PHOTONICS
spectra

May / 2010

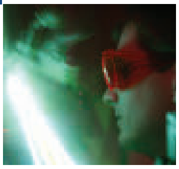
LASERS AT 50

Life Before and After the Birth of the Laser

PHOTONICS spectra

May | 2010

t | TABLE OF CONTENTS



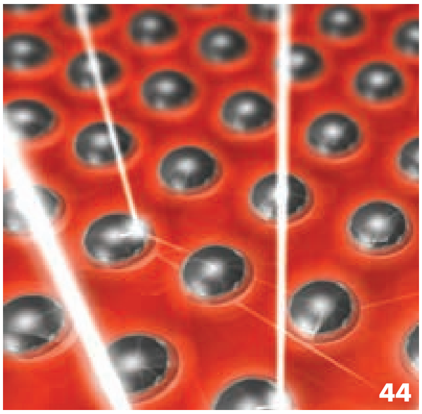

NEWS & ANALYSIS

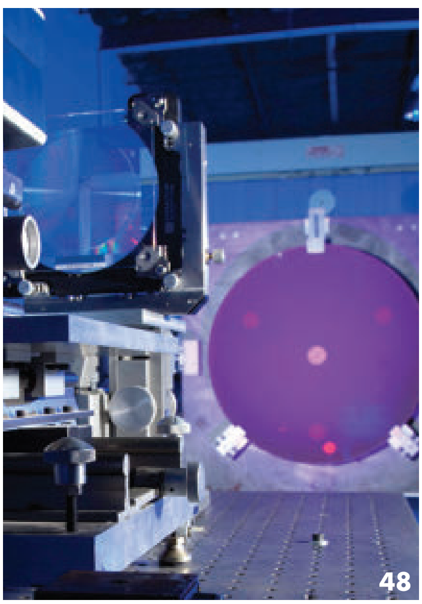
DEPARTMENTS

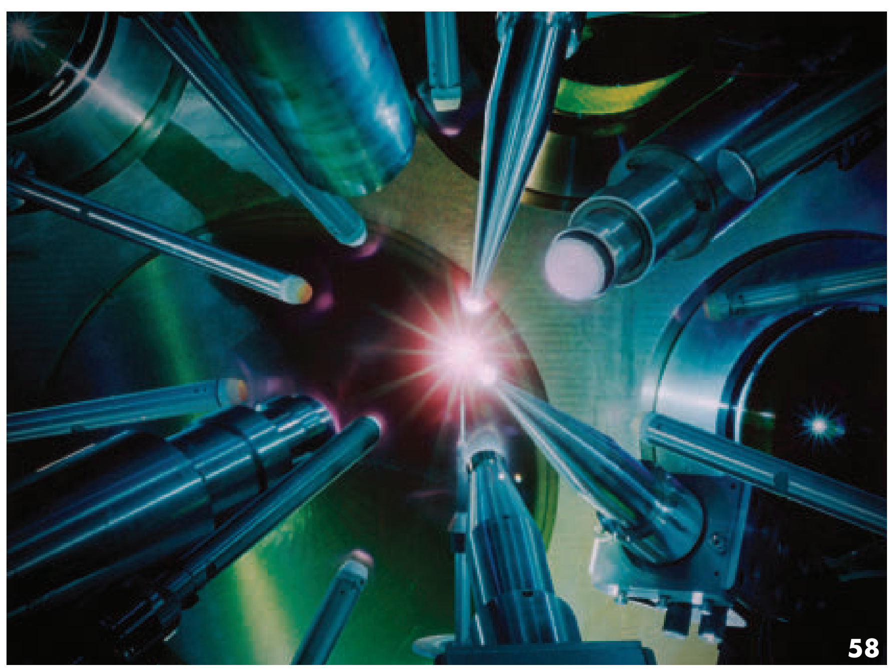
THE COVER
Pictured is the original ruby laser. Photo courtesy of HRL Laboratories LLC. Colorized by Senior Art Director, Lisa N. Comstock.

FEATURES

LASERS AT 50



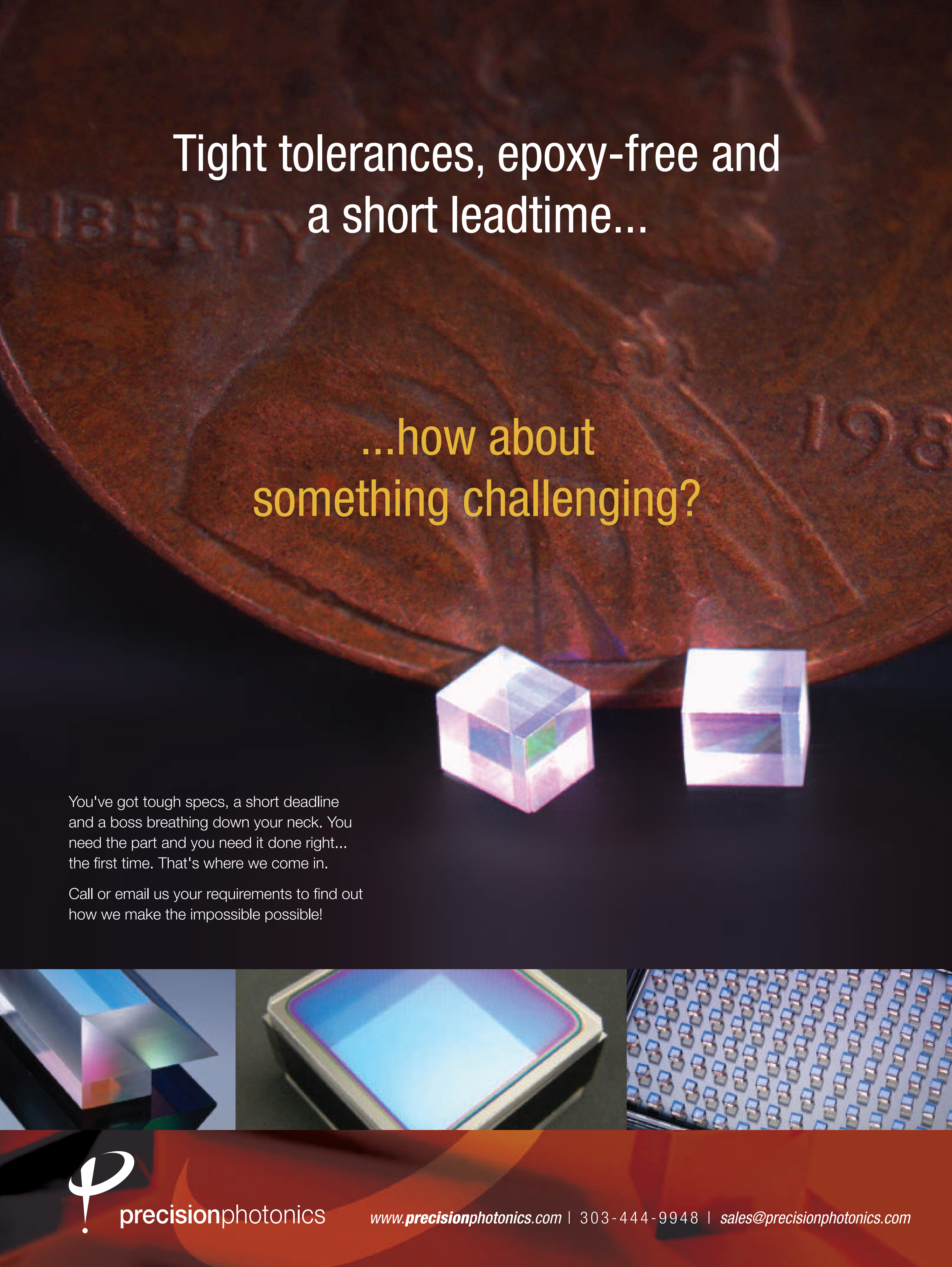




PHOTONICS SPECTRA (USPS 448870) IS PUBLISHED MONTHLY BY Laurin Publishing Co. Inc., Berkshire Common, PO Box 4949, Pittsfield, MA 01202, +1 (413) 499-0514; fax: +1 (413) 442-3180; e-mail: photonics@laurin.com. ISSN-0731-1230. TITLE reg. in US Library of Congress. Copyright ® 2010 by Laurin Publishing Co. Inc. All rights reserved. Copies of Photonics Spectra on microfilm are available from University Microfilm, 300 North Zeeb Road, Ann Arbor, MI 48103. Photonics Spectra articles are indexed in the Engineering Index. POSTMASTER: Send form 3579 to Photonics Spectra, Berkshire Common, PO Box 4949, Pittsfield, MA 01202. Periodicals postage paid at Pittsfield, MA, and at additional mailing offices. **CIRCULATION POLICY:** Photonics Spectra is distributed without charge to qualified scientists, engineers, technicians, and management personnel. Eligibility requests must be returned with your business card or organization's letterhead. Rates for others as follows: $122 per year, prepaid. Overseas postage: $28 surface mail, $108 airmail per year. Inquire for multiyear subscription rates. Publisher reserves the right to refuse non-qualified subscriptions. **ARTICLES FOR PUBLICATION:** Scientists, engineers, educators, technical executives and technical writers are invited to contribute articles on the optical, laser, fiber optic, electro-optical, imaging, optoelectronics and related fields. Communications regarding the editorial content of Photonics Spectra should be addressed to the managing editor. Contributed statements and opinions expressed in Photonics Spectra are those of the contributors – the publisher assumes no responsibility for them.

PHOTONICS spectra

www.photonics.com



Tight tolerances, epoxy-free and a short leadtime...
...how about something challenging?
You've got tough specs, a short deadline and a boss breathing down your neck. You need the part and you need it done right... the first time. That's where we come in.
Call or email us your requirements to find out how we make the impossible possible!
precisionphotonics
www.precisionphotonics.com | 303-444-9948 | sales@precisionphotonics.com

PHOTONICS spectra

www.photonics.com

Unique Applications... "Custom" Solutions.

You might have noticed that Power Technology, Inc. uses the phrase "putting the 'custom' back in customer" in tandem with our company logo. That phrase is not only an integral part of our corporate identity, but is an undeniable factor of our almost 40 years of success within the photonics industry. With wavelengths ranging from 370 – 1600nm, output powers from 1mW – 7W, and both CW and pulsed power offerings, thousands of laser solutions are made available to our customers. Let Power Technology, Inc. produce a custom laser solution for your unique application.

Fiber Coupled for Clean Beam Output

Microprocessor Controlled for Maximum Control and Monitoring

Compact Units for Space-Constrained Applications

Temperature Control for Ultimate Wavelength and Power Stability

Dual Beam Combining for Added Wavelength and Power Flexibility

Power Technology Incorporated

Putting the "custom" back in "customer"

P.O. Box 191117
Little Rock, AR 72219-1117
Phone: 501.407.0712
Fax: 501.407.0036
www.PowerTechnology.com
Email: sales@PowerTechnology.com

Fifty years and counting …

Looking back through photo albums, parents and relatives can "ooh" and "aah" over a baby's milestones long after the baby has grown up, graduated from college, gotten married and had babies of his or her own.

This month marks a very important birthday for the laser: On May 16, 1960, Hughes Research Laboratories physicist Theodore H. Maiman demonstrated the first ruby laser.

Fifty years after that first demonstration, lasers are everywhere – they are used in everything from communications to weapons, from manufacturing to sensing and more; that first ruby laser has spawned a whole family of technologies and lent itself to previously unimagined applications.

As the technology began to blossom, *Photonics Spectra* (then *Optical Spectra*) covered its evolution from laboratory oddity with devices that filled a whole room to the far more compact workhorse it is today.

To celebrate this major anniversary, we at *Photonics Spectra* have planned a three-month blowout. This month, we'll look back at the laser's humble beginnings and explosive growth over the years. In the June issue, we will explore the ways in which new companies, safety standards, applications and innovations have developed in the past 50 years. In the July issue, we will examine Ti:sapphire and fiber lasers in depth, and we will follow the history of the Laser Institute of America and look ahead at where the technology is likely to go in the next half-century. And on Photonics.com, you can find an interactive timeline of the key events and figures in the laser's history.

In "A History of the Laser: A Trip Through the Light Fantastic" on page 58 of this issue, senior editor Melinda Rose walks us through the important developments in the laser's long and varied history. (A comprehensive timeline of the laser can be found online at www.lasertimeline.com.) In "On the Shoulders of Giants" on page 70, features editor Lynn Savage paints a portrait of the players who helped make the laser what it is today.

Congratulations are in order for the people, institutions and companies who have done so much to develop and advance this history-changing technology, and we hope that all their wishes come true as they blow out those 50th-birthday candles.


Brighter Fiber Solutions
At Nufern our efforts bring you the brightest in:
• Specialty optical fibers
• Industrial fiber lasers
• Sub-assemblies
• Military fiber lasers and amplifiers
• Scientific fiber lasers and amplifiers
Find intelligent fiber, laser and amplifier solutions at www.nufern.com
NUFERN®
FIBER LASERS - SUB-ASSEMBLIES - OPTICAL FIBERS
866.466.0214 | www.nufern.com

PHOTONICS MEDIA

Welcome to the New

photonics.com

Photonics Media's industry-leading site showcases specific areas of interest, such as optics, imaging, displays and lasers.

FEATURES

- News & Analysis
- Explore by Subject
- Product Page
- Industry Event Coverage
- Videos & Photo Galleries
- Monthly Web Exclusives
- Blogs & Community Forums

WEB EXCLUSIVE:

50th ANNIVERSARY OF THE LASER

Explore Photonics Media's interactive timeline of the history of the laser at www.lasertimeline.com. See how laser pioneers have transformed our world over the past 50 years. From the invention of the maser to the first demonstration of the quantum dot laser, take a walk through decades of historic moments that shaped the world of photonics and optics.

Find the latest news and events from around the globe at Photonics.com

In the June issue of

Photonics Spectra . . .

Lasers in LED Manufacturing
Recent laser techniques used for manufacturing LEDs and adequate selection of laser parameters and beam delivery optics allow for a high-quality, high-throughput process.

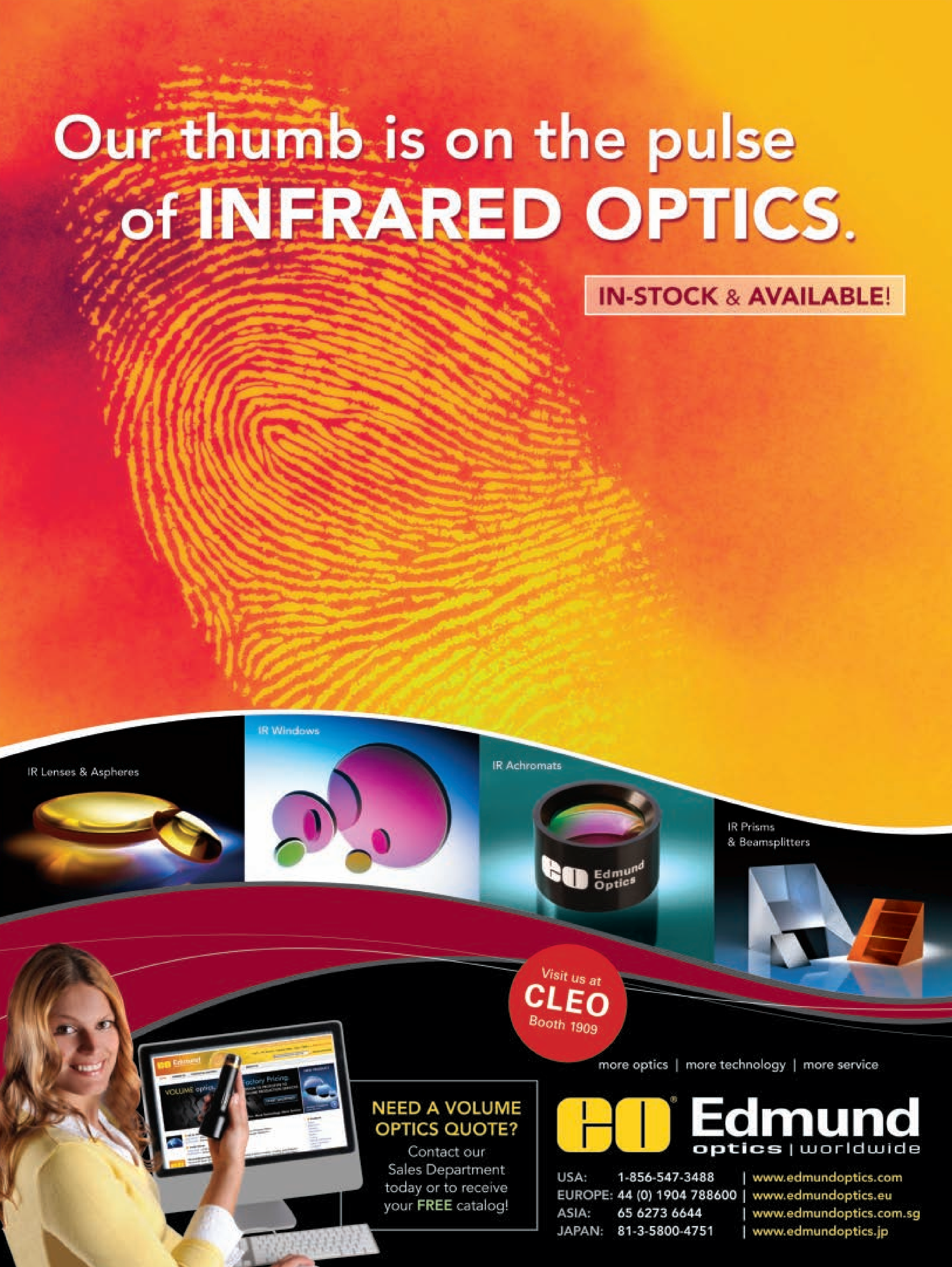
Adaptive Optics to Correct for Wavefront Aberrations
A new approach called "woofer/tweeter" allows for better compensation of large-variance, high-spatial-frequency phase distortion.

GreenLight: A Turning Leaf?
Scientists have presented a design strategy for an "artificial leaf" that captures solar energy and uses it efficiently to change water into hydrogen fuel.

EuroPhotonics: Measurement of Centering Errors, Automated Adjustment and Mounting of Lenses
Electronic collimators and automated adjustment equipment make the lens mounting process quicker and more precise.

You'll also find all the news that affects your industry, from tech trends and market reports to the latest products and media.

Check out a sample of the new digital version of *Photonics Spectra* magazine at www.photonics.com/DigitalSample. It's a whole new world of information for people in the global photonics industry.


Our thumb is on the pulse of INFRARED OPTICS.
IN-STOCK & AVAILABLE!
IR Lenses & Aspheres
IR Windows
IR Achromats
IR Prisms & Beamsplitters
Visit us at CLEO Booth 1909
NEED A VOLUME OPTICS QUOTE?
Contact our Sales Department today or to receive your FREE catalog!
more optics | more technology | more service
Edmund optics | worldwide
USA: 1-856-547-3488 | www.edmundoptics.com
EUROPE: 44 (0) 1904 788600 | www.edmundoptics.eu
ASIA: 65 6273 6644 | www.edmundoptics.com.sg
JAPAN: 81-3-5800-4751 | www.edmundoptics.jp

Bucking the Trend: Offering Greater Value Fuels Growth

BY TERRY L. MOSHIER
REO INC.

The year 2009 was a particularly difficult one for most of the optics industry, characterized by declining revenues and layoffs. But it wasn't all bleak: REO posted a 28 percent gain in sales, and the company has shown a compound annual growth rate of more than 16 percent over the past six years. We are proud of achieving well over $30 million in revenue in 2009. I'd like to share the reasons why we have grown because I believe that our approaches could be adopted by other businesses looking to expand in the current uncertain financial climate.

Founded in 1993, REO manufactures precision thin-film coatings, optics and optomechanical assemblies. Early in the company's history, we decided to focus on producing high-quality superpolished optical surfaces and thin-film coatings, and today we still concentrate exclusively on servicing high-volume OEMs that demand excellent performance. Our primary customers are manufacturers of defense and aerospace systems, laser systems, semiconductor tools, medical systems, life sciences instrumentation and telecom equipment. As is typical in this industry, REO is a privately held company; however, we manage our business and reporting in a public company manner, applying discipline and complete adherence to accounting principles.

One obvious way for any company to increase its sales is to expand the market accessible to it. In our case, that has meant adding coating, fabrication and assembly capabilities so that we can produce a much wider range of products. In the past two years, REO has completed the acquisition and integration of Coherent's Auburn Optics manufacturing operation, which has broadened our potential and taken us into some entirely new areas. In particular, it has brought us equipment and expertise in the fabrication – including diamond turning – of a wide range of infrared materials (such as Ge, ZnSe and ZnS). We have added several coating chambers, increasing our production capacity and further extending our infrared and ultraviolet business. We also gained diverse laser sources that enable us to perform detailed metrology at many wavelengths.

REO also has focused on developing strategic supplier agreements that increase income and establish partnerships with recognized industry-leading companies. Our customer base consists of OEMs and major manufacturing companies, so simply supplying a product that performs as specified at a competitive price is not enough. Our customers' products may be critically dependent on a component we supply, so they need to know that we'll meet their requirements

Above, REO has expanded its coating capabilities to increase volume capacity and to meet a wider range of performance and cost requirements. The company now has 38 coating chambers that use ion beam sputtering, ion-assisted deposition and traditional electron beam evaporative methods.

if volumes increase and that we'll provide the necessary technical support if problems arise. Having agreements with well-known companies gives us an implicit and reassuring endorsement that makes it easier to develop other relationships and that opens the door to a great deal of collaborative innovation, helping us maintain our technology leadership and competitive edge.

It's important to remember that value to customer extends beyond just the product itself. Specifically, REO maintains a large staff of engineers, and the services that the team delivers help us to avoid competing with other vendors solely on price. For example, recently our engineering group, working with a customer who was buying a doublet from us, helped refine the design and turn it into a lower-cost singlet. Although our gross revenue was actually reduced, the cost reduction of the overall system created a much higher-value proposition to the end user, enabling us to maintain significant market share as a first-choice supplier in a competitive area.

Another way for companies that start out as component producers to expand revenue is to move up the value chain by supplying more complex products, assemblies and engineering services. This is a particularly effective approach for an OEM supplier such as REO. It's easier and more cost-effective for us to sell more, or higher-value, products to established customers than it is to find and close business with completely new ones. To this end, we've added to our capabilities for fabricating mechanical parts and for engineering and producing optomechanical assemblies.

Even though we emphasize higher value, we are always looking at creatively lowering cost. For example, the traditional labor-intensive method for producing ultraprecision assemblies involves fabricating lens elements with tight centration tolerances and assembling them in a machined housing. Instead of traditional shim-and-glue techniques, we have developed an assembly system that uses a laser to measure the position of the lens with reference to its housing and a mechanical actuator to adjust the component's position. The most important benefit of this approach is that it reduces the need to hold tight mechanical tolerances for the housing and optics, particularly lens centration, by two orders of magnitude to levels that are easily and quickly reached in normal fabrication processes. The end result is equal assembly performance for a competitive price.

Many optical component manufacturers and coating vendors are feeling tremendous price pressure, especially in the face of low-cost imported products. Focusing solely on shaving off the last penny to come in with the lowest bid is a game that is difficult to win and one that REO doesn't need to play. Instead, we've found that by offering a combination of engineering expertise and highest quality in value-added products to our targeted customer base, we can succeed and thrive, even under difficult market conditions.

Meet the author

Terry L. Moshier is CEO and chairman of REO Inc. in Boulder, Colo.; e-mail: terrym@reoinc.com.

Brighter lights lead to better communications under the sea

FALMOUTH, Mass. – Future oceanographic research could be done more cheaply and efficiently, thanks to a communication innovation powered by the latest LEDs and detectors. Researchers from Woods Hole Oceanographic Institution used these in a demonstration of remote optical communication under water, which they described at the 2010 Ocean Sciences Meeting in Portland, Ore. Unlike acoustic communication techniques that have been the standard, the new approach is fast enough for video.

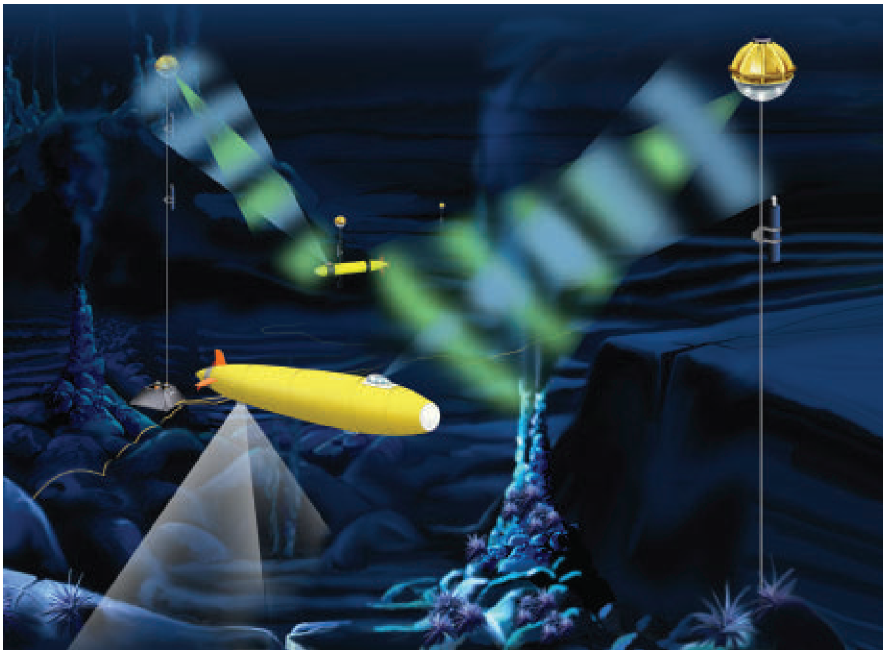
"We've done that, certainly. It's compressed video," said team leader Norman E. Farr. "We can transmit anywhere from, say, 500 kilobits to 15 megabits per second. That's all based on range, rate, power and water clarity."

A senior engineer at Woods Hole, Farr explained that the limit of the optical communication link would be 200 m in clear water. In particulate-laden water, the distance would be less. In either case, the rate would be at the low end of the speed at the extremes in range. At shorter distances between transmitter and receiver, the data rates would be higher.

Typically, underwater communication is done using sound, not light. The acoustic approach offers the advantage of working over great distances. That plus is balanced by slow data rates and transmission, the latter a result of the slow speed of sound in water and the former, of sound's wavelength.

These constraints mean that oceanographic research is done with tethered remote-operated vehicles. The cabling provides video and data connections, but the cost is a more expensive remote vehicle and support ship. Better and faster communication would allow the cable to be cut.

For an optical data link, the Woods Hole team needed a light source in the visible, from about 400 to 500 nm. That's the window for transmission through water. The source had to be low-powered because it would have to run in battery-powered systems. And because of size constraints, it also had to be compact. Finally, it had to be able to be modulated rapidly, as that would determine the maximum data rates possible.



Underwater data communication by light is shown in this artist's conception of how the optical modem could function at a deep-ocean-cabled observatory. Autonomous underwater vehicles (in yellow) collect sonar images (downward bands of light) and other data at a hydrothermal vent site and transmit this through an optical modem to receivers stationed on moorings in the ocean. The moorings connect to a cabled observatory, and the data is sent back to shore. Scientists, in turn, can send new instructions to the vehicles via the optical modem. Illustration by E. Paul Oberlander, Woods Hole Oceanographic Institution.

In developing a solution, the researchers used recently available high-power LEDs. They put these into a hemispherical transmitter, choosing this approach over the alternative of a tight beam because it offered better total performance.

For a receiver, they used photomultiplier tubes, selecting them over avalanche photodiodes because of their sensitivity. They placed bandpass filters before the receiver to suppress everything not in the signal transmission window. As for the rest of the optics, they built these so that the receiver, as with the transmitter, would operate over a hemisphere.

For remotely operated vehicles, communication by light and sound ensures that vessels don't lose contact, Farr said. "As soon as you're outside of the optical hemisphere, you still have acoustic communications, so you can get the vehicle back into high-bandwidth range."

Tests have indicated that the system allows video, an important point, as many of the applications assume a human will be in the loop for control. For example, a pilot might steer a remote vehicle to a location near a hydrothermal vent with the intention of collecting samples and making measurements. To do that, the pilot must be able to see what is going on in real time. In practice, this might be done by having a surface ship on station above the vent, with a line containing an optical transmitter/receiver lowered to about 100 m above the point of interest.

This July, a Woods Hole team will conduct the first large-scale deployment of the system at the Juan de Fuca ridge off the northwestern US. There it will be used to collect and transmit data from wellheads situated near the undersea ridge. Expectations are that the system will last for several years, but part of the reason for the deployment is to test that.

As for the future, Farr noted that longer distances may be possible with brighter LEDs, more sensitive receivers or both. Data rates could go up as well, with higher LED modulation rates.

However, there are limits, he said. “You get to the point where you start to get dispersion because of multipath in the water. But we’re nowhere near that.”

Hank Hogan
hank.hogan@photonics.com

Stacking ‘Lego’ blocks of light

CALGARY, Alberta, Canada – Many of us enjoyed donning our construction hats and building little houses out of Lego blocks when we were young. Now, researchers at the University of Calgary are playing a similar game, but rather than using Legos, they are stacking light particles, which could be an important step on the road to quantum computing.

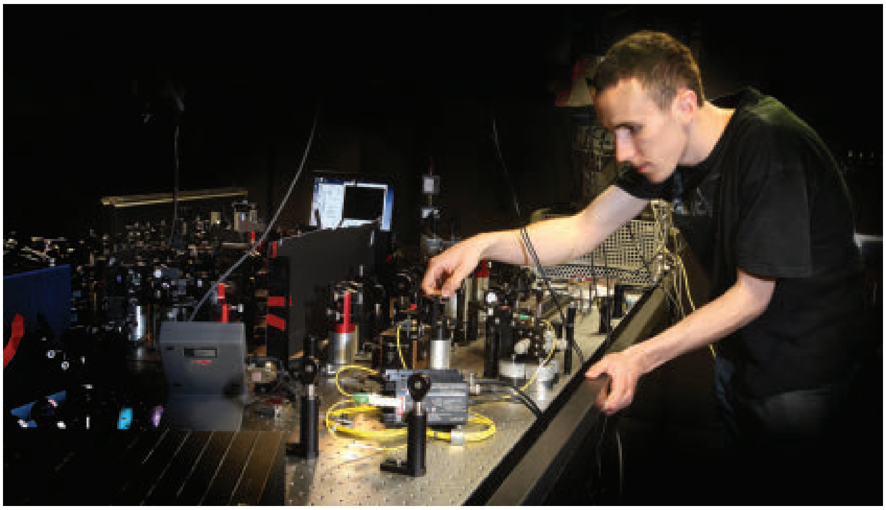
The problem is that working with light particles is notoriously difficult. But the Calgary team has managed to manipulate the quantum properties of light so as to stack two-story quantum houses of any style and architecture.

“Constructing complex quantum entangled systems while maintaining control over their individual components offers unprecedented opportunities for fundamental studies of nature,” said Dr. Alexander Lvovsky, leader of the team. “It also leads to measurement instruments of extraordinary sensitivity, exponentially faster computers, unconditionally secure communication systems and quantum-controlled chemistry.”

Among various physical systems that may be suitable for quantum technological applications, light stands alone as the only one that can serve as a communication agent. The vision of Lvovsky’s research is implementing light as the principal physical medium for quantum information processing.

In his experiments, which are detailed in the February 2010 issue of *Nature Photonics*, arbitrary superpositions of zero-, one- and two-photon states of light are produced. This means that the team has taken a step toward being able to construct any arbitrary quantum state – one of the “holy grails” of quantum information technology. But this was no easy task.

“The degree of control reported in our work has so far been achieved only with other quantum systems – trapped ions and microwave resonators, but not with traveling photons,” Lvovsky said. The previous



Researchers have demonstrated stacking light particles like Lego blocks, which could be an important step on the road to quantum computing. Here, the primary author of the *Nature Photonics* paper, Erwan Bimbard, aligns the experimental setup. Photo by Ron Switzer, courtesy of the Institute for Quantum Information Science at the University of Calgary.

"industry best" in stacking photons was manufacturing superpositions of zero- and one-photon states.

What led to the group's success was a combination of high-intensity parametric down-conversion – which allows multiple photon pairs to be produced from a single laser pulse with a reasonable probability – plus high-bandwidth balanced detection – to measure the states that are produced.

In the setup, mirrors and lenses are used to focus a blue laser beam into a specialized crystal. The crystal takes high-energy blue photons and converts them into a quantum superposition of lower-energy red photons, which emerge in two directions, or "channels." By measuring one of the channels using ultrasensitive single-photon detectors, the team prepared the desired quantum state in the other.

"Such an operation is possible because the photons in the two channels are entangled. This means that a measurement made in one channel would result in an immediate change in the other, regardless of whether the particles were an arm's length apart or light-years away," Lvovsky said. "Albert Einstein called this quantum weirdness 'spooky action at a distance.' "

The researchers' next step is to work on characterizing two basic optical processes: photon creation and annihilation operators. Once this is completed, Lvovsky and his colleagues will experiment with entanglement distillation and also will continue to improve on their technique.

Marie Freebody
marie.freebody@photonics.com

Liquid crystals: Size and shape matter

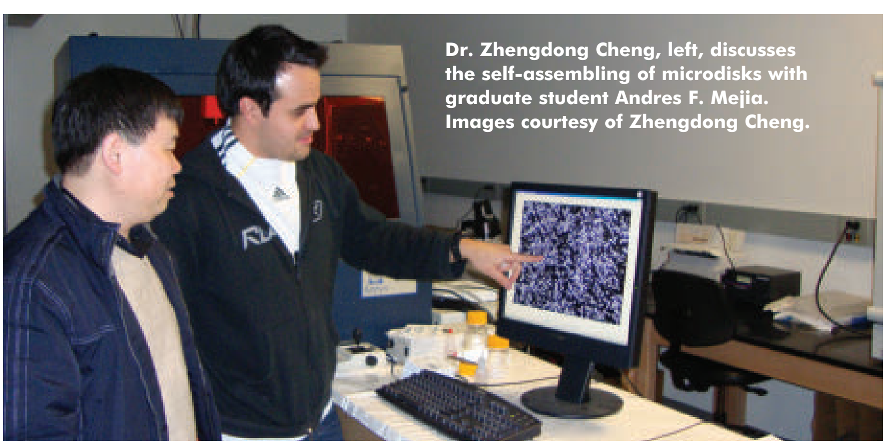
COLLEGE STATION, Texas – When it comes to liquid crystals, scientists at Texas A&M University have discovered that size and shape really matter. Dr. Zhengdong Cheng, an assistant professor of chemical engineering, and his colleagues oriented disk-shaped molecules of liquid crystals into distinct and separate layers for the first time. The achievement could result in more effective industrial sealants, improved food packaging and even enhanced electronic displays.

The molecules used in today's electronic displays are rod-shaped one-dimensional objects, whereas their disk-shaped cousins are two-dimensional and behave very differently. Until now, disk-shaped molecules had never been observed in the form of layers – known as the smectic phase.

It is the discotic smectic phase – several layers of disks stacked together – that Cheng believes will make a better sealant. To illustrate his point, he said that covering a roof with large-size tiles instead of rod-shaped ones provides better coverage.

"If the gaps between tiles in different layers are located in different positions, then it will take longer for water droplets to find ways to penetrate through the layers," he said. "The structure of the discotic smectic phase is similar to the structure of several layers of roof tiles. It offers good barrier properties for paints and food packaging."

The discovery also could be expanded into the field of fuel-cell technology, preventing the problematic methanol cross-



Dr. Zhengdong Cheng, left, discusses the self-assembling of microdisks with graduate student Andres F. Mejia. Images courtesy of Zhengdong Cheng.

over through a polymer electrolyte membrane in fuel cells. These areas – as well as many more that employ liquid crystal technology – stand to benefit from the new finding. For example, liquid crystals are found in soaps and detergents as well as in the proteins and cell membranes within the human body.

Cheng further speculates that future LCD TVs, cell phones and portable gaming devices might boast improved visual properties while being more energy-efficient. This is thanks to the disk-shaped liquid crystal molecules' being easier to manipulate and more sensitive to electric fields than are the rod-shaped liquid crystal molecules currently used in displays.

The trick to manipulating disk-shaped liquid crystal molecules into layers seems to come down to controlling three main molecular properties: thickness, aspect ratio and size. The Texas team found that the molecules had to have identical thickness, a large aspect ratio and polydispersity in size; i.e., a broad size range because uniform-size disks tend to form columnar structures.

In Cheng's experiment, which appeared in the October 2009 issue of *Physical Review E*, each layer is composed of many inorganic crystals with an identical thickness of 2.68 nm and a diameter of approximately 2000 nm. The disks (also referred to as platelets because of their large size-to-thickness ratio) are created by exfoliating crystals of zirconium phosphate into single layers using a positively charged chemical.

The platelet suspensions are left to self-assemble into various phases depending upon their concentrations. "In other words, each individual platelet moves around due to collisions with water molecules and in-

Graduate student Andres F. Mejia, at left, and Shengmei Ye use the UV-VIS spectrometer to investigate the disk suspensions.

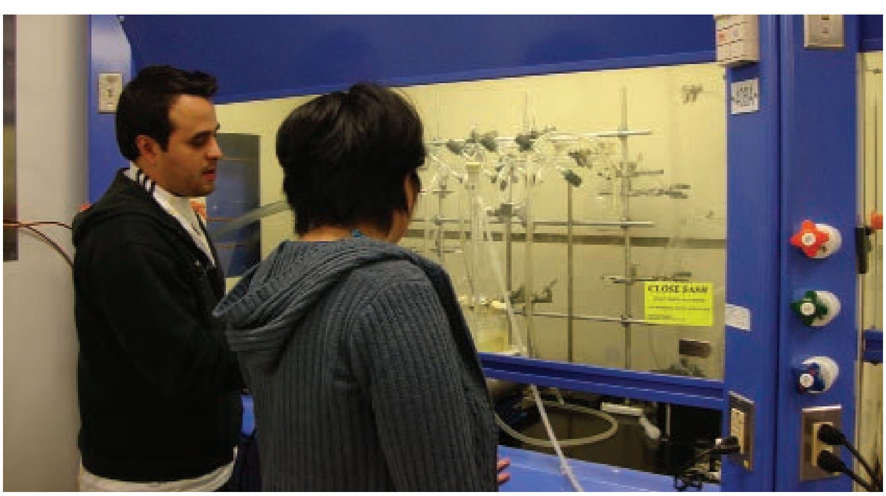
teracts with neighboring platelets," Cheng said. "Given enough time, the sample will find its thermodynamic ground state."

Ground state normally finds the disks aligning into columnlike structures; however, in Cheng's experiment, the disks behaved in an atypical manner, assembling themselves into separate layers.

The next step for Cheng and his collaborators, Dr. Hung-Jue Sue from the department of mechanical engineering at Texas A&M, and Dr. Yuri Martinez-Raton from Universidad Carlos III de Madrid and Enrique Velasco from Universidad Autónoma de Madrid, both in Spain, is to mass-produce the disks.

"We seek industry collaboration to test ideas for practical applications, particularly for photonic applications," Cheng said. "We are testing the response of these disks to electric and magnetic fields, and we hope to develop the next generation of displays using this new discotic liquid crystal phase."

Marie Freebody
marie.freebody@photonics.com



Graduate student Andres F. Mejia, left, and Shengmei Ye discuss nanoparticle synthesis.

Designer molecules promise all-optical processing

ATLANTA – Supporters of all-optical switching say it will allow dramatic speed increases in data communications by eliminating the need to convert photonic signals to electronic signals – and back. All-optical processing – switching light using light – would also facilitate photonic computers, which promise much higher data throughput and speed than electronic processing.

In another step toward all-optical switching, a team at Georgia Institute of Technology has synthesized a material optimized for photonic switching applications. The organic dye material features a combination of large nonlinear properties on the one hand, and low nonlinear and linear losses on the other. Optical media with these features offer the potential to develop all-optical switching devices that require only low switching power but offer high contrast – boosting efforts to realize all-optical computing and communication.

However, big challenges remain for all-optical processing. Switching means manipulating one signal with another. Electrons used for today's electronic processors come with an electrical charge and therefore intrinsically interact with each other, but optical signals – or photons – do not. This lack of interaction has the advantage of supporting parallel transmission of huge amounts of information, but when one light beam has to change another from "on" to "off," such independence is not a plus – at least not by default.

Nevertheless, independent propagation of light waves works only for linear systems, so one way to circumvent the lack of interaction needed for switching is making the medium nonlinear where needed. This way, a nonlinear phase shift (or refractive index change) can be introduced by one beam on another, also known as cross-phase modulation. It has been demonstrated that this works in various switching configurations, such as interferometers (where the phase of one arm is delayed), or microdisk or microring resonators.

Introducing phase shifts in isotropic (noncrystalline) materials requires the so-called third-order nonlinear susceptibility to be large. Finding materials of this type is not a problem in itself, but it usually comes at the cost of high linear and nonlinear losses, which limit the performance of the switch.

This is the problem that the researchers set out to confront. "There are various problems to be solved [finding suitable materials for all-optical switching], but we have decided to tackle the problem by going down the properties of the organic molecules," said Joseph Perry, a professor in the school of chemistry and biochemistry. "We used a mixture of intuitive chemical models and high-performance simulations to crack the problem."

The starting points were carbon-based

polymethine dye molecules, well known for long extension in one direction – and, thus, "being one of the most polarizable molecules we know of." Large polarizability is good, as it is known to give large third-order nonlinearities (susceptibility). On the other hand, large molecular dimensions in one direction mean low-energy one- and two-photon absorption bands, which are not favorable from a linear and nonlinear loss perspective. So the goal for the team at Georgia Tech's Center for Organic Photonics and Electronics, led by Perry and professor Seth Marder, was to increase polarizability – but without making the molecules too long.

Georgia Tech professor Joseph Perry, left, is part of the team that developed a new photonic material that could facilitate all-optical signal processing. Courtesy of Georgia Institute of Technology.

The clue came from two-photon absorption spectra, which exhibit two peaks with a low absorption gap between them – i.e., a window with low loss that can be tuned to match the telecommunications wavelength window, said Perry. To do so, the polymethine molecules were "fitted" with selenium atoms at their ends, which are known to be polarizable themselves. This helped increase the nonlinearity – without increasing the length. As a result, the photon energy of the switched light is smaller than the lowest-lying single-photon transition, while twice this photon energy falls *between* transitions that would excite detrimental two-photon absorption.

Based on this strategy, published in the March 19, 2010, issue of *Science*, the next challenge will be making these molecules suitable for denser packing – as to date they have been studied only in solution. Although spin-coating techniques have been demonstrated, where materials of this type have been applied to other materials to modify their nonlinear properties, the ultimate goal is to incorporate them in a solid phase for use in optical waveguides. Making the molecules suitable for denser operation will be a challenge because their behavior is likely to change if they are densely packed. This will require the molecule designers to make further adjustments, "but evidence from second-order materials shows that this is possible," Perry said.

Dr. Jörg Schwartz
joerg.schwartz@photonics.com

Novel systems detect explosives

MÁLAGA, Spain – The need for technologies that can detect explosives with high sensitivity and from far away is as great as ever. A number of groups are working to develop such technologies.

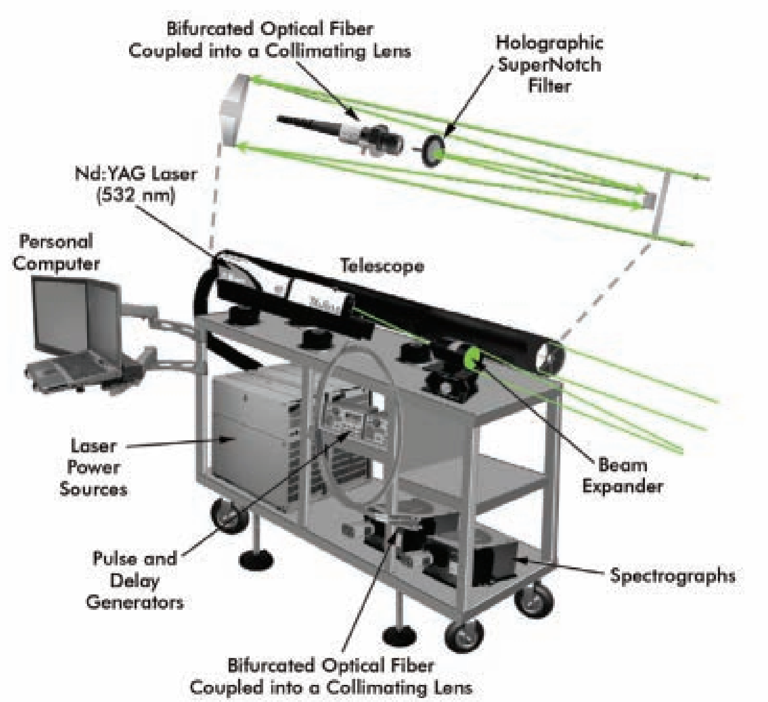
At the University of Málaga, researchers have demonstrated a novel hybrid sensor system that uses Raman spectroscopy and laser-induced breakdown spectroscopy (LIBS) simultaneously for instant and remote standoff analysis of explosives. Combining the atomic sensing of the former with the vibrational spectroscopy of the latter could facilitate the standoff detection of explosives residue in trace quantities – left, for instance, by human fingerprints on car door handles – at distances of up to 50 m.

The system integrates a pair of Andor Shamrock SR303i spectrometers, each fitted with an iStar intensified CCD, a Cassegrain telescope and a Quantel Brilliant Twins Q-switched 532-nm Nd:YAG laser. In the Feb. 15, 2010, issue of *Analytical Chemistry*, the researchers reported simultaneous acquisitions of Raman and LIBS spectra for a variety of explosives, including C4 and H15 (both plastic explosives) and Goma2-ECO (Spanish-denominated dynamite class high explosive).

The hybrid sensor offers an extremely fast response and can operate at relatively long distances, said researcher José Javier Laserna, who led the team that developed it. It is a stand-alone technology and can be controlled remotely using wireless communications. As with other similar devices, a line-of-vision is needed between the sensor and the object in question to ensure effective operation. Research at the university has shown, however, that LIBS can detect explosives through car glass as well as through warehouse windows. "This capability is extremely important for a number of missions involving wide-area surveillance."

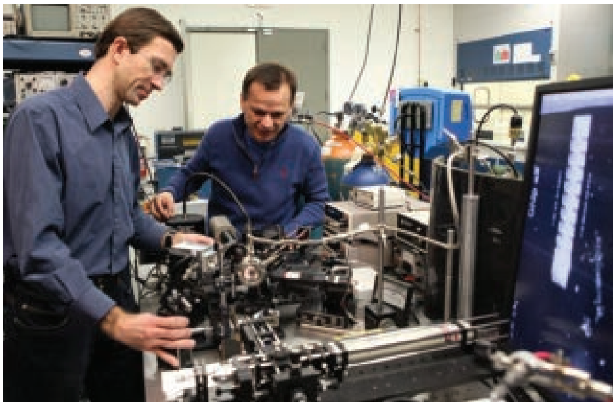
The researchers have been in discussions with a multinational company about commercialization of the sensor. At the same time, they are working to develop data fusion strategies to fit the system with decision capabilities concerning the presence of an explosive in a particular location.

Other novel sensors can be used to detect explosives. At the US Department of



Researchers have described a sensor system that combines Raman spectroscopy and laser-induced breakdown spectroscopy for standoff detection and analysis of explosives. They demonstrated the system using an experimental setup with a 532-nm Nd:YAG laser, a beam expander, a telescope, laser power sources, pulse and delay generators, spectrographs, a bifurcated optical fiber coupled into a collimating lens, a holographic SuperNotch filter and a personal computer. Reprinted with permission of *Analytical Chemistry*.

Energy's Oak Ridge National Laboratory in Tennessee, researchers are developing a device that takes advantage of the nonlinearity associated with nanoscale mechanical oscillators. Investigators typically avoid this nonlinearity, said Nickolay Lavrik, a member of the lab's Center for Nanophase Materials Sciences Div. and a developer of the device. The Oak Ridge researchers believe that, by embracing the nonlinearity, they will be able to detect considerably smaller amounts of explosives than with currently available chemical sensors.



Researchers at Oak Ridge National Laboratory have demonstrated a sensor that takes advantage of the nonlinearity associated with nanoscale mechanical oscillators to detect trace amounts of explosives and other materials. Shown are, from left, Nickolay Lavrik and Panos Datskos, developers of the sensor.

The device uses microscale resonators much like the microcantilevers used in atomic force microscopy, which also has been explored for mass- and force-sensing applications. Panos Datskos, who heads the team developing the device, uses the example of a diving board to illustrate how the device works. A diving board will vibrate up and down with its own resonance frequency, he said. But if a swimmer climbs onto the board and stands there, the resonance frequency will shift because of the additional weight. By measuring these changes, researchers can determine the mass of the swimmer – or of trace amounts of substances, including explosives, biological agents and narcotics, that hit the microcantilevers.

The underlying premise is relatively straightforward. The challenge comes with trying to measure and analyze oscillation amplitudes as small as a hydrogen atom. Conventional approaches seek to achieve this using a sophisticated system of low-noise electronic components, which adds both cost and complexity to a device. The Oak Ridge team instead pumped energy into the system, producing considerably larger amplitudes.

With this approach, the relationship between frequency and amplitude changes is no longer described by a simple bell-shaped resonance curve. "But we used that to our advantage," Datskos said. "Now we can see the amplitude changing more abruptly." Lavrik added that the primary challenge in this regime was coming up with the best algorithm for the device, which would allow users to measure trace amounts of explosives in real time.

The next step in developing the chemical and biological sensor, the researchers said, is gauging interest in the commercial sector in developing a prototype device. Datskos noted that explosives detection is just one of the potential applications, and that the same platform could be used as a natural gas sensor, an emissions sensor for automobiles and more.

Gary Boas
gary.boas@photonics.com

Light moves in not-so-mysterious ways

ERLANGEN, Germany – How can we search the Internet more quickly? How will future quantum computer networks operate? What is happening during the fast energy transfer in photosynthesis? These and many other questions related to the dynamics of complex systems are now being explored, thanks to an all-optical implementation of a quantum walk devised by researchers in Germany in collaboration with theorists Vašek Potocěk, Aurel Gábris, Erika Andersson and Igor Jex, all from Czech Technical University in Prague.

A quantum walk is the path a single

photon of light takes as it travels through a network. If you or I were to take a walk and came to a split in the path, we could walk down only one path at a time. Photons, on the other hand, have the intriguing ability to travel down both paths at the same time, as demonstrated in a simple experiment carried out at Max Planck Institute for the Science of Light (MPL).

Dr. Christine Silberhorn, group leader at the MPL, together with Dr. Katiuscia N. Cassemiro, Dr. Peter Mosley and Andreas Schreiber, have realized five steps of a quantum walk carried out by a single photon. The experiments could provide new insight into statistical processes such as photosynthesis and help to accelerate search algorithms.

"To date, only a few experimental realizations of quantum walks have ever been reported. A major problem faced by the different optical implementations is to achieve interferometric stability and scalability," Schreiber said. "In contrast to other implementations, we have controlled the motion of the walker, observing behaviors in which the photon could be found in any of the final positions or even forcing it to follow a single path."

This control is fundamental for any quantum computational application, and what's more, the MPL group has developed a setup that is highly stable and scalable, thanks to its conceptual idea based on an optical feedback loop.

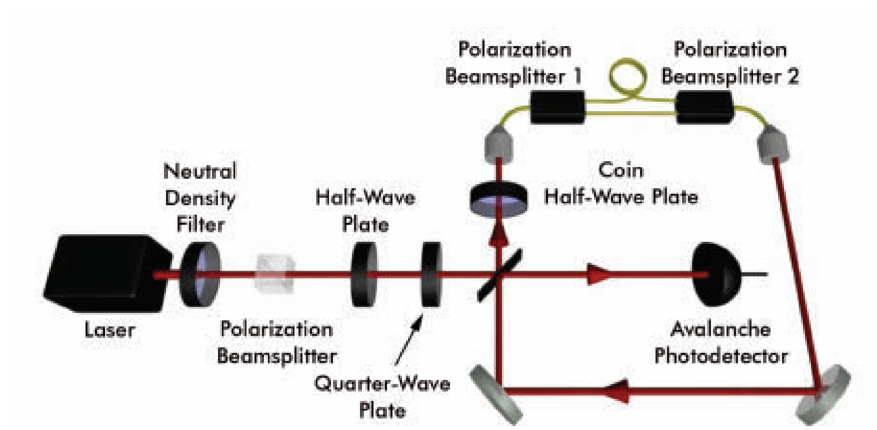
"It has been shown that a quantum walker can reach any site of the network much faster than a walker obeying classical physics," Cassemiro said. "In the same way that random walk is important to classical computation, its quantum version is now the focus of studies concerning its applicability to the design of quantum computers."

In the MPL experiment, which was reported in the February 2010 issue of *Physical Review Letters*, a photon, traveling at the speed of light, passes through a sequence of mirrors and other elements that form a large loop, which includes a split at one point. One path takes a few nanoseconds longer to travel around compared with the other, shorter path.

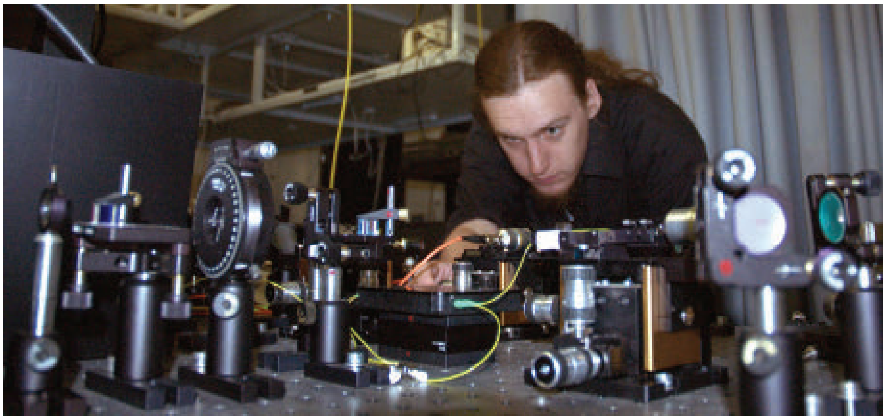
This time difference is enough to be reliably distinguished by a detector after the photon traverses several repeated loops. By repeating the experiment millions of times, the MPL team observed that the particle follows quantum laws while inside the loop.

"The light particle doesn't really choose which path to take when faced with the split in the circuit," Cassemiro said. "Instead, it takes both paths simultaneously, creating a so-called quantum superposition. The various paths that the photon can take with the same escape time leads to quantum interference, which constitutes the principal difference between the quantum and classical walk."

Because after each step of the walk the walker is sent back to the same loop, no further components are needed to increase the number of steps, thus ensuring the scalability. Moreover, the fact that the same optical paths are used in all steps guaran-



In this illustration of the MPL setup, a pulse of light (red arrow on the right) is coupled into the network loop. First, the polarization of the photon is controlled by an optical element, which corresponds to apply a quantum coin. The photon then travels through an optical fiber (yellow) that presents a shorter and a longer path. Two mirrors are used to send the photon back to the in/out coupler, after which the photon is probabilistically sent back to the coin, thus repeating the loop (step of the walk). If the photon is coupled out of the setup, its arrival time at the detector is registered. Images courtesy of Max Planck Institute for the Science of Light.



Doctoral student Andreas Schreiber is working hard to get the experimental results in the MPL laboratory.

tees the stability or coherence of the setup.

The ultimate goal of the MPL team is the realization of quantum algorithms based on quantum walks. In the meantime, it is upgrading its experiments to allow the quantum walk to perform a considerably larger number of steps and is working toward controlling the precise behavior of the particles – essential for performing simple algorithmic tasks.

Marie Freebody
marie.freebody@photonics.com

For fast communication, divide and conquer

DAVIS, Calif. – By splitting up one big, tough problem into many smaller and easier parts, researchers at the University of California, Davis, may have created the basis for ultrafast optical communications. Team leader S.J. Ben Yoo noted that the new approach could offer speeds in the multiple-terabits-per-second line rates, orders of magnitude faster than is now possible.

"The device can eventually scale up to 10,000 times the speed of standard electronics at approximately 10 GHz," Yoo said.

The new technique combines spectral slicing with parallel detection or generation of an optical signal. Done in one direction, devices employing this approach could perform real-time optical waveform measurement, useful for investigating ultrafast optical phenomena or receiving an incoming signal. When run the other way, those devices could be used for transmission, creating a communication link.

For researchers, the method solves the problem of how to measure full-field ultrafast optical waveforms. In making such measurements, it's not enough to capture intensity changes. Phase must be measured as well. Drawbacks of existing methods that do both are that they update too slowly to gauge what is happening on subpicosecond timescales, require too much pulse energy or can measure only for a few nanoseconds' duration.

Yoo credited the idea for a new solution to graduate student Nicolas K. Fontaine, lead author of a *Nature Photonics* paper covering the group's work and published online on Feb. 28, 2010.

In it, the researchers described their scheme and demonstrated it using a silica planar lightwave circuit and balanced photodiodes. The first component sliced an incoming arbitrary light waveform into separate spectral segments. The researchers combined those slices with a coherence-ensuring reference signal from an optical frequency comb, with one reference signal per spectral slice.

They fed everything into the second part, the photodiodes, using four-quadrature spectral interferometry for measurement. Finally, they took that output, sent it through CMOS digital signal processing circuitry and reconstructed the original incoming signal.

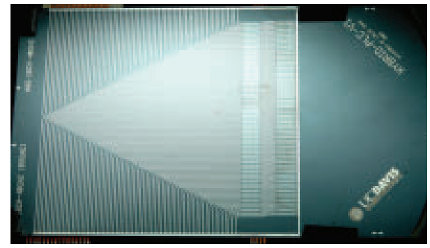
After building the prototype, they tested it, generating an array of complex and different waveforms in the 1.55-µm telecommunications waveband. The test waveforms included static, rapidly changing, bright and dark varieties, Yoo said. "The measurement system works extremely well and captures complex waveforms across a wide dynamic range."

In doing this, they demonstrated an instantaneous bandwidth >160 GHz, with record lengths of 2 μs. This length-to-resolution ratio of more than 320,000:1 represents the largest of any single-shot, full-field measurement technique, the group stated in the paper.

Yoo noted that the technique could be used for a number of applications, including for ultrahigh-speed or highly secure optical communication, lidar and multicolor coherent femtosecond spectroscopy. Of these, he said that high data rate communication is likely to be the most compelling.

One advantage of the new approach, aside from speed, is that it potentially can be done in a single-silicon photonic integrated circuit. Being able to achieve this will make the resulting chips more attractive and useful for all applications.

The process of integration will involve two steps, the first being the merging of the silica planar lightwave circuit and balanced photodiodes into a hybrid-integrated chip. That intermediate integration, Yoo said, the group could do relatively soon.



Using this silica planar lightwave circuit, researchers divided an incoming arbitrary optical waveform into more manageable parts. The approach could form the basis for terabits-per-second line rates. Courtesy of S.J. Ben Yoo, University of California, Davis.

The second step will involve combining the digital signal processing circuitry with everything on the first intermediate chip. That involves making the fabrication of the photonic components process fully compatible with large-scale CMOS manufacturing.

But it will be worth the additional work, Yoo predicts. "Integration of both photonic and electronic circuits on the same silicon CMOS platform opens new possibilities."

Hank Hogan
hank.hogan@photonics.com

Photothermal imaging detects nanorod orientation

HOUSTON – "Fluorescence vector probes and polarization-sensitive single-molecule spectroscopies have been widely used to explore the conformation dynamics of proteins in biological systems – and an ideal probe should yield high signal with low background noise and have good photostability and biocompatibility with a minimum size to avoid interfering with the system of interest," explained Wei-Shun Chang, a postdoctoral scientist in the department of chemistry at Rice University.

He noted that the conventional probes – organic dyes and quantum dots – suffer time-dependent intensity fluctuations (photoblinking) and allow only a limited measurement time due to irreversible photochemical reactions (photobleaching) – and that often they are not biocompatible.

"Gold nanoparticles are very photostable and biocompatible, however," he said. "A surface plasmon of the gold nanoparticle can be photoexcited when the incident light is the same phase and frequency as the collective oscillation of conduction band electrons in metal nanoparticles," he said.

Nanorods vs. spheres

"In particular," he added, "the surface plasmon can be excited with excitation polarization parallel and perpendicular to the long axis of rodlike nanoparticles – nanorods – corresponding to the longitudinal and transverse surface plasmon resonances, respectively. These qualities of gold nanorods make them an ideal vector probe for biological systems."

Nanorods can be used as vector probes to sense structural changes of proteins in living cells or to detect the local order and fluidity of membranes. Knowing the orientation of the probe can provide important information about the conformation and dynamics of the biological system, according to a report by Chang and his colleagues, which was published in the Feb. 16, 2010, issue of *PNAS*. Chang works under the supervision of Stephan Link, principal investigator for the project. Link is an assistant professor in the departments of chemistry and electrical and computer engineering at Rice University.

Detecting smaller particles

"A problem is that single-particle dark-field scattering microscopy cannot detect particles with sizes smaller than 50 nm and, as a result, a new approach was required to detect the orientation of smaller nanoparticles," Chang said. "In a recent study, our group extended photothermal heterodyne imaging to include polarization-sensitive imaging for detecting the orientation of the nanorods (25 and 75 nm in diameter and length, respectively) by exciting either the longitudinal or transverse surface plasmon resonances."

Particularly, he said, determining the orientation of nanorods by excitation of the transverse plasmon mode cannot be achieved by dark-field microscopy because of the small diameter of 25 nm. "In addition," he explained, "the resonance maximum of the longitudinal plasmon mode shifts significantly with changes in the nanorod aspect ratio and refractive index of the surrounding environment. The peak shift results in an inefficient excitation of the longitudinal plasmon band with a single-wavelength laser source, and hence a multicolor laser excitation source is required."

"On the other hand, the transverse surface plasmon is insensitive to changes in the aspect ratio and refractive index of the surrounding environment, which means that excitation with a single wavelength is possible, independent of the nanorod aspect ratio," Chang said.

"Due to the high sensitivity of photothermal imaging, the size of the nanorods can be further reduced to below 10 nm, which then becomes comparable to the size of large fluorophores and semiconductor quantum dots. Overall, such 'small' nanorods, together with polarization-sensitive photothermal imaging, make this combination an ideal vector probe for applications in biology," he explained.

The setup

Photothermal imaging requires a time-modulated heating beam and a probe beam. The scientists used a 514-nm argon-ion laser and a 675-nm diode laser as heating beams to excite the transverse and longi-tudinal surface plasmon resonances, respectively. The polarization of the heating beam was controlled by a quarter- or a half-wave plate. The heating beam was modulated at 400 kHz by an acousto-optical modulator.

Both heating and probe beams were directed into an inverted microscope and focused on the sample through a microscope objective, Chang explained. The signal was collected by the same objective, detected by a photodiode and fed into a lock-in amplifier that was connected to a surface probe microscope controller. Photo-thermal images were acquired by moving a two-dimensional piezoscanning stage on which the sample was mounted.

Alignment of nanomaterials

When asked why it was useful to understand how nanomaterials align, Chang answered that scientists and engineers are interested in fabricating different nanostructures. There are two main strategies of fabrication, he said. Top-down strategies employ conventional lithography and etching techniques to fabricate nanostructures from larger bulk materials. In the bottom-up approach, nanostructures are built from smaller units using chemical or physical interactions between the different units, i.e., building blocks. Understanding how these building blocks align one particle at a time will help the scientists to manipulate them and to build more complex nanostructures.

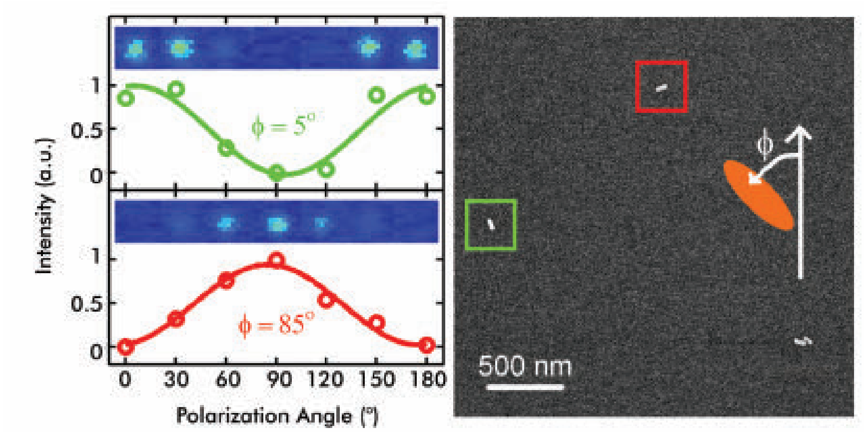
"For applications as sensors in biology, the orientation of the nanorod probe could yield the alignment of proteins or measure the order of the local environment, such as in membranes," Chang said.

Measuring absorption and scattering

"When photoexciting metallic nanoparticles, photons will be either scattered or absorbed by the surface plasmon. The absorbed energy relaxes through nonradiative processes into heat because of a low fluorescence quantum yield," Chang said. Various metallic nanostructures have been developed for many possible applications, such as subdiffraction-limited waveguiding and surface-enhanced Raman spectroscopy. Nanostructures can also be used as photothermal agents for destroying cancer cells or as contrast agents for bioimaging, he added.

To understand the underlying mechanisms for these plasmonic applications, one has to determine both radiative (scattering) and nonradiative (absorption) properties of plasmonic nanoparticles. For example, it is important to measure the pure absorption spectrum of nanoparticles for applications as photothermal cancer agents to ensure an efficient energy conversion from the incident photons to heating the nanoparticle environment.

"Alternatively, large scattering cross sections are required for nanoparticles that are used as imaging contrast agents based on plasmon resonance scattering. However, compared to single-particle studies, an ensemble spectrum of metallic nanoparticles yields the overall extinction, which is the sum of scattering and absorption," Chang said.

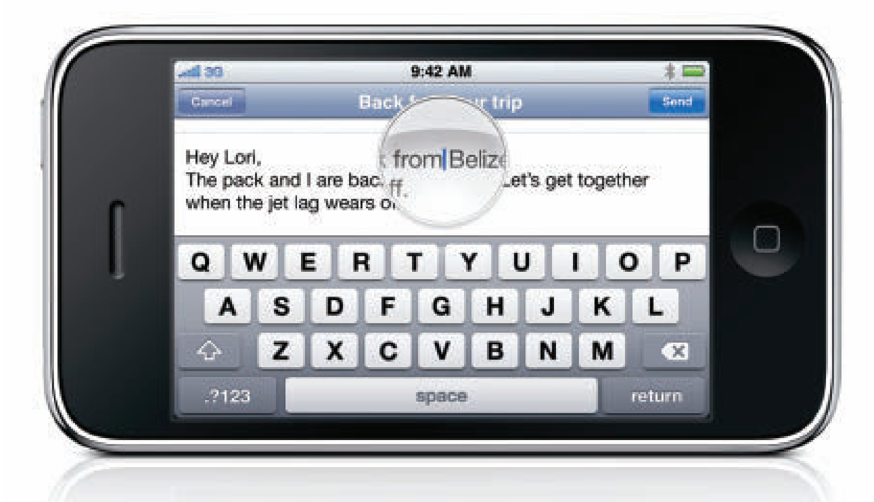


The graph (left) shows how nanorods photographed in an electron microscope (right) appear and disappear, based on their orientation, when their photothermal signatures are detected with polarized lasers. Photo courtesy of Wei-Shun Chang.

"Still, photothermal imaging combined with dark-field scattering microscopy for the same nanostructure allows one to determine the absorption and scattering properties separately and as a function of size when the same sample is also imaged by scanning or transmission electron microscopy," said Chang, who added that the next step will be to incorporate the new technique into a real biological system.

Caren B. Les
caren.les@photonics.com

Touch screen panel market: Smooth operations



Mobile phones such as the iPhone 3GS from Apple are the most common places to find touch screen panels. Courtesy of Apple.

SAN JOSE, Calif. – In terms of units, the touch screen panel market is expected to show a compound annual growth rate of 30 percent through 2013, according to Displaybank, a market analysis firm based in Seoul, South Korea. The company predicts that there will be a demand for more than 800 million touch screen panel units in 2013, up from 280 million units in 2009. In terms of revenue, the market size is expected to reach $7.4 billion in 2013, up from $2.5 billion in 2009.

"Mobile phones dominated the touch screen panel market in 2009 with a 52 percent share, which is expected to expand to 62 percent in 2010. The touch-function equipped mobile phone is a huge trend in 2010, especially for the smart phone section, thanks to Apple's iPhone," said Jae Shin, senior manager, marketing/business development at Displaybank. Other application areas for touch screen panels include printers, automotives, computer/notebook monitors, electronic games, office and medical equipment, media players, kiosk displays, portable navigation devices, point-of-sale systems, and signage and professional displays.

Mobile phone demand was for about 1.16 billion units in 2009, a figure that is expected to grow to 1.27 billion units in 2010. Touch screen panel penetration in mobile phones, which was 12.8 percent in 2009, will probably rise to 20.2 percent in 2010 and to 35 percent in 2013, according to Displaybank analysis.

Capacitive touch technology is very promising, according to Shin. Its demand is likely to reach 120 million units in 2010 and up to 310 million units in 2013. Mobile phones are driving the demand for touch screens and, in these phones, the demand for capacitive technology will rise dramatically because it is suitable for the implementation of soft and multitouch functions. The share of the capacitive market is projected to be around 28 percent in 2010, up from 20 percent in 2009.

A capacitive touch screen panel consists of an insulator glass coated with a transparent conductor such as indium tin oxide. When a human body, also a conductor, touches the screen, it results in a distortion of the body's electrostatic field, measurable as a change in capacitance. Projected capacitive touch technology permits more accurate and flexible operation by etching the conductive layer. It is used in applications such as point-of-sale systems, smart phones and public information kiosks. Resistive touch screen panels, dominating the market with a 79 percent share in 2009, are expected to show a decrease in share, down to 70 percent in 2010, according to Displaybank.

Shin noted that the Microsoft Windows 7 computer operating system, which incorporates multitouch technology, is becoming popular because it seems to provide better performance than its predecessor, Vista. Many new computer notebooks and monitors will incorporate touch functions to apply to Windows 7, he added.

"The emergence of the Frontier integrated touch technology in 2010 appears to be a very hot point in the industry," said Shin, who added that, although the technology will probably have a below-one-percent share of the market in 2010, its presence will probably expand from 2011. As an example, the Datavan Frontier 1478 integrated touch screen is a multifunctional all-in-one point-of-sale terminal that can easily be integrated with magnetic stripe card reading, bar-code scanning and other systems.

Photonics-based touch screens

Lawrence Gasman, principal analyst at NanoMarkets LC, based in Glen Allen, Va., projects that revenues for touch screen displays will grow from $2.2 billion in 2010 to $3.4 billion in 2014. He explained that, although touch screen technology has been around for a long time, the arrival of low-cost and reliable multitouch technology has opened up a range of new applications for it.

"The iPhone and other similar smart phones have made the technology much more familiar, which helps with acceptability. In addition, touch is a natural way to control complex electronic machinery; if you think of the additional functionality that a computer printer now has compared with what it used to have, touch seems a better way to keep all that functionality under control compared with rows of physical buttons or complex software," Gasman said.

"As we see it, the three fastest-growing applications for touch screen technology are office automation/computer monitors, digital signage and motor vehicles," he said, adding that a large segment of the market will continue to come from mobile communications as touch-controlled smart phones become ubiquitous – but the underlying market for such phones is not growing especially fast, so neither is the market for touch screens associated with it.

Infrared and optical touch screens

Gasman noted that some photonics-related touch screen technologies currently have little or no market presence but indicated that this situation could change.

"One reason for the interest in infrared is that it is a mature technology that addresses the needs of the larger display market and therefore seems fairly suitable for the burgeoning digital signage business. However, there are plenty of other technologies that can meet this need, and no one expects infrared technology to really take off in a big way anytime soon," Gasman said.

"Still, infrared has some impressive positives in its favor. These include a high degree of durability and optical performance as well as stable calibration and substrate independence. As far as the latter is concerned, it is really the only practical solution for most 'glass free' applications," he added.

Vision-based optical technology is supported in touch screen displays from a number of companies, including the Illuminate Multi-Touch Table from GestureTek. Courtesy of GestureTek.

"There are also limitations. The display bezel must allow infrared light to pass through, which can prove a design limitation," he explained. "In addition, infrared is arguably the worst technology for creating a flat display because the seating of the touch frame is slightly above the screen. Some OEMs – notably Apple – insist that any touch screen technology that they utilize must enable a completely flat display. The other major limitations on infrared touch screen displays are that they tend to be quite expensive and have a fairly low resolution."

"Waveguide infrared touch screen technology is associated with one supplier, RPO Inc. of San Jose, Calif." It is similar to traditional IR in a number of ways but is much lower in cost. However, it provides limited multitouch and isn't as scalable as many of the other display technologies. RPO's actual product is a 3.5-inch display, but according to sources, this technology is scalable up to 14 inches or so. There will be products using this technology in the marketplace in 2010; there may be already. The first markets being targeted are mobile devices and automotive," he added.

"Optical touch screen technologies are already commercialized and represent a very scalable technology that can be used in displays up to 120 inches, making it a good technology for digital signage, as well as some educational applications, which with touch screen technology can become collaborative and interactive. Today, however, one of the main applications for this technology is consumer monitors and all-in-one systems. It has been adopted by both Dell and Hewlett-Packard, for example," Gasman said.

Vision-based optical touch screens

"Vision-based optical technology is supported by Microsoft (under the name Microsoft Surface), which is obviously a vote in its favor. Other supporters of the technology include Perceptive Pixel, GestureTek and NORTD (a developer kit)," Gasman said.

"Vision-based optical is already beginning to generate some revenues, with all of these revenues coming from large displays; typically these displays are well over 30 inches and have glass or acrylic substrates." Typical applications include digital signage, large retail applications and interactive video walls, he explained, adding that there are limitations to the touch objects that can be used. For the Microsoft Surface product, an IR-reflective object must be used. In other versions, only fingers may be used.

The overall technology is very similar to machine vision, which means that, to some extent, it can build on existing technology and components, Gasman noted. "In part, this is the reason why optical vision touch screen is the multitouch technology being used by a lot of firms that are doing R&D in multitouch; it is easy to build in the lab. This may have longer-term implications in that software and applications are being developed for this technology, and this may help to promote its use in the future. The early systems are fairly large and expensive ones for public, professional or military applications, and the Microsoft Surface product is a complete imaging system. Microsoft has promised low-cost consumer versions of its technology," Gasman said.

Based on his research, he believes there are opportunities in the area of transparent conductors for optical films and coatings, especially as alternatives to indium tin oxide, which is costly and lacking in resilience.

Industry challenges

"Apart from some of the newer and 'cooler' technologies, the technical challenges within the industry are not huge, although analog resistive technology faces the perennial problem of cracked indium tin oxide," Gasman said. "However, there are plenty of business challenges: (1) Most of the patents have expired on the basic touch screen technologies, so how do you get your IP protected while at the same time coming up with a technology that isn't so novel that no one would want to adopt it?

(2) Related to this: Does the world really need 20+ separate touch screen technologies? The answer is probably no. But then which ones bite the dust? (3) How exactly do the display makers get involved in this business now that it has taken off? The sensor suppliers are worried – or should be – that the display makers are going to come in and steal their business."

Gasman added that there are emerging "in-pixel" technologies that let display makers build touch capabilities into the display when they manufacture it. "This is opposed to the regular business practice where a third party builds the sensor and integrates it into a display he has bought in. In-pixel touch could let display companies take over the touch display market, since display makers are usually large companies with lots of resources. The in-pixel technologies are usually variations on pre-existing technologies and are of several types," he said.

Educating with touch screens

Education and conference rooms were the two largest applications for touch screens in the digital signage and professional display market in 2009, accounting for nearly 86 percent of the total unit shipments, according to a January 2010 press release from iSuppli Corp., an analysis firm based in El Segundo, Calif. According to the company, by 2013, the key applications driving this segment of the touch screen market will be education, indoor venues, conference rooms and retail signage.

"Touch screens have great appeal for use in front-projection interactive whiteboards in the education and conference room markets, said Sanju Khatri, principal analyst of signage projection for iSuppli. She wrote the *Emerging Display 2009 Report –Touch Screen Interfaces Continue to Drive Growth in Signage and Professional Applications*, which was released in December 2009.

"The whiteboards make it easy for a teacher or business professional to integrate a wide range of material into a presentation, such as an image from the Internet, a graph from a spreadsheet or text from a Microsoft Word file," Khatri said.

By 2013, optical imaging will emerge as the single leading touch screen technology in the signage and professional display market, accounting for 25.6 percent of worldwide unit shipments, according to iSuppli. The dominant use for optical imaging technology will be in conference rooms.

Other touch screen technologies with capabilities suitable for the overall signage and professional display market segment include resistive, electromagnetic, projected capacitive, bending wave, infrared and surface acoustic wave.

"Optical imaging technology uses cameras to detect touch, gestures or other body movement. The resulting images are then processed by associated software to determine the touch point. In the case of gesture recognition, one's motion triggers an interactive response from the display system with which the person is interacting," states the press release.

Caren B. Les
caren.les@photonics.com

Corporate Name Change Exfo Electro-Optical Engineering Inc. of Quebec City has officially changed its corporate name to Exfo Inc., effective immediately. The name change was made for simplicity's sake and branding purposes, the company said, and will better serve the broad range of business activities that it is currently involved with or may become involved with in the future. Additionally, the company is no longer solely focused on the needs of the installers and operators of fiber optic networks.

Sales Team Expanded Northvale, N.J.-based Photonic Products Group Inc., a manufacturer/developer of products including crystal-based optical components and devices, and optomechanical assemblies, has continued its global expansion with the addition of partners throughout Europe and Asia. The company has increased its presence, with partnerships in Benelux, Germany, Austria, the UK, Ireland, Korea and Israel. It also plans to secure partnerships in South America.

Systems Installation Hillsboro, Ore.-based FEI Co., a scientific instruments company, has announced the completion of a multiple systems installation at the Materials Ageing Institute (MAI) in France, a utility-oriented research center financed by Electricité de France, the Tokyo Electric Power Co., the Kansai Electric Power Co. and the US Electric Power Research Institute. The MAI microscopy laboratory has commissioned FEI's Titan scanning transmission electronic microscope to study the aging of materials. The goal is to improve the reliability and safety of nuclear and non-nuclear power plants and to extend their lifetimes.

European Expansion Edmund Optics has relocated its UK offices to a newly constructed 10,000-sq-ft facility in York, allowing the company to continue to offer service and support throughout Europe. Shipments will be sent from the East Midlands Airport to the distribution center in Cologne, Germany, which provides next-day delivery. Edmund Optics manufactures precision optical components for business, industry and biotech applications.

High-Brightness LEDs In Durham, N.C., Cree Inc. has announced that its high-brightness LEDs are being used in Lighthouse Technologies' high-definition video screens at the American Airlines Center, the Dallas home of the NBA's Mavericks and the NHL's Stars. The company's three-in-one LEDs deliver high-definition images to sports fans throughout the arena and to spectators at concerts and other live entertainment events. The digital screens are expected to increase video visibility and provide instant replays, scoring information and ad content in sharp detail.

Distributor Appointed Andor Technology plc of Belfast, UK, a scientific imaging, spectroscopy solutions and microscopy systems provider, has appointed Microlat SLR of Buenos Aires, Argentina, as its exclusive distributor in Argentina, Chile and Uruguay. The latter company will sell the former's range of electron-multiplying CCD cameras and scientific CMOS detectors.

Display Technology Licensing Agreement Science-based products and services company DuPont Display Enhancements Inc. of Torrance, Calif., and Ocular of Richardson, Texas, a supplier of industrial touch panels and display products, have announced a licensing agreement. Under its terms, DuPont will license its Vertak direct bonding display technology to Ocular for the optical enhancement of a variety of touch panel and other display products. The Texas company's engineers have been trained on the display panels' manufacturing technology and direct bonding techniques at DuPont's facility in Shenzhen, China.

Singapore Office Allied Vision Technologies GmbH Inc. of Ahrensburg, Germany, has established a sales subsidiary in Singapore. The new company, Allied Vision Technologies Asia Ltd., will be in charge of expanding business in the Asia-Pacific region, managing existing distributors and setting up local technical support.

Water purification – ultraviolet style

BY CAREN B. LES
NEWS EDITOR

Created by industrial designer Olivia Blechschmidt, the STER UV portable water sterilization device is tailored to the home kitchen environment. The tool aims to provide an effective alternative to boiling water in the home for those affected by contaminated drinking water, she said. Consisting of a UV light stir stick and induction charger, it was developed for rapid sterilization of drinking water directly in a glass, pitcher or other container.

"The STER UV is designed to sit on a kitchen counter, with the induction charger plugged in. One can simply remove the stir stick from its charging base, insert it into a glass of tap water, push the button for smaller volumes, give a quick stir and then wait until the UV lamp turns off," Blechschmidt said. There are preset timers for glass size, 1½ minutes, and for pitcher size, three minutes.

The water sensor exposes two metal plates that complete the circuit only when the stick is submerged in water, above the UV lamp, Blechschmidt explained. This removes the need for a power button and provides a safety measure that prevents users from having their eyes directly exposed to the UV lamp.

"The lamp applies 254-nanometer technology through a quartz protector. After the user gives a few quick stirs to the water container, the device can be left unattended while it continues to expose moving water molecules to the sterilizing light," she said. Stirring allows all of the water molecules to be exposed to the UV light. The stick is long and lightweight so that it can be left unsupervised in containers of various sizes.

The induction charger is designed to continually power the stir stick when it is stored inside, and it incorporates a blue LED light power indicator. The charger also acts as a docking station that protects the stir stick and holds it in a ready-to-use position. With a 45-cm-long power cord, the charger can be plugged into standard kitchen outlets, eliminating the need for complicated installations in the plumbing system.

In terms of environmental friendliness, the induction charger eliminates the need for battery replacement and disposal. With no heat production or moving parts, the device uses less electricity than an electric toothbrush, Blechschmidt said, adding that use of the device also may discourage bottled water consumption, which has negative effects on the environment.

Boil water advisories

When asked how she became interested in the STER UV project, Blechschmidt said that the water purification market has been growing because of increased concerns over the quality of drinking water.

"In Canada, for example, where I worked on the device, the number of 'boil water advisory' days in various municipalities across the country increased by 24 percent between 1993 and 1998, and dozens of communities are under 'standing' boil water alerts that have remained in place year after year. Health Canada estimates unsafe drinking water causes 90,000 illnesses and ninety deaths every year.

"Bacteria and viruses pose the most immediate threat of illness or death and cause most drinking water emergencies. Although many home water filtration and purification systems have appeared on the market, they largely do not address the need for bacteria and virus removal, which is why people still resort to the tedious process of boiling water. Currently in Canada, there are no federal government regulations for water filtration products, such as those found in food and drugs by Health Canada.

Effectiveness of UV purification

"Ultraviolet light kills microorganisms such as bacteria (including *E. coli*), viruses, protozoa, gardia cysts and cryptosporidia by damaging the DNA. UV radiation disrupts the chemical bonds that

The STER UV water sterilization device is designed for use in residential kitchens. Photos courtesy of Olivia Blechschmidt.

hold the atoms of DNA together in the microorganism. If the damage is severe enough, the bacteria cannot repair the damage and will die. In contrast to chemical treatments, UV light penetrates the cells but does not alter the water being treated.

"Although UV light kills microorganisms, it generally has no impact on chlorine, heavy metals or other chemical contaminants. However, these types of pollutants are not life threatening and can be removed with many filtration devices on the market today."

The STER UV is designed to disinfect as well as to thoroughly boil drinking water. "The process of boiling water in the home typically means doing so in large batches, filling up pots with water, boiling over high heat and letting the water cool before distributing it into plastic bottles which then need to be stored. The STER UV could be a tool to ensure the availability of clean drinking water without advance planning or a long wait," Blechschmidt said.

She added that it could be useful in any location that experiences boil-water advisories, particularly for rural homes that do not rely on a municipal water supply.

The product is not commercially available as of March 2010, but Blechschmidt said she would be happy to pursue its development for mass production if the opportunity to do so should arise.

The device has not been tested because the project was not taken as far as a fully functional prototype. However, the technology that it is based on – the application of UV light to sterilize water – has been tested and proved to be effective.

caren.les@photonics.com

Argonne offers integrated approach

DoE lab combines materials design, systems analysis and more in developing solar technologies

BY GARY BOAS
CONTRIBUTING EDITOR

Researchers anticipate that the world's energy needs will double by 2050. To help meet these ballooning needs, the US Department of Energy (DoE)'s Argonne National Laboratory in Illinois recently launched an Alternative Energy & Efficiency Initiative. The initiative seeks, in part, to achieve advances toward the large-scale implementation of solar energy by drawing on the laboratory's strengths in basic and applied research and in collaborating with industry and other research organizations.

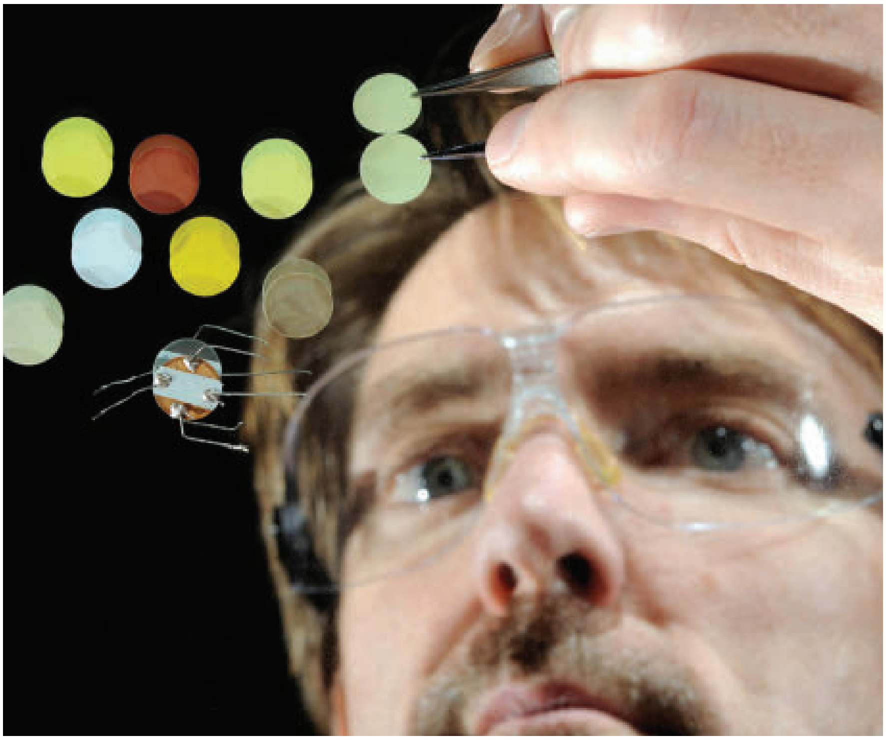
"Solar energy has more potential than any other renewable source," said Seth B. Darling, a researcher with the laboratory. But realizing that potential is always going to be challenging – particularly with respect to cost. "Government subsidies can artificially lower the cost of a technology, but you need the unsubsidized cost to be competitive."

And then, it must be competitive in the long term. Consider cadmium telluride. Using this, we could reach grid parity – the point at which renewable energy costs as little as or less than grid power – in a relatively few years. But tellurium, which comprises half of cadmium telluride, is one of the rarest materials on Earth. "It will be great as a stopgap," said Darling, "but, ultimately, it cannot supply the world's needs." Therefore, we need new materials and new technologies.


The US Department of Energy's Argonne National Laboratory in Illinois has launched an Alternative Energy & Efficiency Initiative, through which it seeks to develop new technologies, working toward large-scale implementation of solar energy, for example. Photos courtesy of Argonne National Laboratory.

This much is generally understood. The trick, of course, is to identify the technologies that will successfully address the energy security issue. "What we believe here," Darling said, "is that having a basic researcher sitting in his or her lab developing a new technology, hoping to serendipitously hit upon something that will solve the problem, is not the most efficient approach. Likewise, endlessly tweaking an existing technology may not be the answer."

Argonne is working toward an integrated approach combining its materials design, device science and process engineering. This will help to determine early in the process, for example, whether a technique can be scaled up to the necessary extent. Systems analysis is another



Argonne National Laboratory is exploring the potential of atomic layer deposition, among other techniques. Here, researcher Jeffrey W. Elam examines solar cell materials prepared using the method at various stages of fabrication.

strength that Argonne will add to the mix, studying the impact and interplay of resource limitations, the variability of sunshine, consumer behavior and more, with respect to a potential technology.

This approach is not necessarily unique, but applying it to technologies that look promising can help us to achieve energy security more quickly than we would otherwise, Darling said. And that, of course, is the ultimate goal.

One technology the researchers are exploring is atomic layer deposition (ALD), which allows them to prepare extremely thin layers of transparent conductors, essential components of most solar cells. With conventional dye-sensitized solar cells, performance is limited by sluggish charge transport through the photoanode. “ALD offers the potential to improve DSSC [dye-sensitized solar cell] efficiency by enabling the fabrication of high-surface-area photoanodes with high conductivity,” said Jeffrey W. Elam, director of the atomic layer deposition program at Argonne.

The technique has further advantages: It produces highly conformal coverage, even on three-dimensional structures, and allows synthesis of a broad range of materials relevant to dye-sensitized solar cells, including titanium dioxide, indium oxide and tin oxide.

Elam noted a significant challenge in working with the technique: Every new material one might want to prepare requires research to develop the appropriate atomic layer deposition “recipe,” providing the necessary self-limiting surface chemistry.

Early in its DSSC development work, the Argonne group encountered the lack of an appropriate atomic layer deposition chemistry for indium oxide, the main ingredient in indium tin oxide (ITO), one of the best transparent conductors known. To address this, he said, “we invented a method for preparing highly conformal ALD ITO coatings on nanoporous structures and used this method to fabricate DSSCs with excellent charge-transport properties.”

The researchers believe that applying the technique to the deposition of ITO will help usher in the next generation of photovoltaics, enhancing the performance and reducing the cost. Also, extending it to alternative, Earth-abundant transparent conductors ultimately could enable production of efficient solar energy devices on a massive scale.

gary.boas@photonics.com

GreenLight

LED streetlights shine in cradle-to-grave study

BY ASHLEY N. PADDOCK
DEPARTMENTS EDITOR

Researchers at the University of Pittsburgh report that LED lamps outshine other lighting technologies in terms of balance of brightness, energy efficiency, life span, cost and low environmental impact.

Researchers at the University of Pittsburgh have conducted the first cradle-to-grave assessment of LED streetlights. The report revealed that, compared with other options, the increasingly popular lamps strike the best balance between brightness, affordability, and energy and environmental conservation when life span from production to disposal is considered.

A team of engineers at the Mascaro Center for Sustainable Innovation, based at Pitt's Swanson School of Engineering, reported that, while LEDs may carry a heftier price tag than the country's two most common lamps – the high-pressure sodium (HPS) lamps found in most cities and the metal halide lamps akin to those in stadiums – they consume half the electricity, last up to five times longer and produce more light. Gas-based induction bulbs, another emerging technology deemed bright and energy-efficient, proved only slightly more affordable and energy-efficient than LEDs. However, they may have a greater environmental impact when in use.

The City of Pittsburgh commissioned the report as it was debating whether to replace its 40,000 streetlights with LEDs. Several other US cities had taken the initiative to replace energy-zapping HPS lamps with LEDs, and pilot programs and retrofits are under way in cities including Los Angeles, San Francisco, Raleigh, N.C., and Ann Arbor, Mich. The City of Pittsburgh estimated that, per year, the cost to replace HPS lamps with LED streetlights would save the city $1 million in energy costs and $700,000 in maintenance. Additionally, carbon dioxide emissions would be reduced by 6818 metric tons.

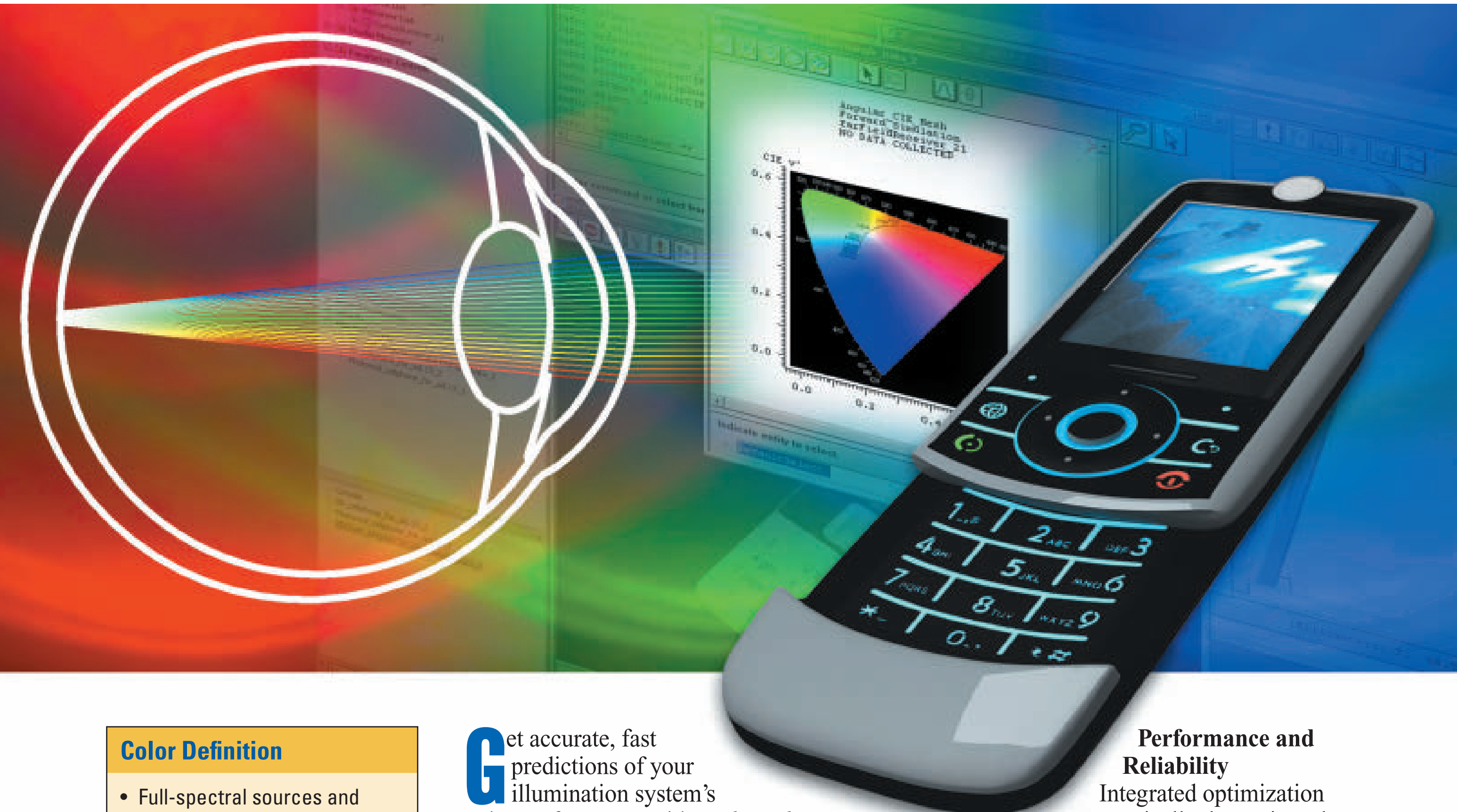
Melissa Bilec, a professor and a co-author of the study, said that, despite the nationwide embracing of LEDs, no comprehensive analysis of LED streetlights had been done earlier. With the help of professor Joe Marriott, two students from Pitt and one from the Georgia Institute of Technology, the group created a "life cycle assessment" for each of the four lighting technologies.

The assessments for each technology,

ILLUMINATION DESIGN SOFTWARE

The Full Spectrum of Color Analysis

Flexibility, performance, and innovation—LightTools delivers it all.



Color Definition

- Full-spectral sources and chromaticity calculations based on real colors using CIE coordinates
- Spectral-dependent materials, reflectors, and diffusers
- Color ray data, wavelength or tri-stimulus based
- Fully dispersive ray tracing
- Backward ray tracing for illuminance, intensity, and spatial and angular luminance calculations
- Wavelength-dependent bulk absorption, reflectance, and transmittance

Color Analysis

- Color meshes and points
- RGB true-color plots
- Smart output smoothing
- Spectral power distribution and CRI
- Photorealistic rendering
- Individual or combined CRI calculations on any receiver

Get accurate, fast predictions of your illumination system's color performance with *LightTools*. Tailored to meet diverse application demands, our robust design and analysis capabilities provide a seamless package to achieve any color performance goal, from uniformity to quality to saturation.

Spectral Flexibility
LightTools provides flexible design options while specifying color in your optical system. Easily define the color of materials and surfaces, or use the industry's most complete phosphor capability to add color to the components. Accurately simulate the colorimetric performance of any source, from LEDs to CFLs, from filaments to the Sun.

Performance and Reliability
Integrated optimization automatically determines the best design that meets color specifications and ensures performance and reliability when manufactured. Evaluate the lit or unlit true color appearance of your system with photorealistic rendering.

Innovation
Smart output smoothing uses a unique algorithm to reduce statistical noise and provide rapid, accurate color analysis results. Verify your design's compliance with performance requirements at any stage of the design process.

Unsurpassed color definition, comprehensive color analysis—from the optical design innovation leader you've trusted for over 45 years.

LightTools®

www.opticalres.com

OPTICAL RESEARCH ASSOCIATES

Corporate Headquarters: 3280 East Foothill Boulevard, Pasadena, CA 91107-3103 (626) 795-9101
Fax (626) 795-0184 E-mail: info@opticalres.com Web: www.opticalres.com
Offices: Tucson, AZ | Westborough, MA | Pittsford, NY

made with information drawn from sales companies, manufacturers, government documents, lighting professionals and industry reports, catalogued the environmental effect of the streetlamps during their complete life span, from extraction of raw materials and assembly, to electricity consumption and disposal.

According to the report, LEDs have the most negative environmental and health impact during manufacturing. Because the LED "bulbs" consist of small lights embedded in circuit boards that require a vast number of raw materials, they require considerable energy to produce and can be difficult to recycle. Producing LED housing, however, consumes less energy than manufacturing aluminum-heavy HPS casings, the team learned, because LED housing is composed mostly of plastic and wire. Additionally, the bulbs contain no mercury and fewer toxins than HPS and metal halide bulbs, both of which pack an average of 15 mg of mercury, while induction bulbs average roughly 6 mg.

The most noteworthy aspect of the report proved to be that electricity consumption has up to 100 times the environmental impact of manufacturing. The study found that LED lights burn at approximately 105 W, while HPS lamps burn at 150 W, and metal halide lights clock in at 163 W.

When electricity consumption is converted into kilograms of carbon dioxide produced, metal halide bulbs are shown to produce nearly 500 million over the course of 100,000 hours, whereas HPS bulbs produce more than 400 million, induction bulbs approximately 350 million and LEDs, slightly more than 300 million. Additionally, in comparison to metal halide and HPS lights, LED technology reduces by one-third the airborne toxins and particulates from coal-fired plants.

Outputs of chlorofluorocarbon, a chemical compound contributing to the ozone layer's depletion, and nitrogen oxides, the noxious by-products of burning fossil fuels that can return to Earth in rain and snow as harmful nitrate, were also studied. The researchers found that, in both categories, LEDs ranked highest of the four technologies during the bulb manufacturing stage but had the lowest ranking during actual use. Metal halides produced the greatest emissions of both pollutants in the final phase.

When it comes down to pennies per lumen, the team found that the prices of LED lights were highly inconsistent, ranging from $9.20 to $322 per fixture. However, the technology's longer life span could offset the price. Initially, Pittsburgh could purchase 40,000 LED lamps for $21 million versus approximately $9 million for metal halide streetlights. In the long run, however, replacing metal halides could cost as much as $44 million before the LED lamps need a first replacement.

While LED lights shine the brightest for their energy efficiency, balance of brightness, life span, cost and low environmental impact, the researchers encourage municipalities considering making the switch to seek out vendors wisely. Because the technology is new and still under development, they recommend choosing a company based on its age, past performance and on whether the technology has been vetted by independent laboratories.

ashley.paddock@photonics.com

Invisibility cloaks get all the publicity, but they may just be the beginning if the promise of transformation optics can be realized. The discipline could lead to smaller photonic and electronic devices and more cost-competitive solar cells – in addition to those long-sought-after invisibility cloaks.

Achieving these and other advances assumes that the challenges confronting transformation optics can be successfully overcome. Chief among these are dealing with losses and building the tiny structures needed in metamaterials, the composite materials that make the field possible.

Taking the shortest path

Transformation optics work by exploiting how light travels, researcher Vladimir M. Shalaev said. “Light propagates in such a way that it minimizes the optical path, which is a product of the geometrical path and the refractive index.”

Shalaev, a professor of electrical and computer engineering at Purdue University in West Lafayette, Ind., is a key player in the new field. He noted that bulk homogeneous materials have a single refractive index. Thus, the path of light through them is determined by geometry.

Metamaterials, in contrast, can have a varying refractive index. This can be done by building rings and rods, by embedding metallic nanoparticles or by other means. The key is that the structures must be much smaller than the wavelength of the light of interest and that the structures must interact with the photons.

The result is an apparent refractive index at specific wavelengths that is not restricted to being more than 1, as is the case with bulk materials. Instead, it can be less, with values close to 0 and even negative possible.

Because of this, light then can be made to curve around objects, which is how an invisibility cloak would work. It can be made to disappear into a concentrator, never to re-emerge. It can even be made to reverse direction, all courtesy of metamaterials with the right refractive index value and profile.

For Shalaev, the physics behind this is exciting, but he acknowledges that applications ultimately will drive funding and the field itself. He noted ongoing announcements of advances in invisibility cloaking and pointed out that making an object look like something else has been demonstrated, which is a step toward cloaking. Such mimicry can be beneficial when trying to hide something and is of interest to the military.

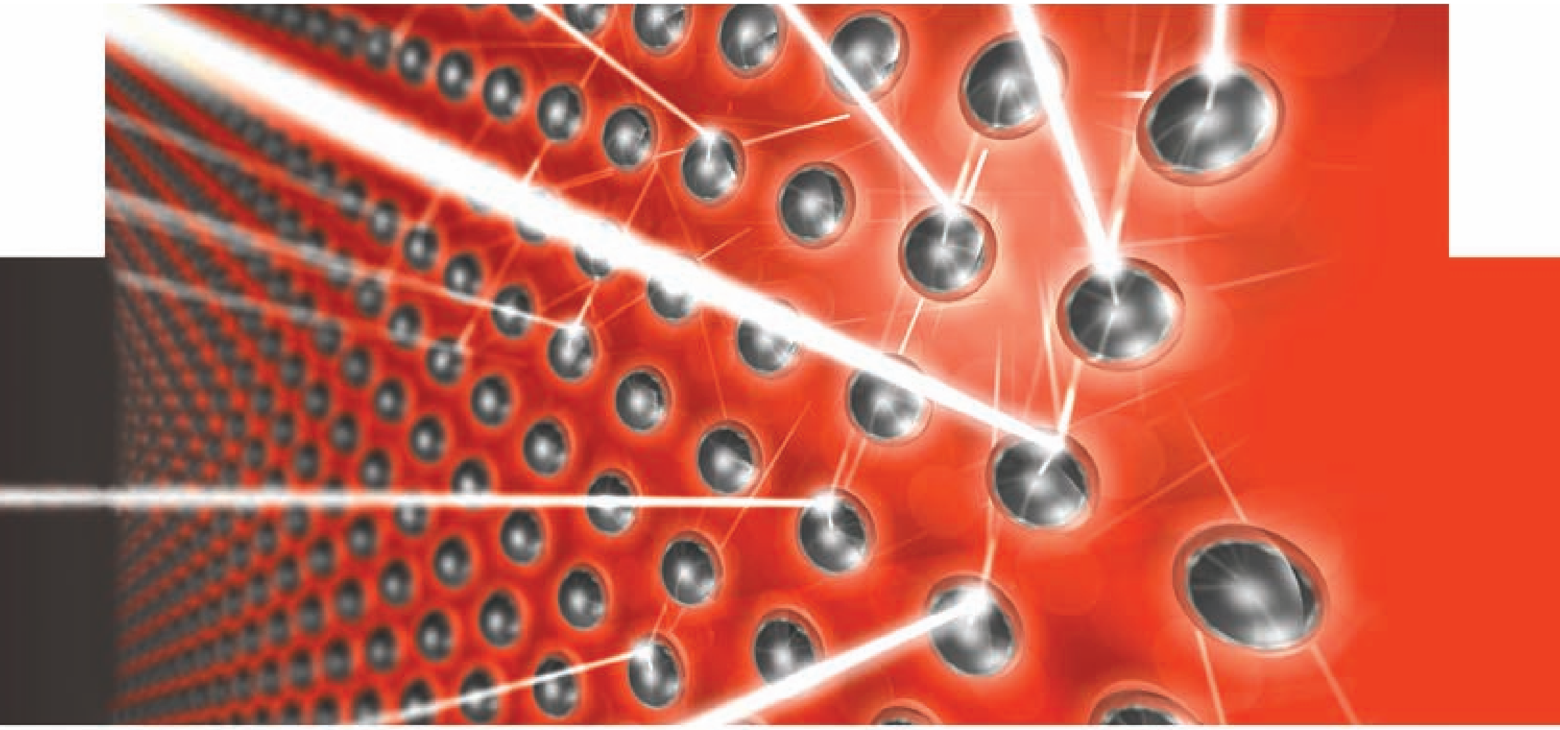
But cloaking and mimicry are not where some of the first important uses could arise, Shalaev said. “One of the first key applications of metamaterials and transformation optics I expect to be in the area of subdiffraction imaging. The most promising thing here is a planar magnifying hyperlens.”

Such a hyperlens would magnify objects that were below the traditional diffraction limit, about a half-wavelength of light, so that they could be imaged with conventional optics. A researcher using a standard microscope equipped with a hyperlens could observe objects currently too small to see.

Just as importantly, a hyperlens would work in the opposite direction, concentrating light into spots smaller than can be achieved with standard optics. That capability could be of critical importance to the semiconductor industry, which manufactures chips using nonlinear optical-based processing. That will be the basis for the 22-nm technology node, expected to debut in 2011, but trouble looms beyond that for the current 193-nm immersion lithography. A hyperlens would allow the extension of current tricks to even smaller features and could be a boon to the chip industry.

Let the sun shine in

Besides a hyperlens, another potential transformation optics application involves solar cells. Most are built using crystalline silicon wafers with a thickness of up to 300 μm. That distance is required to efficiently capture the red part of the



spectrum, which is poorly absorbed by silicon.

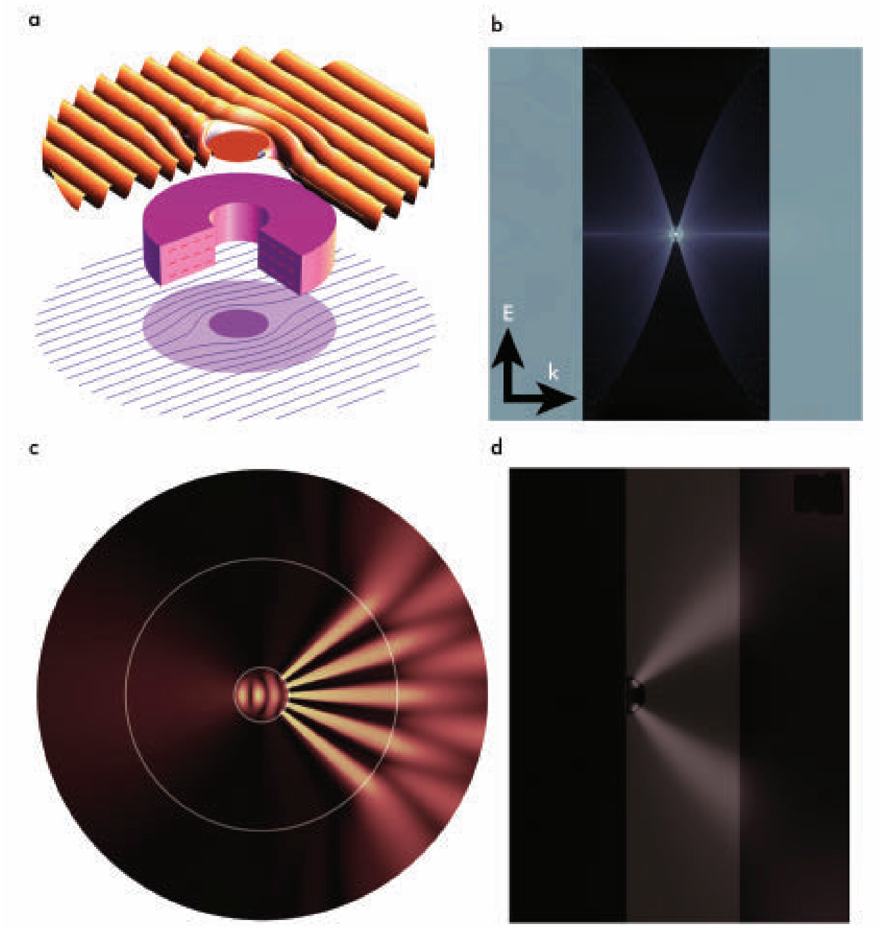
However, silicon adds significantly to the cost of solar cells. It is part of the reason why solar power is anywhere from two to five times as pricey as it would have to be to be cost-competitive.

Transformation optics offers a solution to this problem through the construction of plasmonic solar cells. These use metallic nanostructures that support surface plasmons, excitations of the conduction electrons at the interface between a metal and a dielectric. Properly engineered, these metallic-dielectric structures can concentrate and fold the light into the semiconductor layer, making possible more cost-effective solar cells.

"Plasmonic solar cells have the potential to make solar cells ten to twenty times thinner, while keeping the efficiency the same. Because materials costs constitute a large price of the solar cell, the needed two- to fivefold reduction in price is within reach," said Albert Polman, scientific group leader at the FOM Institute for Atomic and Molecular Physics in Amsterdam, the Netherlands.

A pioneer in the plasmonic solar cell field, Polman said that research results are encouraging. The addition of the metallic nanoparticles does add to the cost of the solar cell, partly because the material of choice is silver or gold. The cost, however, is minimal because the structures measure in the 100-nm range.

There is also some added cost resulting from additional processing. There are solutions to this issue, however. For example, Polman's group has developed a technique that allows the nanostructures to be added in a roll-to-roll soft imprinting process to the back of the solar cell.



Transformation optics could be used to create (a) an invisibility cloak, (b) a light concentrator or (c and d) a hyperlens. These applications depend on steering light where desired: around an object for invisibility or to a point for a concentrator. Courtesy of Vladimir M. Shalaev, Purdue University.

The current state of affairs, Polman explained, is that the concepts have been proved in the lab, and the results agree with what models predict. It is now a question of implementing a solution tailored to a particular solar cell manufacturing process and showing the benefit in a real-world installation. He reported that his group is working with manufacturers to do just that.

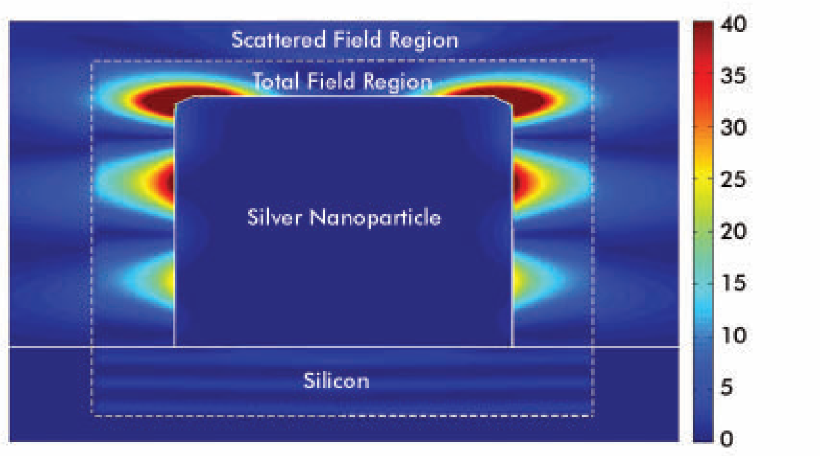
Kylie R. Catchpole, a research fellow at the Canberra-based Australian National University, is an active collaborator of Polman's. She noted that one knob that researchers can turn to boost performance involves adjusting the plasmon resonance, the wavelength of maximum photon interaction and scattering.

"There is much more scope for tuning the plasmon resonance than we realized.

bending light at will with transformation optics

BY HANK HOGAN
CONTRIBUTING EDITOR

A plasmonic solar cell, shown in this artist's rendering, at left, could cut the cost of solar power. Light is scattered and trapped using an array of metal nanoparticles placed either in front or in back of the solar cell. Less silicon is then needed. Courtesy of AMOLF/Tremani.



Standing waves form around a tall silver nanoparticle on a silicon substrate when light comes from above. Such nanoparticles scatter more light into the silicon, making it absorb like a much thicker sample. Courtesy of Kylie R. Catchpole, Australian National University.

This makes it very easy to make the scattering strongest in the part of the spectrum where absorption most needs improving," she said.

The overall behavior of the nanoparticles is strongly dependent on their size, shape and arrangement, she added. Thus, fabrication techniques, as well as design and characterization strategies, will be important in producing these plasmonic solar cells.

Dealing with loss

There are some problems to be overcome, however, before a hyperlens, plasmonic solar cell or an invisibility cloak can be built. One is manufacturing. Because the metamaterials must have features well below the wavelength of the light of interest, the structures involved can be quite small.

For the visible range of 400 to 700 nm, the dimensions may have to be much less than 100 nm. That is one reason why so many demonstrations are done first using microwaves. The longer wavelength means that the structures can be much larger and, therefore, easier to construct.

Progress in this area is being made, however. Shalaev's group at Purdue, for instance, has made metamaterials with a negative refractive index at 500 nm, well into the visible. Negative refraction is possible for only a relatively narrow spectral window, but Shalaev pointed out that going negative is not necessary for many applications. For these, the refractive index need only be near 0 or vary between 0 and 1. Because of that, broadband use of transformation optics is possible.

Another problem is optical loss. As photons traverse a metamaterial, they can disappear into it. For some applications, that is not an issue. For others, it can be a killer. An invisibility cloak that hides you but that looks black because of light loss, for instance, wouldn't be of much use.

There are solutions. One that has been proposed is to compensate for the loss by adding something like dye molecules or quantum dots to the dielectric. These would create optical gain, potentially negating any loss.

Such a scheme would have to be done carefully, cautioned Mikhail A. Noginov, a professor of physics at Norfolk State University in Virginia. Too much gain could lead to nonlinear effects and, with feedback, could result in a laser. The goal would be to balance gain and loss, with the outcome a small loss.

Noginov also has done work in which the loss was reduced without gain by alloying two metals together. In another loss-reducing scheme, he modified the surface of a metal with dye molecules, which led to elongation of the surface plasmon polariton propagation length. Both of these approaches, however, have their own issues. The first, for instance, helps only at some wavelengths and actually makes loss higher at others.

But, in speaking about the future, Noginov predicts that the loss issue will be resolved. He said that silicon today is a nearly perfect material, but this came only after decades of work. That history gives hope for tomorrow's transformation optics applications and the metamaterials that make them possible.

Speaking of the metamaterials, Noginov said, "Now they're not as good as we want, but probably after some time and some effort, they may be significantly improved."

hank.hogan@photonics.com

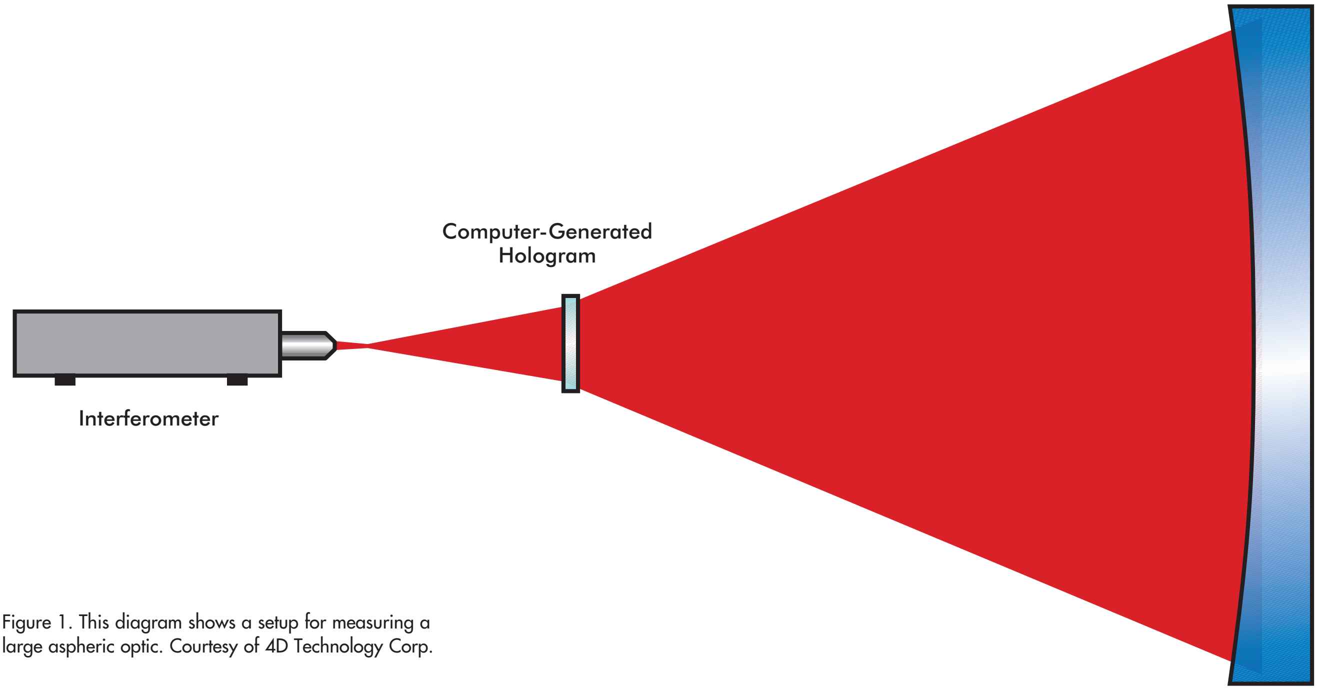


Figure 1. This diagram shows a setup for measuring a large aspheric optic. Courtesy of 4D Technology Corp.

HIGH-THROUGHPUT MEASUREMENT SPEEDS PRODUCTION OF LARGE OPTICS

BY MIKE ZECCHINO, 4D TECHNOLOGY CORP.

Dynamic laser interferometry is an established technique for measuring optical-grade surfaces in the presence of vibration and air turbulence. Unlike traditional laser interferometry, dynamic interferometry does not require expensive vibration isolation systems, extensive mechanical coupling between the instrument and test optic, or air flow abatement. The method provides a cost-effective means of assessing the quality of large optics, often 1 m in diameter or larger, even when the optic must be placed many meters from the interferometer to enable measurement.

While dynamic interferometry is useful for verifying an optic's final shape, it also can provide accurate shape data to guide polishing. This data, gathered early in – and even throughout – the process, allows more aggressive polishing that greatly shortens manufacturing time.

There are challenges in measuring large optics during polishing, but dynamic interferometry has been applied to overcome them.

Measuring optics during polishing

Measuring a large optic in a shop-floor environment presents multiple difficulties. Figure 1 shows a typical setup for measuring a large aspheric optic. The size and curvature of the optic dictate that it must be located many meters from the measurement system.

This measurement poses difficult challenges for a temporal phase-shifting laser interferometer. Because a temporal phase-shifting system acquires data over a sequence of frames, its acquisition time is long, on the order of hundreds of milliseconds. Over the duration of the measurement, vibration and air flow would hinder or, more likely, prevent the acquisition of data. Vibration and turbulence would therefore need to be tightly controlled, which would mean coupling the instrument and optic through a single vibration-isolated pad or stand, as well as carefully controlling air flow and temperature differentials in the facility. All of these measures would be expensive and would require significant alteration of a facility.

The polishing process presents additional metrology challenges. Maximizing polishing throughput requires that the measurement process, including setup, alignment, data acquisition and analysis, be as fast as possible.

Also, the surface quality of an optic in its rough shape will exceed the measurement capability of most systems. Early in the polishing process, a large optic may have local surface deviations exceeding 40 µm. Such high local slopes are difficult for measurement systems to resolve. Qualitative methods provide some degree of process feedback, but the sooner a manufacturer can acquire quantitative data, the faster and more accurate the polishing process can be. This early quantitative feedback becomes even more critical for guiding automated polishing equipment.

Polishing feedback

In an instantaneous interferometric measurement, all data is acquired simultaneously in a single frame, rather than sequentially across several frames. Acquisition time can be only tens of microseconds, making the systems virtually insensitive to vibration. This insensitivity allows measurement when the test optic is located far from the instrument, even on a separate concrete pad. Furthermore, the effects of air turbulence can be easily removed from data using averaging techniques. Where a traditional interferometric measurement will be compromised by even minor air perturbations, an instantaneous measuring system actually performs better with a degree of fast-moving turbulence.

Several methods have been developed and commercialized for instantaneous phase data acquisition:

1. In the software-based spatial carrier method, high-frequency tilt fringes are applied by tilting the reference surface relative to the test beam. The tilt fringes are then filtered out by the software algorithms that determine the phase and thus the surface heights.

2. In an off-axis Fizeau interferometer, the test and reference beams pass through separate internal apertures, which select the correct polarization states from the test and reference optics. The apertures also filter the tilt fringes and high spatial frequencies.

3. In a stitching interferometer, multiple data sets covering small portions of an optic are stitched together to provide a full measurement of the total surface.

4. In dynamic interferometry, polarization elements separate the test beam into four or more phases. All phase data is recorded simultaneously and analyzed to determine surface heights.

Each of these instantaneous methods may be able to provide final quality control for large optics. However, most methods cannot provide feedback for the early stages of polishing. In a spatial carrier

Figure 2. Pictured is a measurement setup for a 1.4-m parabolic optic. The interferometer is in the foreground, along with the computer-generated hologram and optic. Courtesy of Optical Surface Technologies.

Figure 3. Dynamic interferometric measurement of a large aspheric surface during the early stages of polishing is seen in this image. Courtesy of 4D Technology Corp.

system, the filtering required to remove the tilt fringes limits the spatial resolution and thus the range of slopes that can be resolved. High spatial frequencies are also filtered out by the apertures used in Method 2, again resulting in a reduced range of measurable slopes. A stitching interferometer retains high spatial frequencies, but great care must be taken to preserve low-frequency data during the stitching process. Only dynamic interferometry has proved capable of measuring the full range of spatial frequencies present during polishing across a large aperture in an environment typical of a polishing process.

Measuring a large aspheric optic

Optical Surface Technologies of Albuquerque, N.M., designs, manufactures and coats custom optical components for specialized applications. In a current project, the company is polishing six 1.4-m-diameter parabolic mirrors. Stringent requirements dictate that the final surface quality will have to be 29 nm root mean square (rms) roughness, so both large-scale shape and small-scale structure are important to monitor during polishing.

The test setup requires the optic to be located approximately 3 m from the interferometer, which means the optic must be located on a separate concrete slab. The measurements must be completed in an environment with significant background noise and vibration since the facility is located near the intersection of two major expressways.

The manual polishing process consists of two phases: first polishing the blank to a sphere and then polishing in the final shape. Acquiring reliable measurement data early in the process is critical for producing the mirrors on a tight schedule, noted Rod Schmell, optical fabrication manager at Optical Surface Technologies. “If we can see surface deviations when the surface quality is at 33 waves rms, then we can polish more aggressively and converge on the final shape faster,” he said.

For these measurements, the company first employed an off-axis Fizeau interferometer, but because of the extreme local slopes, reliable data could not be obtained. A dynamic interferometer was then used and was found to measure accurately (Figure 3) even at the rough blank stage. “We had data we could believe, and we tracked it throughout the polishing run,” Schmell said. “The data gave us confidence to work the part more quickly.”

Also important was the dynamic interferometer’s ease of use for in-process measurement. Setting up the off-axis Fizeau system required alignment of two spots per optical element; determining which spot was correct required significant time and effort. The Twyman-Green-type dynamic interferometer did not have this limitation. This advantage, along with minimal system drift and other benefits, enabled the polishing team to reduce downtime for a measurement to 15 min.

Dynamic interferometry provides quantitative feedback for manual and automatic polishing operations, from rough polishing to final shaping. Overcoming the difficult measurement environments found in most polishing operations, dynamic interferometry enables aggressive polishing with less downtime, so manufacturers can deliver high-quality finished optics in less time.

Meet the author

Mike Zecchino is applications engineer at 4D Technology Corp. in Tucson, Ariz.; e-mail: mike.zecchino@4dtechnology.com.

Back-Illuminated CMOS Image Sensors Come to the Fore

BY RICHARD D. CRISP AND
GILES HUMPSTON, TESSERA INC.

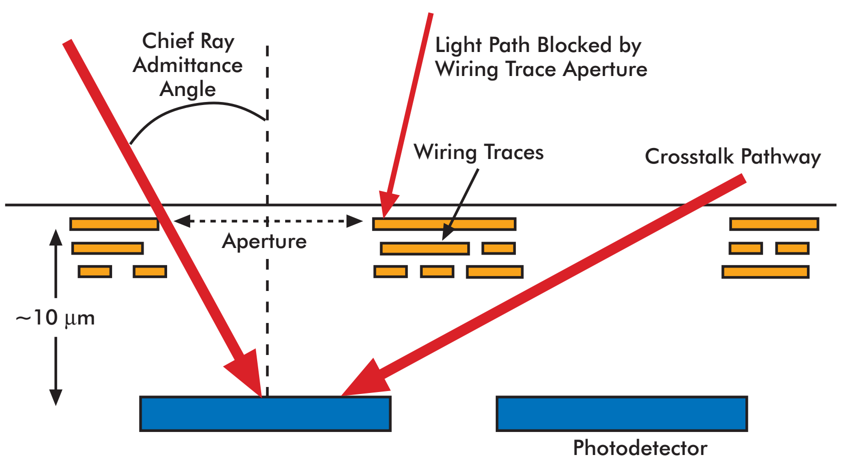


Figure 1. This schematic cross section is through a front-illuminated CMOS image sensor. For reasons of physics, the photodetectors are buried ~10 µm deep in the silicon. The wiring trace that connects to each pixel is built on the surface of the wafer and carefully routed to minimize pixel obscuration. The resulting aperture influences the maximum angle of captured incident light and gives rise to a potential crosstalk mechanism. Images courtesy of Tessera.

CCD advantages:	CMOS advantages:
1. Mature technology	1. Higher level of integration: Lower system cost, fewer support components
2. Textbook-quality images: Nearly perfect operation	2. Smaller pixels typically; higher resolution in a smaller form factor: reduced cost for a given resolution
3. High sensitivity	3. Higher-speed readout, more suitable for video
	4. Improved radiation immunity
Tasks that favor CCD:	**Tasks that favor CMOS:**
1. Long-exposure scientific applications such as astronomy, biofluorescence	1. Low-cost video
2. Very low signal level applications	2. Miniaturized cameras
3. Physically large sensors; i.e., full-wafer sensors	3. Highly integrated single-chip cameras
4. Near-IR applications	4. Cost-sensitive cameras (sensor yield/cost, total bill of material cost)
	5. High-radiation environments

Solid-state image sensors come in two variants: CCD and CMOS. CCDs generally offer superior image quality. However, CMOS dominates in manufacturing volume because it permits an integrated solution in which both the imaging device and processing electronics can be fabricated in a single die.

The vast majority of CMOS image sensors are front-side illuminated; i.e., the light from the scene to be imaged falls on the processed face of the semiconductor. Another variety is back-side illuminated, where the die is mounted inverted and the light falls on the unprocessed face of the semiconductor. This configuration yields performance comparable to CCD imagers but with higher manufacturing cost and more complex packaging requirements. Recent breakthroughs in semiconductor processing and wafer-scale packaging techniques make back-illuminated image sensors attractive candidates for higher-resolution imagers on mobile platforms, where small size and good light sensitivity are highly prized.

CMOS imager design trade-offs

The cost of a camera module is directly proportional to two size metrics: the diagonal of the imager die and the diameter of the optics. Image sensors from only a few years back had pixel dimensions of tens of microns. In 2009, 1.4-µm pixels were considered standard, and most sensor manufacturers had road maps out to 0.9 µm. However, small pixels exhibit poor performance in low-light environments. There are three reasons for this:

1. Reduced light collection area of each pixel. All other factors being equal, a large pixel will collect more light flux than a small pixel, resulting in a better signal-to-noise ratio in the image.

2. With a CMOS image sensor, off-axis light rays are blocked by the aperture

formed by the dielectric and wiring layers above the pixel (Figure 1). The smaller the pixel, the proportionately smaller the unobscured window, allowing less light through to the photodetector.

3. The vertical separation between the wiring aperture and the photodetector forms an optical tunnel that restricts the field of view of each pixel. This is termed the chief ray admittance angle and is most acute for small pixels. Unless the optics are configured so that light falls on the image sensor at a perpendicular angle, light-collection efficiency will fall off, particularly at the sensor edges. The required telecentric lenses are generally incompatible with cheap, compact optical trains because the train requires the rear optical surface to be both large diameter and large radius of curvature.

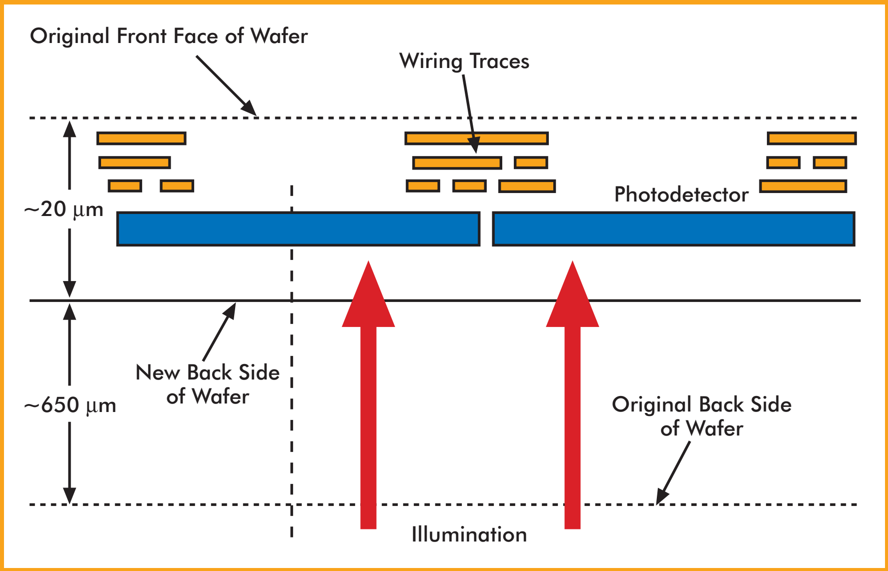


Figure 2. In this schematic cross section through a back-illuminated CMOS image sensor, the die is fabricated in the conventional orientation, but the bulk silicon is then removed, exposing the photodetectors. Making the photodetectors large and easily accessible trades manufacturing cost against performance and/or size.

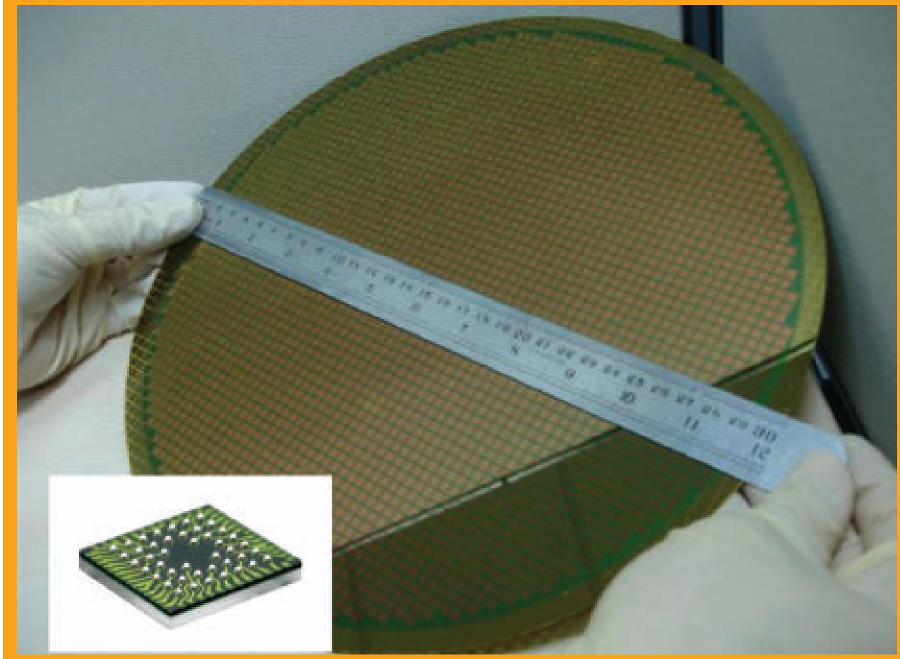


Figure 3. This imager die, housed in a wafer-scale package, uses a low-cost via-through-pad interconnect to connect the die bond pads to the package lands and the ball grid array interface. It is based on polymer technology with a single redistribution layer for the wiring trace, making it very low cost and highly reliable compared with other variants of through-silicon via.

Back-illuminated CMOS image sensors

CMOS back-illuminated image sensors largely solve the above problems. In this configuration, the wiring trace is underneath the photodetector (Figure 2). The entire area of each pixel can be used for photon capture with no restrictions on the chief ray admittance angle and almost complete elimination of adjacent pixel optical crosstalk. Although a typical front-side-illuminated image sensor has a quantum efficiency (QE) – the effective conversion of photons to electrons – of 20 percent, the QE of a back-side illuminated imager can exceed 80 percent. This performance gain can be used to dramatically boost low-light sensitivity or to reduce imager size. For example, reducing a 2.8-μm pixel (at 20 percent QE) to 1.4 μm (at 60 percent QE) results in the same sensitivity but decreases the area of a corresponding VGA imager by 62 percent.

Visible light can penetrate only a short distance into silicon. Therefore, to expose the photodetectors in a back-illuminated CMOS sensor, the majority of the original wafer thickness must be removed. The thinning uniformity must be extremely precise because excess silicon presents an effectively opaque barrier. Thickness variation manifests itself as sensor shadowing, and high average thickness will render the sensor unresponsive. Clearly, there also are basic handling and yield issues with 30-mm-diameter silicon wafers that have been thinned to 20 μm.

A simple way to accurately control wafer thinning is to fabricate imagers on silicon-on-insulator (SOI) wafers because the buried oxide layer provides an effective stop for the silicon etch. The drawback of this approach is that these wafers are more expensive than conventional device-grade silicon. However, SOI wafers also provide a less obvious benefit that makes their use as the starting material for CMOS back-illuminated image sensor manufacture rather attractive.

Achieving high quantum efficiency and wide dynamic range from a photodetector essentially requires keeping dark leakage current low and efficiently collecting charge generated by photon absorption. Both goals can be accomplished with an accumulation layer in the form of a *p*-type surface doping. A simple way to do this is to exploit the SOI wafer structure. Before sensor fabrication, the device layer of the SOI wafer is doped with a heavy *p*-type element at the interface to the buried oxide layer. The various heat treatments during device fabrication will activate and redistribute the impurities, forming the desired surface accumulation layer when it is exposed by the etch process.

Back-illuminated CMOS image sensors are not without problems. But a general truism is that they provide improved imaging performance for increased die cost.

Back-illuminated CMOS image sensor packaging

As with their front-face counterparts, back-illuminated CMOS image sensors require a cavity package for their function and longevity. However, packaging of back-illuminated image sensors poses special challenges, not least because the die are used inverted, so the bond pads face the package substrate and are therefore inaccessible.

The generally adopted solution is to use through-silicon via technology to connect the bond pads to new lands on the optically active face of the die. The die then can be wire-bonded in the conventional manner. The principal objection to this arrangement is cost because it entails implementing two interconnect technologies. A preferred solution is to use a wafer-scale package with a ball grid array interface so that the contacts remain underneath the die and do not have to pass through it. A modern wafer-scale package for image sensors is shown in Figure 3. The package thickness is approximately 500 µm, making it eminently suitable for electronic products where the current fashion is for extreme thinness.

Conclusion

Back illumination offers the prospect of a new generation of mass-produced CMOS image sensors for both optical and nonoptical imaging. It permits a significant improvement in quantum efficiency, which can be used to reduce pixel size. The ability to manufacture small pixels permits imager resolution to increase while the size of the resulting camera module decreases.

Back-illuminated image sensors are preferably housed in wafer-scale packages that use via-through-pad interconnects to a ball grid array interface because this arrangement obviates the need to use costly through-silicon vias. The primary application is likely to be higher-resolution cameras for mobile platforms, where the increased imager cost can be borne, with camera size being paramount.

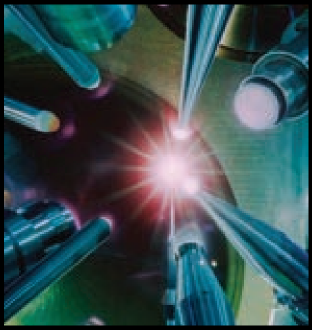
Meet the authors

Richard D. Crisp is the director of semiconductor technology and applications, and Giles Humpston is the director of applications, both at Tessera Inc.; e-mail: rcrisp@tessera.com; ghumpston@tessera.com.

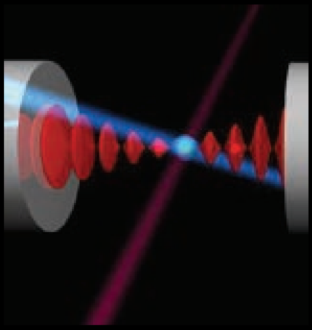
HAPPY 50TH BIRTHDAY,

LASER

HRL Laboratories LLC



LLNL



University of Innsbruck © Piet Schmidt

Since its invention half a century ago, the laser has made possible a staggering number of applications in a wide range of fields: industry, science, medicine, the military and more. On the 50th anniversary of the laser, *Photonics Spectra* takes you down memory lane with a look at the laser's history and the key players who influenced the development of this important technology.

Be sure to visit Photonics Media's www.lasertime line.com to check out our interactive laser history timeline, which will let you slide through the significant moments that have arisen since that fateful day in May 1960.

LASERS AT 50

A HISTORY OF THE LASER

A TRIP THROUGH THE LIGHT FANTASTIC

BY MELINDA ROSE
SENIOR EDITOR

In honor of the laser turning 50, here is a timeline of some of the more notable scientific accomplishments related to light amplification by stimulated emission of radiation (laser). An interactive version is available at www.lasertimeline.com. The laser would not have been possible without an understanding that light is a form of electromagnetic radiation. Max Planck received the Nobel Prize in physics in 1918 for his discovery of elementary energy quanta. Planck was working in thermodynamics, trying to explain why "blackbody" radiation, something that absorbs all wavelengths of light, didn't radiate all frequencies of light equally when heated.

In his most important work, published in 1900, Planck deduced the relationship between energy and the frequency of radiation, essentially saying that energy could be emitted or absorbed only in discrete chunks – which he called quanta – even if the chunks were very small. His theory marked a turning point in physics and inspired up-and-coming physicists such as Albert Einstein. In 1905, Einstein released his paper on the photoelectric effect, which proposed that light also delivers its energy in chunks, in this case discrete quantum particles now called photons.

In 1917, Einstein proposed the process that makes lasers possible, called stimulated emission. He theorized that, besides absorbing and emitting light spontaneously, electrons could be stimulated to emit light of a particular wavelength (for more on the pioneers of the laser, see "On the Shoulders of Giants" by Lynn Savage, page 70). But it would take nearly 40 years before scientists would be able to amplify those emissions, proving Einstein correct and putting lasers on the path to becoming the powerful and ubiquitous tools they are today.

melinda.rose@photonics.com

AP Photo

Max Planck

AP Photo

Charles Hard Townes

April 26, 1951: Charles Hard Townes of Columbia University in New York conceives his maser (microwave amplification by stimulated emission of radiation) idea while sitting on a park bench in Washington.

1954: Working with Herbert J. Zeiger and graduate student James P. Gordon, Townes demonstrates the first maser at Columbia University. The ammonia maser, the first device based on Einstein's predictions, obtains the first amplification and generation of electromagnetic waves by stimulated emission. The maser radiates at a wavelength of a little more than 1 cm and generates approximately 10 nW of power.

1955: At P.N. Lebedev Physical Institute in Moscow, Nikolai G. Basov and Alexander M. Prokhorov attempt to design and build oscillators. They propose a method for the production of a negative absorption that was called the pumping method.

1956: Nicolaas Bloembergen of Harvard University develops the microwave solid-state maser.

Sept. 14, 1957: Townes sketches an early optical maser in his lab notebook.

Nov. 13, 1957: Columbia University graduate student Gordon Gould jots his ideas for building a laser in his notebook and has it notarized at a candy store in the Bronx. It is considered the first use of the acronym laser. Gould leaves the university a few months later to join private research company TRG (Technical Research Group).

1958: Townes, a consultant for Bell Labs, and his brother-in-law, Bell Labs researcher Arthur L. Schawlow, in a joint paper published in *Physical Review Letters*, show that masers could be made to operate in the optical and infrared regions and propose how it could be accomplished. At Lebedev Institute, Basov and Prokhorov also are exploring the possibilities of applying maser principles in the optical region.

April 1959: Gould and TRG apply for laser-related patents stemming from Gould's ideas.

March 22, 1960: Townes and Schawlow, under Bell Labs, are granted US patent number 2,929,922 for the optical maser, now called a laser. With their application denied, Gould and TRG launch what would become a 30-year patent dispute related to laser invention.

May 16, 1960: Theodore H. Maiman, a physicist at Hughes Research Laboratories in Malibu, Calif., constructs the first laser using a cylinder of synthetic ruby measuring 1 cm in diameter and 2 cm long, with the ends silver-coated to make them reflective and able to serve as a Fabry-Perot resonator. Maiman uses photographic flashlamps as the laser's pump source.

July 7, 1960: Hughes holds a press conference to announce Maiman's achievement.

November 1960: Peter P. Sorokin and Mirek J. Stevenson of the IBM Thomas J.


Wikimedia Commons

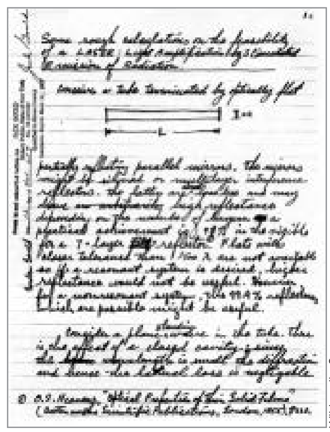
Nikolai G. Basov


Wikimedia Commons

Alexander M. Prokhorov

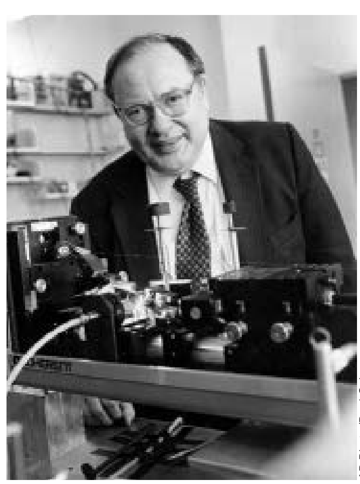

HRL Laboratories LLC

Theodore H. Maiman


Some rough calculations on the feasibility of a LASER: Light Amplification by Stimulated Emission of Radiation.

Wikimedia Commons

This is the first page of Gordon Gould's famous notebook, in which he coined the acronym LASER and described the essential elements for constructing one. This notebook was the focus of a 30-year court battle for the patent rights to the laser. Notable is the notary's stamp in the upper left corner of the page, dated Nov. 13, 1957. This date stamp established Gould's priority as the first to conceive many of the technologies described in the book.


AP Photo/Paul Sakuma

Professor Arthur Schawlow

SOURCES

www.photonics.com

www.hrl.com

www.bell-labs.com/history/

www.alcatel-lucent.com

www.nobelprize.org

www.nasa.gov

www.union.edu

www.corning.com

www.nationalbarcode.com

www.mit.edu

www.philips.com

www.laserfest.org

www.llnl.gov

www.ucsb.edu

www.intel.com

www.ecs.soton.ac.uk

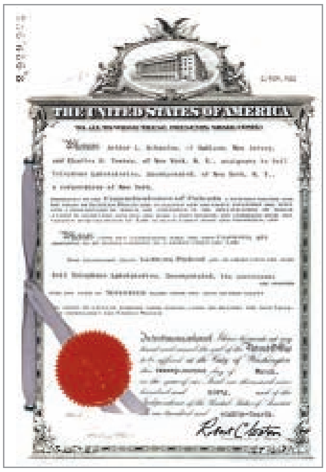
The Laser in America, 1950-1979
Joan Lisa Bromberg
Laser History Project/MIT Press, 1991

Laser: Light of a Million Uses
Jeff Hecht and Dick Teresi
Dover Publications Inc. 1982, 1998

Laser Pioneers
Jeff Hecht
Academic Press Inc. 1985, 1992

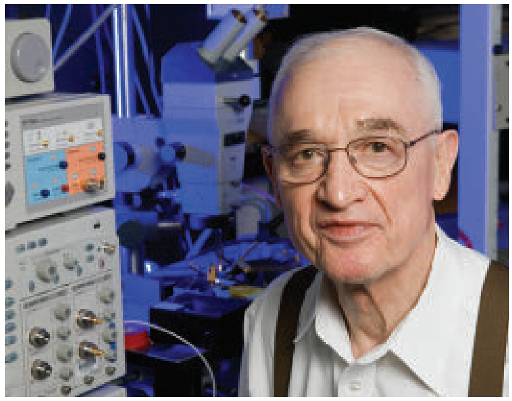
Laser Community
The Laser Magazine from Trumpf
Issue 02:2009

Lasers & Applications magazine, Jan. 1985



Bell Labs

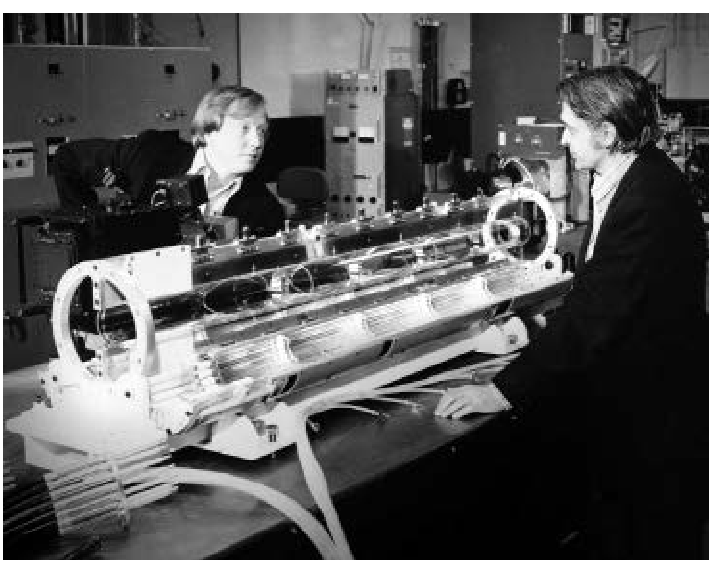
US patent number 2,929,922


L. Brian Stauffer/University of Illinois

Nick Holonyak Jr.


NASA Archives

This Electronics Research Center study of the molecular properties of liquids was conducted using laser technology. ERC opened in September 1964 and has the particular distinction of being the only NASA Center to close, shutting down in June 1970. Its mission was to develop new electronics and training new graduates as well as NASA employees. The ERC actually grew while NASA eliminated major programs and cut staff in other areas. Between 1967 and 1970, NASA cut permanent civil service workers at all Centers with one exception, the ERC, whose personnel grew annually until its closure.


Lawrence Livermore National Laboratory

Physicists John L. Emmett (left) and John H. Nuckolls were the key Lawrence Livermore National Laboratory pioneers in laser and fusion science and technology. Emmett co-invented the multipass laser architecture still in use today.

Watson Research Center demonstrate the uranium laser, a four-stage solid-state device.

December 1960: Ali Javan, William Bennett Jr. and Donald Herriott of Bell Labs develop the helium-neon (HeNe) laser, the first to generate a continuous beam of light at 1.15 μm.

1961: Lasers begin appearing on the commercial market through companies such as Trion Instruments Inc., Perkin-Elmer and Spectra-Physics.

March 1961: At the second International Quantum Electronics meeting, Robert W. Hellwarth of Hughes Research Labs presents theoretical work suggesting that a dramatic improvement in the ruby laser could be made by making its pulse more predictable and controllable. He predicts that a single spike of great power could be created if the reflectivity of the laser's end mirrors were suddenly switched from a value too low to permit lasing to a value that could.

October 1961: American Optical Co.'s Elias Snitzer reports the first operation of a neodymium glass (Nd:glass) laser.

December 1961: The first medical treatment using a laser on a human patient is performed by Dr. Charles J. Campbell of the Institute of Ophthalmology at Columbia-Presbyterian Medical Center and Charles J. Koester of the American Optical Co. at Columbia-Presbyterian Hospital in Manhattan. An American Optical ruby laser is used to destroy a retinal tumor.

1962: With Fred J. McClung, Hellwarth proves his laser theory, generating peak powers 100 times that of ordinary ruby lasers by using electrically switched Kerr cell shutters. The giant pulse formation technique is dubbed Q-switching. Important first applications include the welding of springs for watches.

1962: Groups at GE, IBM and MIT's Lincoln Laboratory simultaneously develop a gallium-arsenide laser, a semiconductor device that converts electrical energy directly into infrared light but which must be cryogenically cooled, even for pulsed operation.

October 1962: Nick Holonyak Jr., a consulting scientist at a General Electric Co. lab in Syracuse, N.Y., publishes his work on the “visible red” GaAsP (gallium arsenide phosphide) laser diode, a compact, efficient source of visible coherent light that is the basis for today’s red LEDs used in consumer products such as CDs, DVD players and cell phones.

June 1962: Bell Labs reports the first yttrium aluminum garnet (YAG) laser.

Early 1963: *Barron’s* magazine estimates annual sales for the commercial laser market at $1 million.

1963: Logan E. Hargrove, Richard L. Fork and M.A. Pollack report the first demonstration of a mode-locked laser; i.e., a helium-neon laser with an acousto-optic modulator. Mode locking is fundamental for laser communication and is the basis for femtosecond lasers.

1963: Herbert Kroemer of the University of California, Santa Barbara, and the team of Rudolf Kazarinov and Zhores Alferov of A.F. Ioffe Physico-Technical Institute in St. Petersburg, Russia, independently propose ideas to build semiconductor lasers from heterostructure devices. The work leads to Kroemer and Alferov winning the 2000 Nobel Prize in physics.

March 1964: After two years working on HeNe and xenon lasers, William B. Bridges of Hughes Research Labs discovers the pulsed argon-ion laser, which, although bulky and inefficient, could produce output at several visible and UV wavelengths.

1964: Townes, Basov and Prokhorov are awarded the Nobel Prize in physics for their “fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser-principle.”

1964: The carbon dioxide laser is invented by Kumar Patel at Bell Labs. The most powerful continuously operating laser of its time, it is now used worldwide as a cutting tool in surgery and industry.

1964: The Nd:YAG (neodymium-doped YAG) laser is invented by Joseph E. Geusic and Richard G. Smith at Bell Labs. The laser later proves ideal for cosmetic applications, such as laser-assisted in situ keratomileusis (lasik) vision correction and skin resurfacing.

1965: Two lasers are phase-locked for the first time at Bell Labs, an important step toward optical communications.

1965: Jerome V.V. Kasper and George C. Pimentel demonstrate the first chemical laser, a 3.7-µm hydrogen chloride instrument, at the University of California, Berkeley.

1966: Mary L. Spaeth of Hughes Research Labs invents the tunable dye laser pumped by a ruby laser.

1966: Charles K. Kao, working with George Hockham at Standard Telecommunication Laboratories in Harlow, UK, makes a discovery that leads to a breakthrough in fiber optics. He calculates how to transmit light over long distances via optical glass fibers, deciding that, with a fiber of purest glass, it would be possible to transmit light signals over a distance of 100 km, compared with only 20 m for the fibers available in the 1960s.

A laser in operation at the Electronics Resource Centers Space Optics Laboratory is checked by Lowell Rosen (left) and Dr. Norman Knable. They investigated energy levels of atoms in very excited states as a step to improving the laser's efficiency in space. The ERC opened in September 1964, taking over the administration of contracts, grants and other NASA business in New England from the antecedent North Eastern Operations Office (created in July 1962), and closed in June 1970. It served to develop the space agency's in-house expertise in electronics during the Apollo era. A second key function was to serve as a graduate and postgraduate training center within the framework of a regional government-industry-university alliance. Research at the ERC was conducted in 10 different laboratories: space guidance, systems, computers, instrumentation research, space optics, power conditioning and distribution, microwave radiation, electronics components, qualifications and standards, and control and information systems. Researchers investigated such areas as microwave and laser communications; the miniaturization and radiation resistance of electronic components; guidance and control systems; photovoltaic energy conversion; information display devices; instrumentation; and computers and data processing. Although the only NASA center ever closed, the ERC actually grew while NASA eliminated major programs and cut staff in other areas. Between 1967 and 1970, NASA cut permanent civil service workers at all centers with one exception, the ERC, whose personnel grew annually until its closure in June 1970.

Kao receives a 2009 Nobel Prize in physics for his work.

1966: French physicist Alfred Kastler wins the Nobel Prize in physics for his method of stimulating atoms to higher energy states, which he developed between 1949 and 1951. The technique, known as optical pumping, was an important step toward the creation of the maser and the laser.

February 1968: In California, Maiman and other laser pioneers found the laser advocacy group Laser Industry Association, which becomes the Laser Institute of America in 1972.

1970: Gould buys back his patent rights for $1 plus 10 percent of future profits when TRG is sold.

1970: Basov, V.A. Danilychev and Yu. M. Popov develop the excimer laser at P.N. Lebedev Physical Institute.

Spring 1970: Alferov's group at Ioffe Physico-Technical Institute and Mort Panish and Izuo Hayashi at Bell Labs produce the first continuous-wave room-temperature semiconductor lasers, paving the way toward commercialization of fiber optic communications.

1970: At Corning Glass Works (now Corning Inc.), Drs. Robert D. Maurer, Peter C. Schultz and Donald B. Keck report the first optical fiber with loss below 20 dB/km, demonstrating the feasibility of fiber optics for telecommunications.

1970: Arthur Ashkin of Bell Labs invents optical trapping, the process by which atoms are trapped by laser light. His work pioneers the field of optical tweezing and trapping and leads to significant advances in physics and biology.

1971: Izuo Hayashi and Morton B. Panish of Bell Labs design the first semiconductor laser that operates continuously at room temperature.

1972: Charles H. Henry invents the quantum well laser, which requires much less current to reach lasing threshold than conventional diode lasers and which is


AP Photo

Gordon Gould


AP Photo/Bill Sikes

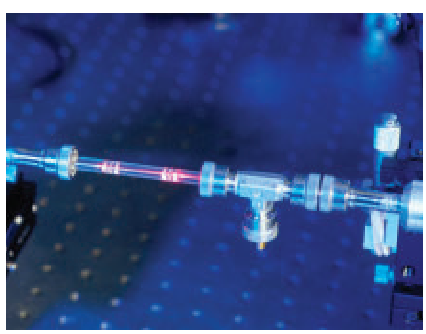
Donald B. Keck


Wikimedia Commons

LaserDisc vs. CD


US Department of Energy

Energy Secretary Steven Chu


University of Colorado

Extreme nonlinear optical techniques have succeeded in upconverting visible laser light into x-rays, making a tabletop source of coherent soft x-rays possible.

exceedingly more efficient. Holonyak and students at the University of Illinois at Urbana-Champaign first demonstrate the quantum well laser in 1977.

1972: A laser beam is used at Bell Labs to form electronic circuit patterns on ceramic.

June 26, 1974: A pack of Wrigley's chewing gum is the first product read by a bar-code scanner in a grocery store.

1975: Engineers at Laser Diode Labs Inc. in Metuchen, N.J., develop the first commercial continuous-wave semiconductor laser operating at room temperature. Continuous-wave operation enables transmission of telephone conversations.

1975: First quantum-well laser operation made by Jan P. Van der Ziel, R. Dingle, Robert C. Miller, William Wiegmann and W.A. Nordland Jr. The lasers actually are developed in 1994.

1976: First demonstration, at Bell Labs, of a semiconductor laser operating continuously at room temperature at a wavelength beyond 1 µm, the forerunner of sources for long-wavelength lightwave systems.

1976: John M.J. Madey and his group at Stanford University in California demonstrate the first free-electron laser (FEL). Instead of a gain medium, FELs use a beam of electrons that are accelerated to near light speed, then passed through a periodic transverse magnetic field to produce coherent radiation. Because the lasing medium consists only of electrons in a vacuum, FELs do not have the material damage or thermal lensing problems that plague ordinary lasers and can achieve very high peak powers.

1977: The first commercial installation of a Bell Labs fiber optic lightwave communications system is completed under the streets of Chicago.

Oct. 11, 1977: Gould is issued a patent for optical pumping, then used in about 80 percent of lasers.

1978: The LaserDisc hits the home video market, with little impact. The earliest players use HeNe laser tubes to read the media, while later players use infrared laser diodes.

1978: Following the failure of its videodisc technology, Philips announces the compact disc (CD) project.

1979: Gould receives a patent covering a broad range of laser applications.

1981: Schawlow and Bloembergen receive the Nobel Prize in physics for their contributions to the development of laser spectroscopy.

1982: Peter F. Moulton of MIT's Lincoln Laboratory develops the titanium-sapphire laser, used to generate short pulses in the picosecond and femtosecond ranges. The Ti:sapphire laser replaces the dye laser for tunable and ultrafast laser applications.

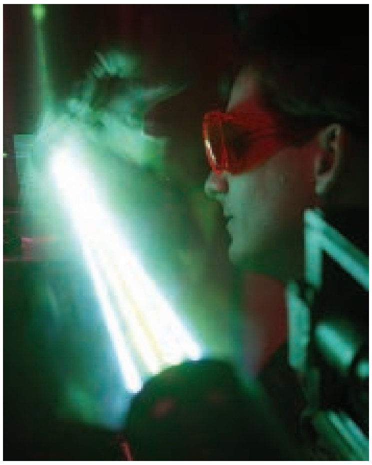
October 1982: The audio CD, a spinoff of LaserDisc video technology, debuts. Billy Joel fans rejoice, as his 1978 album "52nd Street" is the first to be released on CD.

1985: Bell Labs' Steven Chu (now US Secretary of Energy) and his colleagues use laser light to slow and manipulate atoms. Their laser cooling technique, also called "optical molasses," is used to investigate the behavior of atoms, providing an insight into quantum mechanics. Chu, Claude N. Cohen-Tannoudji and William D. Phillips win a Nobel Prize for this work in 1997.

1987: David Payne at the University of Southampton in the UK and his team introduce erbium-doped fiber amplifiers. These new optical amplifiers boost light signals without first having to convert them into electrical signals and then back into light, reducing the cost of long distance fiber optic systems.

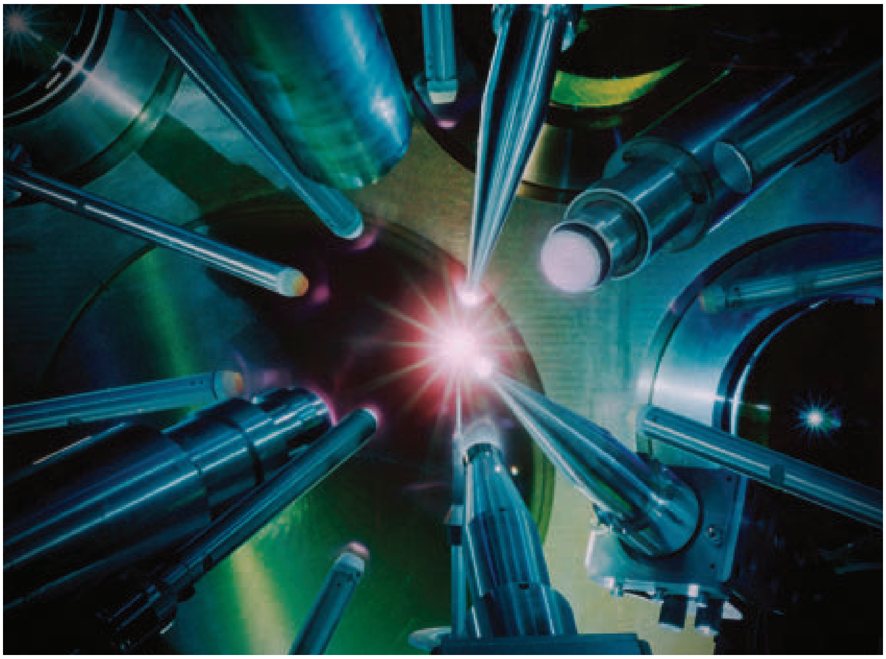
1988: Gould begins receiving royalties from his patents.

1994: The first semiconductor laser that can simultaneously emit light at multiple widely separated wavelengths – the quantum cascade (QC) laser – is invented at Bell Labs by Jérôme Faist, Federico Capasso, Deborah L. Sivco, Carlo Sirtori, Albert L. Hutchinson and Alfred Y. Cho. The laser is unique in that its entire structure is manufactured a layer of atoms at a time by the crystal growth technique called molecular beam epitaxy. Simply changing the thickness of the semiconductor layers can change the laser's wavelength. With its room-temperature



NASA Archives

In 1997, an engineer at the Marshall Space Flight Center (MSFC) Wind Tunnel Facility uses lasers to measure the velocity and gradient distortion across an 8-in. curved pipe with joints and turning valves during a cold-flow propulsion research test, simulating the conditions found in the X-33's hydrogen feedline. Lasers are used because they are nonintrusive and do not disturb the flow like a probe would. The feedline supplies propellants to the turbo pump. The purpose of this project was to design the feedline to provide uniform flow into the turbo pump.



Lawrenec Livermore National Laboratory

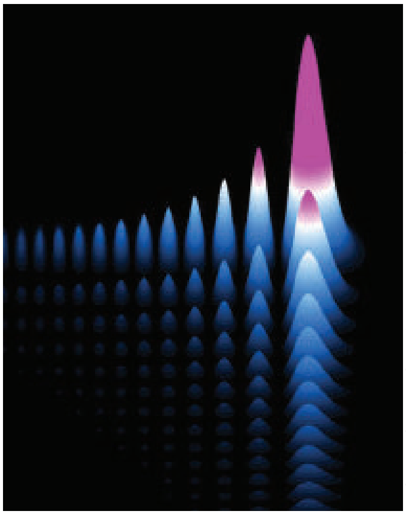
The international inertial confinement fusion community, including LLNL researchers, uses the OMEGA laser at the University of Rochester's Laboratory for Laser Energetics to conduct experiments and test target designs and diagnostics. The 60-beam OMEGA laser at the University of Rochester has been operational since 1995.

Fraunhofer ILT

Remote laser cutting.

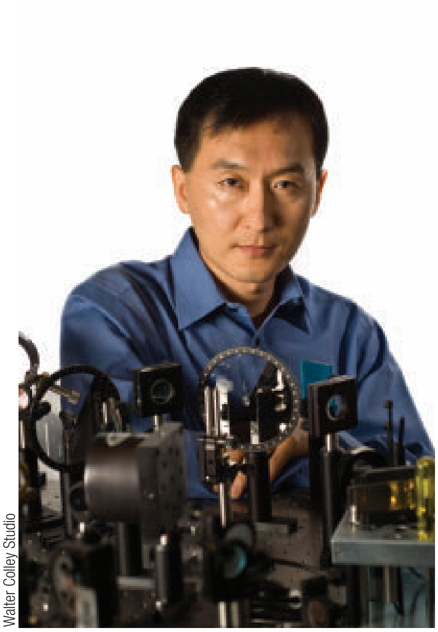
While orbiting the moon, the Lunar Reconnaissance Orbiter will take pictures and gather information about the moon's surface.

NASA



Dr. Georgios Siviloglou, Center for Research and Education in Optics and Lasers, University of Central Florida

An ideal finite-energy Airy Beam is a light beam that can bend and propagate without spreading.



Walter Colley Studio

Dr. Chunlei Guo of the University of Rochester stands in front of his femtosecond laser.

operation and power and tuning ranges, the QC laser is ideal for remote sensing of gases in the atmosphere.

1994: The first demonstration of a quantum dot laser with high threshold density is reported by Nikolai N. Ledentsov of A.F. Ioffe Physico-Technical Institute.

November 1996: The first pulsed atom laser, which uses matter instead of light, is demonstrated at MIT by Wolfgang Ketterle.

January 1997: Shuji Nakamura, Steven P. DenBaars and James S. Speck at the University of California, Santa Barbara, announce the development of a gallium-nitride (GaN) laser that emits bright blue-violet light in pulsed operation.

September 2003: A team of researchers from NASA's Marshall Space Flight Center in Huntsville, Ala., from NASA's Dryden Flight Research Center at Edwards Air Force Base in California and from the University of Alabama in Huntsville successfully flies the first laser-powered aircraft. The plane, its frame made of balsa wood, has a 1.5-m wingspan and weighs only 311 g. Its power is delivered by an invisible ground-based laser that tracks the aircraft in flight, directing its energy beam at specially designed photovoltaic cells carried onboard to power the plane's propeller.

2004: Electronic switching in a Raman laser is demonstrated for the first time by Ozdal Boyraz and Bahram Jalali of the University of California, Los Angeles. The first silicon Raman laser operates at room temperature with 2.5-W peak output power. In contrast to traditional Raman lasers, the pure-silicon Raman laser can be directly modulated to transmit data.

September 2006: John Bowers and colleagues at the University of California, Santa Barbara, and Mario Paniccia, director of Intel Corp.'s Photonics Technology Lab in Santa Clara, Calif., announce that they have built the first electrically powered hybrid silicon laser using standard silicon manufacturing processes. The breakthrough could lead to low-cost, terabit-level optical data pipes inside future computers, Paniccia says.

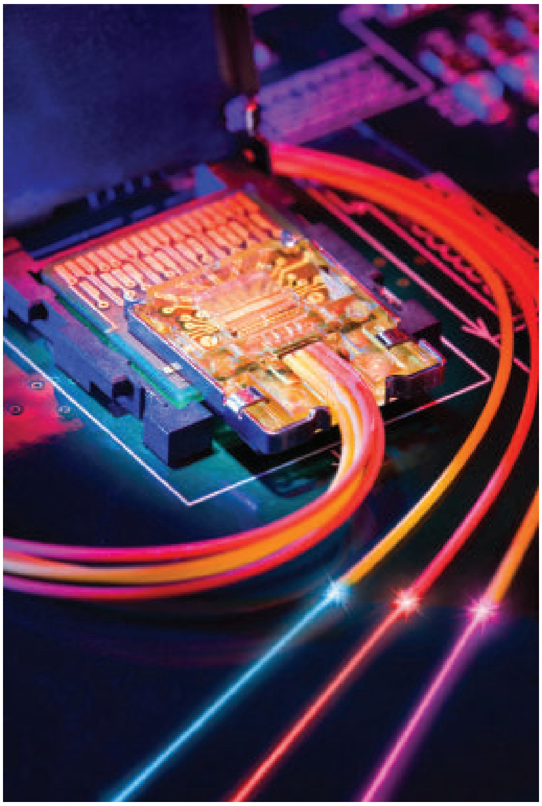
August 2007: Bowers and his doctoral student Brian Koch announce that they have built the first mode-locked silicon evanescent laser, providing a new way to integrate optical and electronic functions on a single chip and enabling new types of integrated circuits.

May 2009: At the University of Rochester in New York, researcher Chunlei Guo announces a new process that uses femtosecond laser pulses to make regular incandescent lightbulbs superefficient. The laser pulse, trained on the bulb's filament, forces the surface of the metal to form nanostructures that make the tungsten become far more effective at radiating light. The process could make a 100-W bulb consume less electricity than a 60-W bulb, Guo says.

May 29, 2009: The largest and highest-energy laser in the world, the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory in Livermore, Calif., is dedicated. In a few weeks, the system begins firing all 192 of its laser beams onto targets.

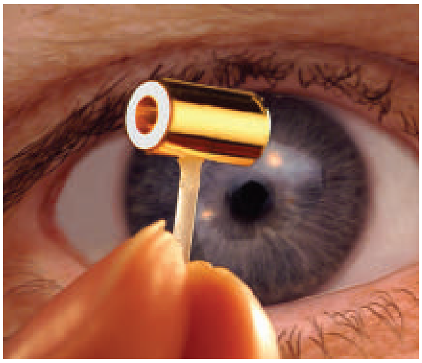
June 2009: NASA launches the Lunar Reconnaissance Orbiter (LRO). The Lunar Orbiter Laser Altimeter on the LRO will use a laser to gather data about the high and low points on the moon. NASA will use that information to create 3-D maps that could help determine lunar ice locations and safe landing sites for future spacecraft.

September 2009: Lasers get ready to enter household PCs with Intel's announcement of its Light Peak optical fiber technology at the Intel Developer Forum. Light Peak contains vertical-cavity surface-emitting lasers (VCSELs) and can send and receive 10 billion bits of



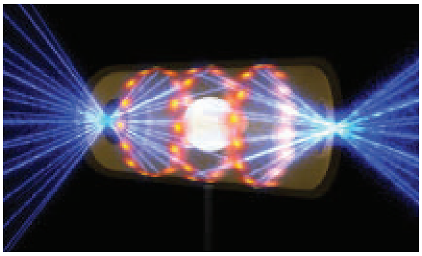
Jeffrey Tseng/Intel

Light Peak module close-up with laser light added for illustration (actual infrared light is invisible to the eye).

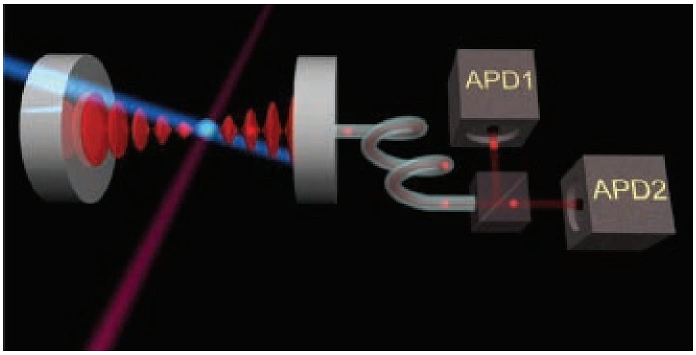


NIF/LLNL

A National Ignition Facility (NIF) hohlraum. The hohlraum cylinder, which contains the fusion fuel capsule, is just a few millimeters wide, about the size of a pencil eraser, with beam entrance holes at either end. The fuel capsule is the size of a small pea. Credit is given to Lawrence Livermore National Security LLC, Lawrence Livermore National Laboratory and the US Department of Energy, under whose auspices this work was performed.


NIF/LLNL

This artist's rendering shows an NIF target pellet inside a hohlraum capsule with laser beams entering through openings on either end. The beams compress and heat the target to the necessary conditions for nuclear fusion to occur. Ignition experiments on NIF will be the culmination of more than 30 years of inertial confinement fusion research and development, opening the door to exploration of previously inaccessible physical regimes. Credit is given to Lawrence Livermore National Security LLC, Lawrence Livermore National Laboratory and the US Department of Energy, under whose auspices this work was performed.



University of Innsbruck © Piet Schmidt

A high-finesse optical cavity consisting of two mirrors traps and accumulates the photons emitted by the ion into a mode. The ion is excited cyclically by an external laser and at each cycle a photon is added to the cavity mode, which amplifies the light.

data per second, meaning it could transfer the entire Library of Congress in 17 minutes. The product is expected to ship to manufacturers in 2010.

December 2009: Industry analysts predict the laser market globally for 2010 will grow about 11 percent, with total revenue hitting $5.9 billion.

January 2010: The National Nuclear Security Administration announces that NIF has successfully delivered a historic level of laser energy – more than 1 MJ – to a target in a few billionths of a second and demonstrated the target drive conditions required to achieve fusion ignition, a project scheduled for the summer of 2010. The peak power of the laser light is about 500 times that used by the US at any given time.

March 31, 2010: Rainer Blatt and Piet O. Schmidt and their team at the University of Innsbruck in Austria demonstrate a single-atom laser with and without threshold behavior by tuning the strength of atom/light field coupling.

ON THE SHOULDERS OF GIANTS

BY LYNN SAVAGE
FEATURES EDITOR

For millennia, scholars in the old and new worlds have realized that their efforts depend largely on the works of those who came before. The "eureka!" moments experienced by scientists and other observers of nature do arise, but there must exist first a foundation of knowledge that has been passed down from earlier investigators.

This has never been more true than in the world of laser technology, celebrated globally on the 50th anniversary of the firing up of the first ruby beauty. It would be shocking to find someone in the field who is unaware of names such as Maiman, Townes, Schawlow and Basov, but the pioneering developments of today depend on the efforts of many more innovators who toiled at the same time, or even earlier.

Entire books have been given over to untangling the web of published papers, patents (submitted, approved or contested), conference presentations, lab tests and handwritten, notarized paper journals that comprise the forensic evidence of who did what, when. The following is a brief tour of some of the bright lights who, over the past five decades, have brought the laser to prominence. For a comprehensive timeline of the laser's history, see "A Trip Through the Light Fantastic," p. 58.

Though no one could have known it at the time, **Charles Fabry** and **Alfred Perot** became forever tied to the story of the laser through the creation of the interferometer in the late 19th century. Two perfectly parallel mirrors were the key to stimulating both solid and gaseous molecules to produce an inverted population. Without the Fabry-Perot device, you're just exciting particles randomly and to no avail.


Library of Congress

Charles Fabry


Wikimedia Commons

Alfred Perot

LASER SCIENCE DOESN'T SLEEP

Listed here are some of the breakthroughs that followed the first ruby laser demonstration. Nearly all of the devices mentioned here have played major roles in science or everyday life right through today.

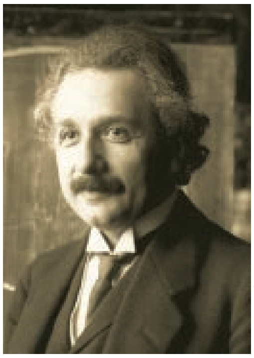
Narinder Kapany
"Father of fiber optics" – coined the term in *Scientific American*, 1960

Leo Johnson, Kurt Nassau, G.D. Boyd and R.R. Soden, Bell Labs
Demonstrated first continuous-wave laser that operated at room temperature (no cooling necessary) – a 1.06-µm device made with Nd-doped calcium tungstate ($CaWO_4$), 1961

Peter Franken, A.E. Hill, C.W. Peters and G. Weinrich, University of Michigan
Discovered second harmonic generation, 1961

Alan D. White and J. Dane Rigden, Bell Labs
Developed first HeNe laser at visible wavelength (632.8 nm), 1962

Robert W. Hellwarth and R.J. McClung, Hughes Labs
First demonstration of Q-switching, 1962


Wikimedia Commons
Albert Einstein


Wikimedia Commons
Nikolai G. Basov


Wikimedia Commons
Alexander M. Prokhorov

NEARLY PIONEERS

Willis Lamb Jr. and R.C. Retherford

Came close to pursuing induced emissions, but didn't.

Joseph Weber/A.M. Prokhorov and Nikolai G. Basov

Weber, at the University of Maryland, and the Russians, at Lebedev Physics Institute in Moscow, separately pursued construction of a maser at the same time as Charles Townes, but Townes got there first.

Robert H. Dicke

In 1954, Dicke proposed an "optical bomb" that would use a short excitation pulse to produce a population inversion, which in turn would create an intense burst of spontaneous emission. In a 1958 patent, he suggested that parallel mirrors would form a resonant optical cavity, but he didn't build it.

H.J. Round

In 1907, Round saw electroluminescence when he applied an electric field to silicon carbide, which is a semiconducting material. However, the first semiconductor maser wasn't developed until 1962.

Photo: Lynn Savage.

❊A couple of decades later, in 1917, while he was tinkering with other concepts that also caused a stir, **Albert Einstein** became the first theoretician to stipulate ways in which atoms might interact with photons, including the practicality of producing the stimulated emission of light.

❊Scientists in the US, Europe and the Soviet Union picked at the edges of light-and-matter interactions for several years, with two global wars causing deep distractions. In 1940, the young physicist **Valentin A. Fabrikant** of the Moscow Power Institute described how population inversion – having more molecules excited than not – would necessarily lead to "molecular amplification," aka stimulated emission. He applied for a patent (in the USSR) for "a method for the amplification of electromagnetic radiation," on June 18, 1951. The application was rejected at first, but was eventually approved in 1959 – too late for most of the acclaim he deserved.

❊While Fabrikant's patent churned through the Soviet bureaucracy, **Joseph Weber** of the University of Maryland made the first public description of coherent microwave radiation in 1952.

❊Then, from within the heavy-laboring crowd of microwave specialists, came **Charles Hard Townes**, who, in 1954, conceived and built the very first operating maser, using ammonia gas as the excitation material. He also coined the term, which is an acronym for "microwave amplification by the stimulated emission of radiation." Townes, who cut his teeth on microwave technologies while working for Bell Telephone Laboratories from 1933 to 1947, got his maser ideas into operation after moving from Bell to Columbia University in 1948. Herbert Zeiger and James Gordon were his assistants on the maser development project, but he had others, who also went on to carve their niches in the maser and, ultimately, laser fields. Among these were Isaac Abella, Herman Cummins, Ali Javan and Arthur Schawlow.

Robert N. Hall, GE Research and Development Laboratories
First semiconductor (GaAs) diode laser, 1962

Marshall I. Nathan, IBM Watson Research Center
Second semiconductor laser, 1962

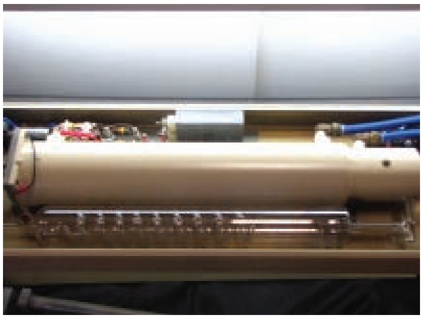
C. Kumar N. Patel, Bell Labs
First high-power gas laser (CO_2), 1964

J.E. Geusic, H.M. Marcos and L.G. Van Uitert, Bell Labs
First Nd:YAG laser, 1964

Earl Bell and Arnold Bloom, Spectra-Physics Inc.
First pulsed ion laser (Hg+), 1964

William Bridges, Hughes Aircraft
Invented pulsed argon-ion laser, 1964

❊**Arthur L. Schawlow**, who ultimately shared the 1981 Nobel Prize in physics for his breakthroughs in laser-based spectroscopy, worked very closely with Townes during the hectic early years of masers and lasers. Not only did they become close friends, but Schawlow married Townes' sister, Aurelia.



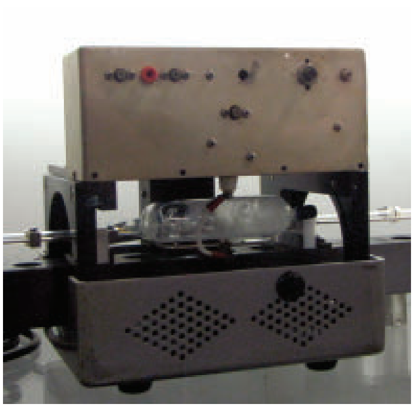
Photos: Lynn Savage.

Hughes Corp. made the first argon-ion laser in 1964. Shown here is one of the first commercial models (left), with its power supply (right).

❊Among those working feverishly in the nascent maser field at about the same time period as Townes in 1954 were **Alexander M. Prokhorov** and **Nikolai Basov** of the Lebedev Physics Institute in Moscow. Together, but independently of Townes, they made pioneering steps toward a working ammonia maser. After Townes, Zeiger and Gordon produced the first working model, Prokhorov and Basov theorized the first three-level maser system. Although they never built a working device, the concepts they brought forth set up exciting new leaps in several fields, especially spectroscopy. In 1964, Townes, Prokhorov and Basov were jointly rewarded with the Nobel Prize for their maser efforts. Basov later went on to become the first to apply lasers to the creation and study of thermonuclear plasmas as well as to the initiation of chemical processes.

❊Nearly two years later, **Nicolaas Bloembergen** of Harvard University produced the second description of a three-level maser, but this scheme differed in that it used solid matter instead of ammonia gas. Bloembergen, who had already established himself as the builder of the first operating nuclear magnetic resonance (NMR) device, used some of those principles to outline the three-level solid-state maser, but he wasn't the first to make one. Later, he would share the 1981 physics Nobel with Schawlow and Kai Siegbahn.

❊**Derrick Scovil**, working with **George Feher** and **Harold Seidel** at Bell Telephone Labs, beat Bloembergen to the first operating three-level maser. The three constructed their device using lanthanum ethyl sulfate doped with gadolinium ions and published their results in 1957.



Photos: Lynn Savage.

Perkin-Elmer and Spectra Physics collaborated to make the early HeNe laser (left) in 1963. Perkin-Elmer modified the design to create the model shown on the right in 1966.

George C. Pimentel, UC Berkeley
With J.V.V. Kasper, developed first chemical laser (3.7 μm, HCl), 1965

Peter Sorokin, IBM
Developed, with Mirek Stevenson, first uranium-doped and samarium-doped lasers, 1960
First pulsed, fixed-wavelength dye laser, 1966

Bernard H. Soffer and B.B. McFarland, Korad Inc.
First wavelength-tunable pulsed dye laser, 1967

William Silfvast, Bell Labs
First continuous-wave HeCd laser, 1967

Izuo Hayashi, Bell Labs
First room-temperature continuous-wave semiconductor laser, 1970

Nikolai Basov, V.A. Danielychev, Yu M. Popov, and D.D. Khodkovich
First excimer laser (176 nm, Xe_2), 1970

❊Also in 1957, several years before the first operating laser was turned on, another of Townes' assistants, **Gordon Gould**, coined the term ***laser***, obviously based on maser, with the first letter standing for "light." Gould's coinage, along with his technical notes, ultimately helped him gain several important patents for the technology 20 years after the fact. (For more, see "Gordon Gould's Scientific 'Patent' Method," October 2008 *Photonics Spectra*, p. 131.)

❊Masers, of course, create coherent radiation out of long microwaves. But even as the technology became established, many scoffed that you could get the same results with more compact infrared or – heaven forfend! – visible wavelengths. This didn't stop others from trying, with various levels of support or funding. Of those making the wild dash toward the modern laser, **Theodore H. Maiman** of Hughes Research Laboratories was the ultimate "winner of the race." Maiman built the first laser, using synthetic pink ruby, in May 1960. From there, the field exploded, as did tempers over who created the laser.

❊Within months, research groups all over were attacking "optical masers." **Ali Javan**, whose efforts at Columbia University and Bell Labs led him to work on three-level masers also, turned his interest in population inversions within gases into the development of the first helium-neon laser on Dec. 12, 1960. This was also the first laser to emit coherent light continuously rather than in pulses. Javan was aided by **William R. Bennett Jr.**, who moved on to Yale University and the subsequent development of the first chemical laser, and by **Donald R. Herriott**.

Since the initial flurry of attempts simply to observe lasing action, the race has continued in many directions – some toward new useful laser media, some toward new applications. Perhaps not too astonishingly, most of the researchers circa 1960 already suspected that coherent light would be a uniquely potent tool for communication, spectroscopy, imaging, surgery and even displays.

They did not disappoint.

lynn.savage@photonics.com

John M.J. Madey, Stanford University
First free-electron laser, 1971

Stuart Searles et al, Naval Research Lab
First rare-gas halide (XeBr) laser, 1975

Dennis Matthews et al, Lawrence Livermore National Laboratory
First laboratory x-ray laser, 1984

PHOTONICS spectra Free Subscription Form

IMPORTANT: This form must be completely filled out; all questions answered, signed and dated.

I wish to continue to receive Photonics Spectra free of charge. ☐ Yes ☐ No

This is a: ☐ Renewal ☐ Change of Address ☐ New Subscription

Company and address must be filled in even if your magazine is to be sent to your home address.

☐ Mr. ☐ Dr. ☐ Ms. First Name | Init. | Last Name

Job Title | Mail Stop

Company Name at this Location (No Abbreviations)

Company Division/Address Line 1

Address Line 2

AFFIX COVER LABEL HERE

City | State/Prov. | ZIP/Postal

Country

Business Telephone | Fax

E-Mail

Photonics Spectra privacy policy.
E-mail is used for subscription renewals and is required for a subscription. Other information may also be sent from photonics manufacturers/institutions — if you prefer NOT to receive e-mails from manufacturers, please check here. ☐

I would also like to receive Photonics Directory (limited quantities available). ☐ Yes

How would you like to receive Photonics Spectra Magazine? ☐ Electronic/Digital
(Please select only one) ☐ Print

If your company would prefer delivery to your home, please complete home address. Company name and address are still required to qualify.

Home Address

Street or PO Box

City | State/Prov. | ZIP/Postal

1 ☐ My principal job function is: (Please insert one letter only.)

Engineering- and Science-Related
- A research & development
- B design
- C application
- D manufacturing or production
- E measurement (testing, quality control or safety)
- F other engineering or science function (please specify) ____________

Management- or Business-Related
- G corporate
- H engineering/technical
- J manufacturing or production
- K purchasing
- L other management function (please specify) ____________

Other
- M consultant
- N educator
- P other functions (please specify) ____________

2 ☐ Please indicate the primary end product or service of your company at this location. (Please insert one letter/number only.)

- A aerospace/aviation systems
- B agriculture, food, forestry & mining
- C analytical, test or measurement instrumentation
- D automotive or transportation
- E cable TV/video/broadcasting
- F cameras, detectors, sensors & electro-optical components
- G chemical or pharmaceutical products
- H communications equipment or services (incl. telcos, RBOC & other carriers)
- J computer displays, peripherals, office & business equipment
- K consumer electronics & appliances
- L electronics, semiconductors & IC
- M environmental monitoring
- N fiber optic components or systems
- P hospital/medical university or office
- Q industrial control systems & robotics
- R laboratory, government
- S laboratory, industrial
- T lasers/laser systems
- U manufacturing equipment, machinery or metal products
- V medical & biotechnology equipment
- W military equipment
- X navigation & guidance systems or equipment
- Y optical components, materials or systems
- Z plastics, polymers, rubber
- 1 printing, publishing, graphic arts
- 2 university/institution/college
- 3 utilities, energy, petroleum & coal
- 4 government personnel not classified elsewhere
- 5 industrial company or commercial user incorporating photonic products not classified elsewhere
- 6 other ____________

Principal Product or Service ____________

3 Which of the following publications do you read regularly? (Please check all that apply.)

- A ☐ Advanced Imaging
- H ☐ Laser Focus World
- K ☐ Lightwave
- M ☐ NASA Tech Briefs
- N ☐ Nature
- P ☐ OLE
- R ☐ Physics Today
- S ☐ Science
- T ☐ Semiconductor International
- V ☐ Vision Systems Design
- X ☐ None of the above

4 ☐ The number of employees at this location is: (Please insert one letter only.)

- A 1-10
- B 11-25
- C 26-50
- D 51-100
- E 101-500
- F 501-1000
- G 1001-5000
- H over 5000

5 Which of the following technologies/sciences do you and/or your organization work with? (Please check all that apply.)

A.
- A ☐ aerospace/aviation
- C ☐ astronomy
- D ☐ automotive
- E ☐ biotechnology
- G ☐ chemistry, chemical engineering
- J ☐ chromatography
- L ☐ communications
- N ☐ computer engineering
- P ☐ displays
- R ☐ environmental monitoring/sensing
- T ☐ forensic science
- V ☐ holography
- W ☐ lighting/illumination
- X ☐ imaging
- Z ☐ inspection/identification

B.
- A ☐ machine vision
- C ☐ materials processing/ production
- E ☐ materials research
- G ☐ medical/biomedical
- J ☐ microscopy
- L ☐ military/tactical
- N ☐ nondestructive testing
- P ☐ optical character recognition
- R ☐ optical computing/ data storage
- T ☐ photonic component mfg.
- V ☐ process control
- X ☐ quality control
- Z ☐ remote sensing/lidar

C.
- A ☐ reprographics/printing
- C ☐ robotics
- E ☐ semiconductor processing
- G ☐ simulation/modeling
- J ☐ signal processing
- L ☐ spectroscopy
- N ☐ test & measurement
- P ☐ ultrafast/time-resolution studies
- R ☐ other ____________

6 Which of the following products do you buy, use, recommend and/or specify? (Please check all that apply.)

A. Optical Components & Software
- A ☐ coatings
- C ☐ filters & beamsplitters
- E ☐ gratings
- G ☐ infrared optics
- J ☐ laser optics
- L ☐ lenses
- N ☐ mirrors & reflectors
- P ☐ optical design software
- R ☐ polarizing optics
- T ☐ prisms
- V ☐ ultraviolet optics
- X ☐ windows & domes

B. Lasers
- A ☐ semiconductor, diode
- C ☐ solid-state, diode-pumped
- E ☐ solid-state, Nd:YAG
- G ☐ solid-state, Ti:sapphire
- J ☐ solid-state, tunable
- L ☐ solid-state, VCSELs
- M ☐ fiber lasers
- N ☐ gas lasers, CO_2
- P ☐ gas lasers, excimer
- R ☐ gas lasers, HeNe
- T ☐ gas lasers, ion
- V ☐ gas lasers, other
- X ☐ dye
- Z ☐ other lasers ____________

C. Laser Systems
- A ☐ biometric/forensic
- C ☐ biotechnology
- E ☐ communications
- G ☐ industrial (cutting/ welding/marking)
- J ☐ entertainment
- L ☐ environmental monitoring
- N ☐ holography
- P ☐ materials processing
- R ☐ medical
- T ☐ military
- V ☐ remote sensing
- X ☐ reprographics (printing/graphic arts)
- Z ☐ spectroscopy & photochemical analysis

D. Fiber Optics
- A ☐ cables
- C ☐ communications lasers
- E ☐ connectors or couplers
- G ☐ detectors or receivers
- H ☐ fiber
- K ☐ gratings
- M ☐ lightguides
- N ☐ network components
- O ☐ optical amplifiers
- Q ☐ optical switches
- S ☐ splicing & polishing equipment
- U ☐ test equipment
- W ☐ transmitters
- Y ☐ WDM or DWDM
- Z ☐ other fiber optic components ____________

E. Cameras
- A ☐ CCD or CID
- C ☐ CMOS
- E ☐ high speed
- G ☐ infrared
- J ☐ line scan
- L ☐ other camera ____________

F. Detectors/Sensors
- A ☐ CCD or CID
- C ☐ CMOS
- E ☐ detector arrays
- G ☐ infrared
- J ☐ photodiodes
- L ☐ photomultipliers
- N ☐ semiconductor

G. Imaging Equipment & Software
- A ☐ frame grabbers
- C ☐ image intensifiers
- E ☐ imaging software
- G ☐ infrared imagers
- J ☐ illumination equipment
- L ☐ vision systems
- N ☐ x-ray imaging

H. Manufacturing Equipment for Photonic Components
- A ☐ assembly or packaging equipment
- C ☐ cleanroom equipment
- E ☐ coating equipment
- G ☐ cooling & cryogenic equipment
- J ☐ diamond machining equipment
- L ☐ grinding & polishing equipment
- N ☐ optical design software
- P ☐ photonics test equipment
- R ☐ vacuum equipment
- T ☐ other manufacturing equipment ____________

J. Positioning/Vibration Isolation Equipment
- A ☐ benches, rails & slides
- C ☐ micropositioners
- E ☐ mounts for photonic components
- G ☐ positioning equipment
- J ☐ position-sensing equip.
- L ☐ stepper motors & drivers
- N ☐ tables, optical
- P ☐ vibration-isolation equipment

K. LEDs and Displays
- A ☐ CRTs
- C ☐ flat panel
- E ☐ LCDs
- G ☐ LEDs
- J ☐ light valves
- L ☐ OLEDs
- N ☐ plasma

L. Test & Analysis Equipment
- A ☐ interferometers
- C ☐ microscopes, optical
- E ☐ microscopes, other
- G ☐ monochromators
- J ☐ optics testing equipment
- L ☐ power/energy meters/ wavelength meters
- N ☐ radiometers/ photometers
- P ☐ spectroscopy equipment
- R ☐ spectrum analyzers
- T ☐ telescopes

M. Electronics & Signal-Analysis Equipment
- A ☐ amplifiers
- C ☐ oscilloscopes
- E ☐ power supplies
- G ☐ pulse & signal generators
- J ☐ signal analyzers
- L ☐ time-delay generators

N. Laser Accessories
- A ☐ beam analysis
- C ☐ flashlamps
- E ☐ laser chillers
- G ☐ laser dyes, gases or rods
- J ☐ laser power & energy meters
- L ☐ laser power supplies
- N ☐ laser safety
- P ☐ laser scanners

P. Light Sources
- A ☐ arc sources
- C ☐ flashlamps
- E ☐ infrared
- G ☐ LEDs
- J ☐ ultraviolet

Q. Materials & Chemicals
- A ☐ cements, adhesives & epoxies
- C ☐ coating materials
- E ☐ crystals
- G ☐ grinding & polishing materials
- J ☐ transmissive materials, IR
- L ☐ transmissive materials, UV
- N ☐ transmissive materials, visible

R. Computers & Software
- A ☐ computer hardware (PCs, servers, workstations, mainframes)
- C ☐ data acquisition
- E ☐ scientific/engineering software

S. Nanophotonics
- A ☐ microscopes
- C ☐ nanophotonic devices
- E ☐ nanophotonic materials
- G ☐ quantum dots

T. A ☐ Other ____________

X. ☐ None of the above (6A-6S inclusive)

7

Signature ____________ Date ____________

IMPORTANT: Unsigned or Incomplete Cards Are Disqualified.

spotlight

Lasers, Laser Accessories & Light Sources

The CO_2 Laser Industry's Technology-Enabling Optics Foundry
From the beginning of CO_2 lasers to today, II-VI Infrared remains the premier supplier of these laser optics. The enabler to the CO_2 laser industry – producing built-to-spec optics that give OEMs the ability to push laser designs and output powers forward – II-VI's combination of consistent quality, low absorption and high-volume production have made II-VI the OEMs' #1 choice.

II-VI INFRARED
(724) 352-5217
info@iiviinfrared.com
www.iiviinfrared.com

Mid-IR Polarizers: 2 to 12 µm

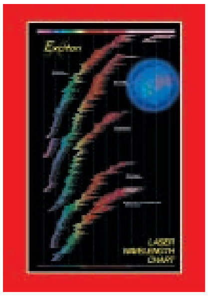
- Performs comparably to Glan laser polarizer
- High-contrast (100,000:1) output beam
- All faces are AR-coated
- Power rating 100 MW/cm^2
- 2° field of view
- 5 mm aperture

In stock for immediate delivery

innpho.com INNOVATION PHOTONICS
(973) 857-8380
info@innpho.com
www.innpho.com

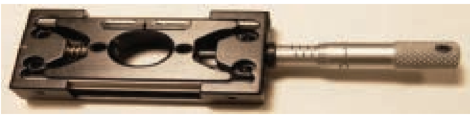
Hybrid LaserTable-Base™ Vibration Cancellation
TMC's newest addition to its STACIS® iX product family is the LaserTable-Base™ hybrid piezoelectric/air active vibration cancellation system for optical tables. It combines TMC's patented STACIS technology and air into one integrated system to cancel vibration at both very low and high frequencies. The result is unprecedented levels of vibration isolation for the most sensitive research on the most severe floors.

TMC Technical Manufacturing Corporation
(800) 542-9725
sales@techmfg.com
techmfg.com



Laser Wavelength Chart
Exciton is dedicated to providing its customers with the highest-quality laser dyes on the market today. To assist its customers in choosing laser dyes, Exciton offers a free four-color laser wavelength chart, an essential reference for your laboratory or office wall.

Exciton
(973) 252-2989
info@exciton.com
www.exciton.com



Precision Linear Stage
NAI introduces a new small-profile 32 × 19 × 7.6-mm manual stage with precision micrometer adjustment. The small profile is ideal and will support a direct top load of 0.5 kg and has adjustment sensitivity of 1 µm. With a travel range of 5 mm, this stage exhibits very low wobble, yaw, pitch and roll. Visit our Web site for complete specifications.

NAI Precision Micro-Apertures Miniature Positioners Motion Control Software
(800) 360-4598
sales@nationalaperture.com
www.nationalaperture.com

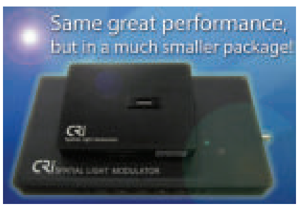
spotlight

Lasers, Laser Accessories & Light Sources

High-Resolution Spectrum Analyzer for IR Lasers

The 721B-MIR laser spectrum analyzer provides the most complete spectral characterization of lasers that operate at mid-infrared wavelengths. Absolute wavelength is measured to an accuracy of ±1.0 part per million, and spectral properties are determined to a resolution as high as 2 GHz. Now, researchers working with quantum cascade lasers for high-resolution spectroscopy, photochemistry or optical sensing applications can achieve more meaningful experimental results with accurate spectral information.

Bristol Instruments
(585) 924-2620
info@bristol-inst.com
www.bristol-inst.com



Compact Spatial Light Modulator for Pulse Shaping

New, small-form-factor SLM with 128 pixels: same pixel size in a smaller enclosure. CRi has been supplying the ultrafast laser pulse-shaping community for more than a decade. We developed the modern liquid crystal linear array SLM and are the exclusive provider of technology for bonded masks providing *simultaneous* phase and amplitude control. 128- and 640-pixel masks available in VIS or NIR ranges.

CRi
(781) 935-9099
sales@cri-inc.com
www.cri-inc.com/slm

Brightlock® Ultra-G™

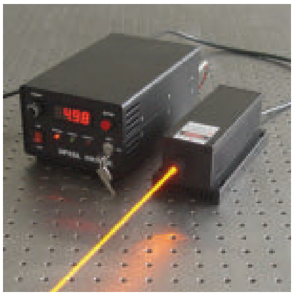
Brightlock® Ultra-G™, Prism Awards winner, provides 6-W CW output power at 532 nm in a compact and passively cooled package. Laser Operations LLC, manufacturer of the industry-leading QPC Lasers product line, is a vertically integrated laser diode manufacturer shipping high-brightness lasers globally into several markets, including medical, defense, industrial and consumer displays, from its high-volume 40,000-sq-ft laser manufacturing facility in Sylmar, Calif.

QPC Lasers
By Laser Operations LLC
(818) 986-0000
info@laseroperations.net
www.qpclasers.com

USB Shutter

The Picard Industries USB-Shutter offers a compact and simple method of automating the blocking of a beam path. The pivoting-paddle shutter is powered and controlled through a USB port. This provides a self-powered, hot-pluggable method of control unmatched in the industry. Multiple shutter control is possible with an externally powered USB hub. Custom software operates on any standard PC running Windows XP/Vista. LabView drivers and DLL files are provided for integrating the shutter control into your own automation. Visit our Web site for more details about this and our other unique USB-powered devices.

Picard Industries
ServO Designs
(585) 589-0358
info@picard-industries.com
www.picard-industries.com/products.html



Newly Released 589-nm Yellow Laser up to 2.5 W

Changchun New Industries (CNI), founded in 1996 and located in Changchun, China, is a leading Chinese manufacturer of solid-state and diode laser systems. Our products include green, blue, yellow, red, RGB, infrared, UV, single-longitudinal-mode and Q-switched laser systems. Our lasers are ISO-9001-, FDA-, CE-, RoHS- and JQA-certified.

CNI 希爱®
+86 431 8560 3799
info@cnilaser.com
www.cnilaser.com

Laser Stabilizer Removes Noise and Drift

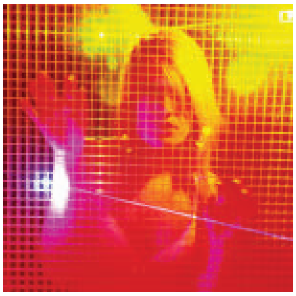
Spend your time monitoring your experiment, rather than your laser, with a BEOC laser stabilizer. Our LPC, placed in the optical path, does the work of a power meter, a variable attenuator and a laser intensity stabilizer. Reduce DC drift to less than 0.03% long term. Standard, custom and OEM models are available to meet your requirements in the 325- to 1700-nm wavelength range.

BEOC
Brockton Electro-Optics Corp
(508) 559-9958
sales@brocktoneo.com
www.brocktoneo.com

LaserTurn® Cylindrical Laser Processing Systems

LaserTurn® series integrated motion subsystems for cylindrical laser processing applications combine automated material handling with direct-drive linear and rotary motion. Systems feature a three-jaw gripper with a 25-mm aperture for ID or OD gripping, precision collets for 0.1- to 30-mm-diameter materials, travels up to 300 mm and up to a 30-mm clear aperture for product feed through.

AEROTECH®
(412) 963-7470
sales@aerotech.com
www.aerotech.com



Laser Kingdom

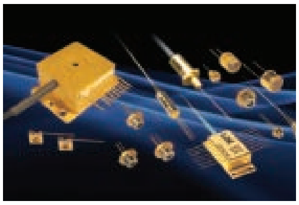
High-energy pulse lasers with output energies (per pulse) of more than 20 to 40 J, or more than 100 W, CW, are now available from our laboratories. In addition, we have one of the broadest lines of DPSS, dye and diode lasers. We have been designing and building these, and many other types, from "scratch," for more than 25 years. All are FDA-/CDRH-/IEC-compliant. We also specialize in custom and OEM laser designs.

ELK INDUSTRIES
(321) 259-8114
laserob@aol.com
www.elkindustries.com

New High-Definition Spectrum Analyzer

The new high-definition spectrum analyzer is designed to measure the entire spectral range from 400 to 900 nm at once while analyzing emission spectra of any complexity. Our solid-state technology, no moving optics, enables the HDSA to measure CW and pulsed light sources with absolute accuracy at 3 GHz! Once again, demonstrating leading technology!

TOPTICA PHOTONICS
(585) 657-6663
sales@toptica-usa.com
www.toptica.com



High-Quality Advanced Optoelectronic Devices

Laser Diode Incorporated, a premier optoelectronics company supplying to the military, telecom, test & measurement, industrial and medical markets for more than 40 years. LDI offers single- and multi-emitter CW and pulsed lasers as well as APDs for high-power applications. For telecom applications, LDI offers OTDR lasers and ELEDs, PINFET/PINAMP receivers, APD photodiodes and Combiner/TriBiner devices. Also, LDI offers custom packaging services.

LDI.
(732) 549-9001
peggy.scarillo@
macomtech.com
www.laserdiode.com

BRIGHT IDEAS

Three-Chip Color Camera

Toshiba Imaging Systems Div.'s IK-TF7 three-CCD progressive-scan color camera has been integrated into the Micron III retinal imaging microscope developed by Phoenix Research Labs. The system enables new modalities in high-resolution imaging for in vivo eye research, including white-light imaging of mice and rats, fluorescein angiography, diabetic retinopathy, retinoblastoma, choroidal neovascularization, retinitis pigmentosa and anterior segment slit-lamp. Live-animal fluorescent studies such as green and yellow fluorescent protein are also possible. Camera features include 1024 × 768-pixel resolution, 4.65 × 4.65-μm pixel size and color shading. Proprietary prism block color technology captures fast-moving items under test. The compact camera operates at up to 90 fps and eliminates image jitter via the ⅓-in. CCDs, whose co-site sampling arrangement eliminates red-green-blue shift.

Toshiba
vincent.giovinco@tais.toshiba.com

UV Laser

The Genesis CX355-250 from Coherent Inc., a solid-state CW ultraviolet laser, delivers more than 250 mW of output power. Its TEM_{00} output beam has an M^2 value of <1.2, enabling optimum collimation and/or refocusing to a diffraction-limited spot, and its optically pumped semiconductor technology provides <0.5% noise, enabling OEM instruments to achieve good signal-to-noise characteristics. Its high-throughput cytometers incorporate two parallel laser interaction cells. Applications include flow cytometry of live cells such as eggs, fertilized-egg sorting, fluorescence-based applications such as confocal microscopy, and 3-D prototyping applications such as stereolithography.

Coherent
tech.sales@coherent.com

InGaAs SWIR Cameras

Sensors Unlimited Inc., part of Goodrich Corp., has introduced two InGaAs cameras that expand the dynamic range of short-wavelength infrared (SWIR) imagery. The SU320KTX model, with a 320 × 240-pixel format and a 40-μm pixel pitch, and the SU640KTSX, with a 640 × 512-pixel format and a 25-μm pixel pitch, both automatically compensate for variations in light levels up to five orders of magnitude. The RS170 analog and 12-bit Camera Link digital outputs provide plug-and-play video for image processing or transmission. The cameras can be integrated into mobile, hand-held or aerial surveillance systems and are suitable for military, medical and commercial applications.

Sensors Unlimited
sui_info@goodrich.com

Molecular Characterization

Wyatt Technology Corp. has launched the Möbiuζ, a laser-based instrument for noninvasive measurement of macromolecular electrophoretic mobilities. The device provides reproducible data on the mobilities of large particles such as liposomes and viruslike particles and of protein samples that are hard to measure, including antibody formulations, bovine serum albumin (BSA) and lysozyme. Through parallelism of detection, it measures in <1 min, preserving fragile protein samples and providing sufficient data to average away molecular diffusion and extend the measurable molecular size range below 2 nm. Detection sensitivity is 2 mg/ml for lysozyme and 0.5 mg/ml for BSA. Simultaneous measurement of the macromolecular hydrodynamic radius is available with the WyattQELS (quasielastic light scattering) option, which uses backward scattered light to determine the sample translational diffusion coefficient.

Wyatt Technology
info@wyatt.com

Translation Stages

Edmund Optics has introduced its TechSpec single-axis translation stages featuring a crossed-roller guide system. Their single-piece design combines the top and bottom plate with the guide rails, and their positioning has a straight-line accuracy of 2 μm. Offered in either English or metric configurations with solid tabletop and through-hole models, the stages are available in 30-, 40-, 70- and 125-mm versions. Each is engineered to integrate with the other sizes and with other TechSpec components, allowing various system arrangements in up to six-axis configurations. Applications include laser and vision systems, microscopy and automation.

Edmund Optics
medmund@edmundoptics.com

Manually Tunable Filter

Yenista Optics SA has released the WSM-160, a bench-top manually tunable optical filter. It is used in optical manufacturing and laboratories to extract one channel from a dense wavelength division multiplexing signal or to cut adjacent amplified spontaneous emission noise. With a wavelength tuning range from 1495 to 1650 nm and a bandwidth tunable range from 0.25 to 80 nm, the filter allows engineers to extract channels with low insertion loss and no distortion of signal, thanks to its flattop shape. It is suitable for studying new modulation formats, cascaded reconfigurable optical add/drop multiplexers, high-bit-rate transmission, pulse shaping and optical parametric amplification.

Yenista
sales@yenista.com

Showerhead Reactor

Aixtron AG is offering the close-coupled nitride showerhead Crius metallorganic chemical vapor deposition system in 31 × 2-, 30 × 2-, 12 × 3-, 7 × 4-, 3 × 6- and 1 × 12-in. configurations. Used in LED epiwafer production, it is equipped with a dynamic reactor height adjustment feature that facilitates growth at elevated pressures. The reactor is fitted in an integrated circuit system design and features six optical ports and a moly liner.

Aixtron
info@aixtron.com

Line-Scan Cameras

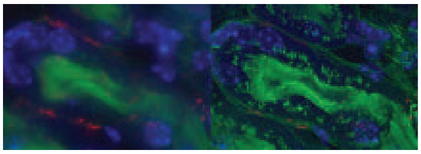
The XH8800 line-scan cameras introduced by X-Scan Imaging Corp. for imaging high-energy x-ray and gamma ray scanning have a tungsten shielding and fiber optic design that resist detector damage and extend the camera energy range. They are suitable for imaging metal castings and steel objects from 101.6 to 304.8 mm thick and can be used for other radiography and nondestructive testing applications that can be penetrated at energy levels below 450 keV. They are available in seven active sensor lengths ranging from 154 to 1542

mm, with resolutions ranging from 96 to 30,720 pixels on centers down to 50 µm. They incorporate proprietary CMOS silicon imaging detector array chips with on-chip signal processing circuits. Inspection speeds are >100 cm/s, and typical dynamic range is 4000:1. All cameras include a contiguous linear array of photodiodes, low-noise signal-processing circuitry, 16-bit analog-to-digital converters and a Camera Link interface.
X-Scan Imaging
linbo@x-scanimaging.com

Round and Oval LED Lamps

Avago Technologies has introduced surface-mount-technology high-brightness oval and round LED lamps for use in indoor and outdoor electronic sign applications. Available in amber, red, green and blue, the round ALMD-xx3D and oval ALMD-Lx36 LEDs target manufacturers of full-color and monochrome traffic signs, highway variable message signs, gas station price signs and full-color video wall applications used for advertising. Made with an optical-grade epoxy for good performance in outdoor applications, they are compatible with industrial reflow soldering processes. Features include a compact form factor with a well-defined spatial radiation pattern, tinted lenses and a moisture sensitivity level of 2A. Viewing angle for the round models is 30° and, for the oval, 40° × 100°.
Avago
support@avagotech.com

White-Light Confocal System



For performing confocal microscopy with a white-light source, Andor Technology plc has launched Revolution DSD, based on a differential spinning disk optical system working in conjunction with an Andor Clara high-sensitivity interline CCD camera and controlled by a proprietary IQ workstation. Using white light, as opposed to lasers, cuts costs. The compact system fits the side port of any microscope and uses active background subtraction to deliver

purely confocal or wide-field images, simplifying switching between techniques as well as binding and focusing of the specimen. The system delivers strong optical sectioning even at low magnification and moderate frame rates per second.
Andor
marketing@andor.com

Analyzer Plug-In Module

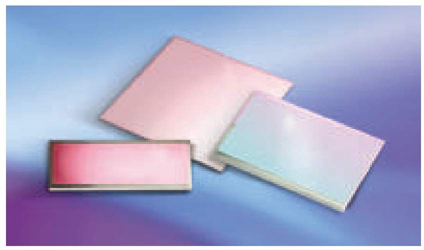
Agilent Technologies Inc. has introduced the 86115D optical receiver plug-in module for its 86100C digital communications analyzer (DCA), which allows engineers to test multiple optical signals simultaneously. As more optically based communications systems rely on a parallel scheme to increase transmission rates, the ability to observe several lanes of data at once becomes important, and testing several single-lane devices in parallel can reduce the cost. The module can be configured with two or four optical ports, and the 86100C DCA mainframe can accept up to two 86115D plug-in modules, enabling waveform analysis of optical transceivers operating at 8-x or 16-x fiber channel and 10-Gb SONET/SDH/Ethernet rates.
Agilent
janet_smith@agilent.com

Micromechatronic Module

New Scale Technologies Inc. has announced its M3 micromechatronic module design platform for development of custom closed-loop microactuator modules. Building on proprietary miniature Squiggle motor and Tracker position sensor technology, the platform yields a complete closed-

loop actuator on a printed circuit board measuring 12 × 30 mm or less. The devices require 3.3-V input voltage for battery-powered operation. No external control board is necessary, and simple serial commands drive an onboard proportional integral derivative controller using a standard I2C, SPI or USART interface. Modules based on the platform are suitable for high-resolution positioning in miniature optical instrumentation, lasers and photonics systems, aerospace controls and biomedical systems.
New Scale Technologies
fhaas@newscaletech.com

LWIR Bandpass Filters



Deposition Sciences Inc. provides long-wavelength infrared (LWIR) bandpass filters that operate at temperatures between ambient and 10 K. The thin-film coatings are manufactured via proprietary physical vapor deposition with the ion-assist process, making them durable and robust. They feature precise band edge placement for critical sensing applications. The filters are suitable for use in imaging sensor filters, order-sorting filters, thermal and/or night vision tasks, and forward-looking infrared optics. Substrates including germanium, silicon, zinc sulfide, zinc selenide, quartz, sapphire and polymers are available, depending upon the customer's wavelength requirements. Multispectral filters can be provided when multiple filters are needed on a single substrate. Sizes from a few millimeters to >50.8 mm in diameter can be provided.
Deposition Sciences
solutions@depsci.com

Camera Driver Package Upgrade

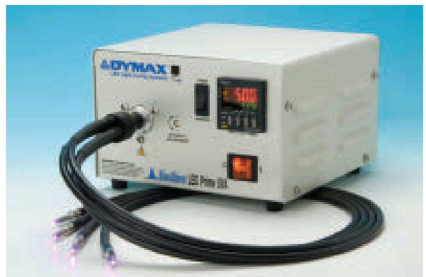
Basler Vision Technologies has released version 2.2 of its pylon camera driver package, which can be downloaded free from the company's

Web site. It includes a software development kit and release notes describing the new features and improvements for the driver, which has been enhanced to include any kind of vision application. C++ programming language support has been expanded to include standard C and Microsoft Visual Basic 6.0., and Microsoft's newer C# and VB.NET also are supported. Camera Link interface configuration is via a GenICam-compliant API. All of the new APIs have full access to all of the camera and grabbing features on the company's FireWire and Gigabit Ethernet vision camera families.
Basler
vc.sales@baslerweb.com

Fiber-Coupled Module

Dilas' high-brightness, conduction-cooled fiber-coupled diode laser module is based on diode laser bars and provides up to 40-W output power from a 100-μm fiber core at 976 nm, with a numerical aperture of <0.22. Wall-plug efficiency of >40% ensures high power, brightness and power efficiency. The electrically isolated single-bar package measures 70 × 30 × 17 mm. The laser power is delivered via a non-detachable fiber core, which is terminated with a standard SMA 905 connector or a cleaved fiber end. With good heat removal via direct thermal contact, this industrial package is designed for uses ranging from fiber laser pumping to micromaterials processing to medical applications.
Dilas
sales@dilas.com

Spot Curing



Dymax Corp.'s BlueWave LED Prime UVA high-intensity spot-curing system has no consumable bulbs to change, requires no warm-up, and provides cool cures and constant intensity for thousands of hours. It generates curing energy using high-intensity LEDs and delivers it through

a 5-mm-diameter lightguide, with output of up to 15 W/cm^2. The unit is CE-certified, RoHS-compliant and easy to operate, and it offers an LED lifetime of >50,000 h. Users can adjust and control intensity output from 0 to 100% to assist with process validation and control. The system is suitable for spot curing of various coatings as well as adhesive bonding of polycarbonate, polyvinyl chloride, polyethylene terephthlate, metal and glass.
Dymax
info@dymax.com

CMOS Camera

Hamamatsu Corp.'s ORCA-Flash2.8, a digital camera based on a scientific CMOS image sensor, is designed for low-light imaging at high frame rates. The FL-280 sensor features 2.8 megapixels and a pixel size of 3.63 × 3.63 μm. Wavelength sensitivity ranges from the UV to the visible, with peak sensitivity and >60% quantum efficiency at ~450 to 500 nm. The camera's readout speed ranges from 45 fps at full resolution to 1273 fps with subarray readout. Features include external trigger, real-time corrections and analog gain. The camera is designed for quantitative measurements with 12-bit output, and it interfaces with a PC via the included Camera Link frame grabber. Applications include ratio imaging, Förster resonance energy transfer, fluorescence in situ hybridization and total internal reflection fluorescence microscopy, real-time confocal microscopy, semiconductor inspection and industrial imaging.
Hamamatsu
usa@hamamatsu.com

Optical Fiber Testing

M2 Optics Inc. has released the FiberLab 800HE testing platform for applications involving rough

handling and harsh conditions, including field and laboratory testing, manufacturing environments and military systems. The company also is making the platform available for customization with preconfigured flaws in the fiber to support CATV and telecom test equipment training. Training configurations include fiber with fusion splices, mechanical splices and/or connectors at customer-specified locations along the fiber. A protective enclosure contains the fiber and holds panel-mounted optical connectors to prevent damage, to facilitate handling and to minimize the space required for fiber-based tests. Customers can specify any fiber type and name by manufacturer, any length up to 25 km and a connector type with any angle polish.
M2 Optics
sales@m2optics.com

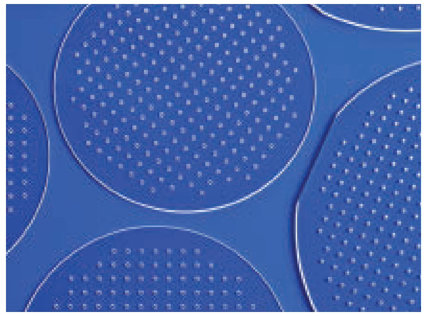
Epoxy System

Master Bond Inc.'s EP21FL is a two-part epoxy resin system that features low to moderate viscosity. It is suitable for potting, coating and sealing electronic assemblies and for bonding dissimilar substrates with different coefficients of expansion. Typical viscosity of Part A (clear) is 4000 cycles per second and, of Part B (amber), 10,000 cycles per second, at 25 °C. The system produces strong castings, bonds and seals that are resistant to thermal cycling and shock. Its bond strength is >1500 lb/sq in., and its tensile strength is >1100 lb/sq in. The hardened compound is an electrical insulator and is available

in ½-pint, pint-, quart-, and 1- and 5-gallon-container kits. It cures at room temperature and, more quickly, at elevated temperatures, with a 4:1 mix ratio by weight. It is 100% reactive and contains no solvents or other volatiles.
Master Bond
technical@masterbond.com

Sapphire Wafer Carriers

A low-cost line of sapphire wafer carriers perforated with custom patterns for vacuum hold-down or delamination and more durable than quartz and other materials (second only to diamond in terms of hardness, according to the company) is available from Meller Optics Inc.



They are designed for thinning semiconductor materials, such as GaAs, and feature Moh 9 hardness. Sapphire offers good mechanical strength due to its off-axis crystal growth that permits custom fabrication of wafer carriers as thin as 0.4572 mm. Available with diameters from 50.8 to 152.4 mm, with flats and laser markings, the wafer carriers are chip-, chemical- and scratch-resistant, and they can withstand repeated use.
Meller Optics
sales@melleroptics.com

Photonics Control Devices

Newport Corp. has introduced the Conex family of compact photonics control instruments, featuring three new devices that connect easily via USB plug-and-play technology and allow simple and highly functional PC control solutions. Multiple units can be connected to a single USB

port and, for the PSD9 and IOD models, the USB port also powers the modules, eliminating the need for additional power supplies and/or cables. The intuitive LabView-based utility program software provides a graphical user interface for each module, and a comprehensive set of LabView virtual instruments is available.
Newport
beda.espinoza@newport.com

PAPERS

MOC 2010 (October 31-November 3) Hsinchu, Taiwan
Deadline: submissions, June 13
Papers are sought for the 16th Microoptics Conference for the update and review of scientific and technical information in the field. Among the conference categories are measurements, passive and active devices, dynamic and functional devices, materials and fabrication, integration and packaging, and theory, modeling and design. Contact Lu Tien-Chang, +886 3 5712 121; timtclu@mail.nctu.edu.tw; www.moc2010.org.tw.

IS&T/SPIE Electronic Imaging (January 23-27) San Francisco
Deadline: abstracts, June 28
The Society for Imaging Science and Technology (IS&T) and SPIE invite papers for oral and poster presentation at their conference on electronic imaging. Topics to be considered are image processing; digital imaging sensors and applications; image and video communications and processing; and 3-D imaging, interaction and measurement. Contact SPIE, +1 (360) 676-3290; customerservice@spie.org; www.spie.org/electronic-imaging.xml.

ECLIM 2010 (September 6-10) Budapest, Hungary
Deadline: abstracts, June 30
Organizers of the 31st European Conference on Laser Interaction with Matter encourage papers in such areas as high-power lasers and ignition facilities, laser and ion beam interaction with matter, hot-dense plasma atomic processes, the extreme light infrastructure laser, and interactions with ultrashort laser pulses, attophysics. Contact István B. Földes, Hungarian Academy of Sciences, fax: +36 1 395 9151; foldes@rmki.kfki.hu; www.top-congress.hu/2010/eclim.

JUNE

Photonics North 2010 (June 1-3) Niagara Falls, Ontario, Canada. Collocated with Photovoltaics Canada First National Scientific Conference. Contact Mélanie Lemay, +1 (418) 522-8182; melanie.lemay@conferium.com; www.photonicsnorth.com.

EIPBN: 54th International Conference on Electron, Ion and Photon Beam Technology and Nanofabrication (June 1-4) Anchorage, Alaska. Contact Marty Feldman, +1 (225) 578-5489; feldman@ece.lsu.edu; www.eipbn.org.

Optical Interference Coatings (June 6-11) Tucson, Ariz. Contact OSA, +1 (202) 223-8130; info@osa.org; www.osa.org/oic.

Sensors Expo & Conference (June 7-9) Rosemont, Ill. Contact Questex Media Group Inc., +1 (617) 219-8300; www.sensorsexpo.com.

Imaging and Applied Optics (June 7-10) Tucson, Ariz. Collocated topical meetings and tabletop exhibits: Applied Industrial Optics: Spectroscopy, Imaging and Metrology; Digital Image Processing and Analysis; Imaging Systems; Optical Remote Sensing of the Environment; Optics for Solar Energy; and Photonics Metamaterials and Plasmonics. Contact OSA, +1 (202) 223-8130; info@osa.org; www.osa.org/topicals.

Automatica 2010: International Trade Fair for Automation and Mechatronics (June 7-11) Munich, Germany. Collocated with the International Symposium on Robotics 2010. Contact Messe München GmbH, +49 89 9 49 2 01 21/22; info@automatica-munich.com; www.automatica-munich.com.

LASYS 2010 (June 8-10) Stuttgart, Germany. Includes a short course titled "Basics on Lasers and Laser Material Processing." Contact Messe Stuttgart International, +49 711 258 9550; fax: +49 711 258 9440; www.messe-stuttgart.de.

EuroLED 2010 (June 9-10) West Midlands, UK. Contact Eve Gaut, +44 121 250 3515; eveg@astonsciencepark.co.uk; www.euroled.org.uk.

Photonics Festival in Taiwan: Opto Taiwan, LED Lighting Taiwan, Solar Taiwan, Optics Taiwan; concurrent exposition: Display Taiwan 2010 (June 9-11) Taipei, Taiwan. Contact Pamela Hsiao, +1 866 2 235 140 26, Ext. 805; exhibit@mail.pida.org.tw; www.optotaiwan.com.

Optical Fabrication and Testing (June 13-16) Jackson Hole, Wyo. Contact OSA, +1 (202) 223-8130; info@osa.org; www.osa.org/oft.

International Optical Design Conference (June 13-17) Jackson Hole, Wyo. Contact OSA, +1 (202) 223-8130; info@osa.org; www.osa.org/iodc.

Optatec 2010: The International Trade Fair for Future Optical Technologies, Components, Systems & Manufacturing (June 15-18) Frankfurt, Germany. Contact P.E. Schall GmbH & Co. KG, +49 7025 9206 0; Fax: +49 7025 9206 620; www.optatec-messe.com.

Advanced Photonics: OSA Optics & Photonics Congress (June 21-24) Karlsruhe, Germany. Collocated with Access Networks and In-House Communications; Bragg Gratings, Photosensitivity and Poling in Glass Waveguides; Nonlinear Photonics; Optical Sensors; and Signal Processing in Photonic Communications. Contact OSA, +1 (202) 223-8130; info@osa.org; www.osa.org/topicals.

Renewable Energy: OSA Optics & Photonics Congress (June 21-24) Karlsruhe, Germany. Collocated with Solid-State and Organic Lighting; and Optical Nanostructures for Photovoltaics. Contact OSA, +1 (202) 223-8130; info@osa.org; www.osa.org/topicals.

Nanotech Conference & Expo 2010 (June 21-25) Anaheim, Calif. Collocated with Clean Technology Conference & Expo; Microtech Conference & Expo; BioNanotech Conference & Expo; and TechConnect Summit & Expo. Contact Sarah Wenning, +1 (925) 353-5004; Fax: +1 (925) 886-8461; www.techconnectworld.com.

SPIE Astronomical Telescopes and Instrumentation 2010 (June 27-July 2) San Diego. Contact SPIE, +1 (360) 676-3290; customerservice@spie.org; www.spie.org.

Laser Optics 2010 (June 28-July 2) St. Petersburg, Russia. Contact Program and Organizing Committee, Institute for Laser Physics of Vavilov SOI Corp., +7 812 328 5734; conf2010@laseroptics.ru; www.laseroptics.ru.

JULY

SEMICON West (July 13-15) San Francisco. Contact Kelli Torres, +1 (408) 943-6979; ktorres@semi.org; www.semiconwest.org.

17th International Conference on Ultrafast Phenomena (July 18-23) Snowmass Village, Colo. Contact OSA, +1 (202) 223-8130; info@osa.org; www.osa.org/up.

Integrated Photonics Research, Silicon, and Nanophotonics (July 25-29) Monterey/Santa Cruz, Calif. Contact OSA, +1 (202) 223-8130; info@osa.org; www.osa.org/ipr.

Photonics in Switching (July 25-29) Monterey/Santa Cruz, Calif. Contact OSA, +1 (202) 223-8130; info@osa.org; www.osa.org/ps.

23rd International Vacuum Nanoelectronics Conference (July 26-30) Palo Alto, Calif. Contact Ralph Nadell, +1 (212) 460-8090, Ext. 203; rnadell@pcm411.com; www.ivnc2010.org.

SOLARCON India 2010 (July 28-30) Hyderabad, India. Contact Semi Tech Services India Pvt. Ltd., +91 80 4040 7103; solarconindia@semi.org; www.solarconindia.org.

DISKCON Japan 2010 (July 29-30) Tokyo. Contact Idema Japan, info@idema.gr.jp; www.idema.gr.jp/diskcon.

AUGUST

SPIE Optics + Photonics: Optical Engineering + Applications (Aug. 1-5) San Diego. Contact SPIE, +1 (360) 676-3290; customerservice@spie.org; spie.org.

NIWeek 2010 (Aug. 3-5) Austin, Texas. Contact National Instruments Corp., +1 (800) 531-5066; www.ni.com/niweek.

International Conference on Coherent and Nonlinear Optics (ICONO)/Lasers, Applications and Technologies (LAT) (Aug. 23-27) Kazan, Russia. Contact ICONO/LAT Organizing Committee, +7 843 272 05 03; iconolat10@kfti.knc.ru; congress.phys.msu.ru/iconolat10.

SEPTEMBER

CIOE 2010: 11th China International Opto Electronic Expo (Sept. 6-9) Shenzhen, China. Contact Shenzhen BMC Herong Exhibition Co. Ltd., +86 755 8629 0901; fax: +86 755 8629 0951.

EWOFS 2010: European Workshop on Optical Fibre Sensors (Sept. 8-10) Porto, Portugal. Contact INESC Porto, University of Porto, +351 220 402 301; ewofa@inescporto.pt; www.ewofs.org.

DISKCON USA 2010 (Sept. 9-10) Santa Clara, Calif. Contact Trudy Gressley, +1 (408) 294-0082; tgressley@idema.org; www.idema.org.

International Congress on Applications of Lasers & Electro-Optics (ICALEO) (Sept. 27-30) Anaheim, Calif. Contact Gail Lolacono, Laser Institute of America, +1 (800) 345-2737; icaleo@laserinstitute.org; www.icaleo.org.

Photonics Media Advertising Contacts

Please visit our Web site Photonics.com for all your marketing needs.

Robert J. Briere, Director of Sales
Voice: +1 (413) 499-0514, Ext. 101
Fax: +1 (413) 443-0472
bob.briere@photonics.com

New England, Southeastern US, Yukon & British Columbia
Rebecca L. Pontier, Regional Manager
Voice: +1 (413) 499-0514, Ext. 112
Fax: +1 (413) 443-0472
becky.pontier@photonics.com

NY, NJ & PA
Timothy A. Dupree, Regional Manager
Voice: +1 (413) 499-0514, Ext. 111
Fax: +1 (413) 443-0472
tim.dupree@photonics.com

Northern CA, NV, Pacific Northwest, Central & Southern CA,
Karen Hardison, Regional Manager
Voice: +1 (916) 990-1473
Fax: +1 (916) 933-0752
karen.hardison@photonics.com

Rocky Mountains, AZ, NM, HI, Eastern, Central & Western Canada, FL
Jason A. Camboni, Regional Manager
Voice: +1 (312) 253-4028
Fax: +1 (312) 277-0912
jason.camboni@photonics.com

South Central US
Susanna L. Rogers, Regional Manager
Voice: +1 (413) 499-0514, Ext. 229
Fax: +1 (413) 443-0472
sue.rogers@photonics.com

Europe & Israel
Penny Pretty, European Sales Manager
Voice: +44 1494 564411
Fax: +44 1494 461198
penny.pretty@photonics.com

Austria, Germany & Liechtenstein
David Round, Advertising Associate
Voice: +44 208 773 9944
Fax: +44 208 181 6178
david.round@photonics.com

China
Hans Zhong
Voice: +86 755 2157 3066
Fax: +86 755 2872 6973
hans.zhong@yahoo.com.cn

Japan
Scott Shibasaki
Voice: +81 3 5225 6614
Fax: +81 3 5229 7253
s_shiba@optronics.co.jp

Reprint Services
Voice: +1 (413) 499-0514
Fax: +1 (413) 443-0472
editorial@laurin.com

Mailing addresses:
Send all contracts, insertion orders and advertising copy to:
Laurin Publishing
PO Box 4949
Pittsfield, MA 01202-4949

Street address:
Laurin Publishing
Berkshire Common, 2 South St.
Pittsfield, MA 01201
Voice: +1 (413) 499-0514
Fax: +1 (413) 443-0472
E-mail: advertising@photonics.com

Lasers leap from the lab to the comics

When Ted Maiman fired up the first working laser in May 1960, it marked the beginning of a golden age of scientific research and technological innovation that continues today. See "A Trip Through the Light Fantastic," p. 58, and "On the Shoulders of Giants," p. 70.

However, despite all of the advances brought about by and for lasers, there were other reasons to be excited 50 years ago. The world was in the midst of the atomic age and at the beginning of the space age – with all of the accompanying hope and terror. After news of the laser broke out from the labs and into the national spotlight, it was only a matter of time before the more gee-whiz aspects filtered down to the youngsters.

Superman already had a plethora of vision-based powers that electrified kids in the '40s and '50s. Although he did not possess them when he was originally conceived by Joe Shuster and Jerry Siegel in the late '30s, the Man of Steel eventually picked up telescopic and microscopic vision, the ability to project heat rays from his eyes and the capacity to see a deep range of wavelengths, from infrared to ultraviolet.

Surprisingly, "laser vision" was not added to the panoply of Superman's optical powers after Maiman's breakthrough, but the laser did apparently inspire another giant of the comics industry.

In the early 1960s, Stan Lee and a dynamic bullpen of artists including Jack Kirby, Steve Ditko and Don Heck were making Marvel Comics a force to be reckoned with. After a string of hits (and only a couple of misses), Lee and Kirby introduced the X-Men in 1963 – a group of angst-ridden teenage mutants holed up in a boarding school.

One of the main members of the colorful group was a serious young man named Scott "Slim" Summers, whose crime-fighting moniker was "Cyclops." He earned the nickname not because of an actual facial deformity but because his costume featured a visor that spanned both eyes. Cyclops' power manifested through his eyes, much as Superman's ocular abilities, but rather mainly created a concussive force.

Cyclops' eye blasts appeared as straight crimson lines of various widths, controlled by the mechanically operated visor he wore at all times. What tied the character to the laser, though, was the fact that the visor's lens was made of ruby quartz; what breaks the spell, perhaps, is that Lee wrote it so that the ruby was the only thing that *stopped* the optical energy. Summers/Cyclops wore the device at all times because he could not shut the power off. The visor, with its ruby lens, gave him control over his power.

The tweaking – or outright mangling – of physics was, and is, common in superheroic tales, which insist on a suspension of disbelief by the reader, but Lee did better a few years later, in 1966, with the introduction of the "Living Laser."

With this villainous character, Lee and artist Don Heck drew from a somewhat more realistic technical stance. The Living Laser got his start as a research scientist named Arthur Parks, who worked on developing lasers as offensive weapons. Parks ultimately created miniature, wrist-mounted, high-power lasers but turned to crime because of bad anger-management issues.

After decades of appearances and a parade of writers, both Cyclops and the Living Laser had their powers altered, in part to rectify misunderstandings of real physics (Cyclops' eyebeams can't be optical!), in part to make the characters even more fantastical. But, as with all of their superpowered brethren, Cyclops and the Living Laser provide gentle introductions to the extraordinary nature of real-life science.

lynn.savage@photonics.com

Cyclops of the X-Men. Art by Jack Kirby. Images courtesy of Marvel Comics.

The Living Laser. Art by Don Heck.