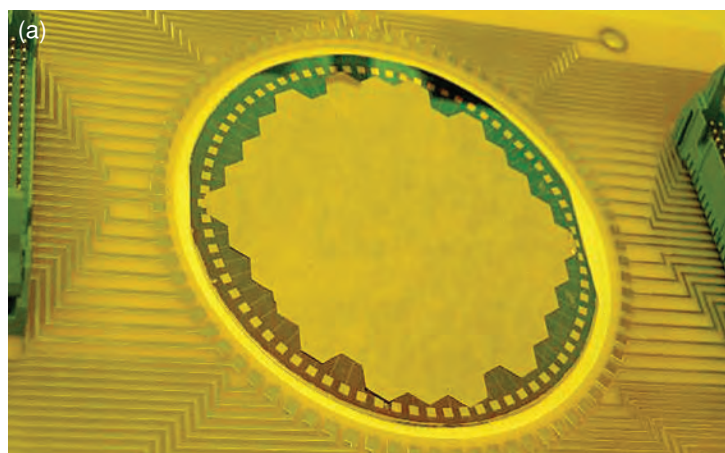
However, technology has not been sufficiently developed to enable all-optical signal processing, in which photons operate on or reroute other information-carrying photons. The problem is that photons do not interact with each other nearly as readily as electrons do. Therefore, most modern communication architectures use hybrid systems in which electronics process the photons and optics merely channel them.

According to Heebner, a potential technology for unlocking the promise of all-optical systems is microresonators. “In any optical material, at a sufficiently high intensity, one light beam can control a second beam by altering the refractive index it experiences,” he says. A material’s refractive index is a measure of the slow-down factor for light propagating inside it. Delaying the propagation time by a half-cycle is enough to enable an optical switch or gate. Unfortunately, these effects are very weak, typically requiring long devices or impractically high intensity levels.

Microresonators could be an effective solution to this problem. Says Heebner, “Microresonators strengthen the interactions of photons in a compact device.” One type of microresonator consists of a ring structure made with a semiconductor material such as silicon or gallium arsenide. The microring confines light so it circulates in tight bends, enhancing both the interaction time and the intensity level of electromagnetic waves at

(a) Microring resonators with diameters that vary from 50 to 5 micrometers are etched in aluminum gallium arsenide. The waveguide cross sections that channel the light are smaller than 1 square micrometer, or 100 times smaller than conventional optical fibers. (b) In a microring resonator, incident light propagating in a waveguide evanescently couples into the ring, traversing the ring for many trips while building up its circulating intensity. The combined action of these effects can delay the propagation by a half-cycle at a significantly reduced intensity threshold. Compact all-optical switches can be built by using this effect to augment the constructive and destructive interference.





(a) This 76-pixel deformable mirror made from nanolaminate foil provides a lightweight alternative to the glass mirrors typically used in telescopes.
 (b) When electrodes stimulate the spring layer, it deforms and adjusts the mirror pixels.

specific resonant frequencies. With these enhancements, two pulses of light interact with each other 1,000 times more strongly while preserving the high speed.

Heebner leads a CMNT team that is investigating whether arrays of microring resonators can be used to design all-optical systems. The concept of a ring resonator has been around for some time, but limitations in existing optical materials and fabrication techniques have restricted

the development of the arrays. Part of the Livermore project is to determine what improvements in fabrication techniques are needed to enable an all-optical system. The ring resonators are also being used in optical filtering and sensing applications.

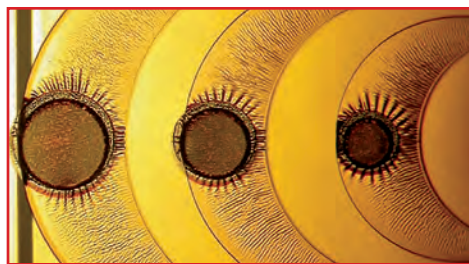
Heebner is also working with a team from the NIF Programs and Defense and Nuclear Technologies directorates to design an all-optical oscilloscope or streak camera. These traditionally electron-based recording instruments are a staple of experimental facilities that measure high-speed events. The optical device being designed by Heebner's team uses an intense, auxiliary pulse of light to instantly create a microprism that rapidly

deflects a primary light beam. The team's goal is to provide a faster alternative to conventional recording instruments by implementing novel all-optical recording technologies.

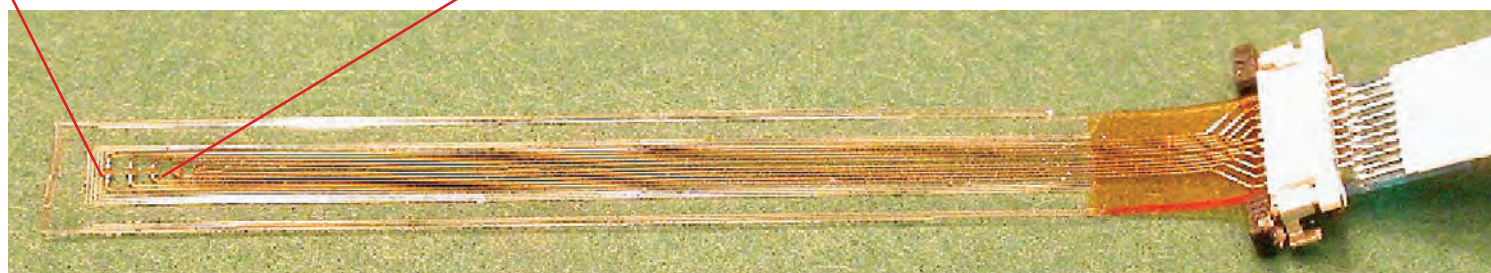
Foils Replace Glass Mirrors

CMNT also applies its optics expertise to research in MEMS-based adaptive optics (AO) for use in telescopes. (See *S&TR*, June 2006, pp. 14–21.) These systems adjust for the distortions of light caused by atmospheric aberrations, so observers have a clearer view of objects in space.

The deformable mirrors on AO systems are traditionally made of etched silicon



Conductive lead and metal electrodes are embedded in a polymer substrate for the retinal prosthesis. A close-up shows the electrode region of the retinal implant.



glass. MEMS actuators adjust the shape of each pixel on a mirror hundreds of times per second. The largest AO systems built to date have arrays of mirrors with no more than 1,000 pixels. Tens of thousands of pixels are needed for AO systems on space-based telescopes. Newer terrestrial systems, such as the proposed Thirty Meter Telescope, will require thousands of pixels. But mirror size is limited by the weight of glass and the fabrication techniques available.

To solve this problem, mechanical engineer Alex Papavasiliou worked with colleagues in the Chemistry, Materials, and Life Sciences (CMLS) and Physics and Advanced Technologies (PAT) directorates to develop lightweight deformable mirrors using nanolaminate foils instead of glass for the mirror surface. Nanolaminate foils are composed of thousands of alternating

layers of copper and zirconium, each of which are a few nanometers thick. Nanostructuring limits the material's grain size, giving the foil the strength and toughness to handle bonding during fabrication and the flexibility to withstand rigorous deformations as the individual pixels adjust many times.

Papavasiliou also devised a microfabrication technique that creates the actuator for nanolaminate foils. Mirrors can be fabricated in batches rather than individually by hand as in the conventional process. In addition, the design can be scaled from a few centimeters to 1 meter or larger.

Restoring Sight

Many experienced engineers join the Laboratory because of its broad scope of research. CMNT engineer

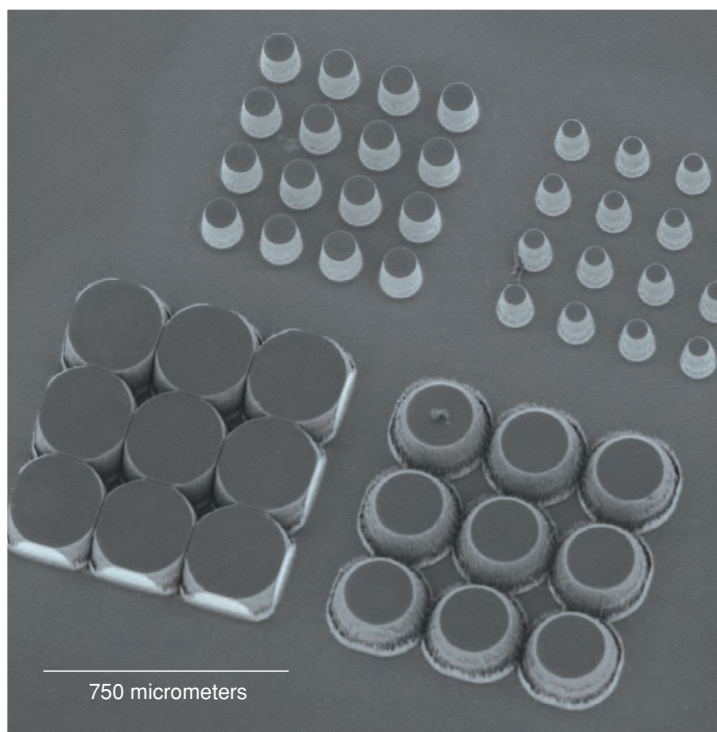
Satinderpall Pannu previously worked at Onix Microsystems, Inc., developing micromirrors to be used in optical switches for telecommunications. In his current assignment at Livermore, Pannu leads a multi-institutional effort funded by the Department of Energy's Office of Science to develop a prosthesis for treating retinal diseases such as macular degeneration and retinitis pigmentosa. (See *S&TR*, November 2003, pp. 11–13.)

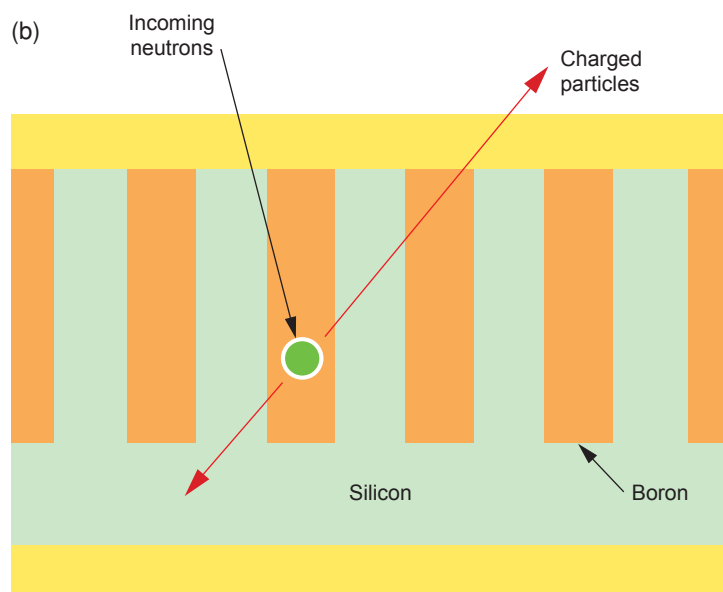
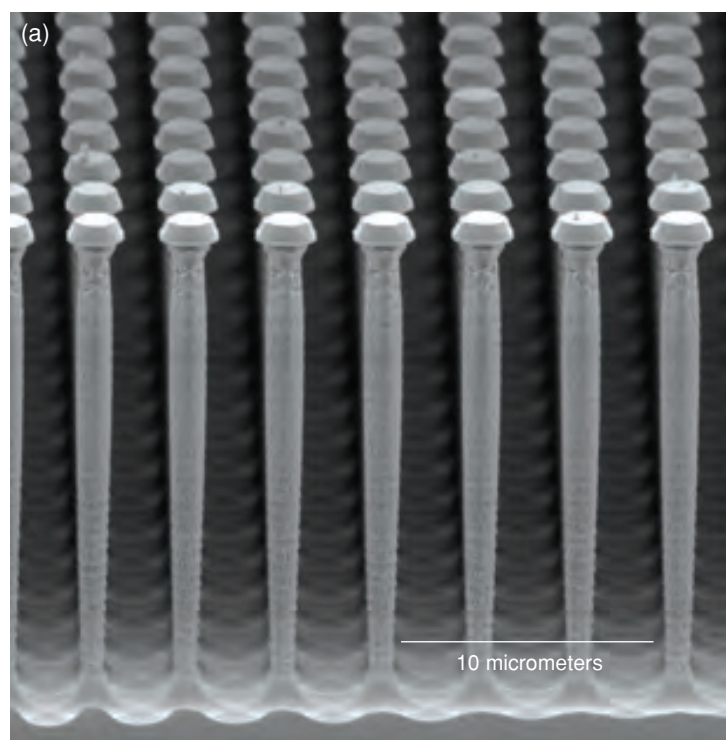
The retinal prosthesis consists of a microelectrode array embedded in a polymer substrate. CMNT is fabricating a 240-electrode array that will serve as the interface between an electronic imaging system and the retinal tissue. The array, which sits on top of the retina, uses electrical impulses to stimulate the retinal tissue. Therefore, the device must be very small and compatible with biological tissue.

Researchers at Argonne National Laboratory are using an ultrathin coating called ultrananocrystalline diamond, which they developed for use on microchips, to package a complementary metal oxide semiconductor chip onto the electrode. North Carolina State University is modeling the prosthesis, and Los Alamos National Laboratory is conducting experiments to ensure that all components are thermally safe to the retina. Elias Greenbaum tests the implants at Oak Ridge National Laboratory to determine their biocompatibility.

Wen Tai Liu, an engineer at the University of California at Santa Cruz, designed wireless radio-frequency communication to connect the implant to external equipment. This innovative system includes a video camera that sits on eyeglasses and transmits images to the implant. Mark Humayan, a retinal surgeon and biomedical engineer at the University of Southern California's Doheny Eye

Grayscale lithography can be used to fabricate microdevices with various three-dimensional shapes, such as the rounded and tapered lens-type features shown here.





(a) The etched silicon pillars used in the pillar detector are 20 micrometers in height and spaced about 2 micrometers apart. (b) In a thermal neutron detector, incoming neutrons interact with the pillars within a semiconductor matrix.

Institute, is developing procedures to implant the device.

The team plans to test a prototype device in June 2007. If additional funding can be acquired, they want to expand the array to 1,000 electrodes.

Etching in Three Dimensions

One technology that may benefit future versions of the retinal prosthesis is grayscale lithography—a technique for creating a three-dimensional (3D) microstructure. Conventional photolithography produces a two-dimensional (2D) structure from a silicon wafer. The wafer is coated with a light-sensitive material called a photoresist and patterned with a photomask. When ultraviolet light is sent through the mask, it exposes parts of the wafer. Chemical etching is then used to reveal the pattern created by the photomask.

Light exposure in the 2D process is all or nothing, so photoresist features have a uniform height. Grayscale lithography allows researchers to adjust the light's intensity, resulting in 3D photoresist profiles with a variety of shapes. After chemical etching, the profiles can be transferred to a substrate. CMNT engineer Chris Spadaccini is exploring the technique's potential for devices such as micro-optics and targets for physics experiments as well as for other types of 3D structures such as the retinal prosthesis. Spadaccini says, "Grayscale lithography opens up many possibilities in microfabrication because we don't have to design in 2D."

Spadaccini joined the Laboratory in 2004 to extend his experience from aerospace propulsion and power. He is also using CMNT's capabilities to develop nanostructured thermoelectric devices

that can work as power sources in sensors and as coolers in biodetection systems. Thermoelectric devices convert thermal energy into electrical energy to generate power. They also can operate in reverse, using electrical energy to move heat for cooling. These systems have a longer lifespan than conventional electrical power generation and cooling methods, they produce no gaseous emissions, and they are highly reliable. However, they typically have low efficiency, which limits their use in field applications.

Spadaccini and his collaborators in the CMLS and PAT directorates want to solve this problem so thermoelectric devices can be adapted for homeland security applications. The team's concept is to design composite material of carbon nanotubes and polymers that will improve electron transport while simultaneously

blocking phonon transport. “Research shows that carbon nanotubes dispersed in polymer matrices form highly conductive electrical networks while retaining the thermal properties of the polymer material,” says Spadaccini. “Powering micro- and nanoscale sensors for homeland security applications is a challenging problem. Many conceptual ideas have been proposed, but none has been adequately developed yet.”

Coin-Size Neutron Detector

An important homeland security effort is developing systems to detect threat sources of nuclear or radiological materials. Detectors to be used in the field have special requirements. They must operate efficiently at ambient temperature and be small enough for use in covert operations. They also must be inexpensive and robust so they can be widely deployed with minimal maintenance. Because nuclear materials emit both gamma rays and neutrons, Livermore is designing devices that can detect the signatures of both. (See the highlight on pp. 6–7.)

To meet all of these needs, engineers are modifying the detector technology currently available. For example, many gamma-ray detectors are cooled with liquid

nitrogen, which significantly increases the system’s size. Neutron detectors used in the field typically have tubes filled with helium gas. These instruments are large, require high voltage to operate, and are sensitive to vibration.

With funding from Livermore’s Laboratory Directed Research and Development (LDRD) Program, CMNT engineer Rebecca Nikolic and Tzu-Fang Wang from CMLS are using microscale materials to fabricate a high-efficiency thermal neutron detector. Thermal neutrons are more easily absorbed than high-energy neutrons, and their energy level is similar to that of molecules in a room-temperature gas. Thus, a thermal neutron detector can operate at room temperature. The challenge for Nikolic and Wang is improving the system’s efficiency.

A typical thermal neutron detector has a 50-millimeter-diameter vacuum tube filled with helium gas and operates with about 1,000 volts of power. In laboratory experiments, its detection efficiency is greater than 70 percent. Efficiency drops to about 20 percent in smaller instruments designed for field applications because adjustments are needed to make the helium-tube equipment more stable for long-term deployment.

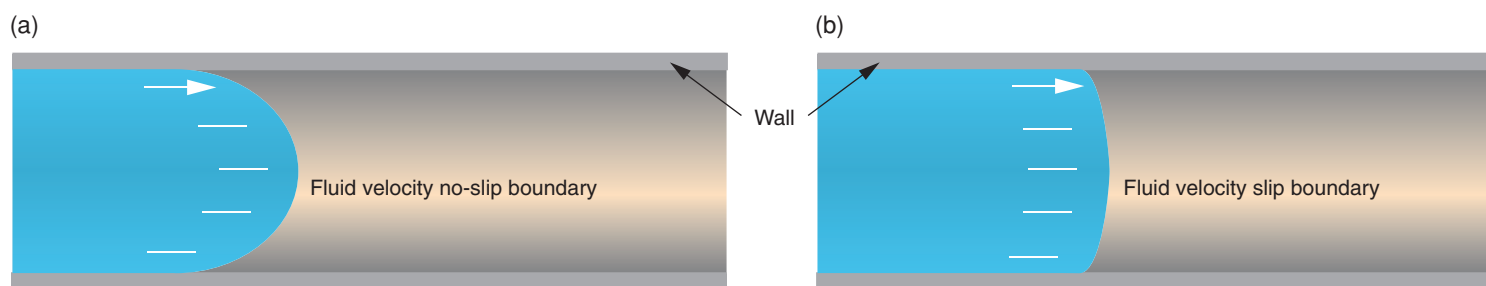
The Livermore team has designed a device called the pillar detector that offers at least twice the efficiency of conventional thermal neutron detectors used in the field. Instead of helium, the pillar detector relies on a carefully constructed platform of etched silicon pillars interspersed with boron.

Incoming neutrons interact with the boron to produce alpha particles. The alpha particles, in turn, interact with the semiconductor and create the current that provides the electronic signal.

According to Nikolic, the 3D structure of the detector maximizes the capture of neutrons. “We can adjust the pillar etch depth to provide a thicker boron layer for high neutron capture,” she says. “We can also adjust the spacing between the pillars so the alpha particles don’t have to travel far, which provides the device with high efficiency.” Project collaborators from the University of Nebraska at Lincoln are using chemical vapor deposition to apply the boron layer. The team plans to have a prototype device ready for testing at the end of this year.

Fluid Flow at the Nanoscale

Biological pathogens pose another significant threat to the nation. In the early



(a) A continuum model of fluid velocity treats particles uniformly and assumes that particles traveling near a channel wall have zero velocity, or no slip.

(b) A particle-based model can more accurately simulate micrometer-size channels because it allows particles near the wall to exhibit slip and not slow to zero velocity.

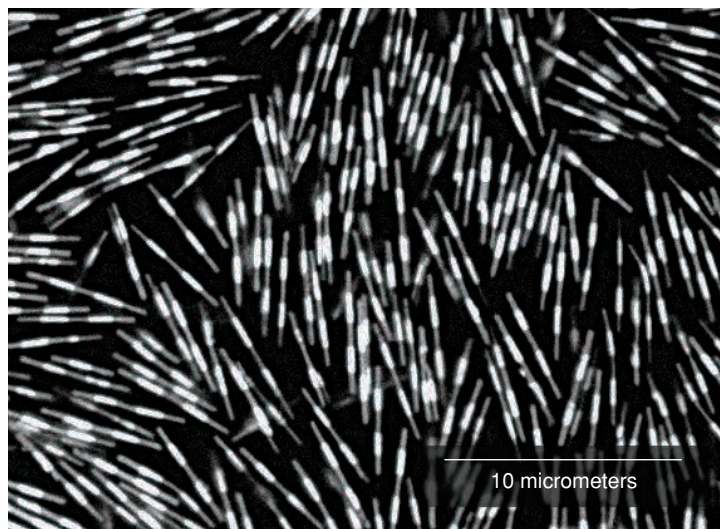
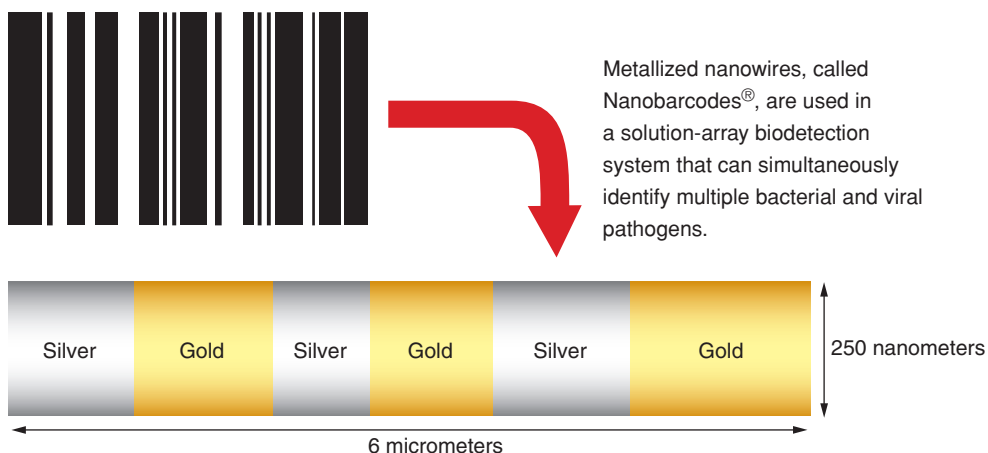
1990s, CMNT responded to this growing threat by developing microfluidic detection devices that could identify microbes. (See *S&TR*, December 2001, pp. 4–11.)

To help design the microfluidic devices, CMNT engineer Todd Weisgraber has developed new methods to simulate fluid transport in these devices. Traditional simulations of fluid flow use a continuum model. Continuum models assume that fluid properties and velocity vary independently from the movement of individual molecules. Such assumptions can distort a simulation of flow in micrometer- or nanometer-size geometries, where channels are only a few molecules wide.

“Fluid moving through very small channels can exhibit different behavior than it does in larger geometries,” says Weisgraber. For example, a gas flowing in a micrometer-size channel exhibits slip—that is, the fluid velocity at the walls of the channel does not slow to zero. In the continuum model, fluid at the wall has zero velocity, an assumption researchers refer to as the no-slip condition.

Particle-based simulations are effective at capturing noncontinuum behavior, but they require more intensive computational resources. “Instead of the particle-based approach, we’re modifying our continuum models to incorporate noncontinuum effects in a computationally efficient manner,” says Weisgraber.

In an LDRD project, Weisgraber and chemical engineer David Clague simulated gas flows in 1-micrometer-wide channels. Building on the results of their research, Weisgraber is developing a particle-based physical model called direct simulation Monte Carlo to examine flow in microchannels measuring 100 micrometers long and 1 micrometer wide. The results will help the team



In a solution-array biodetection system, bar-coded particles can be viewed using image processing software and a standard optical microscope.

improve their continuum codes to incorporate noncontinuum behavior.

Bar-Coded Particles

LDRD funded another CMNT effort led by materials scientist George Dougherty to demonstrate a solution-array biodetection system that uses bar-coded particles. The multiplexed assay builds on the particle-based solution array developed for Livermore’s Autonomous Pathogen Detection System

(APDS). (See *S&TR*, January/February 2002, pp. 24–26; October 2004, pp. 4–5.)

A major advantage of particle-based solution arrays over conventional biomarker systems that use 2D microarray chips is that they can simultaneously target multiple types of markers (DNA, RNA, or protein). And because the particles are in solution rather than fixed on a chip, they have greater interaction with potential threat agents,

allowing faster results. In the APDS array, polymer beads are coated with antibodies, and each microbead is colored according to the type of agent it detects. Dougherty and CMLS biochemist Jeff Tok used fabrication techniques developed at CMNT to combine APDS technology with Nanobarcodes[®], which are developed by the team's industrial partner, Oxonica, Inc. (formerly Nanoplex Technologies, Inc.).

Nanobarcodes are metallized nanowires approximately 250 nanometers in diameter and 6 micrometers long and composed of alternating segments of silver, gold, or other metals. Electrodepositing the metals within porous alumina templates produces striping patterns similar to the bar codes on merchandise.

Dougherty and Tok use a multistep process to fabricate the microfluidic card for the miniature system. First, a polymer layer is cast onto a patterned mold, which is then bonded to a glass substrate to form liquid microchannels. Particles in the solution are coated with a special compound to prevent them from aggregating. The molecules of this compound self-assemble and bind to the surface of the Nanobarcodes. The exposed ends of the molecules are chemically treated so that particles will

have a biochemical affinity for a specific antibody. To ensure that particles do not overlap as they flow through the device, the team devised a technique to lithographically etch parallel grooves into the surface of the glass substrate, aligning the particles for easy viewing.

Particles traveling within microscopic channels are subject to several physical forces, which researchers can exploit to move particles of interest within the channels for further study. Dougherty's team, which includes Livermore engineer Klint Rose, collaborated with professor Juan Santiago's group at Stanford University on experiments to determine optimal approaches for moving particles in the device.

The particles are examined with image processing software and a standard optical microscope. The assay panel used in developing the system includes four particle patterns, which represent possible bacterial, viral, and biotoxin threats. In a demonstration project, the system successfully detected multiple agents simultaneously.

A Road Map for Innovation

Many CMNT researchers such as Dougherty have experience in multiple disciplines. These skills are

valuable in the center's collaborative efforts, whether these are projects with colleagues at Livermore or with external partners. Krishnan notes, "One of the Laboratory's goals is to recruit experts for new science and technology areas and connect them to the ongoing programmatic work."

Part of Krishnan's responsibility as the center's director is to establish a technology road map that prioritizes future developments and factors in the cost and lead time necessary to demonstrate novel technologies. CMNT's talented staff and unique fabrication facilities promise innovative solutions to a wide range of national security problems for years to come.

—Gabriele Rennie

Key Words: Center for Micro- and Nanotechnology (CMNT), deformable mirror, grayscale lithography, microelectrode array, microelectromechanical systems (MEMS), microfluidic device, microresonator, Nanobarcodes[®], nanolaminate, photonics, pillar detector, retinal prosthesis, thermal neutron detector.

For further information contact
Anantha Krishnan (925) 423-9497
(krishnan8@llnl.gov).

Patents

Adaptable Radiation Monitoring System and Method

Daniel E. Archer, Brock R. Beauchamp, G. Joseph Mauger, Karl E. Nelson, Michael B. Mercer, David C. Pletcher, Vincent J. Riot, James L. Schek, David A. Knapp

U.S. Patent 7,064,336 B2

June 20, 2006

This portable radioactive-material detection system can detect radioactive sources moving at high speeds. The system has at least one detector that can detect gamma radiation coupled to a multichannel analyzer (MCA). The MCA can collect spectral data in time bins of less than about 150 milliseconds. A computer processor connected to the MCA determines whether a triggering event has occurred. Spectral data are stored on a data storage device, and a power source supplies power to the detection system. The system may be adapted for various radiation detection scenarios. In one embodiment, the computer processor operates as a server that receives spectral data from other networked detection systems and communicates the collected data to a central data reporting system.

Radiation Detection System for Portable Gamma-Ray Spectroscopy

Mark S. Rowland, Douglas E. Howard, James L. Wong, James L. Jessup, Greg M. Bianchini, Wayne O. Miller

U.S. Patent 7,064,337 B2

June 20, 2006

A portable apparatus has a gamma-ray detector encapsulated by a compact isolation structure with at least two volumetrically nested enclosures, at least one of which is a thermal shield. The enclosures are suspension-mounted to each other to successively encapsulate the detector without structural penetrations through the thermal shields. A low-power cooler can cool the detector to cryogenic temperatures without consuming cryogenics. The heat load is reduced by the isolation structure and the reduction in power requirements of the cooler. The apparatus also includes a lightweight portable power source, which reduces the device's weight to enable portability and handheld operation.

Aerodynamic Drag Reduction Apparatus for Gap-Divided Bluff Bodies such as Tractor-Trailers

Jason M. Ortega, Kambiz Salari

U.S. Patent 7,073,845 B2

July 11, 2006

This apparatus reduces the aerodynamic drag of a bluff-bodied vehicle in a flow stream, such as a tractor-trailer with a leading portion, a trailing portion, and a gap between the two defining a recirculation zone. The apparatus is preferably a baffle assembly, such as a vertical panel, adapted to span the gap between the leading and trailing portions and thus impede cross flow through the gap. The span of the baffle assembly adjusts automatically for variations in the gap width when the leading and trailing portions pivot relative to each other.

Photothermal Imaging Scanning Microscopy

Diane Chinn, Christopher J. Stolz, Zhoulung Wu, Robert Huber, Carolyn Weinzapfel

U.S. Patent 7,075,058 B2

July 11, 2006

Photothermal imaging scanning microscopy produces a rapid, thermal-based, nondestructive characterization apparatus. In addition, a photothermal characterization method can distinguish the surface and subsurface features of meter-size optical materials with micrometer- and nanometer-scale spatial resolution.

High-Throughput, Dual Probe Biological Assays Based on Single Molecule Detection

Christopher W. Hollars, Thomas R. Huser, Stephen M. Lane, Rodney L. Balhorn, Olgica Bakajin, Christopher Darrow, Joe H. Satcher, Jr.

U.S. Patent 7,076,092 B2

July 11, 2006

This apparatus has the sensitivity to detect and identify single target molecules through the localization of dual, fluorescently labeled probe molecules. A target can be attached to a surface or in a two-dimensional flowing fluid sheet that is approximately $0.5 \times 100 \times 100$ micrometers. This device offers 10^3 to 10^4 greater throughput than previous one-dimensional microstream devices with interrogation volumes of 1 cubic micrometer. It would allow for the first time immunoassays and DNA assays at femtomolar concentrations to be performed in short periods (about 10 minutes). Novel labels such as metal or semiconductor nanoparticles may be used to extend the sensitivity, possibly into the attomolar range.

Passive Magnetic Bearing for a Motor-Generator

Richard F. Post

U.S. Patent 7,078,838 B2

July 18, 2006

Conductive lap windings are interleaved with conventional loops in the stator of a motor-generator. The rotor provides magnetic induction lines that, when rotated, cut across the lap windings and the loops. When the rotor is laterally displaced from its equilibrium axis of rotation, its magnetic lines of induction induce a current in the interleaved lap windings. The induced current interacts with the rotor's magnetic lines of induction in accordance with Lenz's law to generate a radial force that returns the rotor to its equilibrium axis of rotation.

Amphiphilic Mediated Sample Preparation for Micro-Flow Cytometry

David S. Clague, Elizabeth K. Wheeler, Abraham P. Lee

U.S. Patent 7,081,227 B2

July 25, 2006

This flow cytometer includes a flow cell with an oil phase and a water phase, an oil-water interface between the two phases, and a device for detecting the sample at the oil-water interface. A hydrophobic unit is connected to a sample and placed in an oil and water combination. The sample is detected at the interface between the two phases.

Diode Pumped Alkali Vapor Fiber Laser

Stephen A. Payne, Raymond J. Beach, Jay W. Dawson, William F. Krupke

U.S. Patent 7,082,148 B2

July 25, 2006

This apparatus produces near-diffraction-limited laser light, or amplifying near-diffraction-limited light, in diode-pumped alkali vapor photonic-band-gap fiber lasers or amplifiers. Laser light is both substantially generated and propagated in an alkali gas instead of a solid, to circumvent the nonlinear and damage limitations of conventional solid-core fibers. Alkali vapor is introduced into the center hole of a photonic-band-gap fiber, which can then be pumped with light from a pump laser and operated as an oscillator with a seed beam. The fiber also can be configured as an amplifier.

Dedicated Heterogeneous Node Scheduling Including Backfill Scheduling

Robert R. Wood, Philip D. Eckert, Gregg Hommes

U.S. Patent 7,082,606 B2

July 25, 2006

This system is designed to perform job backfill scheduling of dedicated heterogeneous nodes in a multinode computing environment. Heterogeneous nodes are grouped into homogeneous node subpools. For each subpool, a free node schedule (FNS) is created so that the number of free nodes can be charted over time. For each prioritized job, the FNS indicates the subpools that have nodes usable by a particular job and then determines the earliest time range (ETR) that a job can be run. Once ETR is determined for a particular job, the job is scheduled to run. If the ETR for a lower priority job (LPJ) is earlier than that for a higher priority job (HPJ), the LPJ is scheduled in the ETR provided that doing so would not

disturb the anticipated start times of any HPJ previously scheduled for a future time. Thus, efficient utilization and throughput of such computing environments may be increased by using resources that would otherwise remain idle.

Nano-Ceramics and Method Thereof

Joe H. Satcher, Jr., Alex Gash, Randall Simpson, Richard Landingham, Robert A. Reibold

U.S. Patent 7,087,544 B2

August 8, 2006

This method produces ceramic materials using the solgel process. Intimate homogeneous dispersions of materials can be prepared while controlling the size of one component within another. The method also can be used to prepare materials that will densify at reduced temperature.

Awards

Livermore plasma physicists **Max Tabak** and **Scott Wilks** along with two physicists from Japan and one from Great Britain received the **2006 Award for Excellence in Plasma Physics Research** from the **American Physical Society**. The recipients are cited “for developing the fast ignition inertial fusion concept and for demonstrating key aspects of it in a series of experiments that have catalyzed the worldwide effort on the concept.” Fast ignition, a technique for developing fusion energy, optimizes laser energy by giving a target a preliminary burst of laser energy followed by second shorter burst that ignites the resulting plasma.

Livermore retiree **Mike Uzelac**, who previously served as director of the Conflict Simulation Laboratory, was honored by the **Department of Defense** for his contributions to the Joint Conflict and Tactical Simulation (JCATS) software. JCATS is a high-resolution conflict simulation model that is widely used to train for combat operations. Richard Wightman, deputy commander of the Joint Forces Command, presented Uzelac with several mementos, including a framed U.S. flag that had flown over the Joint Forces Command Headquarters and commemorative CDs containing the first version of JCATS, which was delivered to the military in 1997, and version 7.1, which was delivered in 2006. The **Secret Service** also recognized Uzelac for the contributions made by JCATS to the service’s mission.

Former Laboratory postdoctoral researcher **Wendelin Wright** and Livermore collaborator **Michael Zingale** received **Presidential Early Career Awards for Scientists and Engineers** (PECASE). Wright, who is now a professor at Stanford

University, was cited “for research into the deformation and failure of metals and polymers under dynamic loading using high-speed and spatially resolved infrared measurements of temperature, for guidance and leadership of fellow researchers, and for her exceptional ability to communicate difficult technical concepts to colleagues and students.” Zingale, an assistant professor at Stony Brook University, was cited “for advancing the detailed simulation of turbulent combustion and demonstrating parallel, multi-physics methods used in national security-related applications, for pioneering collaborations with fellow researchers, and for training students in computational astrophysics.” Wright and Zingale are among 56 researchers to receive PECASE awards. They also received the **Early Career Scientist and Engineer Award** from the **Department of Energy’s Office of Defense Programs**.

Livermore researchers **Jim Trebes** and **Mike Newman** are part of a research team that received the **U.S. Army’s Ten Greatest Inventions for 2005** for developing an around-the-clock surveillance technology to track terrorists and protect U.S. military forces. The team also includes researchers from the Army’s Program Management for Robotics and Unmanned Sensors, the U.S. Army Research Laboratory, and Lockheed Martin Corporation. The Army gives these awards to recognize technologies that improve Army capabilities, demonstrate inventiveness, and have potential use outside the Army. The surveillance technology, which was deployed in Iraq in October 2004, helps U.S. forces prevent terrorist attacks, capture terrorists, and discover weapons caches.

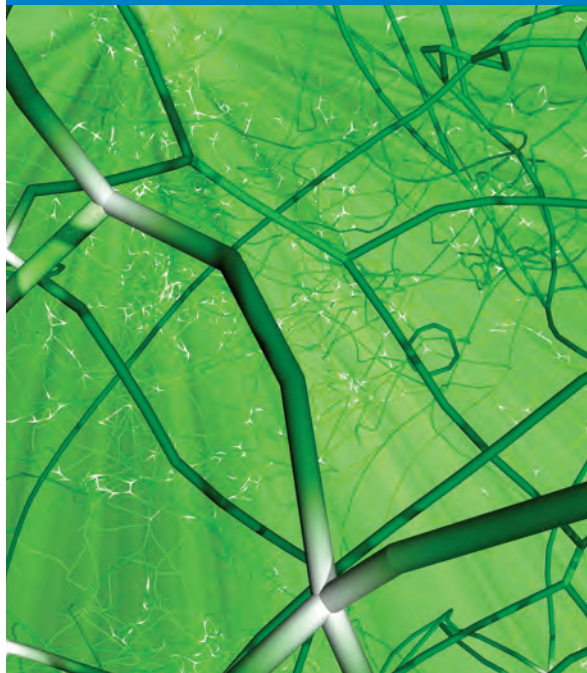
Tailor-Made Microdevices Serve Big Needs

Engineers at Livermore's Center for Micro- and Nanotechnology (CMNT) are inventing and fabricating a range of micro- and nanoscale technologies for Laboratory and commercial needs. One team is exploring designs for optical analogs of traditional electronic devices such as switches, transistors, oscilloscopes, and streak cameras. CMNT researchers are also developing the first deformable mirrors that use lightweight nanolaminate foils instead of glass for space-based and terrestrial telescopes. Other center researchers are fabricating a 240-microelectrode array for a retinal prosthesis to treat diseases such as macular degeneration and retinitis pigmentosa. The CMNT's micro- and nanofabrication capabilities are also being used to develop technologies for homeland security applications, such as a high-efficiency thermal neutron detector the size of a coin and a solution-array biodetection system that uses barcoded particles. To improve the design of microfluidic devices, the center's engineers are developing new methods to model fluid transport through microchannel devices.

Contact:

Anantha Krishnan (925) 423-9497 (krishnan8@llnl.gov).

The Power of Thunder



Lawrence Livermore's Thunder supercomputer allows researchers to model systems at scales never before possible.

Also in November

- *A new system called ICE is helping analysts find important but often obscure image details.*
- *Laboratory researchers are trying to determine why oxygen is a key to evolution.*
- *A Livermore scientist finds that hitting a crystal with a sharp mechanical shock will produce laserlike light.*

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