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PHOTONICS: The technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon. The range of applications of photonics extends from energy generation to detection to communications and information processing.

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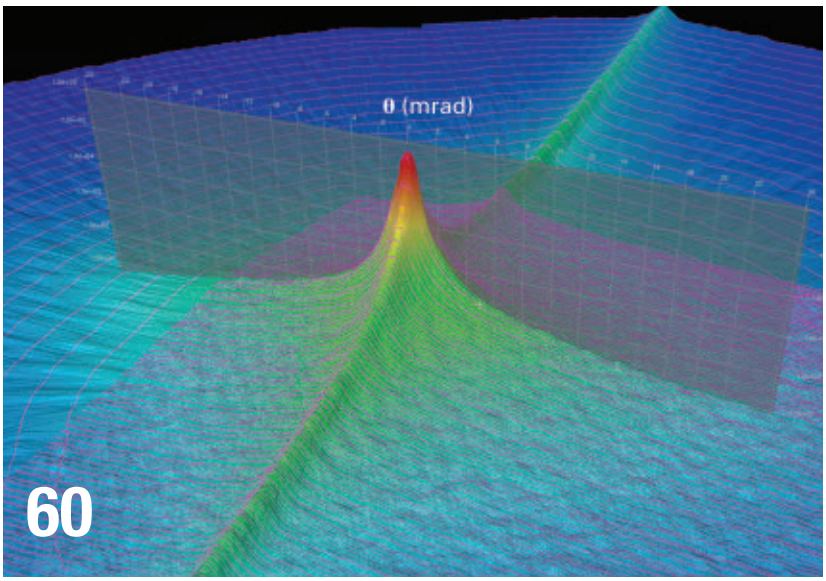

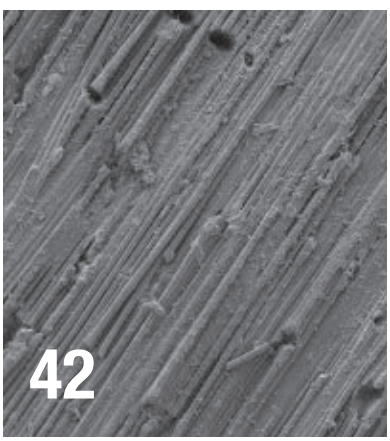

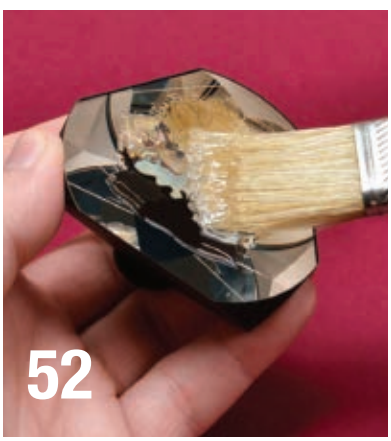

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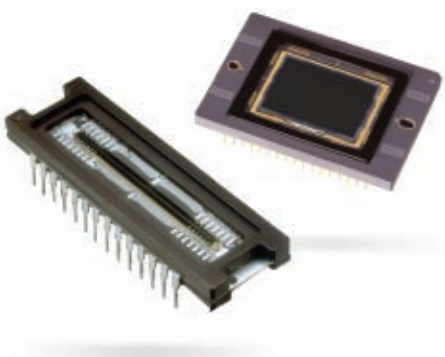

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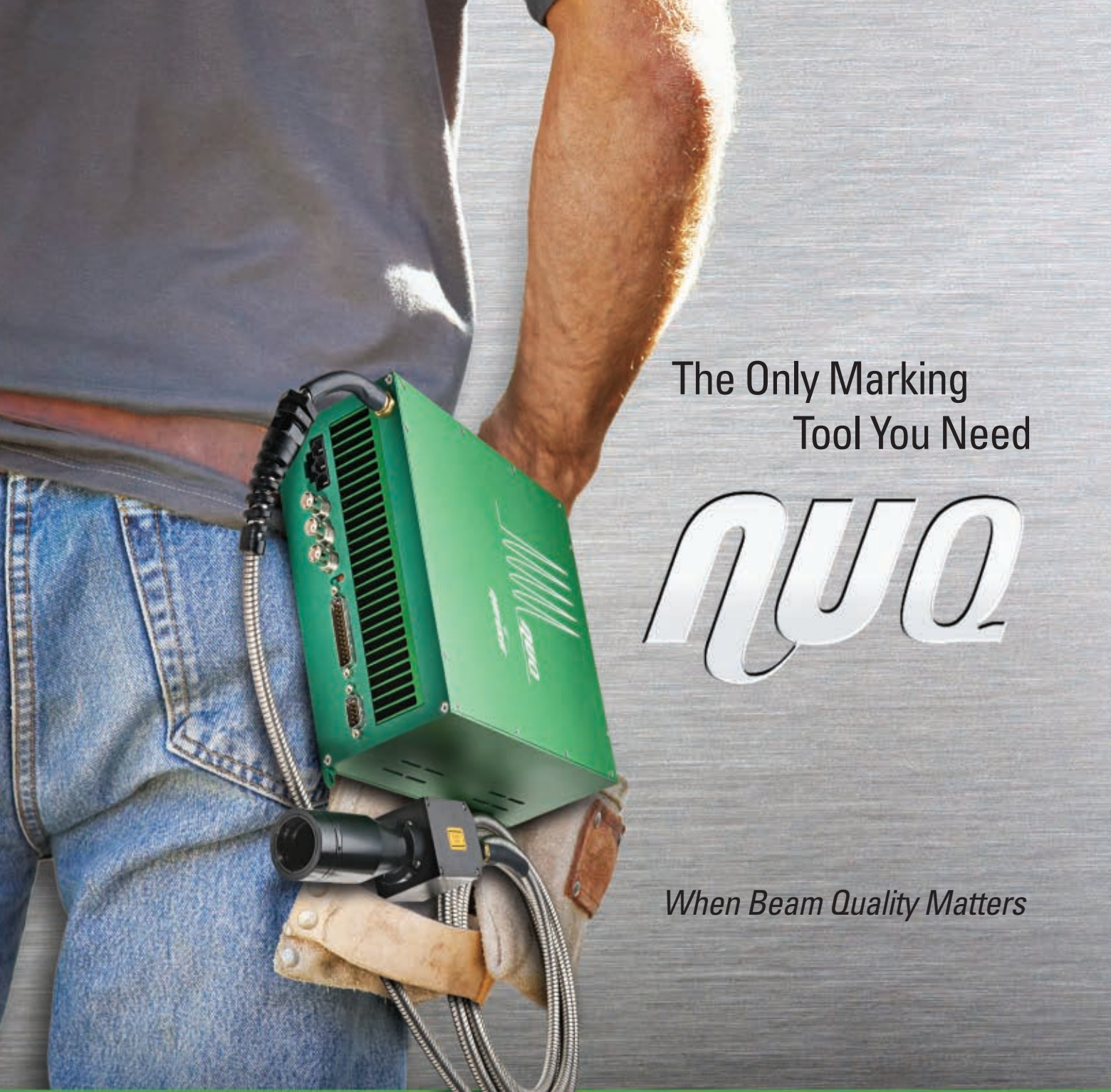

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editorial COMMENT

A Brighter Future for Manufacturing?

In the US, as in Europe, initiatives are proposed or under way to link optics and photonics technologies to a strong and highly innovative economic future by developing public-private partnerships.

We have been covering one such initiative in the US for many months now, and Photonics Media was on hand when industry leaders announced the release of the National Academy of Sciences report *Optics & Photonics: Essential Technologies for Our Nation*. Senior Editor Melinda Rose filed a report from SPIE's Optics and Photonics conference in August, and you can find it at Photonics.com.

Last month, several organizations presented the report to crucial audiences in Washington. "Optics and photonics are incredibly important to the US economy and its competitiveness in the 21st century," said former Intel president and CEO Craig Barrett in his address to an audience of 100 federal agency staff and other stakeholders as part of the effort. The event, *Essential Technologies for Our Future: Optics and Photonics Leading the Way*, was sponsored by OSA, the American Physical Society, the IEEE Photonics Society and SPIE.

"As the report concludes, the promise of optics and photonics can be realized if the United States acts now to cultivate this versatile scientific field through collaborative research and development activities and coordinated support from the public, academic and private sectors working together," OSA Vice President Philip H. Bucksbaum said as he welcomed attendees to the event.

The report examined optics and photonics in several application areas – communications, information processing and data storage; defense and national security; energy; health and medicine; advanced manufacturing; strategic materials; and displays – focusing on their enabling nature and their role in facilitating economic growth.

Better robots and more

It seems fitting that the focus of our feature content this month is photonics in manufacturing, including the latest on 3-D imaging for robots used in manufacturing. Please visit our features section, beginning on page 37; in addition to the story on robot vision, you'll find articles about light sources for both micromachining and for extreme-ultraviolet lithography.

For Photonics Media's continuing coverage of the NAS report and the future of its proposed initiatives, visit Photonics.com for news as well as video coverage on Light Matters, the industry's premier weekly newscast. We'll continue to talk with leaders at the forefront of the effort to bring to life the report's initiatives, and we'll let you know what we find out – and what it all means for you. In the meantime, we'd like to know what you think. I invite your comments at karen.newman@photonics.com.

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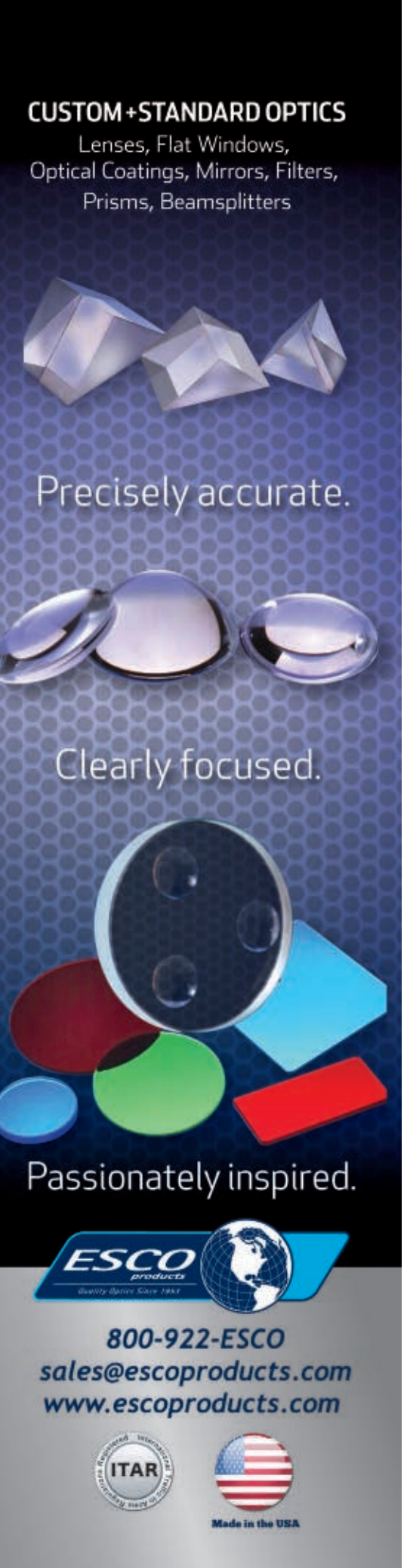

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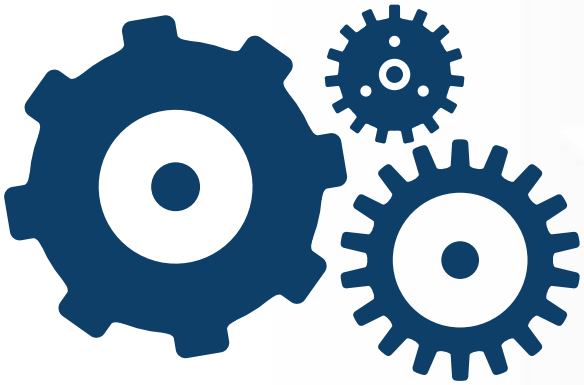

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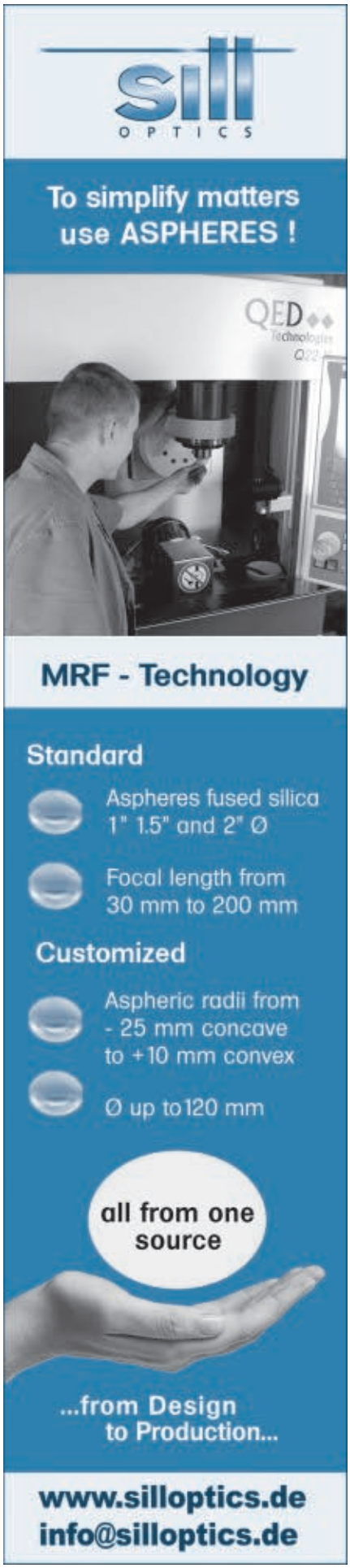

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In the November issue of
Photonics Spectra...

- **Polishing Telescope Optics**
- **Image Storage & Analysis**
- **Lasers in Space**
- **Optical Thin-Film Deposition**

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

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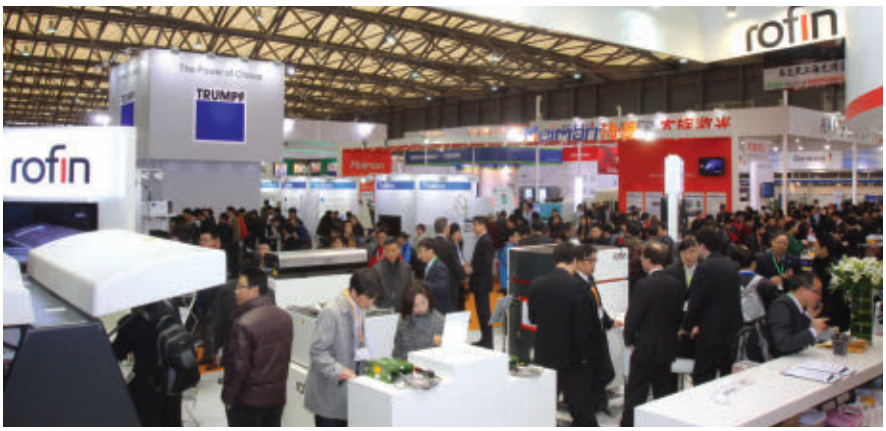


Messe München International

Laser China to connect international industry

Covering topics ranging from components to industrial applications, Laser World of Photonics China 2013 will bring together researchers and professionals from institutions and companies worldwide March 19-21 at the Shanghai New International Expo Center.

Organizers at Messe München International expect that the approximately 600 exhibitors at the eighth Laser China will occupy an area of 370,000 sq ft. Products on display will represent categories such as lasers and optoelectronics, optics and optics manufacturing technology, test and measurement, sensors, laser systems for production engineering, optical measurement systems, optical information and communications, biophotonics and medical engineering, imaging, illumination and energy, and security and services.

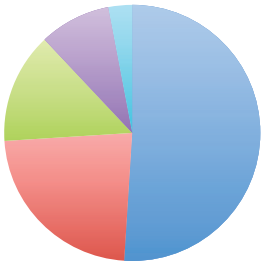
In 2012, Laser China attracted 475 exhibitors from 19 countries and districts, an increase of 31.6 percent over 2011, as well as 34,326 professional visitors from 40 countries and districts, an increase of 19 percent.

Once again, Photonics Congress China will be held in conjunction with Laser China. The conference covers several sectors of lasers and photonics; topics range from research and development in lasers and optical technology to renewable energy. The congress includes: LPC 2013, the eighth International Conference on Laser Processes and Components; Optics Frontier – the eighth Conference on Laser Technology and Optoelectronics; and the OSA Photonics Technology Program and Technical Training Courses Series. Both the conference and the trade fair will combine science, research and industrial applications, supporting exchange between the scientific and industrial communities.

For more information, visit: www.photonicschina.net.

"There are over a million lasers in one data center at Google. We're not talking about grinding some lenses in a basement somewhere."

– Harnessing Light II Committee Co-Chairman Paul McManamon, speaking on the impact of optics and photonics on daily life



This month's Light Exchange Poll Question: We asked Photonics.com visitors, "What energy area do you think will feel the greatest impact from photonics technology?"

Attendance on the rise at SPIE Photonics West

SPIE Photonics West is experiencing a growth trend, and attendance at the annual conference is expected to top 19,500 in 2013, organizers say. The international photonics and laser show, which will be held Feb. 2-7 at the Moscone Center in San Francisco, encompasses the major conferences SPIE BiOS, LASE, OPTO, MOEMS-MEMS and Green Photonics. More than 1200 companies will exhibit devices and components for a variety of applications.

Attendees will have the opportunity to learn about new developments in photonics, including new biomedical optics treatments for critical diseases and for restoring sight, the latest in green photonics for sustainable energy, and laser innovations for manufacturing.

Numerous technical sessions, industry panels and other events will cover areas such as displays; communications; medical therapeutics and diagnostics; micro- and nanofabrication; microelectromechanical systems; optoelectronic materials and devices; and semiconductor, gas, fiber and diode lasers. Technical courses and professional development workshops will be offered.

• eMagin wins $2.4M OLED microdisplay contract • Hamilton Thorne granted European patent • GSI Group rebrands as JK Lasers •

• BAE Systems receives $23.5M US Army order • Carl Zeiss Meditec revenue climbs steadily • Leoni Fiber Optics acquires Richard Losch Inc. •

"It has the potential to extend nonlinear optics into the x-ray range as a useful tool."

– Jerome Hastings, photon science professor at Linac Coherent Light Source, on the successful probing of the effects of light at the atomic scale by mixing x-ray and optical light waves at LCLS

EPIC: PV industry growing strong

Revenues in the photovoltaics (PV) industry reached a record high of $93 billion in 2011, a 13.4 percent gain over 2010 – and 150 percent over 2009 – according to a recent report by EPIC, the Paris-based European Photonics Industry Consortium.

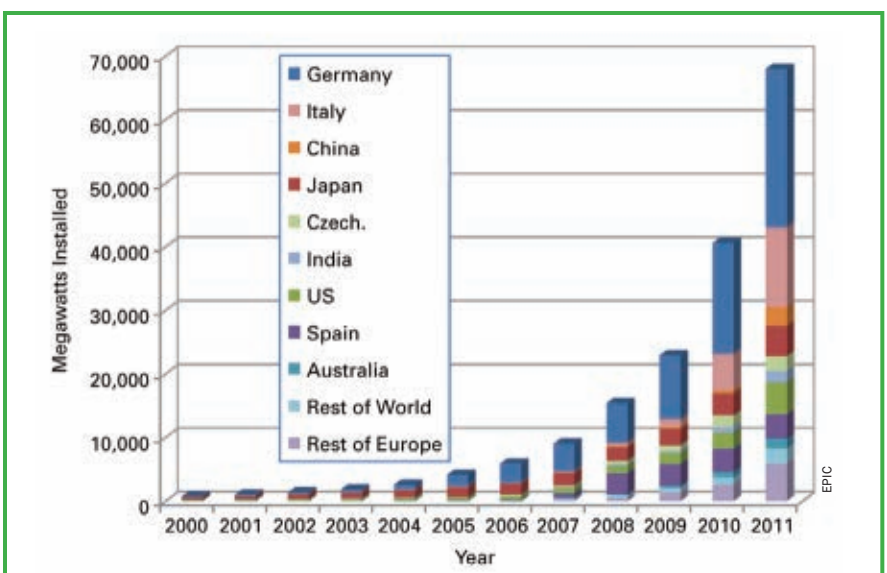
EPIC Report on Photovoltaics: PV Market Overview 2012 cites three developments that affected the level of photovoltaic revenues in 2011. The first was an increase in the supply of polysilicon source material, which led to a nearly 50 percent drop in the cost of a key solar module component. The corresponding decreases in the prices of polycrystalline and crystalline silicon modules gave a big boost to sales volumes (60 percent) and a smaller boost (13 percent) to revenues.

The second development, high production of PV modules in 2010, led to expanded inventory. PV manufacturers rushed to liquidate this higher-cost inventory when the price of the new modules began to drop because of the lower cost of polysilicon in 2011.

The third was distortion in the PV market because of subsidy programs. Nearly 40 percent of the annual PV installations were registered in December 2011 in Italy and Germany, as consumers there dashed to beat the programmed semiannual decrease in the feed-in tariff, EPIC said, adding that feed-in tariffs continue to be a strong driving stimulus for global PV markets.

Globally, PV installations amounted to 27.4 GW in 2011, bringing cumulative PV electrical generation capacity to 68 GW at the end of 2011; installations grew by 56 percent in 2011 compared with 2010, the consortium said. Europe was the world

PV industry, continued on page 18

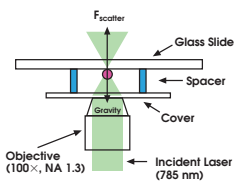


The cumulative installation of photovoltaic generation capacity. Worldwide, 68 GW had been installed by the end of 2011.

This month in history

What were you working on five, 10, 20 or even 30 years ago? *Photonics Spectra* editors perused past October issues and found the following developments:

2007 A remote-controlled aircraft with a thermal-infrared detection system from the Wildfire Research and Applications Partnership Project beefed up wildfire surveillance.



2002 A combined laser tweezer and Raman spectroscopy technique allowed researchers at East Carolina University to catch and analyze transparent and nontransparent particles.

1992 An ultrafast laser at the University of Rochester heated lead above its melting point – without it melting – to image the crystal structure in rarely seen superheated form.

1982 The Laser Div. of the US Army's Night Vision and Electro-Optics Laboratory developed a modification of the Michelson interferometer for more precise measurements of vibration and optical thickness.

• Rubicon receives $4.7M to develop sapphire windows • Sematech reduces defects in EUV mask blanks • ULIS invests €20M in new IR sensor facility •

PV industry, continued

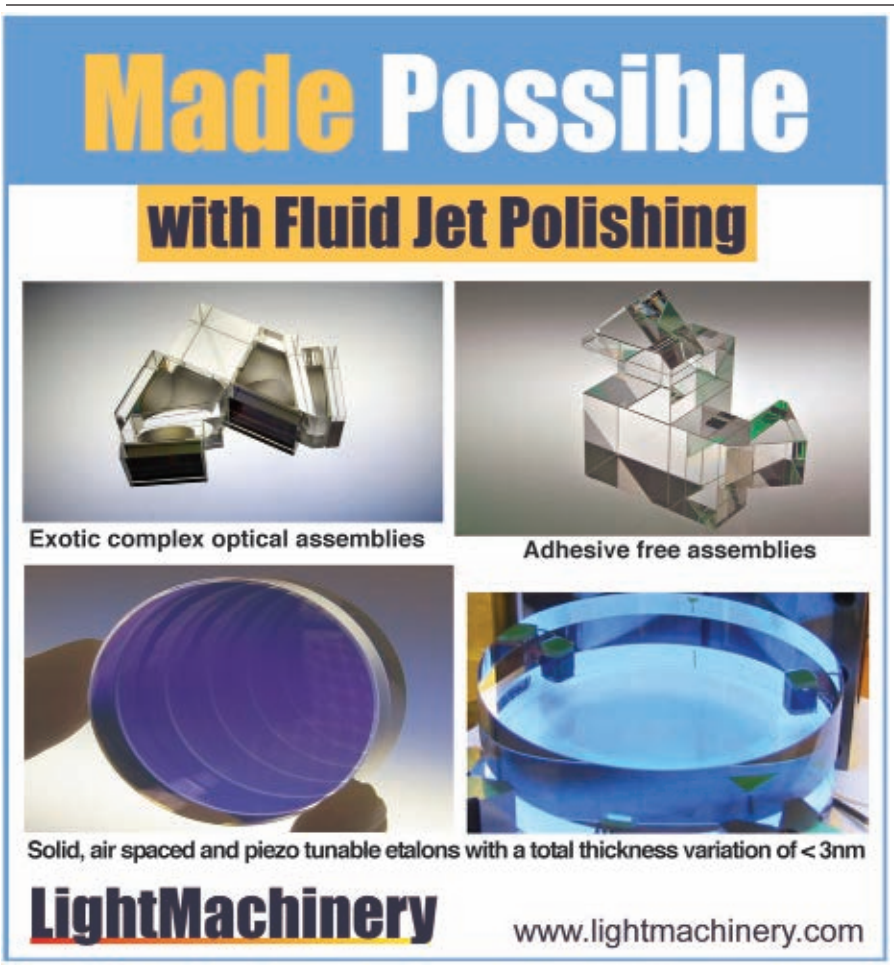
leader in solar deployment in 2011: For the first time, more PV-generating power than any other energy source was installed there; it surpassed both natural gas and wind turbines, EPIC said. European countries represented a more than 63 percent share of the global installation total; Germany alone achieved a 27 percent share of the worldwide total.

The consortium noted that these percentages were down from the 2010 figures and that they indicate the growing importance of PV markets outside of Europe, particularly China. Europe's installation of electrical generation capacity from all sources decreased in 2011, in part because of the economic recession that deepened there throughout the year.

In terms of PV production, Asian manufacturers are now the global leaders. China and Taiwan account for about 74 percent of the world's supply, EPIC said. Production by European companies declined sharply in 2011 to less than 6 percent of the global total. Because many remaining European companies manufacture some of their products in Asia, the actual amount of manufacturing activity in Europe is even less significant, EPIC reported.

The consortium stated that, in 2011, 7.6 percent more wattage of PV cells was manufactured than generating capacity installed. At the end of 2011, less than one month's worth of inventory remained. EPIC's figure of merit (the ratio of total sector revenues to installed PV generation capacity) for 2011 improved significantly to $3.53 per watt compared with $4.60 per watt in 2010.

EPIC's sources for the report included PV-Tech, NPD Solarbuzz, Germany's Federal Network Agency, the International Energy Agency, company annual reports and private communications.



Q&A

Thomas P. Pearsall, author of EPIC's recent report on the photovoltaics (PV) industry, answers a few questions for *Photonics Spectra*:

What do you expect will be the major trends in the PV industry over the next five to 10 years?
Photovoltaics will continue to be dominated by silicon technologies, especially polysilicon and crystalline silicon. Amorphous silicon will disappear from the market. The cost of solar panels will decrease to the point that it is no longer the driving factor in a solar installation decision (installation costs and real estate will dominate).

Are there any technology breakthroughs on the horizon that are expected to help the photovoltaics industry move forward? What technology improvement in particular are manufacturers looking for?
Technology innovations that integrate solar with energy storage, such as hydroelectric, will lead to a disruptive breakthrough. The challenge – to build a new power grid organized around renewable and intermittent energy generation – is comparable to that of building the Internet in 1970.

What would you say are the main challenges for the PV industry going forward (in manufacturing and installation, for example)?
One challenge is reducing the cost of inverters and improving their reliability. Another one is reducing the cost of installation. Still another is the elimination of subsidies for coal, for oil and for solar.

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• AOptix closes $42M funding round • United Technologies completes Goodrich deal • Raydiance $20M funding round led by Samsung •

MOVES & EXPANSIONS

To strengthen its focus on commercial markets, quantum cascade laser manufacturer **Block Engineering LLC** of Marlborough, Mass., has added SKAE Associates of Lexington, Mass., and **Pembroke Instruments** of San Francisco as sales representatives.

Philips (China) Investment Co. Ltd. of Shanghai held a groundbreaking ceremony in August for its LED Professional Lighting Solutions manufacturing facility in the Chengdu High-Tech Industrial Development Zone. As the company's second headquarters in China, the site is expected to begin production in 2013.

IPG Photonics Corp. of Oxford, Mass., has opened an office in Istanbul to provide local support and services for its fiber lasers in Turkey and nearby countries.

Optical coatings and components manufacturer **G5 Infrared LLC** has opened a 6000-sq-ft manufacturing and office facility in Hudson, N.H., where the company is based.

Optical monitoring systems and spectrophotometer manufacturer **EssentOptics** of Minsk, Belarus, is expanding its international presence into Asia and Europe through distribution agreements with **Indeco Inc.** of Tokyo and **VW-TIM** of Jena, Germany, which will distribute EssentOptics' Photon RT spectrophotometers.

Spectrometer manufacturer **Brandywine Photonics LLC** of Philadelphia has tapped **Applied Infrared Sensing** of Artarmon, Australia, to distribute its hyperspectral imagers in that country and New Zealand.

COLLABORATIONS

Tyndall National Institute

The Tyndall National Institute building.

InfiniLED, a spinout of **Tyndall National Institute** in Cork, Ireland, and a portfolio company of London-based **ScienceWorks Ventures plc**, has announced an access agreement with Tyndall National Institute, allowing InfiniLED engineers to work within the institute's ISO 9001-certified compound semiconductor cleanrooms to fabricate its µLED technology.

To accelerate its integration of black silicon image sensors in imaging systems, **SiOnyx Inc.** of Beverly, Mass., has entered into a strategic investment and technology development agreement with independent firm **In-Q-Tel** of Arlington, Va.

"We strongly believe there are significant growth opportunities using advanced fiber lasers to displace traditional laser sources in high-growth applications."

– JPSA founder and CEO Jeffrey Sercel, commenting on his company's Sept. 4 purchase by fiber laser powerhouse IPG Photonics

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PEOPLE IN THE NEWS

Mobius Photonics
Mark "Red" Byer

Mobius Photonics
Manuel Leonardo

• **Mark "Red" Byer** and **Manuel Leonardo**, co-founders of Mobius Photonics Inc., have been promoted to chief operating officer and chief technology officer, respectively, at the fiber-based laser source company.

• **Clark Tooly** has joined Idex's Optics & Photonics organization as global strategic sales manager, the industrial products maker announced.

Idex Optics & Photonics

• **Eric Chandler** has joined Ocean Thin Films as an electro-optical scientist focused on multi-spectral imaging and sensing applications.

Ocean Thin Films

• **Jerry W. Kuper** has joined Toptica Photonics as senior product manager for North America. He co-founded Snake Creek Lasers in 2003 and served as senior scientist and consultant.

• Teledyne Technologies Inc. has announced that **Dr. Lisa Porter** will join its subsidiary Teledyne Scientific & Imaging LLC as senior vice president. She will have responsibility for technology commercialization, technical operations and general management.

• Jenoptik's Lasers & Material Processing Div. has appointed **Stephen Hypsh** as vice president of its lasers business unit in North America. He served most recently as head of business development at Raydiance.

Jenoptik

• **Stuart Cohen** has been appointed sales manager for Xenics USA Inc., a wholly owned subsidiary of Louvain, Belgium-based Xenics nv. He plans to steer the company into the OEM core business segment.

Xenics

• **FEI acquires Visualization Sciences Group** • **First Solar to develop 139-MW Campo Verde Solar Project** •

$106K

– average US earnings, compared with average population of $54,540, of respondents to the SPIE 2012 *Optics and Photonics Global Salary Report*

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Smallest semiconductor laser breaks diffraction limit

"Size mismatches between electronics and photonics have been a huge barrier to realize on-chip optical communications and computing systems."
– Shanjr Gwo.

AUSTIN, Texas – A plasmon-based laser too small to be seen by the naked eye emits continuous green wavelengths at low energy levels and cold temperatures while operating below the 3-D optical diffraction limit.

Physicists at The University of Texas at Austin, in collaboration with colleagues in Taiwan, created the spaser that improves the performance of nanolasers through the growth of a smooth layer of silver on a silicon substrate. Miniaturizing semiconductor lasers is crucial for developing faster, smaller and lower-energy photon-based technologies such as ultrafast computer chips, highly sensitive biosensors and next-generation communications technologies.

These photonic devices could use nanolasers to generate optical signals and transmit information, and potentially replace electronic circuits. But the size and performance of the devices have been restricted by the 3-D optical diffraction limit. That barrier limits the ability of optical instruments to distinguish between objects separated by a distance of less than about half the wavelength of the light used to image the specimens.

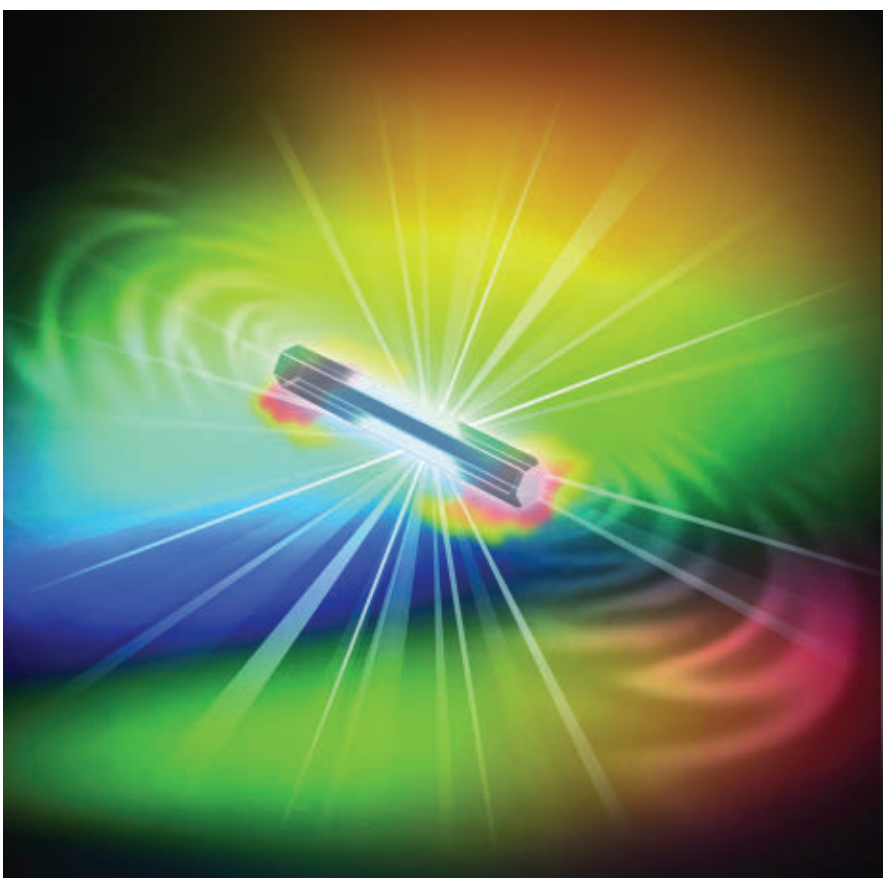
The spaser is constructed of a gallium nitride nanorod that is partially filled with indium gallium nitride. Both alloys are semiconductors commonly used in LEDs. The nanorod is placed on top of a thin layer of silicon that covers a layer of silver film that is atomically smooth.

"Atomically smooth plasmonic structures are highly desirable building blocks for applications with low loss of data," said Chih-Kang "Ken" Shih, a physics professor at UT-Austin who spent more than 15 years perfecting the material.

The new nanolaser device could provide for the development of on-chip communications systems, which would prevent heat gains and information loss typically associated with electronic devices transmitting between multiple chips.

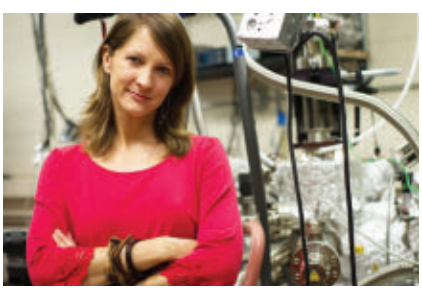
"Size mismatches between electronics and photonics have been a huge barrier to realize on-chip optical communications and computing systems," said Shanjr Gwo, a professor at National Tsing Hua University and formerly Shih's doctoral student.

The findings appeared in *Science* (doi: 10.1126/science.1223504).



Yu-Jung Lu et al., National Tsing Hua University and the University of Texas at Austin

Making semiconductor lasers smaller could lead to faster, smaller photon-based technologies such as ultrafast computer chips, biosensors and communications technologies. Here, an artistic view of the plasmonic nanolaser created at the University of Texas at Austin.



Alex Wang

Research by graduate student Charlotte Sanders, shown, and professor Ken Shih helped develop the world's smallest nanolaser. Sanders stands here with a molecular beam epitaxy machine that she designed and built in collaboration with the department of physics' machine shop and with assistance from co-author Dr. Jisun Kim. The machine is used to create a smooth silver thin film critical to the function of the laser.

Cost-effective infrared lenses produced

FREIBURG, Germany – A new fabrication process that its creators compare with making waffles lowers the cost of infrared lenses for thermal cameras by 70 percent – an accomplishment that could bring luxury-class vehicle features such as night vision within reach of the average car owner.

Infrared lenses are usually made of expensive crystalline materials such as germanium, zinc selenide or zinc sulfide, which can be processed only mechanically. Laborious and expensive processes such as grinding, polishing or diamond-turning are required to shape them correctly.

Because of this, current thermal imagers cost about $2500 and are used mostly in luxury-class vehicles to warn drivers of danger ahead, such as an animal crossing the road.

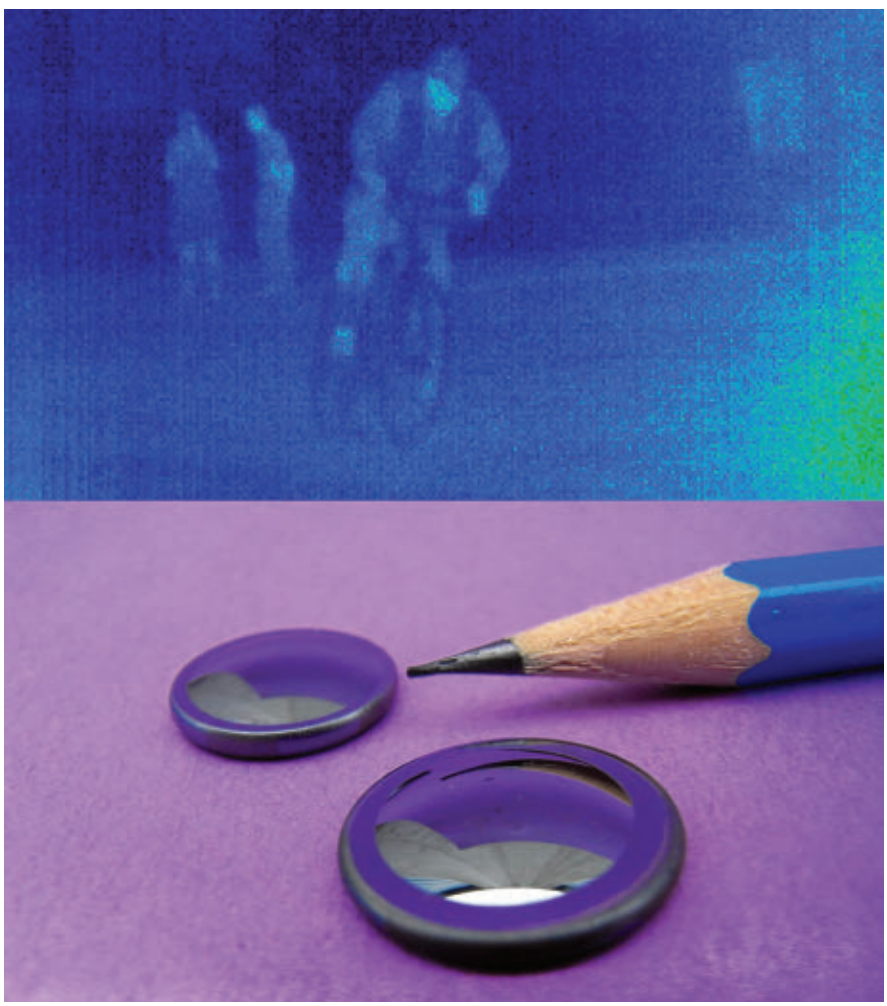
Researchers at Fraunhofer Institute for Mechanics of Materials turned to amorphous chalcogenide glass to make their microbolometer infrared lenses.

"Its softening temperature – that is, the temperature at which it can be formed – is low," said Dr. Helen Müller, a scientist at Fraunhofer IWM. "We can form it using nonisothermic hot stamping."

The two pressing tools used to form the glass resemble a waffle iron. In contrast with conventional processed optics, no further refining is needed, and the lenses exhibit the same optical imaging quality as those that were polished.

Once the process is refined enough to make mass production cost-effective, the microbolometers could become practical for applications such as production process monitoring, warning systems and energy audits, the researchers say.

Once the process is refined enough to make mass production cost-effective, the microbolometers could become practical for applications such as production process monitoring, warning systems and energy audits.



Fraunhofer IWM

(Top) Thermal image, taken with pressed lenses in a test camera. (Bottom) Pressed lenses made of chalcogenide glass.

First nonpolar violet VCSEL could boost laser efficiency

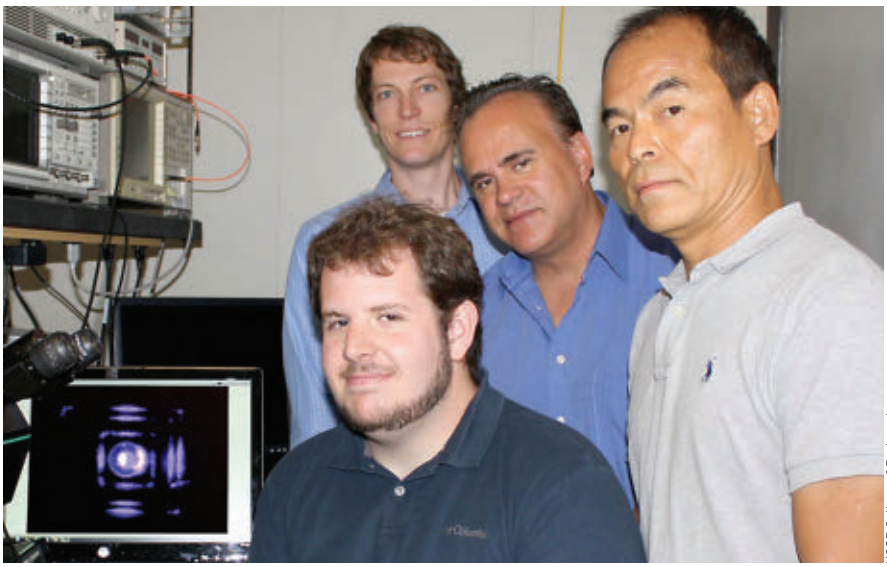
SANTA BARBARA, Calif. – A violet nonpolar vertical-cavity surface-emitting laser (VCSEL) based on m-plane gallium nitride semiconductors has been reported and could lead to more optically efficient lasers for lighting, displays and sensors.

Because VCSELs exhibit low threshold currents, circular and low divergence output beams, and are easily integrated into two-dimensional arrays, they offer advantages over conventional edge-emitting laser technology for some applications. For example, on-wafer testing of VCSEL arrays during manufacture could save costs compared with edge-emitting

Chalcogenide glass is an infrared-transmitting material.

lasers that require additional steps before they can be tested.

The electrically injected nonpolar m-plane nitride VCSEL platform, developed by LED pioneer Shuji Nakamura and his research team at the University of California, Santa Barbara, lases at room temperature and provides high optical gain, helping to increase optical efficiency. The device is naturally polarization-locked along the crystallographic a-direction of the wurtzite crystal, in contrast to the majority of VCSELs, which are typically randomly polarized, said Dr. Daniel Feezell, a project scientist in Nakamura's lab.



UCSB College of Engineering

Shuji Nakamura and his group at UCSB have demonstrated the first violet nonpolar m-plane VCSEL based on gallium nitride. Pictured, from left, Casey Holder, Daniel Feezell (back), Steven DenBaars, Shuji Nakamura.

"Polarization locking, with all devices being polarized in the same direction, is certainly one of the most important features of nonpolar nitride VCSELs," doctoral candidate Casey Holder told *Photonics Spectra*. "In addition to this unique attribute, nonpolar VCSELs are expected to have higher gain than c-plane VCSELs. This should lead to improved performance over c-plane VCSELs, such as lower threshold current and higher optical output power."

Prior attempts by research groups for the back facet and mirror of the fabrication method, such as c-plane GaN VCSELs using an epitaxial distributed Bragg reflector (DBR) mirror or thinned GaN substrates and dielectric DBR mirrors, have offered little control of cavity length. Now, the UCSB team has fabricated a method that offers more precise cavity length control.

"Polarization locking, with all devices being polarized in the same direction, is certainly one of the most important features of nonpolar nitride VCSELs."
— doctoral candidate Casey Holder

"We have developed a novel process where we use photoelectrochemical (PEC) etching of a sacrificial InGaN layer to remove the substrate, allowing us to precisely control cavity length (via placement of the sacrificial InGaN layer during epitaxial growth), while still allowing us to use a dielectric DBR mirror for the rear facet," Holder said. "We believe this novel method is a significant contribution to the field."

VCSELs had not been grown on m-plane substrates because high-quality nonpolar substrates only became available in 2006 through Mitsubishi Chemical Corp., Nakamura said. He added that a new process also was required to make VCSELs using a selective etching, which is how they developed the PEC method.

The team has demonstrated working devices as proof of concept, but Nakamura and Holder agree that displays and sensors will be the most immediate applications.

"Commercial applications are of course hard to predict," Holder said. "We have a lot of work to do in order to take this technology from proof of concept to a commercial product, but we are very optimistic about all of the opportunities listed as well as other applications we haven't even thought of yet. Lighting and displays are certainly much larger markets, but I anticipate that nitride VCSELs could make very important contributions in niche markets such as sensing as well."

"Using the VCSEL, we could reduce the cost of the laser diodes dramatically [in the] near future," Nakamura told *Photonics Spectra*.

Next, the researchers plan to continue improving the device's performance.

"This proof of concept is a great first step, but now we must demonstrate the performance advantages that should be achievable with nonpolar GaN VCSELs beyond polarization-locking, such as lower threshold current and improved optical output powers," Holder said.

Nakamura hopes to achieve continuous-wave operation of the nonpolar VCSEL, then ramp up the power of continuous-wave operation.

The findings have been submitted for publication.

New approach strengthens negative refraction

CAMBRIDGE, Mass. – An "extraordinarily strong" negative refractive index as large as −700 – more than 100 times larger than most previously reported – has been achieved in metamaterials using a technique developed by scientists at Harvard School of Engineering and Applied Sciences (SEAS) in collaboration with Weizmann Institute of Science in Israel.

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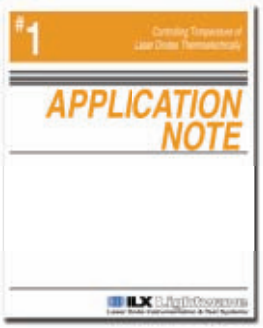

The LDT-5910C and LDT-5940C Thermoelectric Temperature Controllers combine precision temperature control with an intuitive instrument front panel for fast, accurate temperature control of laser diodes and other optoelectronic components. For wavelength sensitive or other high stability applications, the LDT-5910C provides +0.002°C long term temperature stability. Fast setup is accomplished with preset PID values and an auto-tune function or users can enter PID values manually. For applications requiring higher power, the LDT-5940C delivers 60W of control with stability of +0.003°C. These temperature controllers include IEEE 488.1 GPIB and USB 2.0 interfaces for easy integration into any R&D or manufacturing application.

For more information on the new LDT-5910C Thermoelectric Temperature Controller, call **1-800-459-9459** or visit us online at **www.ilxlightwave.com**.

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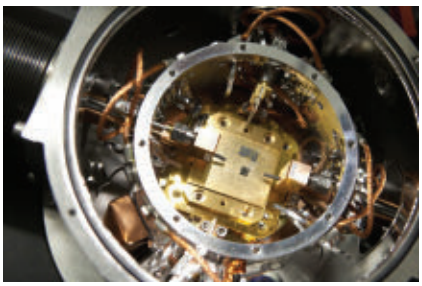
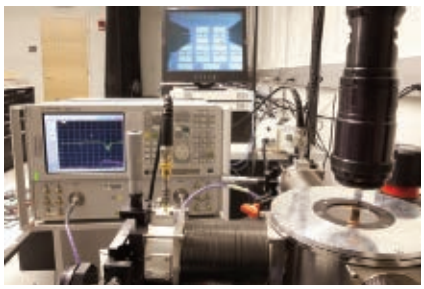


Scientists have demonstrated a new way to achieve negative refraction in metamaterials by applying kinetic inductance. Here, the chamber of the probe station where Donhee Ham's research group tests the new metamaterials.



Eliza Grinnell, Harvard SEAS Communications

The experimental setup in Ham's lab, tests new metamaterials, which are fabricated on tiny chips. The metamaterials themselves are inside the probing chamber at the bottom right. Imaged through the black microscope, they appear on the screen at the top of this image.

In a vacuum, light travels so fast that it can circle the Earth more than seven times in the blink of an eye. When light propagates through matter, however, it slows by a factor of typically less than 5. This factor, called the refractive index, is positive in naturally occurring materials and causes light to bend in a particular direction when it shines on water or glass, for example.

Over the past 20 years, scientists have created artificial materials whose refractive indices are negative, defying normal experience by bending light in the "wrong" direction. These metamaterials have been celebrated by both scientists and engineers for their unusual ability to manipulate electromagnetic waves and for their potential to be harnessed for technologies such as 3-D cloaking.

Now, SEAS and Weizmann Institute scientists have demonstrated a drastically new way of achieving negative refraction in metamaterials by applying kinetic inductance, the manifestation of the acceleration of electrons subjected to electric fields, according to Newton's second law of motion.

"This work may bring the science and technology of negative refraction into an astoundingly miniaturized scale, confining the negatively refracting light into an area that is 10,000 times smaller than many previous negative-index metamaterials," said principal investigator Donhee Ham, Gordon McKay Professor of Electrical Engineering and Applied Physics at SEAS.

The change in strategy from using magnetic inductance to kinetic inductance is based on a simple shift in ideas.

"Magnetic inductance represents the tendency of the electromagnetic world to resist change according to Faraday's law," Ham said. "Kinetic inductance, on the other hand, represents the reluctance to change in the mechanical world, according to Newton's law."

"When electrons are confined perfectly into two dimensions, kinetic inductance becomes much larger than magnetic inductance, and it is this very large two-dimensional kinetic inductance that is responsible for the very strong negative refraction we achieve," said lead author

"This work may bring the science and technology of negative refraction into an astoundingly miniaturized scale, confining the negatively refracting light into an area that is 10,000 times smaller than many previous negative-index metamaterials."

– principal investigator Donhee Ham, Gordon McKay Professor of Electrical Engineering and Applied Physics at SEAS

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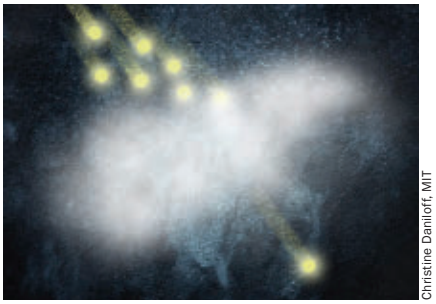
Hosang Yoon, a graduate student at SEAS. "The dimensionality profoundly affects the condensed-matter electron behaviors, and one of those is the kinetic inductance."

Ham and Yoon used a 2-D electron gas (2DEG) to obtain the large kinetic inductance. The very "clean" 2DEG sample, fabricated by Vladimir Umansky of Weizmann Institute, forms at the interface of two semiconductors: GaAs and AlGaAs.

The findings, supported by the US Air Force Office of Scientific Research, were reported in *Nature* (doi: 10.1038/nature11297).

Single-photon beam could lead to quantum computers



Christine Daniloff, MIT

An artist's conception shows how any number of incoming photons (top) can be absorbed by a cloud of ultracold atoms (center), tuned so that only a single photon can pass through at a time. Being able to produce a controlled beam of single photons has been a goal of research toward creating quantum devices.

CAMBRIDGE, Mass. – In a significant step toward quantum computing, scientists at MIT and Harvard University have identified a method that converts laser beams into streams of single photons in a controlled way. The discovery could lead to new quantum devices such as quantum gates, where a single photon switches another photon's direction of travel or polarization.

It is difficult to control photons because the interaction between two photons is very weak at best, said Vladan Vuletic, the Lester Wolfe professor of physics at MIT. Encouraging such interactions requires atoms that interact strongly with photons – as well as with other atoms that, in turn, can affect other photons. For example, a single photon traveling through a cloud of such atoms might pass through easily, but also might change the state of the atoms so that a second photon is blocked when it tries to pass through.

In the new MIT-Harvard system, no matter how many photons are sent into the cloud, only one emerges from it at a time. The cloud acts as a kind of turnstile, forcing the jumbled photons into an orderly succession of individuals. The technique is based on electromagnetically induced transparency (EIT), a technique used previously to slow a beam of light.

The scientists focused a laser beam through a dense cloud of ultracold rubid-

ium atoms at 40 µK to produce the EIT state, exciting the cloud of atoms, which are normally opaque to light, while letting photons pass through at a slow speed. The atoms, which are in a Rydberg state, do not allow a second photon to pass through if the first one has yet to emerge from the cloud. If a single photon enters, it passes through the temporarily transparent medium; if two or more enter, the gas becomes opaque again, blocking all but the first photon.

"If you send in one photon, it just passes through, but if you send in two or three, forcing them to squeeze through the tight focus of the laser beam, just one passes," said Ofer Firstenberg, a Harvard postdoc. "It's like a lot of sand going into an hourglass, but only one grain at a time can pass through."

The technique could be used to alter the state of atoms according to the number of photons striking them, with a second laser beam detecting those changed states. This could help scientists measure a photon without altering it.

The system could form the basis of a single-photon switch and also could be used to develop quantum logic gates, an essential component of an all-optical quantum information-processing system. Such systems, in principle, could be immune from eavesdropping when used for communication, and could allow for more efficient processing of some kinds of computational tasks.

The work appeared in *Nature* (doi: 10.1038/nature11361).

Toward an "unbreakable" message exchange

WÜRZBURG, Germany – Single particles of light produced and implemented into a quantum key distribution (QKD) link could pave the way for unbreakable communication networks.

The single photons were produced by a collaboration of German scientists using two devices made of semiconductor nanostructures that emitted a photon each time they were excited by an electrical pulse. Composed of different semiconductor materials, the two devices emitted photons of different colors.

QKD is not new; one of its first uses was to encode national election ballot results in Switzerland in 2007. The process enables two parties, "Alice" and "Bob," to share a secret key that can protect data they want to send to each other. The secret key is made up of streams of photons that spin in different directions according to the senders' preferences.

The laws of physics state that it is not possible to measure the state, or spin, of a particle such as a photon without altering it, so if "Eve" attempted to intercept the key that was sent between "Alice"

and "Bob," Eve's activity would become instantly noticeable.

"The random nature of emission events from strongly attenuated lasers sometimes results in the emission of two photons very close to each other," said project coordinator Dr. Sven Höfling of the University of Würzburg. "Such multiple photon events can be utilized by an eavesdropper to extract information."

Today, the technique is used commercially and relies on lasers to create the source of photons. Researchers, however, soon hope to further increase the efficiency of QKD by returning to the original concept of using single photons for generating a secure key.

"The nature of light emitted by lasers is very different from light emitted by single-photon sources," Höfling said. "Whereas the emission events in lasers occur completely random in time, an ideal single-photon source emits exactly one photon upon a trigger event, which in our case is an electrical pulse."

In the scientists' experiment, the single photons were produced with high efficiency, then made into a key and successfully transmitted from the sender to the receiver across 40 cm of free space in the laboratory.

For the experiment to become more practical and commercially viable, it must be scaled up so that quantum keys can be sent over larger distances, the researchers say. To achieve this, quantum repeater stations must be incorporated into the network to amplify the message.

Quantum keys have been sent over 500 m of free space atop roofs in Munich, Höfling said.

Several projects have received funding to further develop the technology.

The work appeared in the Institute of Physics and German Physical Society's *New Journal of Physics* (doi: 10.1088/1367-2630/14/8/083001).

System simultaneously uses loss, gain

ERLANGEN, Germany – Light absorption or loss, usually seen as a disadvantage in optical metamaterials, actually can have useful applications.

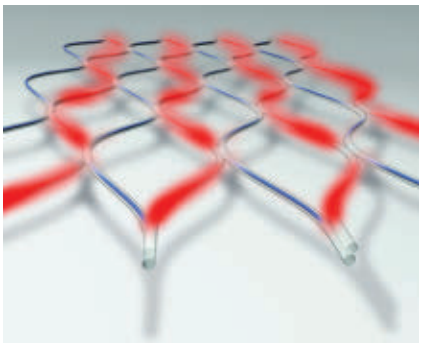
Physicists at Friedrich Alexander University Erlangen-Nuremberg borrowed a concept from quantum field theory in designing a new metamaterial. By applying the abstract idea of "parity-time (PT) symmetry," they altered the way light is transported and produced unusual optical behavior – invisibility in one direction, for example.

Previous experimental work in this area had been limited to small-scale systems; the work by Ulf Peschel and colleagues is the first experimental observation of light transport in a large-scale synthetic material.

"Our experimental results represent a step in the application of concepts from parity-time symmetry to a new generation of multifunctional optical devices and networks," the team wrote in its paper, which appears in *Nature* (doi: 10.1038/nature11298).

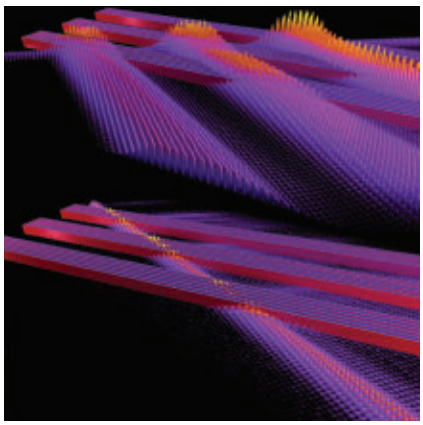
Currently, metamaterials are based mainly on the manipulation of light refraction in the subwavelength range, and optical invisibility cloaks work according to the same principle. Only recently did scientists discover that light propagation also can be influenced substantially by adjusting amplification and loss. This involves maintaining the PT so that light amplification and loss merge into each other in a space-time-reflection.

In their setup, the physicists injected a sequence of light pulses into two connected optical fiber loops designed to exhibit PT symmetry. By alternating gain and loss in the two loops, they attained the imaginary part of the refractive-index profile. The real component of



Gerd Beck, Alois Regensburger

Physicists have applied the abstract idea of "parity-time (PT) symmetry" to alter the way light is transported. Here, a spatial fiber coupler network equivalent to the temporal PT-symmetric lattice is realized in the Friedrich Alexander University experiment. Gain/loss regions are shown in red/blue. This is the first experimental observation of light transport in a large-scale synthetic material.



Christoph Bersch

An artist's illustration of experimental data demonstrating unidirectional invisibility: If the ray of light hits the medium from the left, the reflections at the red and blue scattering bodies made of PT-symmetrical material are even stronger than the ray of light itself. If the same ray of light hits the active elements from the right, the reflection is suppressed, and the ray can travel through the elements without any obstacles, which means that the scattering bodies are invisible from the right.

the profile was introduced using phase modulators.

The approach "can be easily extended to on-chip configurations," the team wrote, "paving the way for the realization of PT synthetic devices and effective media with new and unexpected optical properties."

Similar concepts can be effectively used in other areas, such as plasmonics and metamaterials, where the harmonic coexistence of gain and loss is ultimately required, they added.

Experiments showed that in loop mirrors with controlled periodical amplification and loss, light travels fundamentally different from conventional materials. The strength of optical fields can change drastically – in certain parameter ranges, the flanks of light pulses travel beyond the speed of light.

The work was done in collaboration with scientists from the university's Institute of Optics, Information and Photonics, the Cluster of Excellence Engineering of Advanced Materials, the Erlangen Graduate School in Advanced Optical Technologies, the Max Planck Institute for the Science of Light and the University of Central Florida.

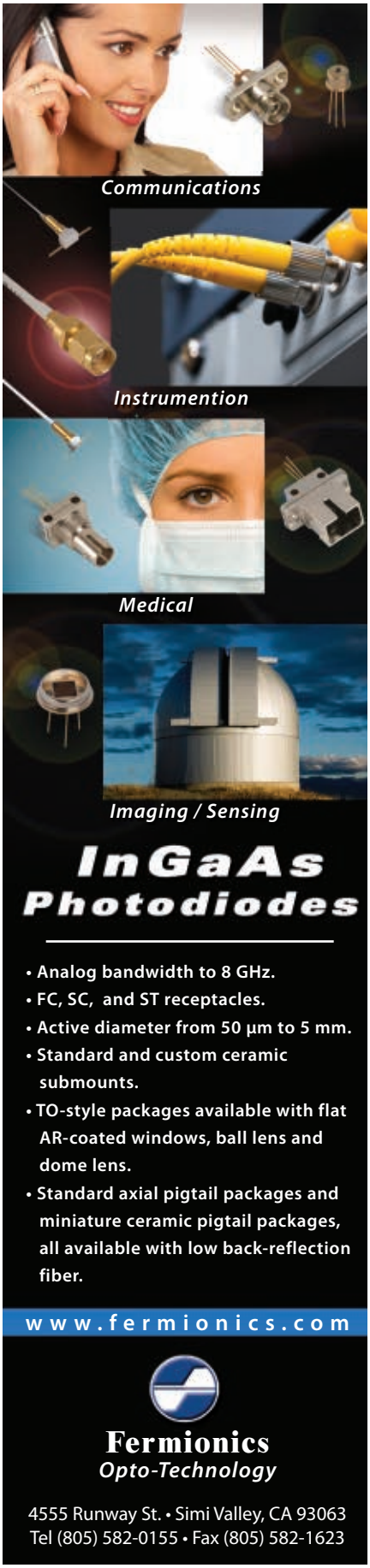
Diamond sharpens x-ray beam razor thin

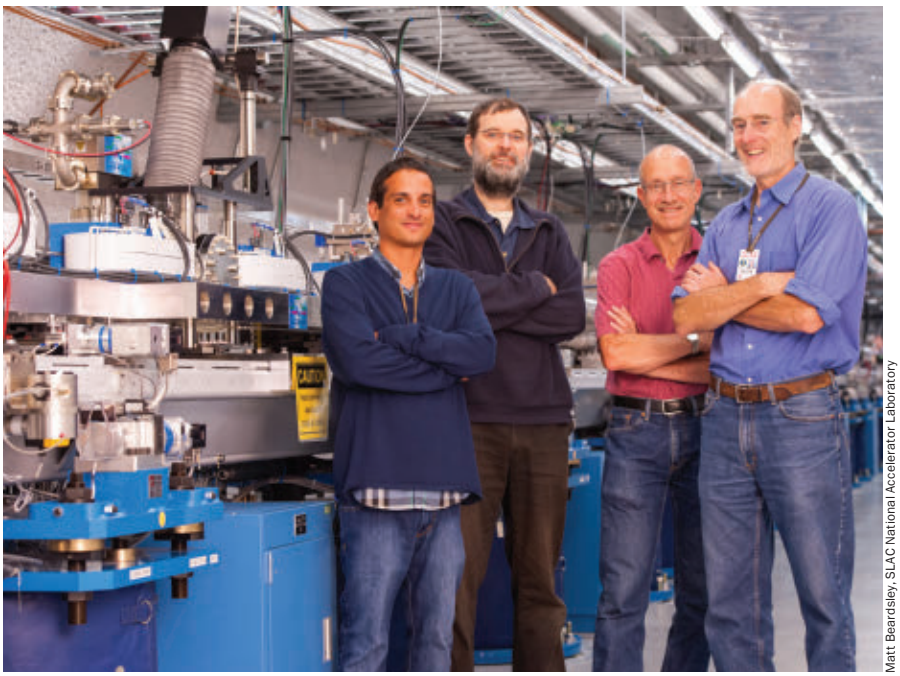
MENLO PARK, Calif. – A thin sliver of diamond can transform the Linac Coherent Light Source (LCLS) into a precise tool for studying and manipulating matter at the atomic level – and may enable experiments never before possible.

In the "self-seeding" technique, conducted by scientists at the US Department of Energy's SLAC National Accelerator Laboratory, the diamond filters the laser beam to a single x-ray color, which is then amplified. The method yields laser pulses focused to higher intensity in a much narrower band of x-ray wavelengths and will deliver sharper images of materials, molecules and chemical reactions.

"The more control you have, the finer the details you can see," said Jerry Hastings, a SLAC scientist and co-author of the research, which appeared in *Nature Photonics* (doi: 10.1038/nphoton.2012.180).

Self-seeding has the potential to produce x-ray pulses with significantly higher density than the LCLS currently produces. The increased intensity in each pulse could be used to probe deeply





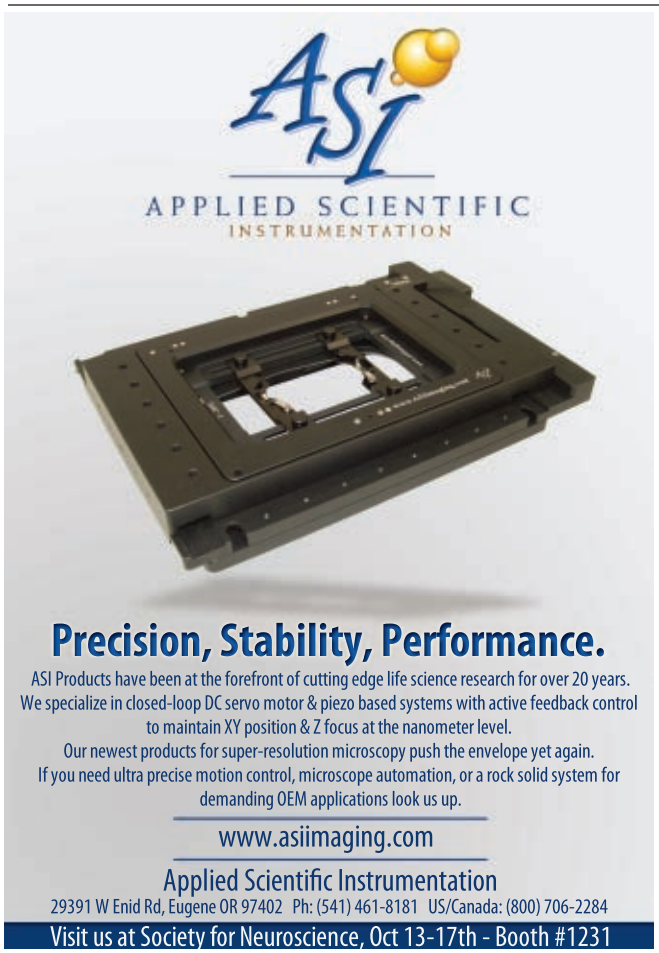
Matt Beardsley, SLAC National Accelerator Laboratory

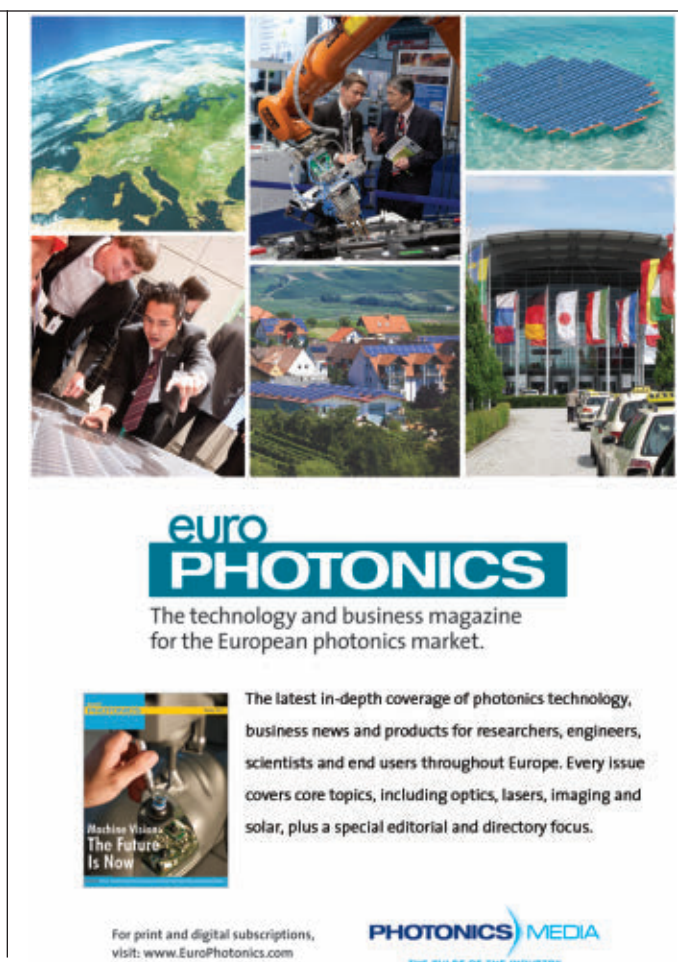
To create a precise x-ray wavelength band and make the Linac Coherent Light Source even more "laserlike," researchers installed this chamber with a slice of diamond crystal. The new hardware sits halfway down the 130-m bank of magnets where the x-rays are generated.

into complex materials, helping answer questions about exotic substances such as high-temperature superconductors or the intricate electronic states found in topological insulators.

"People have been talking about self-seeding for nearly 15 years," Hastings said. "The method we incorporated at SLAC was proposed in 2010 by Gianluca Geloni [of the European XFEL research center and by] Vitali Kocharyan and Evgeni Saldin [both of the DESY research center] ... in Germany. When our team from SLAC and Argonne National Laboratory built it, we were surprised by how simple, robust and cost-effective the engineering turned out to be."

"The more control you have, the finer the details you can see."
– Jerry Hastings, a SLAC scientist





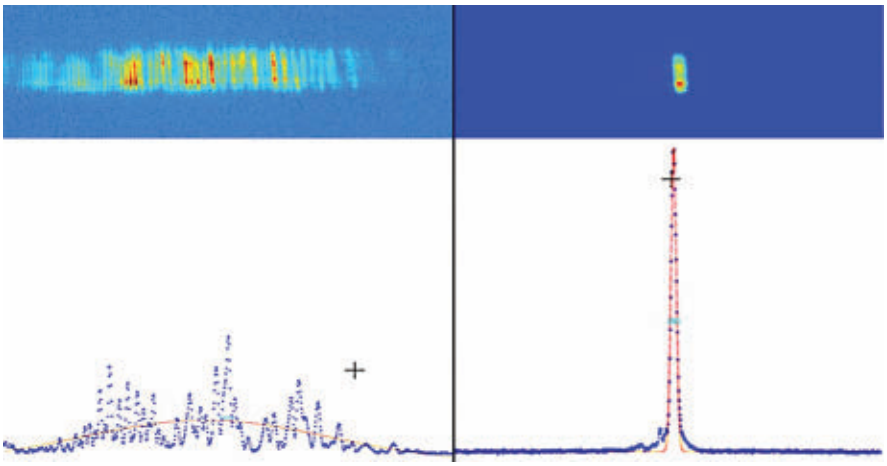
The LCLS generates its laser beams by accelerating bunches of electrons to nearly the speed of light and setting them on a zigzag path with a series of magnets. This forces the electrons to emit x-rays, which are gathered into laser pulses a billion times brighter than any available before and fast enough to scan samples in quadrillionths of a second.

Without self-seeding, the x-ray pulses contain a range of wavelengths in unpredictable patterns that cannot all be used by experimenters. Until now, a narrower-wavelength band could be created at LCLS only by subtracting the unwanted wavelengths, resulting in a substantial loss of intensity.

To create a precise x-ray wavelength band and make the LCLS more "laser-like," researchers installed a diamond crystal slice halfway down the 130-m bank of magnets where the x-rays are generated.

"The resulting pulses could pack up to 10 times more intensity when we finish optimizing the system and add more undulators," said Zhirong Huang, a SLAC accelerator physicist and study co-author.

The self-seeding system has excited the international scientific community. Representatives from other x-ray laser facilities, including FEL in Switzerland, SACLA in Japan and the European XFEL, helped with it and are studying how to implement their own systems.



Greg Steward, SLAC National Accelerator Laboratory

The Linac Coherent Light Source's new self-seeding improvements yield laser pulses focused to higher intensity in a much narrower band of x-ray wavelengths, as seen in these spectrographs comparing a normal SASE (self-amplified spontaneous emission) pulse (left) and a seeded one (right). The results promise to speed research discoveries and may enable experiments that have never before been possible.

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this month's **FEATURES**

- **Robots Work Better with Vision Enhancements**
- **Different Lasers Offer Different Features for Micromachining**
- **Color Cameras Improve Results in Vision Applications**
- **Choosing the Right Epoxy for Optical Applications**
- **Laser-Produced Plasma Source Improvements Drive EUVL Adoption**
- **Scanning Goniophotometers Improve Materials Selection**

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Robots Work Better with **Vision Enhancements**

Machine vision trends in use on (or coming soon to) the factory floor include 3-D and better resolution.

BY HANK HOGAN
CONTRIBUTING EDITOR

Industrial robots with mere vision can't keep up anymore – now they have to image in greater detail and in 3-D.

Where these trends are headed can be seen in the latest research into autonomous vision-based docking. Robots equipped with this technology could have full-color 3-D vision accurate on a scale of thousandths of an inch, making it possible to recognize and verify parts and components on the fly.

For now, recent developments are driving vision capabilities and, therefore, usage. Of prime importance was the introduction of GigE cameras and power-over-Ethernet (PoE) technology, said Maximiliano Falcone, supervisor of product development for Kawasaki Robotics (USA) Inc. in Wixom, Mich.

One benefit has been longer signal runs, Falcone said. "Before, when it was an analog signal, you could only go about 30 feet. Now you're looking at 100-meter (325-ft) lengths with this PoE camera technology."

A second plus is the need for one less cable because power for the camera rides over the Ethernet connection. Fewer cables can be important when robots with many axes of freedom are twisting this way and that.

Another innovation has been the arrival of higher and higher pixel-count cameras. Today, megapixel cameras are appearing in industrial robots. More capable software and the ability to do more up-front calibration of cameras have improved the usefulness of these higher-resolution vision systems.

One thing such advances won't change is the nature of the factory floor. There may be welding going on, causing intermittent bursts of light that a camera or vision system may capture. There are other often overlooked changes to ambient lighting that can bombard a sensor.

"There's traffic going around these plants, whether it be a fork truck or a golf cart. Almost all of them have a strobe on them. Some of those strobes are white. Some of those strobes are orange. Depending on what color strobe, it can affect things," Falcone said.

Alongside higher resolution has come the deployment of 3-D vision systems. Some involve the use of two cameras for a stereo view of an object, where analyzing the slightly different images captured by the cameras yields depth information. Other systems use structured light. Here, the third dimension is extracted from distortions that an object creates when light of a known pattern is projected onto it.

A payoff of these techniques is that manufacturers can really take the measure of what they are making. In the past, they might only get four or five data points on a surface. With 3-D vision, they can get thousands of readings. The much-higher-density point cloud should make it possible to hold parts to tighter tolerances and, thus, lead to more precise manufacturing.

Kawasaki Robotics

A big trend in robotics for manufacturing is 3-D vision. Here, a 3-D vision capture system developed by Kawasaki Robotics measures and inspects parts.

As for the future, technologies developed for cell phones look very promising, Falcone said. He is particularly interested in liquid lens techniques because they allow the smooth adjustment of a lens through a range of focal lengths. All that is needed is a small voltage change. Applying this to machine vision will enable a lens to home in on the best possible focal length for a given task, which will lead to the best possible image and the best possible output.

"To have a 3-D vision system on a robot that can look into a bin, determine what orientation the part is that it's about to pick up, adapt to it and pick it up makes the supply chain much more efficient and much less expensive."

– Henry Loos
Applied Robotics

3-D vision gives manufacturers a **higher-density point cloud** than standard imaging, which could lead to **more precise manufacturing**.

Applied Robotics Inc. of Glenville, N.Y., specializes in end-of-arm tooling for robotic systems. Some of its products involve vision and other photonic systems typically used for inspection. A robot will pick up the vision system, check incoming parts, establish reference points for subsequent processing, and then drop off the camera to pick up the actual tool that will be used for processing or manufacturing.

Three-dimensional vision is a trend largely because it solves a problem, said Applied Robotics applications engineer Henry Loos. With imaging in only two dimensions, incoming components arriving at an industrial robot work cell must be precisely arranged and oriented so that the robot can find the parts on which to work. Three-dimensional imaging enables more relaxed packaging.

"To have a 3-D vision system on a robot that can look into a bin, determine what orientation the part is that it's about to pick up, adapt to it and pick it up makes the supply chain much more efficient and much less expensive," Loos said.

Doug Erlemann is business development manager for vision products for the Southington, Conn.-based US office of the industrial camera maker Baumer Ltd. Most six-axis industrial robotics applications do not require anything more than a few frames per second speed, he said.

However, what is absolutely vital is that there is no downtime resulting from a vision system failure. The penalty for a stopped production line can run in the tens of thousands of dollars a minute, and robot makers understandably want to avoid that cost.

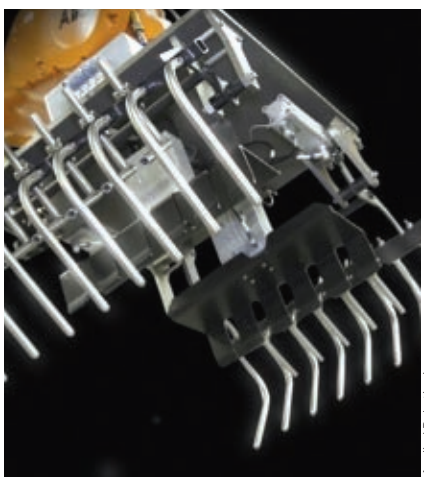
The need for uptime explains why robot makers hate wires – another potential failure point – and prefer power-over-Ethernet technology. The same requirement also explains why Baumer cameras are sealed in enclosures to offer protection against dust and water ingress.

Another need explains a push toward higher resolution that Erlemann predicts is coming. Many vision systems today are used to fix a location in space. From then on, the robot ignores the sensor because it knows where the work product is and its relation to the robot. But in the future, cameras may be called upon to do more than simply locate a point. They could play another role as manufacturers put 2-D bar codes or data matrix codes on components, assemblies and subpanels.

"They need the camera to not only send the position to the software, they need to actually read that code," Erlemann said.

Photonics also allows robots to see in other ways. A case in point comes from PaR Systems Inc. of Shoreview, Minn. The company makes robotic and materials handling equipment and systems. Its laser center of excellence in Pretoria, South Africa, produces a line of atmospheric and high-pressure transversely excited CO_2 lasers.

Those lasers power robotic nondestructive inspection of composite materials used in aviation and elsewhere. The



Applied Robotics Inc.

Advances in vision technology allow robots to do more than ever before.

Baumer

Using a vision system, a robot identifies dice, picks them up and brings them back to the edge of a table. The same vision solution is used in an industrial setting to pick up components or to weld a bead to join two pieces of metal.

PaR

A two-laser system performs nondestructive inspection of composite, the type of material found in advanced aircraft and other applications.

Applied Robotics

A robot uses a vision attachment to locate a part for subsequent processing, which is done by a work tool.

system consists of two lasers, one of which projects a pulse onto the object being inspected. The pulse duration causes the material in the object to vibrate ultrasonically, much as it might if tapped by a hammer. The resulting resonance is picked up by a second laser, allowing non-destructive examination of the material.

"It will show you if there is a crack or whether there's an inclusion or a deformity of some sort," said Carel Swart, laser center general manager.

The system is fast enough to quickly inspect components that measure meters, and it can scan curved parts. It uses optics mounted on robot arms to deliver the pulse and collect the resulting signal. The genesis of the technique came from a request by defense contractor Lockheed Martin, which had to devise a way to inspect the composite materials being used in the F-35 Joint Strike Fighter, now nearing the end of development.

However, the inspection technique is not confined to aviation. It also is being considered for inspection of wind turbine blades, Swart reported.

In another application, robots equipped with the same lasers can remove paint and resins. This is useful because, although composite materials do not tolerate the traditional harsh chemicals used for paint removal, the Federal Aviation Administration requires repainting an aircraft's surface every five years or so.

Fortunately, paint removal can be done using a CO_2 laser mounted on an articulated robot arm. It removes paint, Swart said, "causing no harm to the substrate and no temperature transfer to the substrate. The maximum temperature is around 50 to 60 °C."

As for where vision systems and other photonic sensors may ultimately be headed, one clue could soon be flying overhead. John L. Junkins, an aerospace engineering professor at Texas A&M University in College Station, has been developing sensors and software that will enable an autonomous spacecraft to spot other objects at a distance of miles and to dock with them. At that point, the craft would work on its target; debris would be removed via a safe re-entry path. A

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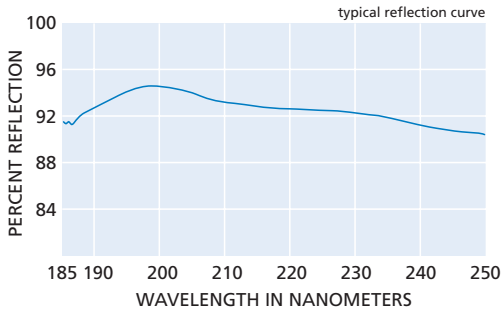

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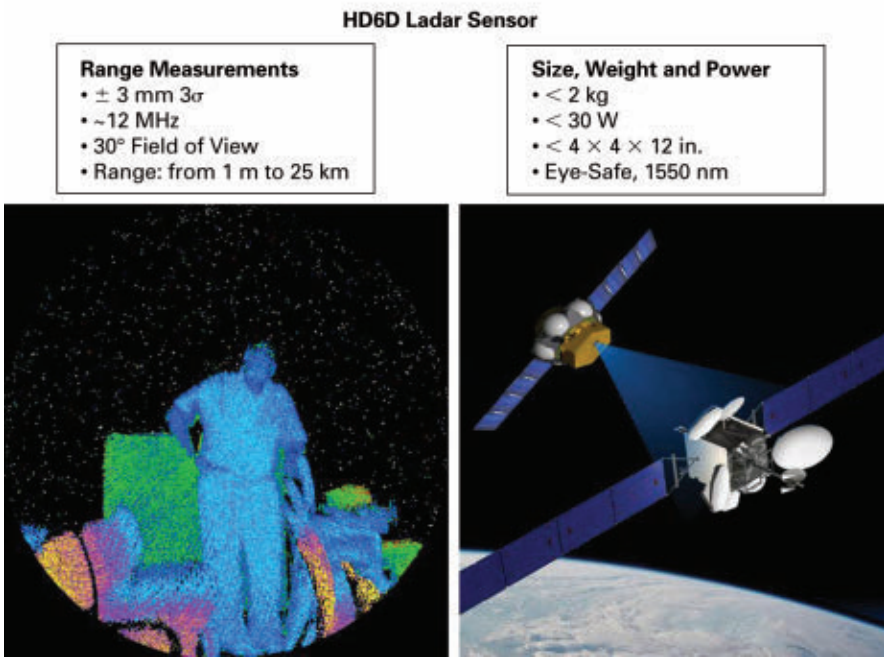
salvageable satellite, on the other hand, might be repaired.

Junkins is working on a prototype laser radar sensor and expects to have it operational this year. It will use a combination of high speed, accurate and dense laser ranging as well as full-color, high-definition video imaging.

The laser radar hardware is being developed by Systems & Process Engineering Corp. of Austin, Texas. The cost of components in laser radar has fallen from tens of thousands of dollars to only a few hundred, bringing into sight the day the technology might show up on a soldier's helmet, an industrial robot or elsewhere, said Bradley Sallee, vice president of sensor systems. Advances in photonics have been accompanied by improvements in computing, and the combination could soon pay off in down-to-earth applications.

"The computational power is increasing rapidly, and the sensors are getting smaller," Sallee said. "We're right on the cusp of it being practical."

hank.hogan@photonics.com



John L. Junkins, Texas A&M University

A prototype laser radar sensor under development for spacecraft operations could find its way into use by earthbound industrial robots, allowing them to see in 3-D with precision and clarity.

Different Lasers Offer Different **Features for Micromachining**

Nd:YAG and fiber lasers play important roles in cutting, welding and drilling small intricate parts.

BY DR. MOHAMMED NAEEM
JK LASERS

The increasing complexity of electronic, medical and engineering devices presents manufacturers with many challenges that must be overcome if they are to remain competitive in today's marketplace. Very small, intricate and often high-value parts must be mass-produced to exacting standards at relatively low cost.

Lasers have become a key enabling technology in this continuing trend toward micromachining. They can be found in many industries, helping to produce a wide range of products, such as catheters, stents, hard disk drive flexure arms, fiber optic couplings, orthodontic brackets and watch parts.

The recent proliferation of industrial lasers means that manufacturers now may have too many choices: How can they know which laser is right for their specific micromachining application?

For years, pulsed Nd:YAG lasers were standard for microcutting, microwelding and microdrilling metals. At wavelengths around 1 µm, the focusing optics are smaller and more simple than those of equivalent CO_2 lasers.

However, demands for more efficient compact lasers with higher beam quality have fueled a rapid rise in fiber lasers. These lasers operate at the near-IR spectral region and offer many advantages over traditional laser sources.

The beam quality of a single-mode fiber laser is a near-perfect M^2 of 1, meaning that the output power can be focused to a much smaller spot size. The fiber laser also can produce high brightness and high power densities up to 10^8 W/cm^2, more than sufficient for cutting and welding thin materials.

Pulsed operation is an area where there is a significant difference between lamp-

Laser Parameters	JK100P	JK125P	JK300P
Maximum Average Power[1]	100 W	125 W	300 W
Maximum Peak Power[1]	10 kW	5 kW	9 kW
Maximum Pulse Energy[1]	0.25 J	17 J	56 J
Pulse Width Range	15-200 µs	0.1-20 ms	0.1-20 ms
Maximum Frequency	350-2000 Hz	1000 Hz	1000 Hz
Pulse-to-Pulse Stability	±1% from Cold	±1% from Cold	±1% from Cold
Beam Quality[2]	5 mm mrad	7 mm mrad	16 mm mrad
Fiber Diameter	100 µm	150 µm	300 µm
Pulse Shaping	–	20 Sectors	–

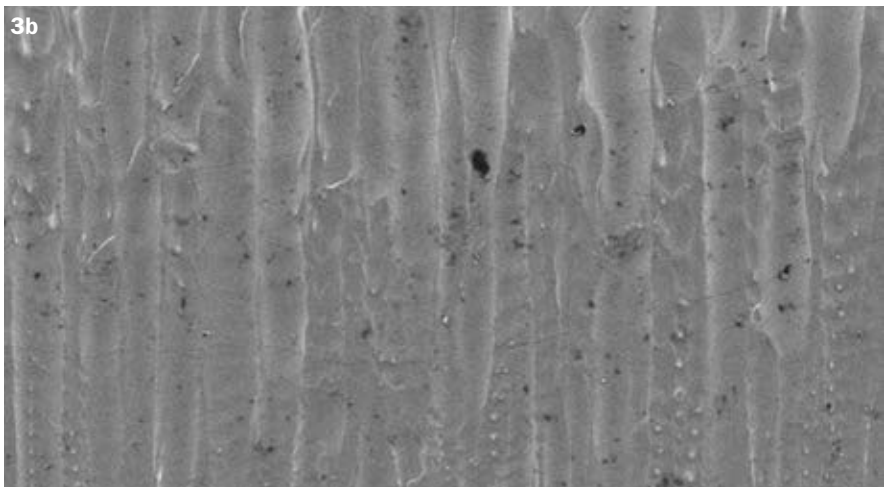
[1] Rated at the end of lamp life.
[2] Half-angle radius.

Figure 1. Performance data for JK Lasers' pulsed lasers. The company conducted micromachining trials using three of its pulsed lamp-pumped and single-mode fiber lasers.

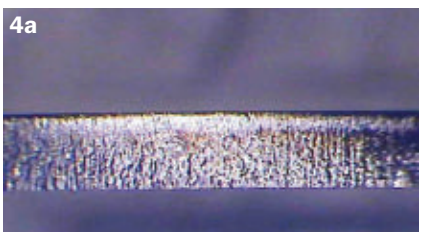
Laser Model	JK50FL	JK100FL	JK300P	JK400FL
Average Laser Power	50 W	100 W	200 W	400 W
Beam Quality	$M^2 < 1.1$, TEM_{00}			
Operating Modes	CW and Modulated Fiber-Pierce™ Option		CW and Modulated	
Wall-Plug Efficiency	>25% (at spec power)			
Output Power Dynamic Range	20%-100%	10%-100%	10%-100%	10%-100%
Minimum Rise/Fall Time	5 µs			
Modulation Frequency	Maximum 50 kHz			

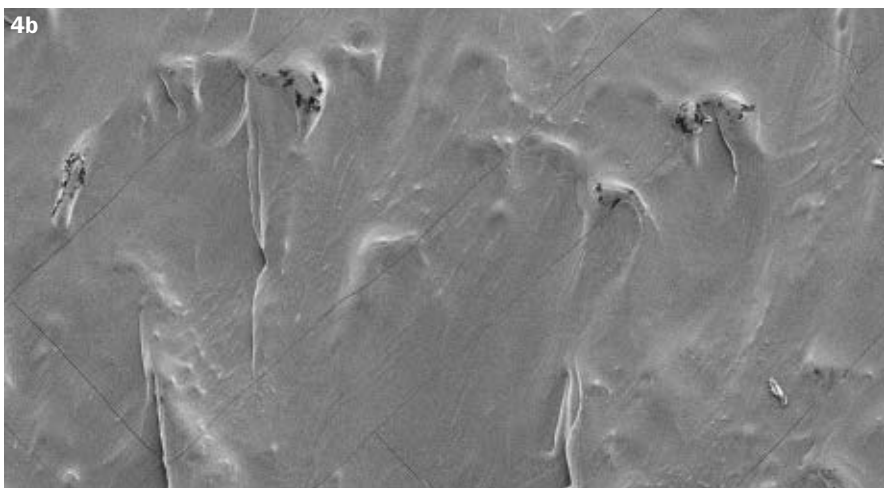
Figure 2. The company also tested its single-mode fiber lasers for micromachining applications. Here, performance data for the lasers.

Images courtesy of JK Lasers.

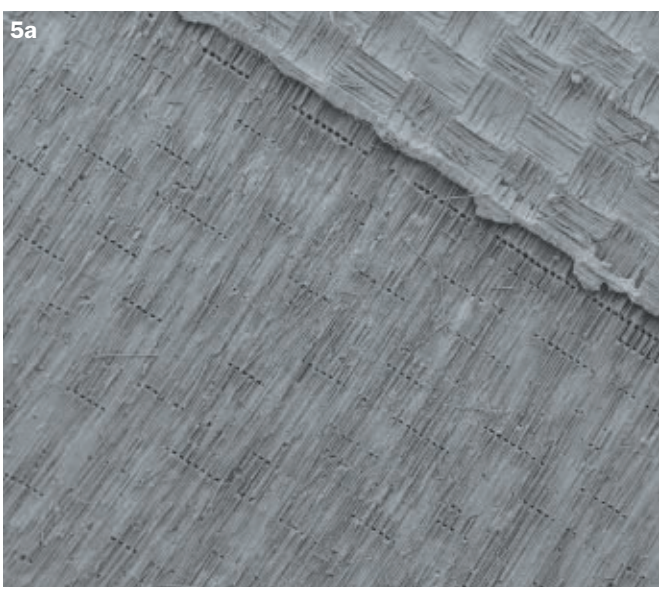


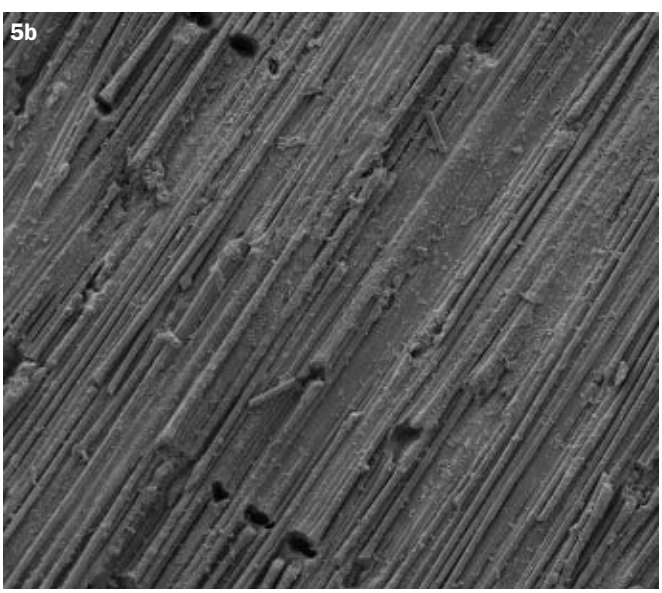
Figures 3a and 3b. The testing produced micrographs of the cut edges for pulsed lamp-pumped and single-mode fiber lasers. Here, a single-mode fiber-cut 1.8-mm-thick wafer was processed with a 10-kHz, 350-W laser at >3.5 m/min using nitrogen assist gas.





Figures 4a and 4b. This 2-mm-thick wafer was cut by a pulsed laser at >0.15 m/min using nitrogen assist gas. The pulsed Nd:YAG laser can cut a range of thicknesses up to 2 mm.





Figures 5a and 5b. The testing showed that the single-mode laser can control the depth of material removed to deliver a high-quality surface finish. Here, a composite surface micromachined by a JK200FL laser at 20 mm/s in air is shown at 80× (a) and 500× (b) magnification.

A **top-hat profile** occurs when a laser beam has **near-uniform energy density**.

Figure 6a. The company conducted microdrilling tests on a variety of materials, including ceramics and silicon wafers. Here, microdrilled holes (0.2 mm thick) in 1000 Al alloy were percussion-drilled using a JK100FL laser with modulated output at 30 µm.

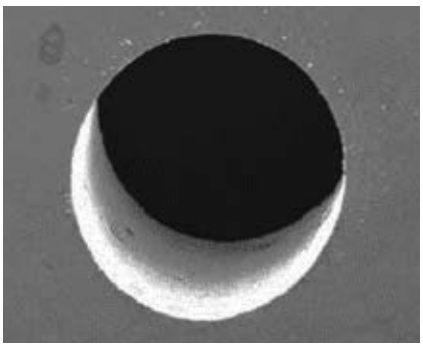


Figure 6b. These 0.5-mm-thick holes in 304 stainless steel were percussion-drilled using a JK100FL laser with modulated output at 50 µm.

pumped Nd:YAG and fiber laser performance. Lamp-pumped lasers can produce long, multimicrosecond pulses with peak powers many times the rated average power of the laser (provided that the duty cycle is sufficiently low). This ability stems from the flashlamp itself, which often is more constrained by the maximum average thermal load than by the peak power output.

These lasers, with their enhanced control and complex pulse-shaping facilities, provide greater flexibility for processing a range of materials, including highly reflective metals. Their beam is transmitted through optical fibers that homogenize the power distribution across the laser beam to produce a top-hat profile. This consistently produces very round entry and exit holes.

In contrast, although the semiconductor laser diodes that are used to pump a fiber laser can be on-off modulated over a wide frequency range (from DC to tens of kilohertz in most industrial applications), they cannot typically be overdriven for long periods in the same way as a flashlamp without reducing the overall lifetime of the device.

Considering the differences in beam quality and pulsed performance between fiber and Nd:YAG lasers, there are different operating regimes for the two types. The lamp-pumped Nd:YAG laser is characterized by long, high-energy pulses but poorer beam quality, while the fiber laser is typified by high-repetition on-off modulation and single-mode beam quality, but low pulse energy.

JK Lasers carried out a series of micromachining trials with low-power pulsed lamp-pumped and single-mode fiber lasers with different beam qualities and laser parameters (Figures 1 and 2).

Microcutting solar cells

Both pulsed Nd:YAG and single-mode fiber lasers can cut the mono- and polycrystalline wafers used in solar cells. The 100-W single-mode fiber laser (JK100FL) successfully cut smooth edges in thin sections (<1 mm). To cut thicker section wafers (>1 mm) with a single-mode fiber laser, higher powers (200 to 400 W) would be required to produce dross-free cuts at speed.

The pulsed Nd:YAG laser (JK100P), with its high peak power and short pulse widths, is well suited for cutting a range of thicknesses up to 2 mm. Microcracks caused by both laser sources measured <10 µm long. Typical micrographs of the cut edges for both lasers are shown in Figures 3 and 4.

Microcutting medical stents

A 100-W fiber laser (JK100FL) produced very small spot sizes, down to 15 µm, making the laser an ideal solution for intricate implantable devices such as stents. Dross-free cuts (20-µm kerf width) combined with very high contour accuracy (<5 µm) vastly reduced the amount of post-processing required.

Modulating the fiber lasers' pulse frequency and duration significantly improved the controllability of fine cuts. These fiber lasers feature a pulse generator on the control card that allows them to run in pulse mode. This can be easily controlled using JK Lasers' integrated FiberView software, which has built-in modulation capability.

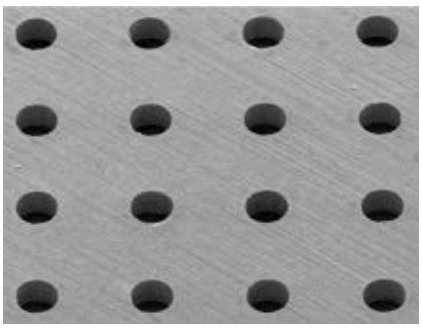


Figure 7a: Pulsed lasers are good at percussion drilling metals and nonmetals. This 1.5-mm-thick nickel-based alloy was percussion-drilled using a pulsed Nd:YAG laser at 150 µm.

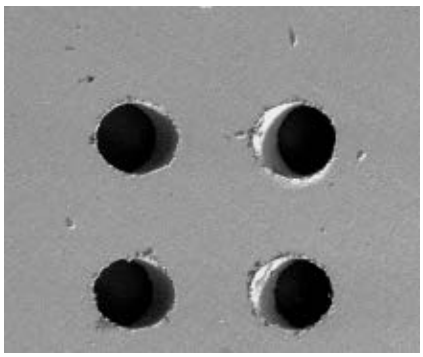


Figure 7b: This 0.6-mm-thick alumina ceramic was percussion-drilled using a pulsed Nd:YAG laser at 50 µm.

Carbon fiber reinforced plastics

Carbon fiber reinforced plastics (CFRPs) composites are low in density, high in strength and have a high stiffness-to-weight ratio, qualities which have attracted considerable interest from the aerospace industry. But the composition of CFRPs – in particular, the high heat conductivity of the carbon fibers themselves – makes processing difficult using traditional techniques. Mechanical milling and drilling have been known to cause costly heat damage, chipping, delamination and tool wear.

A 200-W single-mode fiber laser (JK200FL) can cut a much cleaner edge with minimal thermal damage. Key to controlling this damage is the laser's on-off modulation over a wide frequency and high-quality beam, which limits the interaction time with the material.

Trials also showed that this laser can control the depth of material removed to deliver a high-quality surface finish (Figure 5), suggesting that fiber lasers are an alternative to mechanical abrading.

Microwelding vehicle batteries

Welding electric vehicle batteries can be challenging because they contain different materials with dissimilar metallurgical characteristics.

Using the pulse-shaping capabilities and high-peak-power (125 to 300 W) pulsed Nd:YAG lasers, a range of dissimilar materials up to 2 mm and stainless steel up to 3 mm thick could be spot-welded. With the single-mode fiber laser, the average power needed to join reflective materials (up to 1 mm) was 400 W, and because of the small spot size (43 µm), close attention was paid to the jigs and fixtures to ensure that the parts fitted correctly.

Hard disk drive flexure arms

Low power (100 to 200 W) CW fiber lasers with modulation consistently achieve high-quality spot welds on thin stainless steel foils (20 to 150 µm). With a Gaussian beam profile (M^2 1.06), it was possible to create spatter-free spot welds measuring between 76 and 175 µm in diameter. Although diameters as small as 76 µm are possible, these welds have a low shear strength. To meet normal strength requirements for these parts (>0.40 psi), 90-µm-weld diameters are necessary.

A flattop beam profile from a 100-µm-core-diameter fiber achieved spatter-free welds between 150 and 270 µm in diameter. The larger spot sizes help to improve weld strength.

Correct temporal pulse shaping can improve the quality and speed of microwelding applications, enabling manufacturers to tailor the cosmetic finish and penetration profile. Ramp-down pulse shape can reduce cracking and porosity in welds; ramp-up pulses can weld materials that have low melting points or low reflectivity.

Microdrilling

The automotive, aerospace and electronics industries are particularly interested in drilling small holes (50 to 70 µm in diameter) in metals and nonmetals. The quality of these holes is very important. They must be taper-free, perfectly round, with a minimum recast layer and heat-affected zone.

Microdrilling tests were carried out on a variety of materials, including ceramics and silicon wafers, which are prone

Figure 8. Correct temporal pulse shaping can improve the quality and speed of microwelding applications such as the production of hard disk drive flexure arms, enabling manufacturers to tailor the cosmetic finish and penetration profile.

to cracking under thermal stress. The results show that 50- to 200-W single-mode fiber lasers are good at drilling small holes (<50 µm in diameter) in thin metals less than 1 mm thick. Typical examples of microdrilled holes using a single-mode fiber laser are shown in Figure 6.

In comparison, pulsed lasers are very good for percussion-drilling metals and nonmetals. Examples of microdrilled holes using an Nd:YAG laser are shown in Figure 7. The pulsed lasers can drill difficult materials such as nickel-based alloys for aerospace applications as well as nonmetals such as 99.6% pure alumina, which can prove problematic when using fiber lasers.

All the tests demonstrate that Nd:YAG and fiber lasers have an important role to play when micromachining small, intricate parts.

Lower-power single-mode fiber lasers (50 to 400 W) feature high beam quality and small spot sizes, making them the best choice for microcutting applications. Fine features (10 to 15 µm wide) can be cut with either CW or modulated output. In these applications, accuracy is more important than process speed. The output power dynamic range for fiber lasers is 10 to 100 percent, so it is still possible to produce a very stable output at 10 W with a 100-W single-mode fiber laser.

Nd:YAG lasers deliver the high peak power and complex pulse-shaping facilities required to microweld a greater variety of materials. Correct pulse shaping of the temporal energy variation can produce high-quality welds in highly reflective materials (e.g., aluminum and copper) and in dissimilar materials.

Single-mode fiber lasers are better at spot welding thin foils, such as those used in the manufacture of hard disk drive flexure arms. They also are ideal for drilling holes with <50-µm diameters in thin foils, whereas low-power pulsed Nd:YAG lasers (100 to 125 W) are best suited to fine percussion drilling.

Meet the author

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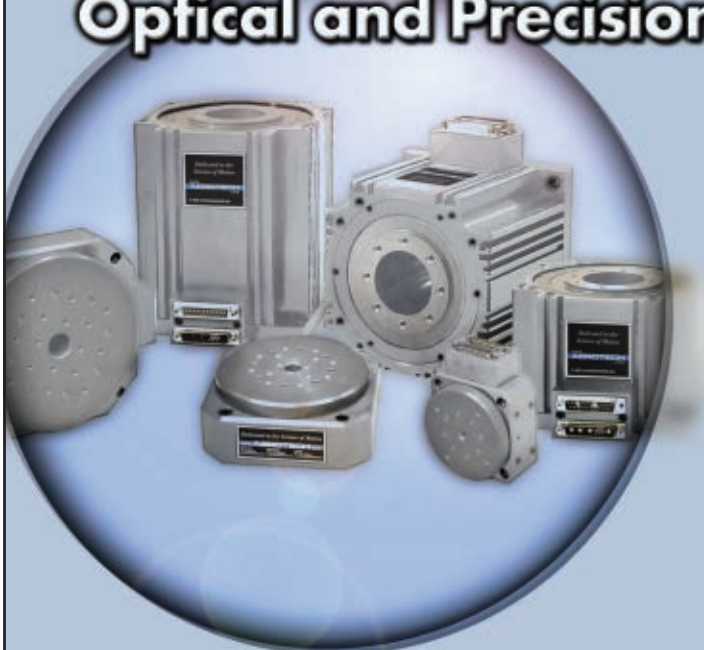
Focus in on High-Performance Optical and Precision-Surface Grinding



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Color Cameras Improve Results in Vision Applications

Color has been considered expensive in terms of money and processing power, but these costs have decreased. Here's how color vision works and why it can be beneficial for today's applications.

BY ROBERT HOWISON AND BRUNO MÉNARD
TELEDYNE DALSA

Industrial quality control applications such as paint inspection can benefit from color vision.

Vision has evolved into a fast and reliable tool for applications such as quality inspection, traffic surveillance and target tracking. In many cases, a vision system can perform optical tasks more quickly and accurately than humans – and at a lower cost. But how does introducing color into the equation help improve the quality of the results?

A vision system acquires images of an object with a camera and uses computers to process, analyze and measure various characteristics of that object – such as color – so decisions can be made.

In the past, color was not widely used in vision systems because the costs and processing power requirements were high. However, as prices have decreased and power has ceased to be an issue, solution providers have begun to consider incorporating color into vision systems for a higher-quality result.

By the end of 2011, color cameras comprised about 20 percent of cameras sold for imaging applications, according to market studies by the Automated Imaging Association (AIA), the industry's trade organization. Most experts believe that the use of color will expand in the vision domain. Color provides much more visual detail than monochrome gray scale and adds a new dimension to real-world data analysis. For example, color increasingly is being adopted in bank note inspection applications for scanning and processing.

In China, Japan and South Korea, color inspection is required by the government because people use a personal seal rather than a signature in issuing personal checks. Another example is traffic surveillance: Color cameras can help identify key information, such as traffic light color or a picture on the background of a license plate.

Color is better, right?

The basic assumption is that color is more "advanced" than black and white, or monochrome, so it must be better; however, in the case of vision, this is not always true.

In typical applications, such as detecting cracks, scratches or other defects, color is not absolutely necessary; the goal is to discern a difference in lightness on the object's surface. For some tasks, monochrome cameras are even better than color. In many other cases, color images do not offer a significant advantage over monochrome in resolving a vision problem. Examples are optical character recognition or verification, bar-code reading, gauging and other applications that rely mainly on high-resolution "spatial" information.

Of course, a machine cannot actually see in color. Machines use mathematical models to approximate human color detection. A machine can be calibrated against the average human response to colors and, hence, "see" them – meaning that it gives consistent responses to colors observed in a controlled setting. This "calibrated color vision" is useful for measuring and matching colorants in paint, plastics and fabrics. We don't think of this as seeing color the way a human

Photos Courtesy of Getty Images

Color: Yes or No?

When deciding whether to use color, ask the following questions:

1. Is measuring the color of objects a key factor in the overall quality of the product?

2. Can color facilitate the detection or the separation of objects?

3. Can color help increase the relative quality of the product?

does, except perhaps as a philosophical exercise. However, it is important to make the distinction between the relative measurements that can be made with a vision system and the absolute measurements that are possible only with devices such as photospectrometers.

Human color vision evolved to extract consistent information about the material properties of objects seen under huge variations of illumination and view. For example, fruit color must be reliably determined in varying lighting conditions so that we can distinguish ripe from unripe or bad fruit. No one wants to eat a blotchy orange or a half-yellow lime.

Human color vision thus has mechanisms to factor out variations in illumination and view that we cannot – or do not bother to – incorporate into machine color vision.

Also, our color vision is relative. Because nearby colors influence our perception of color, and because there are many differences among individuals, human color vision is not a good measuring tool. It also has low resolution, a fact used to transmit color in television with very little bandwidth.

Color machine vision, on the other hand, is a better measuring tool because it is not influenced by nearby colors, and it is high resolution and does not vary much from machine to machine.

Unlike human vision, however, color machine vision does not have color constancy – the ability to perceive the same color independently of the light source. Systems come equipped with a color correction feature composed of precalibrated color coefficients for operation under different types of light sources (LED, halogen, incandescent, daylight, etc.) and varying color temperatures. With the appropriate correction, color cameras can output values such that colors are perceived as in real life.

Machine vision is a reliable tool for traffic surveillance.

For added precision, color may be calibrated in the field using what is commonly known as a Gretag Macbeth color chart. This ensures an accurate measure of the camera's output under a specific light source.

Types of color vision systems

Most color vision systems use a mix of hardware and software to detect colors. For point or spot color measures, a mostly hardware solution is fine. Sophisticated detection systems rely more heavily on software to give flexibility to both designers and users. The main types of color cameras used in vision applications are 3-CCD, trilinear and color filter array (CFA), such as a Bayer pattern.

A 3-CCD has excellent color registration and can be used in the majority of applications; however, because of the design, its cost is high. Trilinear provides high performance and has the advantage of a lower cost. With its very high resolution (up to 16,000 pixels wide), it can be used in many precision applications, such as flat surface inspection. However, in certain applications involving rotating or randomly moving objects, spatial correction cannot be done properly.

CFA cameras round out the mix, offering the lowest-price solution. They tend to be used in lower-end applications and to have reduced color precision compared with 3-CCD and trilinear cameras, but there is broad understanding of the CFA patterns, and many algorithms exist to optimize their color performance. CFA and 3-CCD sensors can be either area scan (2-D) or line scan (1-D); trilinear sensors can be only line scan.

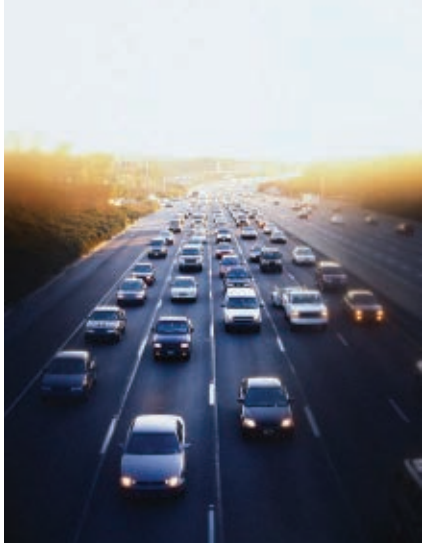
The main types of color cameras used in vision applications are **3-CCD**, **trilinear** and **color filter array**.

In a 3-CCD camera, color is selected using a prism-based interference filter that splits the incoming light into red, green and blue (RGB) primary components. Each primary color is detected by its respective CCD, and the final color image is reconstructed by combining the outputs from the three CCDs. All three color images are simultaneously captured at the same object spot.

In a trilinear color camera, three linear arrays are fabricated on a single die and coated with RGB color filters, respectively. These are absorbing filters using dye or pigment. The arrays detect a slightly different field of view of the object; spatial correction is needed to reconstruct an image.

In a CFA color camera, the sensor is coated with an RGB filter as in a trilinear camera, but the filter is composed of a pattern of alternating colors (one single color per pixel).

Teledyne Dalsa offers the Genie, Falcon, Piranha and Spyder color cameras, each based on either CFA or trilinear technology. As an example, the Spyder line-scan camera supports a type of CFA sensor called "dual line," which provides better quality on the green channel as well as reduced pixel crosstalk; i.e., low neighbor-color interference.



When to use color

The most common machine vision application requiring color remains food inspection; e.g., fruit sorting. Others include measuring the concentration of chemicals or verifying part selection for automotive or electronics assembly. Even though in many applications using color is not necessary, it can sometimes help make a vision task easier by identifying objects, such as the fuse values in a car fuse box.

Should color eventually be used in all vision applications? Not necessarily. Monochrome cameras will always do some things better than color cameras. When faced with an application that raises some doubt, ask yourself the following questions:

1. Is measuring the color of objects a key factor in the overall quality of the product?

   For example, traffic light surveillance is inherently related to color measurement.

2. Can color facilitate the detection or separation of objects?

   A simple monochrome image sometimes leads to ambiguity in the lightness of objects, making them indistinguishable from one another.

3. Can color help increase the relative quality of the product?

   Certain vision tasks are well achieved using monochrome images, but could be improved by adding color; i.e., the success

Industrial quality control applications such as printing inspection can benefit from color vision.

rate would be closer to 100 percent. As an example, Pharmacode bar codes optionally provide color bars.

If the answer to any question is yes, the color side of machine vision could be a big help.

A few real-world applications will help demonstrate whether color is necessary.

As mentioned above, food is probably the one application area that we understand implicitly as daily consumers of food, judging quality and consistency.

For fruit, color vision allows determination of ripeness and quality. In the case of grains and legumes, color also distinguishes foreign matter in a steady stream of product. In meat processing, color can detect spoilage and discriminate fat, bone and gristle for automatic trimming. Color vision can even inspect the "build" quality of frozen pizza. In a monochrome image, one might see whether the density of ingredients is correct; that is, whether the quantity and distribution are adequate. However, in a monochrome image, it is difficult to tell the difference between, for example, chopped ingredients such as red, orange and green peppers.

Color vision also is used in intelligent transport systems. Applications such as license plate recognition, speed and red light enforcement, toll management, traffic control/monitoring and even rail car inspection are more and more commonplace. In many uses, color is used for visualization, while processing algorithms are applied to the monochrome component only. In license plate recognition, the plate number is identified using monochrome, while for legal purposes, such as bringing evidence to court, the storage of color images is mandatory.

Domains that traditionally have been adequately served by black-and-white vision, such as automotive, printed circuit board and print inspection, also might benefit from color for better quality.

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Choosing the Right Epoxy for Optical Applications

An overview of the key characteristics of optical epoxies, including where each type can be used and how to choose among them

BY DR. WALTER BRENNER
MASTER BOND INC.

Technology in the optics industry has steadily advanced over the past several years, which can make the process of selecting an adhesive very complex, considering the number of factors now involved.

Epoxies frequently are used for bonding, sealing, coating and encapsulating applications across optical, optoelectronic, medical and related industries. Given the vast range of properties that epoxy materials offer, perhaps an efficient and effective way to choose a formulation is to explore some of the more significant properties of these systems before and after curing. Before curing, these range from color and viscosity to working life and mix ratios. After curing, optical properties, chemical and temperature resistance, and flexibility are among the features of paramount importance in selecting an optical adhesive.

Two-component epoxies can be cured at room temperature (or slightly higher). Such room-temperature-curing nondrip adhesives are gap filling and adhere well to heat-sensitive substrates.

One- and two-component epoxies

Epoxies are arguably the most versatile and widely used polymers for high-tech applications. They offer outstanding physical attributes, including high physical strength, good chemical resistance, excellent adhesion to a variety of substrates, broad temperature resistance and the ability to cure in thicker sections for sealing and encapsulation applications. In selecting the best system for a particular application, trade-offs are an inevitable and important consideration. Epoxies can be formulated to be more flexible, but this can compromise some of their temperature resistance.

The most basic trade-off is found when deciding between a one- or two-part epoxy because each has its own set of challenges; e.g., two-part epoxies must be mixed, which often requires precise measuring by weight of each component, although some systems are very forgiving and can be mixed by volume. Two-component epoxies cure at ambient temperatures, or faster at elevated temperatures, as desired; this may be their most attractive feature.

One-component epoxies eliminate the need for mixing, but they can cure only with the addition of heat (250-300 °F).

Because one-part materials require this heat cure, they also offer the tremendous benefit of unlimited working life at room temperature. By comparison, the working life of two-component epoxies is limited.

Despite their differences, two-component epoxies are used far more regularly in optical applications because of their versatility and room-temperature (or slightly higher) curing. This is particularly significant in optical applications because many of the components can be heat-sensitive.

Curing epoxies

The curing of epoxies is a polymerization or cross-linking reaction. One-part systems require heat curing, typically at 125 °C or higher, although some newer systems will cure at 80 °C.

Moreover, the cure cannot simply be initiated with heat and then left to finish at ambient temperatures. It is important to let the epoxy fully cure with heat, or the curing process will stop.

For two-part epoxies, cure times can be broken down into three stages:

- **Open:** the time that one has to use the material after mixing parts A and B together.

Epoxies and added fillers

The properties of epoxies can be dramatically altered by adding inorganic fillers such as silica, aluminum oxide or silver. Aside from enhancing dimensional stability, increasing hardness and conferring opacity on the epoxy, fillers also can render the polymer electrically and/or thermally conductive.

Images courtesy of Master Bond Inc.

- **Handling:** the time it takes for the adhesive to set up so that the parts being bonded can be moved. This is also known as fixturing time.
- **Cure:** the time it takes to "fully" cure.

Most two-part epoxies will fully cure at room temperature; depending upon the system, this often can take many days. The speed of cure can be accelerated by adding heat (50-100 °C), which results in additional polymerization and can give the epoxy better properties. There also are some highly specialized two-part epoxies that require a heat cure and provide outstanding physical properties that could not be achieved by a more conventional system.

Properties of epoxies before curing

Although there is a propensity to focus more on the final properties of the epoxy once it is cured, it is just as important to evaluate precuring requirements. Some of the more pertinent aspects include color, viscosity and exotherm generation while curing.

Both one- and two-part epoxies vary in color from transparent to opaque. For optical applications, the tendency is to think that you always need optical clarity, but this is not necessarily so. There is no

Comparison of Epoxy Types.

Product Name	One- or Two-Part System	Mix Ratio, by Weight	Viscosity, RT, cps	Cure Schedule °F	Service Temperature Range, °F	Color	Applications
EP30	2	4:1	A: 400-900 B: 280-500	75 °F: 24-48 min 200 °F: 2-3 h	−60 °F to 250 °F	Clear	Low viscosity, room-temperature curing epoxy adhesive/sealant. 100% reactive. High-strength bonds and excellent dimensional stability. Chemically resistant.
EP37-3FLF	2	1:1	1400-1500	75 °F: 48-72 min 200 °F: 2-3 h	4K to 250 °F	Clear	Highly flexible, impact-resistant, optically clear epoxy system. Resistant to thermal cycling. Low exotherm. Superb potting and encapsulation compound. High peel and shear strength properties.
EP30HT	2	4:1	A: 55,000-110,000 B: 250-500	75 °F: 24-36 min 200 °F: 2-3 h	−60 °F to 400 °F	Clear	High-temperature, two-part optically clear adhesive, sealant and coating. Bonds well to glass with a service temperature of −60 to 400 °F. Exhibits excellent chemical resistance to acids and bases. Superior dimensional stability and low shrinkage upon cure. Resists 1000 h of exposure to 85 °F/85% humidity.
EP21TCHT-1	2	100:60	A: >150,000 B: >50,000 Mixed: Thixotropic Paste	75 °F: 24-48 min 200 °F: 2-3 h	4K to 400 °F	Gray	NASA low outgassing-certified, high-temperature resistant, thermally conductive epoxy. Cryogenically serviceable. Halogen-free.
Supreme 10HTS	1	N/A	Thick Paste	275-300 °F: 45 min	4K to 400 °F	Silver Gray	One-part, heat-cured structural epoxy with long working life. Excellent shear and peel strength. Cryogenically serviceable down to 4K. Heat-resistant to 400 °F. Screen-printable. Low volume resistivity of $<10^{-3}$ ohm-cm.
EP21LSCL-1	2	100:60	A: 1800-2500 B: 600-1200 Mixed: 1000-2000	75 °F: 72-120 min 200 °F: 3 h	−60 °F to 250 °F	Clear	Two-component, room-temperature curing epoxy for bonding, coating, sealing and casting. Offers outstanding non-yellowing characteristics. Featuring low viscosity and exceptionally long open time. Can be utilized in thicker encapsulations.

Nearly all light-transmitting epoxies **work well from 350 nm to 2.5 µm**, but they **vary greatly** in light transmission **above 2.5 µm**.

Optical properties such as light transmission at various wavelengths are important considerations when choosing epoxies. Various grades of epoxy adhesives offer different light-transmission properties.

hard-and-fast rule for color; it depends on the application. Some applications require a transparent product; for others, amber clear is acceptable as long as light transmission is good. In still other scenarios, opaque systems are needed. For example, in certain optoelectronics applications, thermal conductivity is the salient property, and optical clarity must become a

Epoxies also vary in hardness. Some epoxy formulations offer high tensile strength and dimensional stability.

secondary issue because thermally conductive epoxies are opaque. Optical clarity also is not normally required when bonding a mirror to metal.

Viscosity is another critical factor in the epoxy selection process. In certain applications, the material should be very thin or watery; e.g., when it must enter a narrow gap.

In other situations, a more moderate viscosity or even a paste is desirable, which is particularly true for bonding applications. This tends to be the case with one-part epoxies, because when heat is added to cure the material, the epoxy's flow increases.

In general, the best viscosity for an application requires careful consideration of the usage itself. The most fundamental decision is whether the end user is bonding, sealing, coating or potting. Next, the specifics of the application must be examined, including the shapes of the parts and their dimensions. Ultimately, the choice depends upon a whole host of factors, including dimensions, the nature of the application, how the material will be applied and what properties are required after cure, among others. There also is an element of subjectivity and the end user's comfort zone in this process, because it may be necessary to employ the trial-and-error approach to find the viscosity that best suits the application.

Another major factor (often overlooked) to consider in the selection process is the exotherm created when mixing parts A and B together. Systems that generate lower exotherm when mixed consistently have longer open times, cure more slowly and can be used for thicker encapsulations.

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Conversely, systems generating higher exotherm have a far more limited working life, cure more quickly and cannot be used in thicker sections.

Of two-part epoxies, engineers commonly say, "Faster is better," but more often than not, this isn't the case. For example, if long open times are needed or thicker sections are being cast, a faster system is a nonstarter because of the higher exotherm of rapidly curing epoxies. One-part compounds are inherently higher in exotherm and are customarily difficult to cure in sections up to and beyond ¼ in. thick. However, two-part materials can easily cure in sections up to an inch and beyond, making them more suitable for potting applications. In general, however, the larger the mass of epoxy being cured, the greater the exotherm.

Properties of epoxies after curing

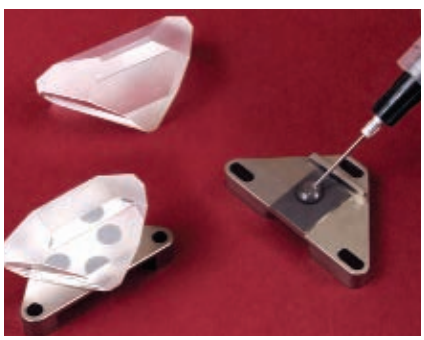
Besides polymerization, salient issues for epoxies include optical properties such as light transmission at various wavelengths. Light transmission values from 200 nm up to 5 µm are of particular interest to many optical engineers. Nearly all light-transmitting epoxies perform well from 350 nm to 2.5 µm. Above 2.5 µm, epoxies vary greatly in their ability to transmit light. Another optical property is index of refraction upon cure. This value normally ranges from 1.5 to 1.65.

Epoxies are exceptionally robust electrical insulators, although they can be formulated to be conductive. As insulators, they offer superb dielectric strength, dielectric constants, volume resistivity and dissipation factors as well as other electrically insulative properties. Epoxy versatility is exemplified by the fact that these insulators can be formulated to be thermally conductive and electrically insulative, or thermally and electrically conductive.

Chemical resistance is another strong suit of epoxies. They can withstand harsh environments when exposed to water, fuels, acids, bases and numerous solvents, many of which are aggressive.

One key reason that epoxies are widely chosen over other types of fasteners is their ability to withstand a wide range of temperatures. Select epoxies can resist cryogenic conditions; others are functional at higher temperatures up to 600 °F. Additionally, many excel in applications involving rigorous thermal cycling.

Low-viscosity epoxies can be used as adhesives for designs where the gaps between substrates are small (two- to five-thousandths of an inch).



Optically clear epoxies have excellent light transmission from 0.35 to 2.2 µm.

In optical applications, epoxies are especially noteworthy for being low outgassing, a quality highly desirable under vacuum conditions or when lenses, semiconductors or optical components are involved. Many epoxies pass the NASA low-outgassing test based on the ASTM C-595 standard, which takes place under vacuum conditions. Epoxies that have not been tested are usually considered "generically" low outgassing.

Hardness is another example of epoxy versatility. Although epoxies are thought of as rigid, many formulations offer varying degrees of toughness and flexibility. Flexible epoxies are particularly useful for bonding dissimilar substrates in conditions where rigorous thermal cycling is taking place. Rigidity is desirable in situations demanding dimensional stability, machining and polishing.

Meet the author

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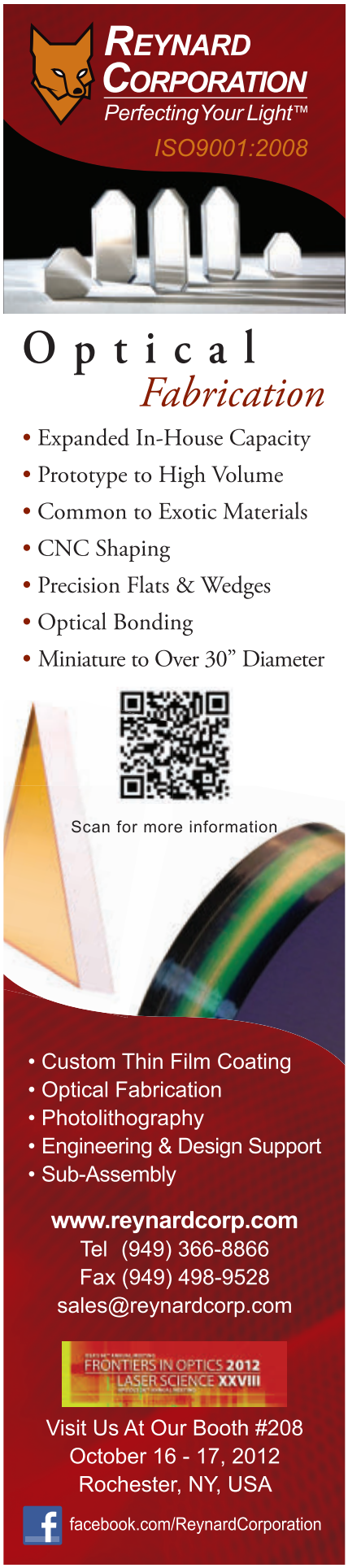

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Laser-Produced Plasma Source Improvements Drive EUVL Adoption

Extreme-ultraviolet lithography is getting ready for high-volume production.

BY NIGEL R. FARRAR
CYMER INC.

Extreme-ultraviolet (EUV) lithography will be ready for introduction into high-volume manufacturing within the next few years. Pilot lithography tools have been delivered to chipmaker fabs and are being used for process development; next-generation systems have been designed based on learning from these pilot systems in the field and are being fabricated.

The leading challenge for cost-effective operation in manufacturing continues to be productivity, driven by high-power light sources and high-sensitivity resists.

Additional focus on reliability and availability also is key to achieving the product maturity needed for volume manufacturing.

Laser-produced plasma (LPP) technology is a light source architecture that enables flexible scaling of power output. LPP sources provide EUV light by focusing a high-power pulsed CO_2 laser beam onto small tin droplet targets to form a highly ionized plasma that emits at the wavelength of interest, 13.5 nm. Power scalability depends upon three key factors: the input power of the CO_2 laser beam, the conversion efficiency (CE) from CO_2 energy to EUV energy, and the collection efficiency of light for redirection into the input aperture of the scanner illuminator. Improvements in all these areas are expected to take source power above 100 W and, eventually, to the 250- to 350-W level required for high-volume scanner throughput.

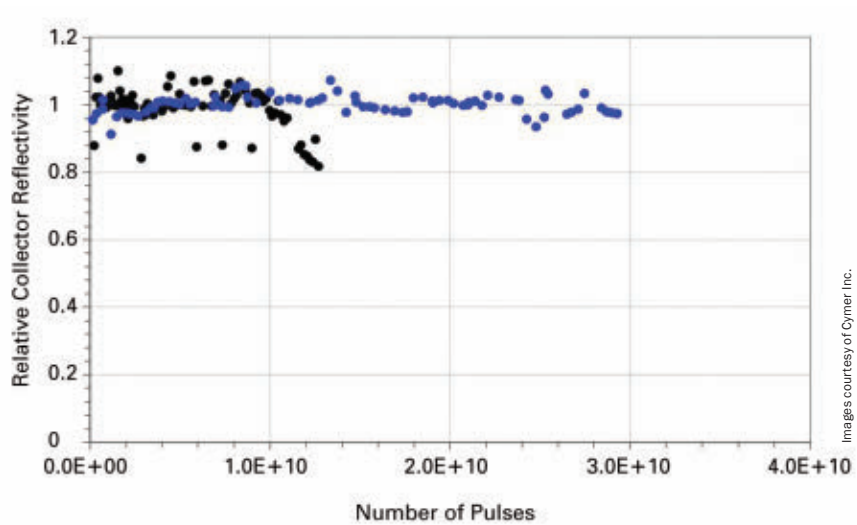
At this time, 10 pilot sources have been built and are operational. Five are installed at chipmaker R&D facilities, three are used at Cymer for technology development and reliability and lifetime testing, and two are being used for scanner integration testing. The source availability, as defined by SEMI E10 standards, has reached an average of 70 percent. Most of the unavailable time is related to scheduled module maintenance. Further increases in source availability will be driven by increasing the lifetime of two critical modules: the collector and the droplet generator.

Extending the lifetime of the droplet generator has been a major focus, and significant improvements in reliability have been realized over the past year through optimization of materials and manufacturing methods. Today, in the field, the maximum usage time is limited by the volume of tin stored in the generator reservoir, if no component failures occur. Elimination of the failure modes, increasing the size of the reservoir and in situ refill of tin are all under development to minimize the time associated with droplet-generator maintenance. For example, data from a single droplet generator on a test stand run for 46 days shows that stable operation can be achieved through multiple in situ refills.

The key technology for high collection efficiency is the use of a large, near-normal incidence multilayer mirror. The mirror collects light over a large solid angle, currently about 5 sr, with high narrowband reflectivity around 13.5 nm. Because the mirror figure is ellipsoidal, the multilayer coating spacing is varied from center to edge to optimize reflectivity at different angles of incidence. Further optimization of the multilayer coating is expected to lead to additional reflectivity improvements.

It also is important to maintain high reflectivity from the mirror in the presence of debris from the tin plasma formed during each laser-droplet interaction. The collector is protected by a debris-mitigation technology based on a hydrogen buffer gas. High-energy ions and fast neutral atoms are buffered by the gas to prevent reflectivity loss resulting from erosion of the mirror surface. Surface coating technologies for the mirror further reduce erosion rates.

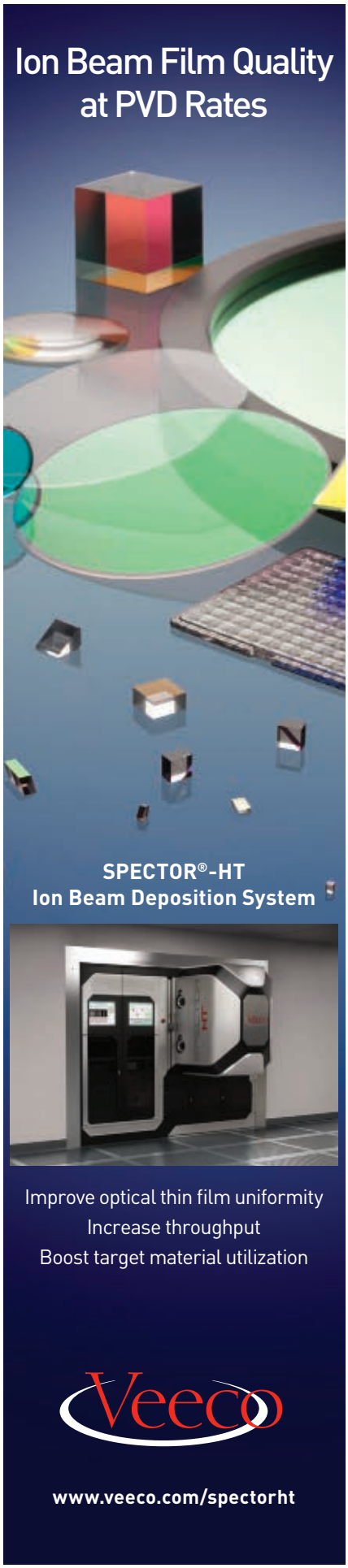
These coatings will be particularly im-



Images courtesy of Cymer Inc.

Figure 1. A large, near-normal-incidence multilayer mirror is essential for high light-collection efficiency. Here, new protective coatings enable stable collector reflectivity.

The **wavelength of interest** for extreme-UV lithography is **13.5 nm**.



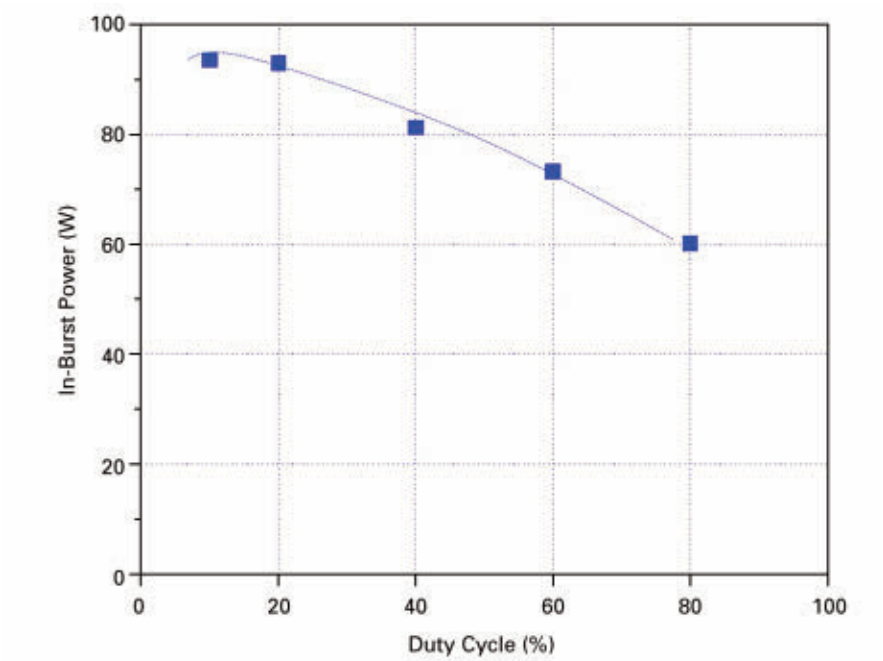


Figure 2. Prepulse technology is the key to higher conversion efficiency and power. Here, current in-burst power levels at different duty cycles are shown for prepulse operation.

portant when using prepulse technology, discussed below, which is expected to result in higher ion flux and ion energies resulting from the more efficient ionization of the tin target. The hydrogen gas also is used to generate hydrogen radicals, which continuously clean the mirror surface of tin deposition, which can reduce reflectivity. Collector lifetime in the field has now been shown to exceed 30 billion pulses (Figure 1). Continued advancements of coatings and debris-mitigation techniques are expected to enable further increases in collector lifetime to meet the ultimate goal of one year.

The current CO_2 laser configuration uses three power amplifiers to produce 10 to 15 kW of output energy. Work on the next-generation drive laser has shown that adding a further amplifier can produce output of up to 28 kW of power. Pulse repetition rates higher than the current 40 to 50 kHz also are under investigation as another path to higher power output. It also is important to maintain high beam quality at different operating conditions to deliver consistent energy density at the target, which results in more stable EUV output.

High conversion efficiency of the laser energy into EUV energy is critical to meeting the required power levels. Although the CE of CO_2 light excitation of tin has been shown to be as high as 4 to 5 percent, consistently achieving CE approaching this level at a high repetition rate and high duty cycle requires significant systems integration work. In currently fielded systems, CE is limited by the mismatch between the diffraction-limited focused spot size of the laser, about 100 µm, and the droplet diameter, about 30 µm. Larger droplets, which could maximize the interaction between the laser beam and droplet and provide higher CE, could result in significantly higher tin debris load, leading to faster collector reflectivity degradation. With the current field configuration, average power levels of 13 W have been qualified with closed-loop active dose control. Simulated die-to-die dose stability over more than 500 wafer-equivalent bursts showed 99.7 percent of die, better than the requirement of ±0.5 percent.

The key to higher CE and higher power is the use of prepulse technology. This scheme uses an additional lower-power laser pulse to prepuff the small droplets to approximately the same size as the focused laser beam, before the main pulse is fired. Performance to date using prepulse technology is shown in Figure 2. The in-burst power is >90 W at 20 percent duty cycle but decreases to about 60 W at 80 percent duty cycle, corresponding to aver-

age power between 18 and 48 W. The decrease in in-burst power at high duty cycle is typical of thermally induced transients, which will be eliminated in the next design iteration.

In these results, dose control algorithms were not used, so the usable dose-controlled power will be slightly lower. The data shows the promise of prepulse technology because high CE is clearly achievable at low duty cycle. The concept of further power scaling has been demonstrated on a separate test system, equipped with a new, higher-power drive laser, but capable of only low-duty-cycle operation. In this case, 160-W in-burst EUV power was achieved. The configuration is the basis of the next generation of sources to be shipped.

Controls technology is a key enabler for stable operation of laser-produced plasma sources. The laser beam is focused to a precise point in space for both the prepulse and main pulse excitation of the tin droplets, with the timing between pulses controlled based on the speed of the droplets. Droplet position is also stabilized within the adjustment range of the laser beam focus and lateral positioning.

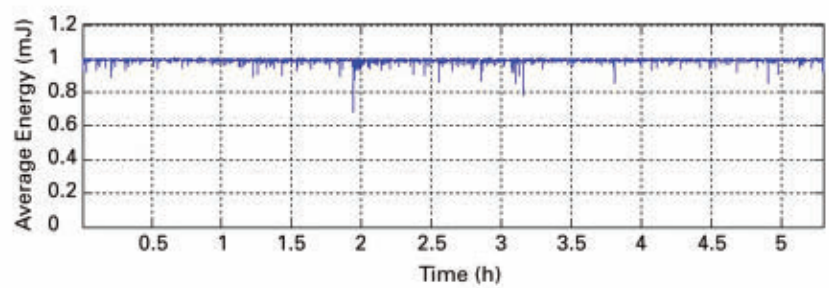


Figure 3. Stable in-burst power for prepulse operation. The prepulse system configuration has been operated for more than five hours under fully automated control, although some optimization for dose control is still needed.

In addition, the energy from each pulse is measured and fed back to the laser driver to stabilize dose control within a burst of pulses equivalent to each wafer exposure die. The prepulse system configuration has now been operated for more than five hours under fully automated control (Figure 3), although some optimization for dose control is still required.

Laser-produced plasma sources offer scalability to provide a path toward higher power for multiple generations of exposure tools. The next generation of sources being built will use prepulse technology to provide the higher power output required to enable cost-effective productivity for EUV exposure tools.

Meet the author

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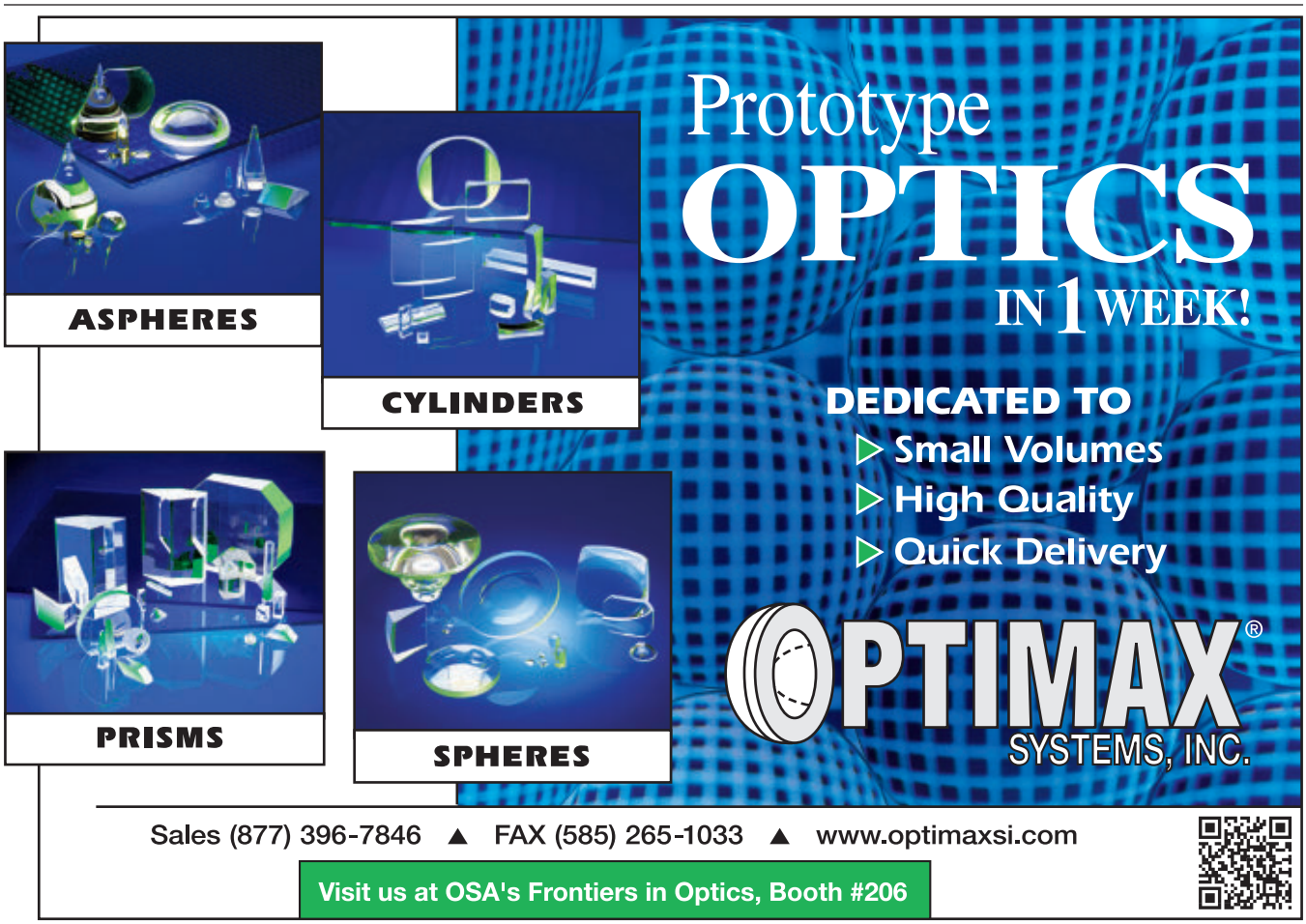

Scanning Goniophotometers Improve Materials Selection

Measurement of a material's specific scattering properties takes the guesswork out of choosing materials for various applications.

BY DR. PETER APIAN-BENNEWITZ
PAB ADVANCED TECHNOLOGIES LTD.

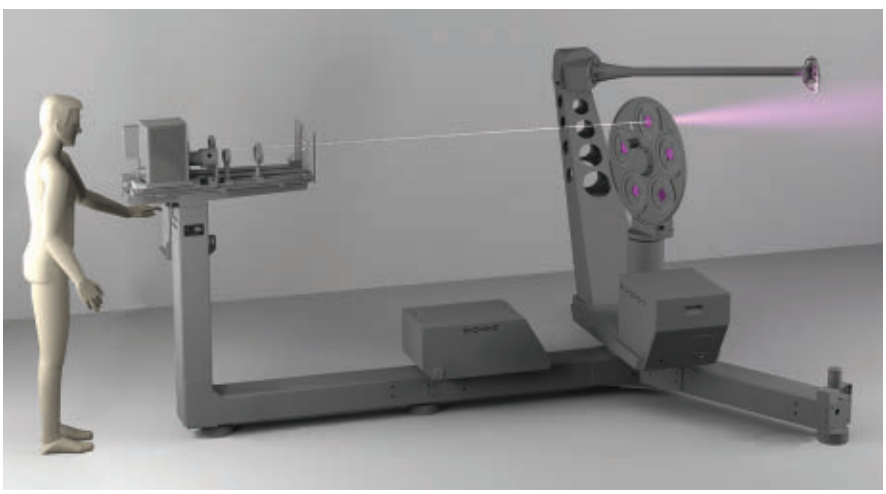

Figure 1. Optical scattering measurements allow engineers to choose materials more accurately for applications ranging from solar concentrators to instrument displays. A modern large scanning goniophotometer (here, pg II) is usable for a broad variety of samples.

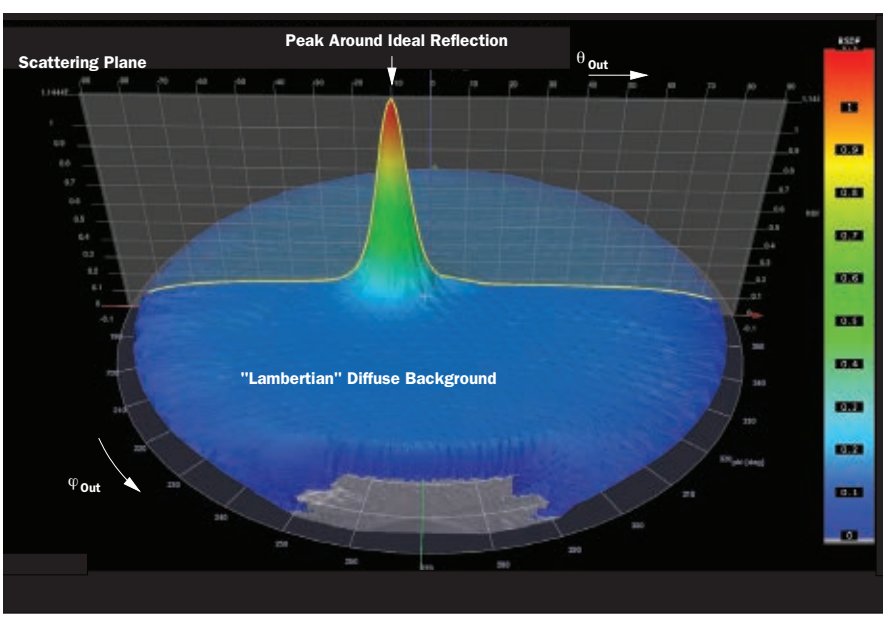

Figure 2. An example of a simple BRDF: semigloss paint with scattering around the forward peak and a near-constant diffuse background. In various kinds of paint, the relation between the forward peak to the diffuse background and the width of the forward peak defines the "gloss" of the painted surface.

Measuring the optical scattering of materials allows engineers to choose the very best materials for projects ranging from solar concentrators and LED lighting to architectural facades and instrument displays. The materials in question include glasses, polymers, metals, paints, IR-selective coatings, holographic diffraction films and structured surfaces in injection-molded parts. Scattering data, read by optical simulation programs, optimizes the internal composition and manufacturing process of the materials, providing a thorough analysis before manufacturing.

Here we will look at an overview and some examples of applied measurements of angular-dependent light scattering in the visible and IR ranges.

Measurement methods

A BSDF (bidirectional scattering distribution function; see box for definition and formulas) measurement setup consists of a light source, a sample mount and a detector. In a simple setup, all components are mounted "in plane" on an optical table, resulting in data along the scattering plane only; for the majority of samples, this is not sufficient.

Out-of-plane setups come in two varieties: Scanning goniophotometers move a detector mechanically around the sample, while imaging goniophotometers use additional optics (e.g., a semitransparent dome) to reflect light in various directions from a sample to the camera.

Dynamic range, homogeneous response, absence of secondary optics and optional polarization make scanning goniophotometers the primary reference instrument. Imaging goniophotometers are faster and therefore well suited for process control.

Machines range in size from benchtop

Images courtesy of Pab Advanced Technologies Ltd.

to room-size setups with 1-m distance between detector and sample. A larger distance r to the sample directly benefits a small solid angle of the detector, which is inversely proportional to r^2. Modern goniophotometers (e.g., pgII in Figure 1) measure "on the fly," without time-consuming start-stop movement of the detector. Their scanning velocity, in combination with a high sample frequency, allows fast, economic measurement times: For example, at 30 rpm for the two axes of the detector and 1-kHz sampling frequency, the angular resolution is still 0.18°. Lower speeds offer increased angular resolution, down to below 0.1 mrad.

Typical measurement times for one incident angle range from five to 20 minutes, resulting in a data set between 50,000 and a few hundred thousand data points for outgoing angles. Adaptive scan paths provide data points that are concentrated where they are needed most, with peaks in the BSDF more finely resolved than near-constant areas. This is crucial when measuring the small-angle scattering of mirrors, films or coatings. A detector head fitted with multiple sensors, taking data in multiple spectral bands simultaneously during one sweep, offers another convenient way to speed up measurements.

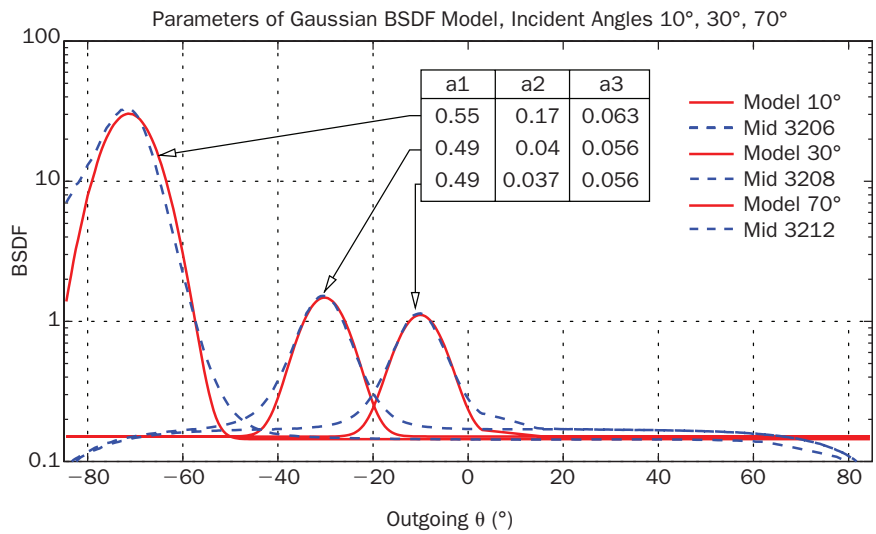

Figure 3. The combination of a Gaussian model for the scattering around the peak and a constant term for the quasi-diffuse background scattering, with the parameters of the Gaussian bidirectional scattering distribution function (BSDF) model (red lines) and measured data (dashed lines) for incident angles 10°, 30° and 70°. Note the change in parameters for larger incident angles.

Absolute BSDF measurements (termed "absolute calibration" in ASTM E2387) use the incoming beam as reference, generating "ab initio" quantitative data without the need for a reference sample. The high dynamic range of the detector (eight decades, at least) makes this feasible, as my colleague and I showed in our 1998 article in *Solar Energy Materials & Solar Cells*.

The spectral range for BSDF measurements is limited only by a suitable detec-

BSDF definition

Within geometrical optics, energy transport by electromagnetic radiation is described in radiometric terms. The central quantity is called radiance, which is the power (watts) per solid angle omega (steradians) and radiating surface element A (m^2), depending on a direction x from a surface element. Radiometric units could depend on additional parameters, such as wavelength or polarization, but do not include information on electromagnetic phase. Unless noted otherwise, they are integral over a specific wavelength range and all polarization states. If the spectral distribution is weighted with the standardized eye response V(λ), the quantities are called photometric (e.g., luminance instead of radiance).

Light scattering at a surface element is shown in Figure A: Incident radiation with radiance L_{in} is received by a surface element from a solid angle Ω_{in} and scattered into a solid angle Ω_{out} with outgoing radiance L_{out}. The scattering quantity depends generally on at least four scalar variables: two angles defining the incident direction, and two angles for the outgoing direction.

The central quantity for light scattering in this context is called BSDF, and it is implicitly defined by the integral given in Figure B. Mathematically, the BSDF is defined as a kernel folding the incoming angular radiance distribution into the outgoing radiation distribution. The implicit definition is robust, powerful and complete, as it includes all special cases. For example, an ideal transparent sample is described by a Dirac delta function of infinite height and infinitesimal width, which, by its definition, collapses the integral into a simply $L_{out} = L_{in}$ in a mathematical, sound way.

A Dirac delta function $\delta(x - x_0)$ has an infinite value at a single value x_0 and zero value elsewhere. It integrates to one. This concept allows a mathematically formal way to write out idealizations and allows a formalism of handling practical cases that approximate the idealization closely.

An ideal mirror is described by a similar Dirac delta function, whereas real mirrors are approximations to this ideally "thin" spike. Real mirrors, even highly polished ones, have a finite width of the BSDF since they scatter light in more then one single outgoing direction. This is relevant in imaging optics or, for example, with increased relevance in concentrating solar power systems.

A constant BSDF defines an ideal Lambert-scattering surface, which is the material of choice for the inner coating of integrating spheres and for diffusers. All existing "white

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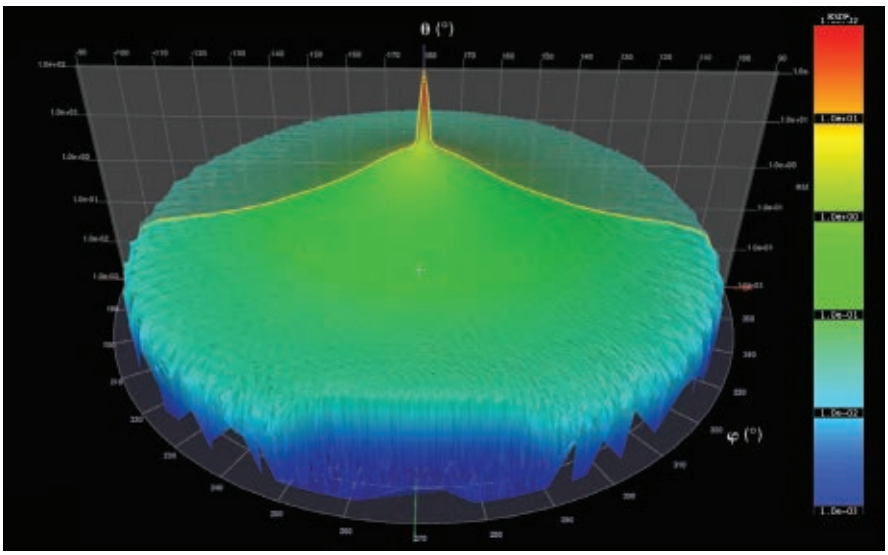


Figure 4. The BSDF of one polymer sheet used for LED lighting, at normal incidence.

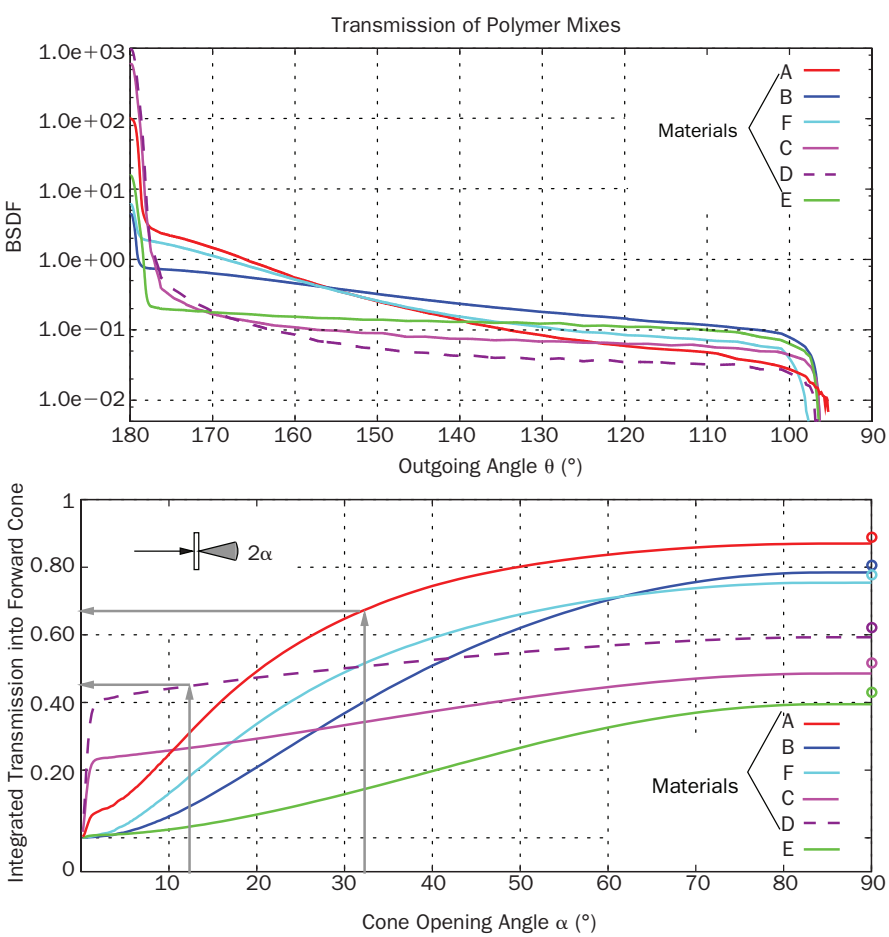


Figure 5. The BSDF cross section of six polymer blends (top graph) and values of the integrated transmission.

tor and sources, ranging from UV into the infrared. Detector materials include Si, InGaAs or HgCdTe. Sources include halogen, xenon short arc and lasers at different wavelengths.

Visualizations

Data visualizations play an important role in comparing materials and in explaining a particular BSDF to a client. It is also very useful to cross-check simulations by comparing them with measured data.

To visualize the BSDF, which depends on four scalar variables, the two incident angles are kept fixed, and the reflective or transmissive part of it is plotted as a 3-D "mountain." Figure 2 shows a reflective BSDF (termed bidirectional reflectance distribution function, or BRDF) with a frequently found shape: Light is scattered around the forward peak, the direction of the incident angle = outgoing angle, and the background is diffuse. In paints, the relation between the forward peak to the diffuse background and the width of the forward peak define the "gloss" of a painted surface: Matte paints have a high diffuse background and no or very broad peak, whereas high-gloss paints show a very small peak and low background (see examples at bsdf.pab.eu/paint).

Visualizations of the BSDF as seen in Figure 2 plot its value as height over a circular disk, using a linear or logarithmic Z-scale. Each point on the disk corresponds with one outgoing direction: The center plots the BSDF value for light leaving along the surface normally, and the circumference plots light leaving the surface tangentially. Angle Θ_{out} is plotted from center to circumference, and φ_{out} is plotted around the disk. (Note: This graph is better adapted to quantitative BSDF display than plotting "lobes" in spherical coordinate systems or Cartesian X-Y-Z systems.)

Applications

Usage of the BSDF typically includes the following:

(a) BSDF data is combined with models of surface- or volume-scattering whose parameters are fitted to the data. Surface models furnish data on the root mean square roughness of a surface; comparing this with directly measured roughness values (e.g., by atomic force microscopes) has

Modern goniophotometers **measure "on the fly,"** without time-consuming start-stop movement of the detector.

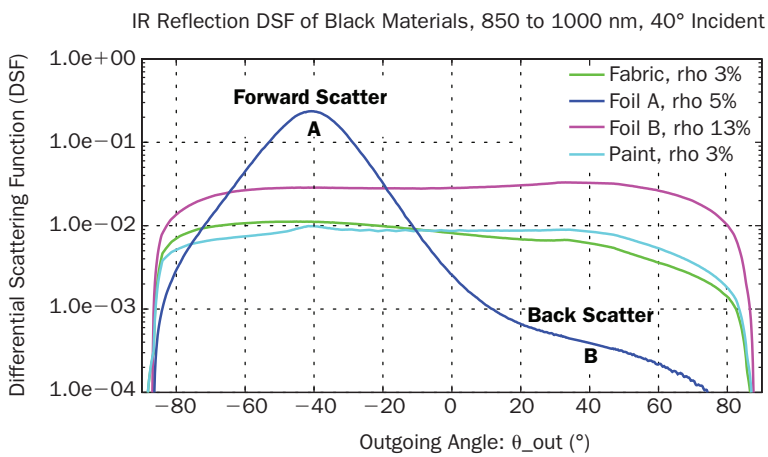


Figure 6. Infrared differential scattering function cross section of four black materials: one fabric, two adhesive foils and a matte paint, all visibly black, for an incident angle of 40°. Data was measured for the near-IR from 850 nm to 1000 nm.

been an area of active research. (F.E. Nicodemus and colleagues originally started the BSDF concept around 1970 to characterize highly polished mirrors in image-forming applications.) Volume-scattering models have applications in selecting polymer mixes used as diffusers in LED lighting applications, and in developing materials with different scattering in the visible and IR ranges.

(b) BSDF usage in optical simulation programs enables accurate calculation. For example, in illumination projects, taking into account specific materials for reflectors and diffusers optimizes the shape of a reflector regarding the BSDF of the reflector material, or the material selection for a specific shape. Most simulation software can read measured BSDF data to model surfaces that are not well described by built-in BSDF mathematical functions.

(c) The most straightforward use of BSDF data is comparing their plots directly. Projection screens are characterized by an angular factor of their BSDF relative to a diffuse screen, for example. Numerical integration of the BSDF over angular regions is the next step, resulting in transmission or reflection values in the interval (0:1). The direct-hemispherical reflection (ρ_{dh}) and transmission (τ_{dh}) are extreme examples of integrating the BSDF over the full hemispheres, but the technique of numerical integration over parts of the hemisphere can do more, as shown below. Other quantities used by specific industries – the gloss parameters for paints, for example – also are numerically deduced from a BSDF data set.

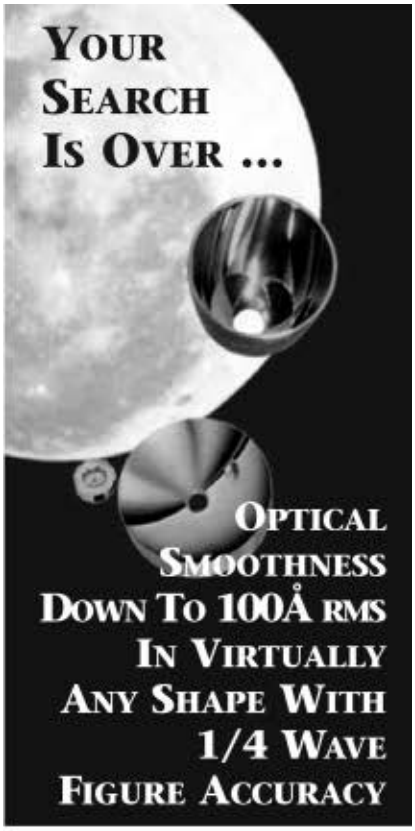
Measuring the BSDF results in a complete angular data set containing more generic information than specific measurement setups such as Coblentz spheres, hazemeters and the like. It also provides a more comprehensive picture of the scattering, examples of which are shown below.

BSDF examples

1. Fitting parameters of simulation models to BRDF data: The data set of semigloss paint shown in Figure 2 can easily be used to fit simple model parameters in an optical simulation program. Figure 3 shows the resulting fit of a combination between a Gaussian model for the scattering around the peak and a constant term for the quasi-diffuse background scattering.

The three parameters of the Gaussian model shown in Figure 3 are as follows: Hemispherical reflection ρ_{dh} (a1) plus height (a2) and width (a2) of the Gaussian part. Note the typical increase of ρ_{dh} and a2 with higher incident angle. Although the fit works well for incident angles 10° and 30°, notable differences exist between measured data and the best model BSDF for the incident angle of 70° (example data was taken from bsdf.pab.eu).

2. Selecting energy-efficient polymer blends in LED lighting: Diffusing elements for LED lighting achieve a uniform and glare-free light while maintaining the high efficiency of LEDs. Polymer blends



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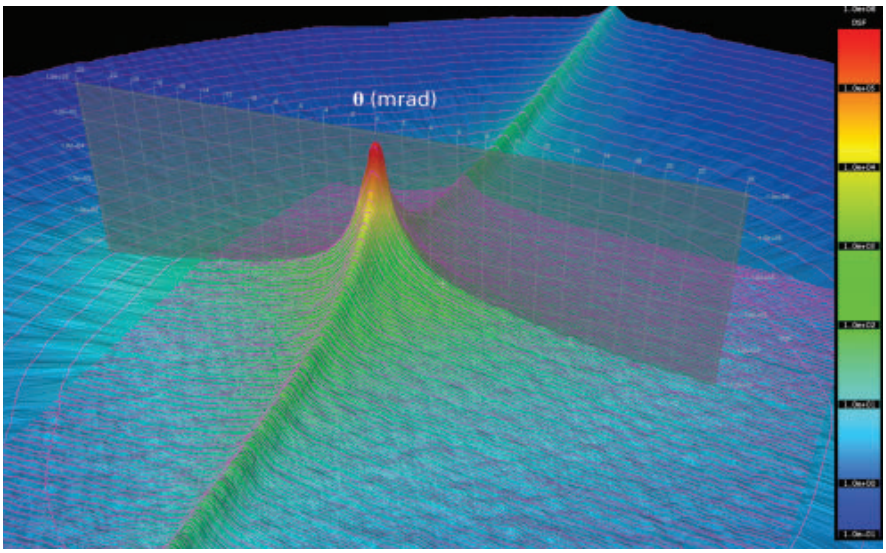

Figure 7. The differential scattering function of a mirror material for solar concentrators. Peak width at 1/10 of maximum is 1 mrad; dynamic range in data set is seven decades. To achieve the high resolution while minimizing speckle patterns, a spatially filtered, beam-shaped HeNe laser was focused on the detector aperture. Asymmetric scattering is observed due to a nonisotropic surface. The project involved multiple mirror materials and supports ongoing research to optimize concentrating solar systems.

are a suitable material with variable optical scattering.

Figure 4 shows the full BSDF of one polymer sheet (material A), and Figure 5 plots the BSDF of six different polymers. The BSDF shows a nonscattered forward peak and a falloff toward larger scattering angles. Integration of the full BSDF over a cone with opening angle α around the forward direction results in a set of curves in the lower plot of Figure 5. An opening of zero contains zero transmission, and a very small opening angle catches all light that is not scattered by the samples, which gives a rapid rise of the curve for materials with a strong forward peak. With increasing opening angle, the transmission increases monotonically, until it reaches the direct-hemispherical transmission (τ_{dh}) for $\alpha = 90°$. Note that only this value would be available if an integrating sphere were used.

The integrated curve in Figure 5 now can be used to directly select the best energy-efficient material for a given application. For a project that needs the diffusing material to illuminate an area with an opening angle $\alpha = 12°$, the best choice is material "D" (highest transmission into that cone), whereas an area with $\alpha = 32°$ would best be served with material "A." This allows relevant materials to be quickly compared, sorted and selected. For a more detailed analysis, the BSDF is then modeled, and a full-fledged simulation using CAD models gives the detailed answer in the context of the application. Both ways are sourced from the full 3-D, out-of-plane BSDF measurement.

3. "Black arts": Black low-IR reflective surface materials that suppress stray light in optical equipment or displays should have an ideal BRDF of zero, or at least as low as possible for all incident angles and all wavelengths. Figure 6 shows the differential scattering function ($BSDF*\cos(\Theta_{out})$) for one fabric, two foils and one matte paint, all visibly black, for an incident angle of 40°. Data in this case was measured for the near-IR from 850 to 1000 nm.

Three of these materials show a relatively flat angular response, with a value between 3 and 13 percent. Foil A has a low direct-hemispherical reflection but a higher value around 40° outgoing angle (A), since it scatters prominently into the forward direction. The choice of the optimal selection among the three low-reflectance materials depends thus on the application context: If a uniform low reflectance is needed, materials "paint" and "fabric" are a good choice. However, if backscatter toward the light source is to be minimized, foil A offers a much lower reflectance, backscattering about 50 times less than any other of these materials (indicated by B). Measured BSDF data offers useful insights into materials quickly.

4. BRDF of a mirror for solar concentrators: Figure 7 shows the finely resolved BRDF around the reflected peak of a metal mirror used in solar concentrators. The pink lines represent a series of data points taken while the detector moved and consists of 299,809 out-of-plane measurement points with an angular spacing below 0.1 mrad. To achieve the high resolution while minimizing speckle patterns, a spatially filtered, beam-shaped HeNe laser was focused on the detector aperture.

The data shows an asymmetric scattering due to a nonisotropic surface. The project involved multiple mirror materials and supports ongoing research to optimize concentrating solar systems.

Meet the author

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References

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P. Apian-Bennewitz (2010). New scanning gonio-photometer for extended BRTF measurements. *Proc. SPIE*, Vol. 7792, 77920O, doi:10.1117/12.860889.

M. Pharr and G. Humphreys (2004). *Physically Based Rendering.* 1st ed. Morgan Kauffmann, p. 1019.

Note

All BSDF/BRDF data used in this publication was measured using a pgII goniophotometer at pab advanced technologies Ltd.

BSDF definition *continued from page 61*

standards," typically made from sintered PTFE or barium sulfate, are an approximation to this ideally flat BSDF. Deviations from the ideal diffuser are routinely measured by national laboratories to calibrate diffuser standards.

There is some discussion as to the usefulness of the cos term in the definition. Measurements and applications actually use the product BSDF*cos frequently. By standard ASTM E2387-05, this product is called DSF, or differential scattering function.

A more common, often seen, and yet mathematically inferior definition results by using ideal "parallel" incident light. This is itself described by a Dirac delta function containing only light from exactly one direction. Inserting this into the formula in Figure A, the explicit formula BSDF = L_{out} / E_{in} follows, with E_{in} being the incident irradiation onto the surface element. In fact, this definition is only marginally useful, since "parallel" light doesn't exist; any light source at all subtends a finite solid angle. This has substantial practical consequences when measuring materials whose BSDF has an angular spread less than or nearly equal to the angular spread of the incoming light. Without taking into account the implicit definition of the BSDF, measured results would depend primarily on the incoming light and not on the material.

Additionally, because any measured signal is received by a detector that covers a finite solid angle on the outgoing side, a second integral over L_{out} in Figure A gives the measured signal. Figure B has all the pitfalls and problems of measuring a BSDF neatly written down. That is, the quantity of interest is inside two integrals, and only the result of the two integrals is known.

The solid angle Ω_{in}, subtended by the light source, and solid angle Ω_{out}, subtended by the detector, must be smaller than the BSDF angular detail one wishes to measure. They should be as small as possible while maintaining reasonable signal level. Collectively, the combination of beam shape and detector response is called the signature of an instrument, which is effectively a BSDF measurement without a sample.

A frequently used term is the scattering plane, spawned by the incoming direction and the surface normal. Since the reflected peak of an ideal mirror lies within the scattering plane, most 2-D plots show a cut of the BSDF along the scattering plane. However, for any but trivial materials, this should be accompanied by 3-D surfaces and/or multiple cuts through the BSDF.

$$L_{out}(\vec{x}_{out}) = \int_{\vec{x}_{in}}^{\Omega_{in} = 2\pi} BSDF(\vec{x}_{in}, \vec{x}_{out}) \cos(\theta_{in})\, L_{in}(x_{in})\, d\Omega_{in} \qquad (1)$$

Figure A. The measured signal from any BSDF measurement device.

$$L_{out}(\vec{x}_{out}) = \int_{\vec{x}_{out}}^{\Omega_{Detector}} \underbrace{\int_{\vec{x}_{in}}^{\Omega_{Source}} BSDF(\vec{x}_{in}, \vec{x}_{out}) \cos(\theta_{in})\, L_{in}(\vec{x}_{in})\, d\Omega_{in}}_{L_{out}(\vec{x}_{out})}\, d\Omega_{out} \qquad (2)$$

Figure B. The implicit, general and robust definition of the BSDF.

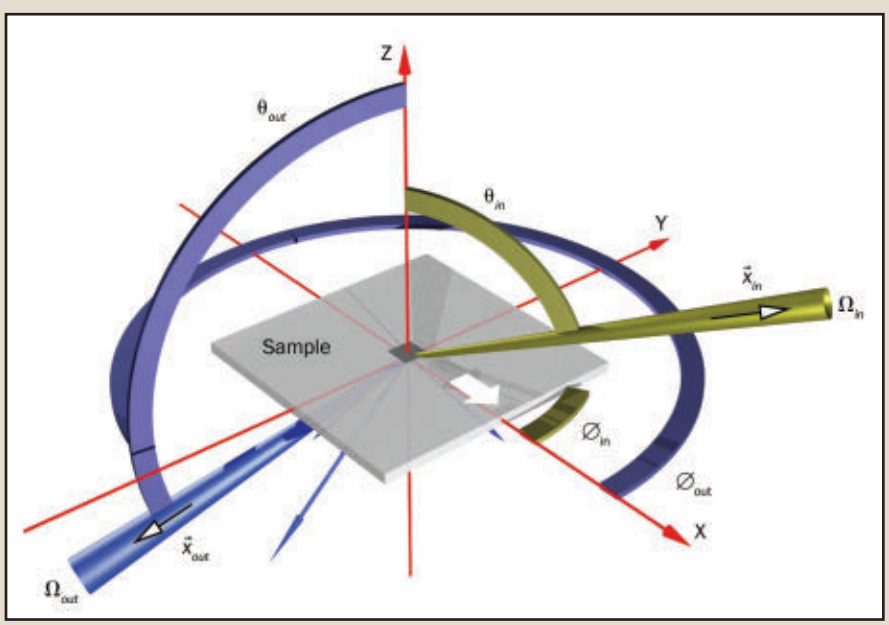


Figure C. The spherical coordinate system used for BSDF definition.

Power measurement could speed solar innovation

A new automated system that quickly measures the electric power output of solar energy devices could soon help researchers and manufacturers to develop next-generation solar energy cells.

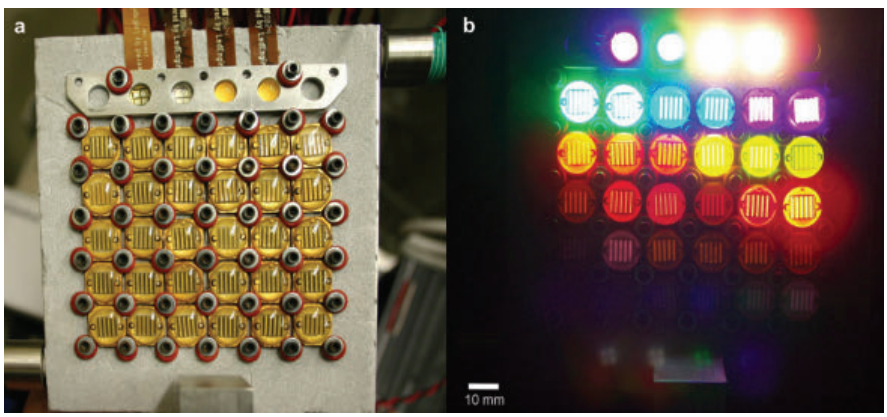
Innovative devices that convert sunlight to electric power more efficiently and cost-effectively than the current generation of solar cell technology are the objects of a global pursuit, say NIST (National Institute of Standards and Technology) researchers, especially in the race to secure pole position in the competition for fast-growing international markets for clean energy resources.

The researchers combined 32 LEDs – each generating light from different segments of the solar spectrum – and other off-the-shelf equipment with their own custom-made technologies to build a system that measures the wavelength-dependent quantum efficiency of solar devices over a relatively large area.

This new approach could offer significant advantages, such as greater speed and ease of operation, more uniform illumination and a service life that is about 10 times longer.

The system for measuring spectral response easily accommodates two unique but complementary methods for determining how much electric current a solar device generates when hit by a standard amount of sunlight. Both techniques are straightforward and use the same hardware setup. With either one, the automated system produces measurements more rapidly than instruments now used to simulate solar radiation and to characterize how efficiently a device converts light to electric energy.

The new system could offer significant advantages, such as greater speed and ease of operation, more uniform illumination and a service life that is about 10 times longer.



NIST

Sections of the new NIST measurement system's LED plate. A water-coolant system on the back (a) keeps the operating temperature constant. Collectively, the various-colored LEDs (b) generate light in wavelengths covering much of the solar spectrum. LEDs in the second row from the bottom emit most of their radiation in the near-infrared region and appear very faint to the human eye. Light from the last row of LEDs is completely invisible.

One method, which activates the LED lights sequentially, is less subject to interference than the other technique, yielding a spectral response measurement in about 6 min.

The other method activates all 32 LEDs simultaneously, but each LED generates pulses of light at a different rate. The solar response of a photovoltaic device over the entire LED-blended spectrum can be determined in about 4 s.

Although the faster method is more susceptible to interference, it has the potential for in-line manufacturing tests for ensuring quality, the NIST scientists say.

Next, the team plans to push its technology further to achieve certain goals, such as matching or exceeding the energy intensity of the sun, broadening the LED-synthesized spectrum to include the infrared portion of the sun's output, and consistently achieving measurement results with uncertainties of less than 1 percent.

Their recent work, however, demonstrated that LEDs are now "technologically viable" for solar simulators and for characterizing photovoltaics and other photoelectric devices, said NIST physicist Behrang Hamadani.

The research was conducted at NIST in Gaithersburg, Md. The findings were reported in *Applied Optics* (doi: 10.1364/ao.51.004469).

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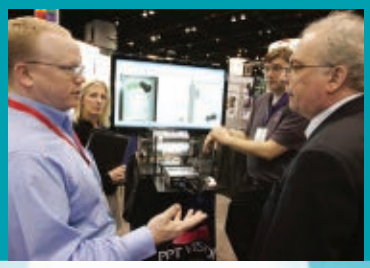

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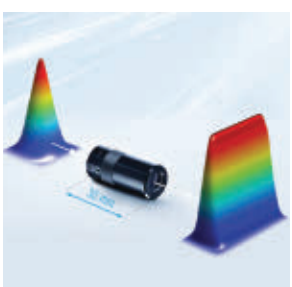

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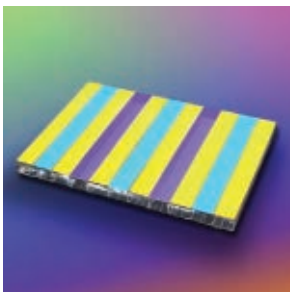

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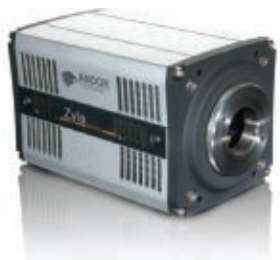

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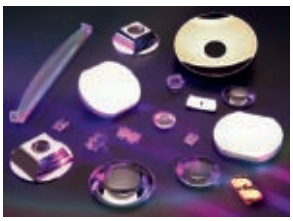

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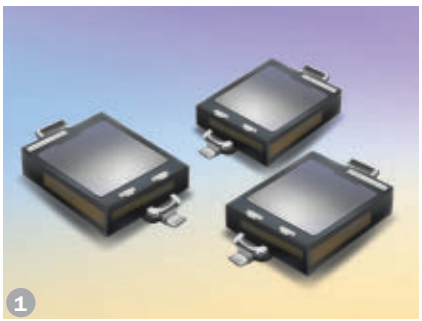

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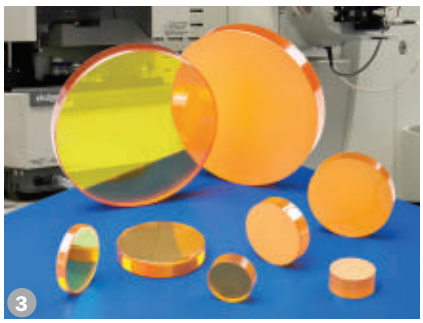

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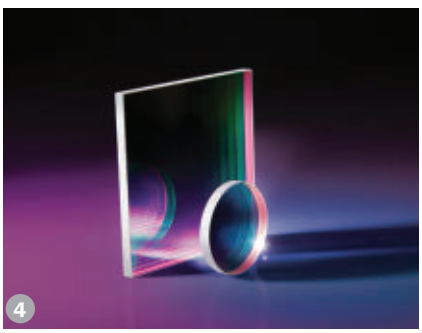

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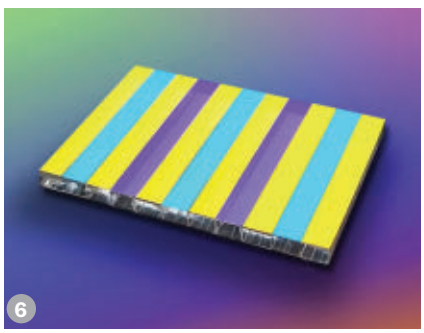

6

1 Surface-Mount Photodiode

Opto Diode Corp. has announced the second in its series of surface-mount photodiodes. With high sensitivity and short switching time, the low-capacitance ODD-900-002 is suitable for medical diagnostics. The surface-mount packaging facilitates integration into new or existing systems. The device operates from 400 to 1100 nm, with peak sensitivity of 940 nm. Typical responsivity is 0.44 A/W, with typical reverse dark current of 5 nA and total capacitance of 25 pF. Operating temperature ranges from −25 to 85 °C. Power dissipation is ≤150 mW at 25 °C free air temperature. Soldering temperature is 260 °C, with maximum soldering time of 5 s.

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2 Integrating Detectors

The Series 819C/D high-power silicon-based integrating sphere detectors from **Newport Corp.** handle 10 W of optical power. The CAL2 models feature a temperature sensor and OD1 attenuator sensor. When connected to the company's 1830-R, 1918-R, 1936-R or 2936-R power meters, they automatically recognize the attenuator on/off position and the detector head temperature. Calibrated and NIST-traceable, the instruments operate from the UV through the visible to the NIR at 1650 nm. They are available for both diverging and collimated input beams. Three sensor materials are used: Si, UV-enhanced Si, and InGaAs. Sphere sizes range from 2 to 5.3 in.

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3 ZnSe Windows

Zinc selenide (ZnSe) windows that can be provided blank, polish-finished or dual-band antireflection-coated for spectrometers and detectors are offered by **Laser Research Optics**. They transmit from 0.6 to 18 µm, have an absorption coefficient of 0.0005/cm at 10.6 µm, and are nonhygroscopic. They can be supplied in 0.5- to 3-in. outer-diameter sizes and in various thicknesses. Chemical-vapor-deposition-grown, the windows are suitable for systems operating at various bands within the material's wide transmission range. Typical surface quality in the infrared is 40-20 scratch-dig, 60-40 in the 0.8- to 7-µm region, and 60-40, 80-50 or 120-80 for the 7- to 16-µm region.

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4 SWIR Longpass Filters

Edmund Optics' TechSpec short-wavelength infrared (SWIR) longpass filters provide high transmission and deep rejection to isolate narrow spectral regions. They are designed to allow SWIR wavelengths to pass through, while blocking all visible light. They increase the image quality of InGaAs cameras in industrial machine vision, defense and solar cell inspection applications. They can be used as extended cold mirrors to eliminate damage or adverse effects as a result of heat buildup. They are available in 700- and 850-nm cut-on (at 50% of peak transmission) wavelengths, in 12.5-, 25- and 50-mm diameters, and in a 50 × 50-mm size.

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5 Input/Output Interfaces

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6 Optical Filter Assemblies

Deposition Sciences Inc.'s multispectral optical filter assemblies (MOFAs) combine individually coated multispectral filter substrates into an array assembly ranging from two- to eight-filter stacks, or more. The MOFAs can employ a variety of adhesives and are used in linear- and planar-array CMOS detectors and in medical instrumentation. By combining numerous complex filters into one device, the filters, once assembled, provide distinct capabilities on each multispectral array. The company also can incorporate stops and apertures on the part surface by using advanced patterned coating technology.

solutions@depsci.com

Digital Laser Diode Drivers

Portable Power Systems Inc. has introduced the PPS series digital laser diode drivers offered in CW, pulsed and CW/pulsed versions. The pulsed models have rise times of <10 s; the CW versions reach maximum current in <100 s. All have electrically erasable programmable read-only memory that allows the user to store and recall up to 16 sets of parameters such as current, pulse width and frequency on pulsed units, and current on CW units. Communications can be from the front panel, analog, RS-232 or USB. Fault alerts include open load, overvoltage, overcurrent, laser and driver overtemperature, remote and coolant interlock. and emergency stop. Some drivers are equipped with automatic compliance voltage adjust through proprietary software. Most have universal input power supplies that allow worldwide operation.
sales@pwrsys.com

Gigabit Ethernet Camera

The 8-megapixel Prosilica GT3300 and 29-megapixel GT6600 Gigabit Ethernet cameras from **Allied Vision Technologies GmbH** operate in extreme environments. The GT3300 features the quad-tap KAI-08050 CCD progressive-scan sensor from Truesense Imaging, which supports 14 fps at full 3296 × 2472-pixel resolution. The 29-megapixel GT6600 features the quad-tap KAI-29050 CCD device from Truesense Imaging, which is supported by a 5.5-µm-pixel architecture. The sensor's vertical overflow drain structure suppresses image blooming and enables electronic shuttering. The GT6600 outputs 6576 × 4384 pixels at 4 fps. Both cameras are equipped with an F-mount, with an M58 mount option available on the GT6600. They feature auto iris, Power over Ethernet and PTP IEEE1588. Applications include industrial imaging,

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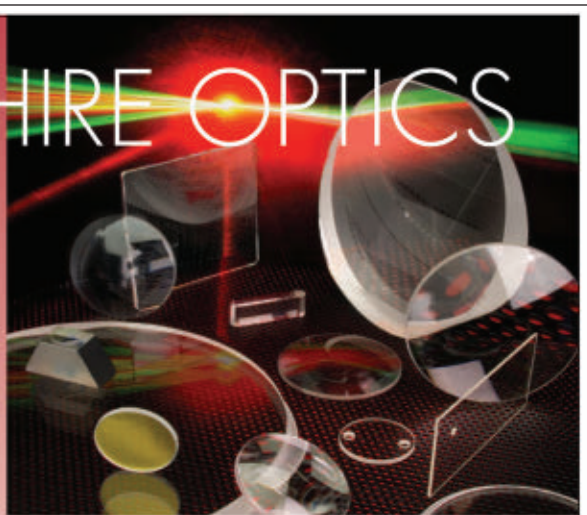

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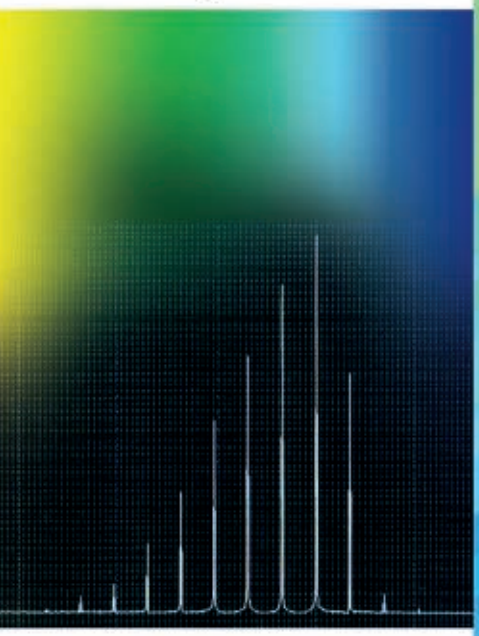

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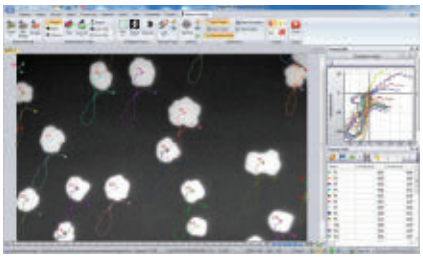

Image Analysis Software

Media Cybernetics' Image-Pro Premier image processing and analysis software for life sciences research, quality control, industrial inspection, and forensic and physical sciences captures, processes, enhances, measures, compares, analyzes, automates and enables sharing of images and data. It includes 64- and 32-bit support; macros and app-building tools; and ways to segment, classify and measure objects. It can stream multigigabyte movies to the hard drive and supports multiresolution files. Image processing can be applied to all opened images or to folders of images via batch processing tools. The smart segmentation tool identifies and segments images that have faintly colored objects, textured objects and uneven backgrounds. Users can download apps from the company's Solutions Zone website, or develop and package their own.
customerservice@mediacy.com

Video Frame Grabber

BitFlow's Karbon KBN-PCE-CXP4 video frame grabber, which leverages the CoaXPress (CXP) digital interface standard, transmits serial data at up to 6 Gb/s while sending control commands, 13-W safe power and camera triggers over a single piece of 75-Ω coaxial cable. Four independent channels allow engineers to synchronize four single-link CXP cameras onto the same board for simultaneous image capture, or to connect a single quad link CXP camera, two dual-link CXP cameras, or a combination of one dual- and two single-link

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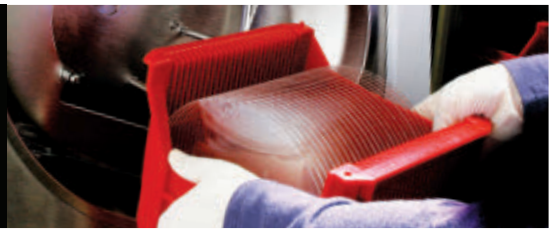

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Sydor Optics manufactures glass wafers from a variety of materials with the utmost in precision quality. Our extensive experience with double-sided grinding and polishing equipment yields exceptional TTV and TWE.

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31 Jet View Drive, Rochester, NY 14624 **p.** 585.271.7300 **f.** 585.271.7309 **e.** sales@sydor.com **sydor.com**

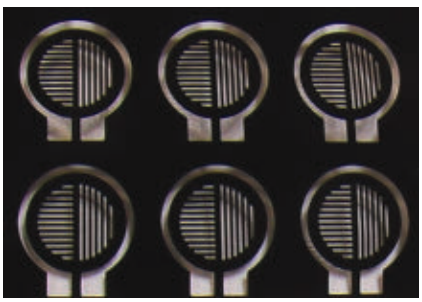
CXP cameras. The board features a PCI Express x8 host interface with a maximum transfer rate of 3.125 Gb/s per link, combined with proprietary FlowThru technology that eliminates the need for onboard memory. Adding the frame grabber to an application is simplified by the company's software development kit, which supports 32- and 64-bit operating systems.
sales@bitflow.com

CCD Detector for UV-VIS-NIR

The Syncerity research-grade OEM spectroscopy camera from **Horiba Scientific** produces low readout noise. The 1024 × 256 CCD detector for UV-VIS-NIR is an open-electrode −60 °C thermo-electrically cooled CCD camera that accommodates OEM and research applications. Its flexible design and software allow customization for industrial requirements, ranging from alternate CCD chips to electronics. Rugged connectors ensure system integrity in industrial environments, and all-metal sealed technology provides a permanent vacuum. Syncerity's ultracompact size is designed for compatibility with microscopes and OEM integration. At its slow scan speed of 45 kHz, the detector offers a dynamic range of 92.5 dB in image mode and delivers nonlinearity of < 0.4%. Its open-electrode CCD technology offers broad spectral coverage with quantum efficiency of 33% at 250 nm and 50% at 800 nm.
joanne.lowy@horiba.com

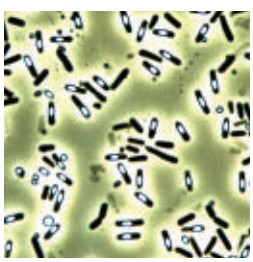
MPO Loopback Assemblies

Alliance Fiber Optic Products Inc. has released a line of MPO (multifiber push-on) fiber optic loopback assemblies for burn-in and testing of MPO network components and systems. They are used to test transmitter capability and receiver sensitivity of network equipment, particularly for telecom and datacom requirements. They are available in a compact housing for high-density use, with or without attenuation. Standard products include a female MPO interface with eight-fiber quad small-form-factor pluggable, 12- or 24-fiber single-mode or multimode ferrules. The streamlined and rugged housing design provides stability and reliability.
sales@afop.com



Metal Velvet Black Coating

Acktar Advanced Coatings is offering foils coated with its Metal Velvet ultra-absorbing black coating for use from the extreme-UV through the far-IR. Specular absorptance is 99.99%. The foil is a stray- and scattered-light-absorbing/suppressing mate-



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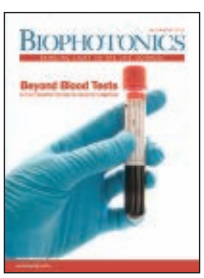

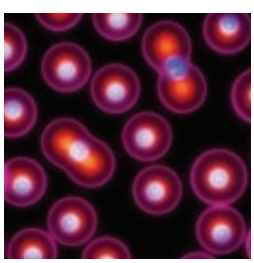

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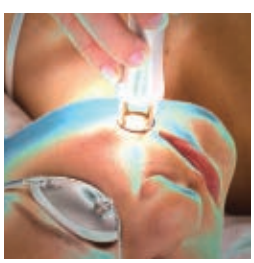

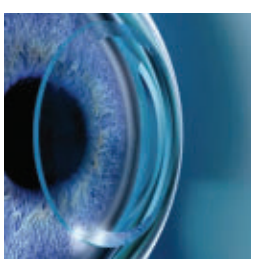

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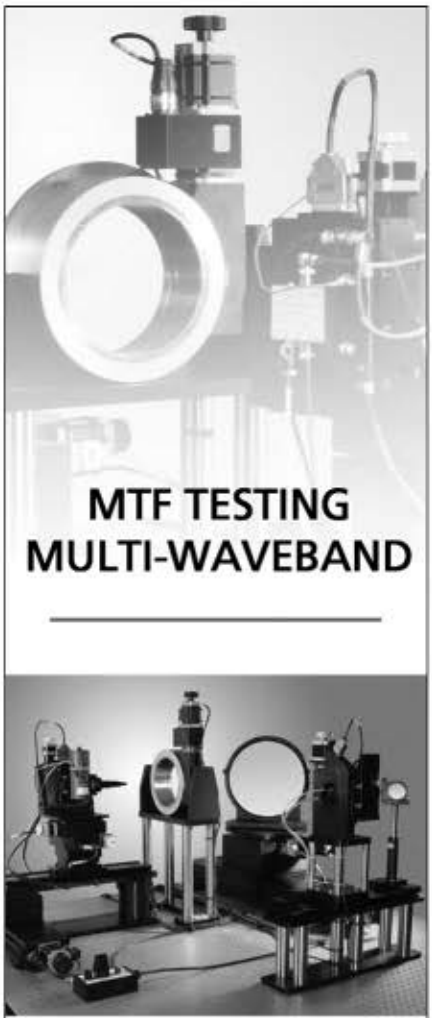

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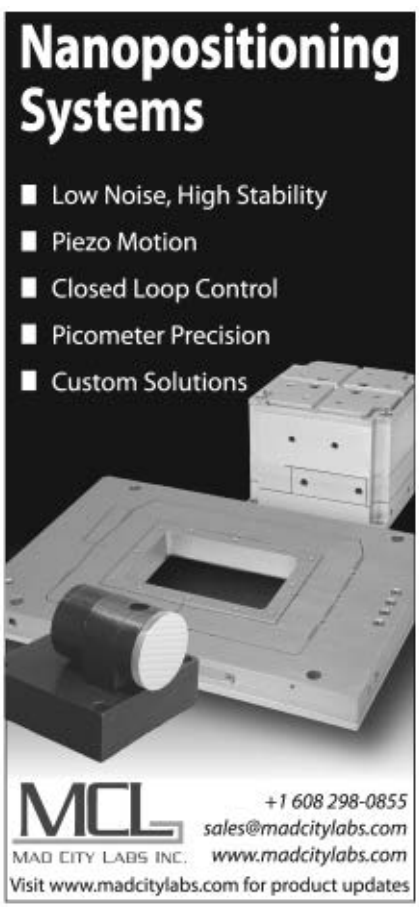
rial available to optical engineers, supplied with or without self-adhesive backing, and either in roll or cut-sheet formats. Metal Velvet is a black inorganic material with hemispherical reflectance <1%. The high-emissivity coating features ultrahigh-vacuum compatibility, low outgassing and high thermal stability at temperatures from 4 to 623 K. The coated foil is easily applied by the end user to metals, glass, ceramics and polymers.
customer-support@acktar.com

OEM Seed Laser Diode Driver

Analog Modules Inc. has releases its Model 763 OEM seed laser diode driver. It drives 14-pin butterfly-packaged laser diode modules or semiconductor optical amplifiers for use in continuous-wave or pulsed fiber master oscillator power amplifier and erbium-doped fiber amplifier systems. It is implemented as a transconductance amplifier (analog voltage in, scaled current out), with operation up to 1.2 A, 3 V, and pulse widths down to 10 ns. The driver circuitry operates from a 5-V source. All other required voltages are generated on the board by high-efficiency switching power supplies. The 763 is manufactured to the RoHS Directive 2002/95/EC requirements.
sales@analogmodules.com

Microscope Series

Olympus America Inc.'s IX3 line of inverted research microscopes for quantitative measurement applications includes three models. The IX83 is automated; the IX73 modular system can be configured in manual, semimotorized or motorized versions; the IX53 is for quick examination of multiple tissue samples. The stands provide a choice of manual control, encoded manual, semimotorized operation or fully automated high-speed motorization. They are suitable for live-cell imaging. All three have a low-profile ultrasonic motorized stage and proprietary UIS2 optics manufactured from lead-free glass. The real-time controller delivers precision in high-speed imaging, with microsecond timing accuracy for light sources and triggered cameras. A fly-eye fluorescence illuminator provides lighting across the specimen.
microscopy@olympus.com



Gloves for Optical Manufacturing

Data Optics Inc.'s gloves for optical manufacturing accommodate handling, cleaning, assembly and inspection of optical and optoelectronic elements. Made of lint-free, continuous-filament nylon or polyester, they can be used under laminar flow hoods and in cleanroom environments to Class 100. The GN120 ultrathin nylon glove can be worn alone or as a liner under vinyl, latex or nitrile gloves or finger cots. The nylon antistatic, medium-weight GN132CF has carbon fibers to discharge harmful electrostatic charges. It has 13-gauge continuous filament, as does the medium-weight GN130 nylon glove. The GP130 lint-free polyester knit glove also is available.
sales@dataoptics.com

Goniophotometer

Instrument Systems' LGS 250 goniophotometer analyzes angle-dependent spatial radiation properties of solid-state luminaires, lamps and LEDs. The Type-C coordinate system is horizontally aligned. Measurements can be taken at ±160° in the forward direction of the test specimen, which may have a diameter of up to 480 mm and weigh 8 kg. When combined with a proprietary spectroradiometer, the color coordinates, color temperature and color rendering index can be determined as a function of angle. The LGS 250 is supplied as a goniometer with a stable base and integrated LGS controller, or as a benchtop version with a 19-in. rack for the controller. SpecWin Pro software permits analysis of the measured data.
sales@instrumentsystems.de

Atomic Force Microscope

The Dimension FastScan Bio atomic force microscope from **Bruker Corp.** enables high-resolution microscopy research in biological dynamics. It allows temporal investigation under physiological operating environments in fluid, while exceeding the diffraction limits of optical microscopy. The microscope provides temporal resolution in frames-per-second for live biological sample observations.

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Applications include studies of the dynamics behind protein, DNA, RNA, membrane, cell and tissue interactions. The X-Y-Z scanner operates at high speeds while producing low drift and low noise. Features include automated laser and detector alignment, an easy sample engaging process, and the ability to investigate samples in a droplet of solution or its 60-µl sample cell.
steve.hopkins@bruker-nano.com

Contamination Identifier Software

Los Gatos Research has documented and validated a software analysis package that enables its water isotope analyzers to simultaneously measure multiple isotopic ratios directly from contaminated samples. Spectral Contamination Identifier software measures isotope ratios from water samples contaminated with methanol and ethanol. Scientists can analyze samples obtained from soils, plants or other complex water sources without performing pretreatment procedures. The effectiveness of the software results from the company's method of recording fully resolved high-resolution laser absorption spectra, which are viewable in real time and archived by its isotopic water analyzers. The software performs a smart analysis on these complex spectra to yield corrected isotopic ratios in the presence of contaminants.
sales@lgrinc.com

Surface Measuring Device

Fries Research & Technology GmbH's MicroSpy Topo DT surface-measuring device combines a confocal microscope and a white-light interferometer. The instrument can characterize flat and structured test pieces that are weakly or highly reflective, on a noncontact and nondestructive basis, within a few seconds. It images roughness, contour and 3-D topography. Adjustment range is 50 mm in height and 100 × 100 mm in area. A rotating turret enables rapid switching between lenses with different magnifications. Structures in the subnanometer range can be characterized with high lateral resolution. Image analysis software enables measurement results to be studied with regard to geometry, roughness and evenness.
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NOVEMBER

Fifth International Photonics and OptoElectronics Meetings (POEM 2012) (Nov. 1-2) Wuhan, China. Contact Wuhan National Laboratory for Optoelectronics, +86 27 877 92 227; poem@mail.hust.edu.cn; poem.wnlo.cn.

SPIE/COS Photonics Asia (Nov. 4-7) Beijing. Sponsored by SPIE and the Chinese Optical Society. Contact SPIE, +1 (360) 676-3290; customerservice@spie.org; spie.org.

Ninth International Conference and Expo on Emerging Technologies for a Smarter World (CEWIT2012) (Nov. 5-6) Songdo, South Korea. Contact Rong Zhao, +1 (631) 632-4633; conference@cewit.stonybrook.edu; cewit.org/conference2012.

MiCom 2012 – Third International Conference on Microbial Communication (Nov. 5-8) Jena, Germany. Contact micom@uni-jena.de; www.micom-conference.de.

Ninth Asia-Pacific Symposium on Information and Telecommunication Technologies (APSITT 2012) (Nov. 5-9) Santiago and Valparaiso, Chile. Contact apsitt2012-secretariat@lab.ntt.co.jp; www.ieice.org/cs/in/APSITT/2012.

● **Vision: International Trade Fair for Machine Vision (Nov. 6-8)** Stuttgart, Germany. Contact Landesmesse Stuttgart GmbH, +49 711 18560; info@messe-stuttgart.de; www.vision-messe.de.

2012 Sixth International Symposium on Telecommunications (IST) (Nov. 6-8) Tehran, Iran. Contact Homeira Moghadami, Research Institute for ICT, +98 21 88 630 077; ist2012@itrc.as.ir; ist2012.itrc.ac.ir.

Clinical Application of Adaptive Optics Retinal Imaging Incubator Meeting (Nov. 6-8) Washington. Contact The Optical Society, +1 (202) 223-8130; info@osa.org; www.osa.org.

Asia Communications and Photonics Conference (ACP) (Nov. 7-10) Guangzhou, China. Contact The Optical Society, +1 (202) 223-8130; info@osa.org; www.acp-conf.org.

Laser Florence 2012 (Nov. 9-10) Florence, Italy. Contact IALMS – International Academy for Laser Medicine and Surgery, +39 055 234 2330; info@laserflorence.org; www.laserflorence.org.

2012 International Conference on Image Analysis and Signal Processing (IASP) (Nov. 9-11) Hangzhou, China. Contact Linda Sun, +1 (770) 973-8732; asppress@yahoo.com; iasp2012.zjicm.edu.cn.

2012 IEEE 14th International Conference on Communication Technology (ICCT) (Nov. 9-11) Chengdu, China. Contact Mengqi Zhou, +86 10 68 160 825; zhoumq@public3.bta.net.cn; www.icctconf.org.

PAPERS

SPIE Optics+Optoelectronics (April 15-18) Prague
Deadline: abstracts, November 5
SPIE invites researchers to submit papers to this conference in a variety of areas, including metamaterials, nonlinear optics, photon counting, optical sensors, microstructured and specialty optical fibers, and the laser acceleration of electrons, protons and ions. Among other topics to be addressed are holography; extreme-UV and x-ray optics; quantum optics and quantum information transfer and processing; and medical applications of laser-generated secondary sources of radiation and particles. Contact SPIE Europe, +44 29 2089 4747; info@spieeurope.org; www.spie.org/oocall.

Blue Photonics 3 (March 18-20) Texel, Netherlands
Deadline: abstracts, November 16
The European Optical Society is accepting papers for the Third EOS Topical Meeting on Blue Photonics – Optics in the Sea. Areas to be considered include fluorometry, ocean color, radiative transfer and modeling, marine bio-optics and remote sensing, AOP-IOP (apparent optical properties-inherent optical properties) 2-D and 3-D, underwater imaging, and innovative subsea optical techniques and instrumentation. Environmental monitoring, including crowd-sourcing and the use of apps, also will be addressed. Contact Julia Dalichow, EOS – Events and Services GmbH, bluephotonics3@myeos.org; www.myeos.org.

SID 2013 (May 19-24) Vancouver, British Columbia, Canada
Deadline: abstracts, technical summaries, December 1
Researchers are encouraged to submit their work, for oral and poster presentation, to SID 2013, the Society for Information Display's International Symposium, Seminar & Exhibition. The Display Week 2013 symposium will emphasize five areas where there has been rapid growth: organic LEDs for television applications, oxide semiconductor thin-film transistors, 3-D displays, solid-state lighting and touch-screen technologies. Contact Shin-Tson Wu, University of Central Florida, +1 (407) 823-4763; swu@mail.ucf.edu; www.displayweek.org.

Latin America Optics and Photonics Conference (LAOP) (Nov. 10-13) São Sebastião, Brazil. Contact The Optical Society, +1 (202) 223-8130; info@osa.org; www.osa.org.

● **Renewable Energy and the Environment: OSA Optics and Photonics Congress (Nov. 11-15)** Eindhoven, Netherlands. Includes Optical Instrumentation for Energy and Environmental Applications (E2); Optical Nanostructures and Advanced Materials for Photovoltaics (PV); Optics for Solar Energy (SOLAR); and Solid State and Organic Lighting (SOLED). Contact The Optical Society, +1 (202) 223-8130; info@osa.org; www.osa.org.

LANE 2012: Seventh International Conference and Exhibition on Photonic Technologies (Nov. 12-15) Fürth, Germany. Contact Bayerisches Laserzentrum GmbH, +49 9131 977 900; info@blz.org; www.lane-conference.org.

Quantum Optics VI (Nov. 12-16) Piriápolis, Uruguay. Contact Facultad de Ingeniería, Universidad de la República – Uruguay, qopticsvi@fing.edu.uy; www.fing.edu.uy/if/qoptics6.

2012 IEEE International Conference on Technologies for Homeland Security (HST '12) (Nov. 13-15) Waltham, Mass. Contact IEEE, +1 (732) 981-0060; contactcenter@ieee.org; www.ieee-hst.org.

Second Annual International Conference on Materials Science, Metal & Manufacturing (M3 2012) (Nov. 19-20) Singapore. Contact Global Science & Technology Forum (GSTF), +65 6327 0166; info@m3-conference.org; www.m3-conference.org.

SPIE Optical Systems Design (Nov. 26-29) Barcelona, Spain. Contact SPIE, +1 (360) 676-3290; customerservice@spie.org; spie.org.

Seventh International Colloquium on Optics (Nov. 27-28) Aachen, Germany. Contact Reik Krappig, Fraunhofer IPT, Fraunhofer ILT, +49 241 8904 327; www.optik-kolloquium.de.

Visual Communications and Image Processing Conference (VCIP) 2012 (Nov. 27-30) San Diego. Contact Kiyoharu Aizawa, University of Tokyo, aizawa@hal.t.u-tokyo.ac.jp; www.vcip2012.org.

19th International Conference on Mechatronics and Machine Vision in Practice (M2VIP 2012) (Nov. 28-30) Auckland, New Zealand. Contact Tom Moir, AUT University, +64 9 9219 999, Ext. 6052; tom.moir@aut.ac.nz; www.m2vip.com.

● Indicates shows **Photonics Media** will be attending.
Complete listings at: **www.photonics.com/calendar**.

DECEMBER

DICTA 2012: Digital Image Computing: Techniques and Applications (Dec. 3-5) Fremantle, Western Australia. Contact dicta2012@csse.uwa.edu.au; dicta2012.csse.uwa.edu.au.

ICARCV 2012: 12th International Conference on Control, Automation, Robotics and Vision (Dec. 5-7) Guangzhou, China. Contact icarcv2012@wpc-sg.com; www.icarcv.org.

International Conference on Fiber Optics and Photonics (Photonics 2012) (Dec. 9-12) Chennai, India. Contact The Optical Society, +1 (202) 223-8130; info@osa.org; www.photonics2012.in.

HONET-ICT 2012: Ninth International Conference on High-Capacity Optical Networks & Emerging/Enabling Technologies – Information and Communication Technologies (Dec. 12-14) Istanbul. Contact M. Yasin Akhtar Raja, University of North Carolina at Charlotte, +1 (704) 687-8156; raja@uncc.edu; honet.uncc.edu.

Conference on Optoelectronic and Microelectronic Materials and Devices (COMMAD 2012) (Dec. 12-14) Melbourne, Australia. Contact Jeffrey McCallum, University of Melbourne, +61 3 8344 8072; jeffreym@unimelb.edu.au; commad2012.physics.unimelb.edu.au.

Photonics Global Conference (PGC 2012) (Dec. 13-16) Singapore. Contact Director, Optimus-Photonics Centre of Excellence, Nanyang Technological University, +65 6790 4685; d-optimus@ntu.edu.sg; www.photonicsglobal.org.

2012 International Conference on Machine Vision and Image Processing (MVIP) (Dec. 14-15) Coimbatore, India. Contact T.K. Vijaya, PSG College of Technology, +91 422 434 4777; tkv@ice.psgtech.ac.in; www.ieee.org/conferences.

● **2012 American Society for Cell Biology Annual Meeting (Dec. 15-19)** San Francisco. Contact ASCB, +1 (301) 347-9300; www.ascb.org/meetings.

Topical Research Meetings on Physics: Quantum Technologies: Taking Concepts Through to Implementations (Dec. 17-18) London. Contact Institute of Physics, conferences@iop.org; qtech.iopconfs.org.

Sixth International Conference on Sensing Technology (ICST 2012) (Dec. 18-21) Kolkata, India. Contact Subhas Mukhopadhyay, Massey University, +64 635 057 99; s.c.mukhopadhyay@massey.ac.nz; seat.massey.ac.nz/conferences/icst2012.

Cairo International Biomedical Engineering Conference (CIBEC 2012) (Dec. 20-22) Giza, Egypt. Contact Dina S. Elkholy, Cairo University, +201 222 608 698; cibec@k-space.org; www.cibec2012.org.

JANUARY

Nanometa 2013: Fourth International Topical Meeting on Nanophotonics and Metamaterials (Jan. 3-6) Tirol, Austria. Contact European Physical Society, +33 3 89 32 94 42; conferences@eps.org; www.nanometa.org.

Advanced Photonics Techniques in Soft Matter and Biology (Jan. 14) London. Contact Jenny Bremner, Institute of Physics, jenny.bremner@iop.org; www.iop.org.

OnSite Annual Meeting for Homeland Security, Forensics and Environmental Remediation (Jan. 23-25) Baltimore. Contact OnSite, +1 (847) 543-6800; infoscience@ais.net; www.ifpac.com/onsite.

FEBRUARY

● **Biophysical Society 57th Annual Meeting (Feb. 2-6)** Philadelphia. Contact Biophysical Society, +1 (240) 290-5600; society@biophysics.org; www.biophysics.org.

● **Photonics West (Feb. 2-7)** San Francisco. Includes the conferences BiOS, LASE, OPTO, MOEMS-MEMS and Green Photonics. Contact SPIE, +1 (360) 676-3290; customerservice@spie.org; spie.org.

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New robot handles with care

Don't you just hate it when your personal robot makes a mess instead of an omelet, crushing the eggs when it tries to pick them up? Well, a new five-digit, human-size robotic hand prototype could put an end to all that.

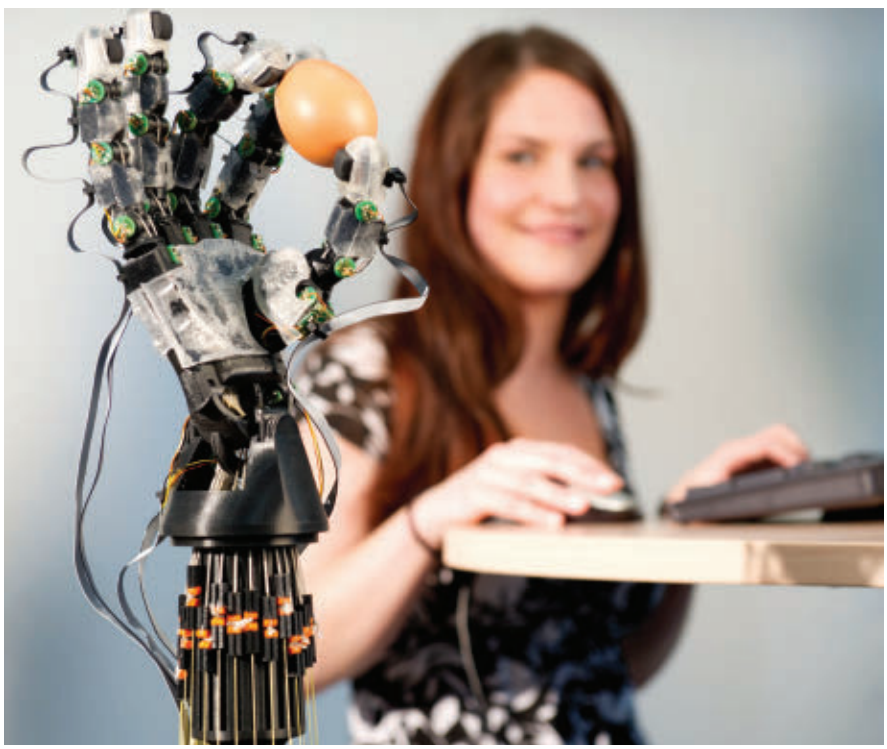
Thanks to optical and other sensors as well as background work on image processing, the robo-hand is dexterous and smart enough to pick up and turn a credit card around, politely accept a pen from a person and even grasp an egg without breaking the shell.

Today, robots typically man the factory floor, but future robots, envisioned for domestic duties, will require higher levels of manipulation and autonomy; this new development could help make that happen.

After all, manipulation has long been a major problem in robotics. The prototype is not simply an upgraded gripper, said Bruno Siciliano of the University of Naples in Italy. "Industry robots are pretty good at picking things up and putting them down," he added. "If robots are to really transform life and work alongside humans, then they must be able to handle items just as humans can with their hands."

As coordinator of the European Union-funded Dexmart project (Dexterous and autonomous dual-arm/hand robotic manipulation with smart sensory-motor skills: A bridge from natural to artificial cognition), Siciliano leads the team of robotics researchers from Saarland University in Saarbrücken, Germany, and the University of Bologna in Italy.

Capable of both powerful and delicate maneuvers, the Dexmart hand can touch, grasp and lift diverse objects and place them gently in a new position. The anthropomorphic device incorporates an innovative actuator system in which strong polymer strings in the handling apparatus are twisted by high-speed motors located in the "forearm" area.



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A robotic hand gently holds an egg. Developments in dexterity and cognition could help bring robots from the factory floor into the home.

Sensors were developed to measure joint angles, tendon forces and tactile interactions with objects. The device's control system takes input from the optoelectronic sensors, then works out the synergies and actuates the finger movements.

Within the tactile sensor, advanced computational analysis of the captured light intensity inside a number of sensitive elements makes it possible to calculate the forces exerted on the object by the fingers and also whether the object is slipping out of the robot's grasp.

"The success of the Dexmart hand is based on the integration of all these novel technologies and concepts – the sensors, the actuators, the control and learning mechanisms," Siciliano said.

To give the robot its cognitive power, scientists from Karlsruhe University in Germany, Second University of Naples in Italy and UK technology firm OMG initially used advanced image processing technology to study the fine details of human hand movement.

Robots also must respond to situations appropriately and in ways that are not preprogrammed, Siciliano noted. "One of the goals of robotics, especially for companion and helper robots in society, is their ability to behave autonomously," he said.

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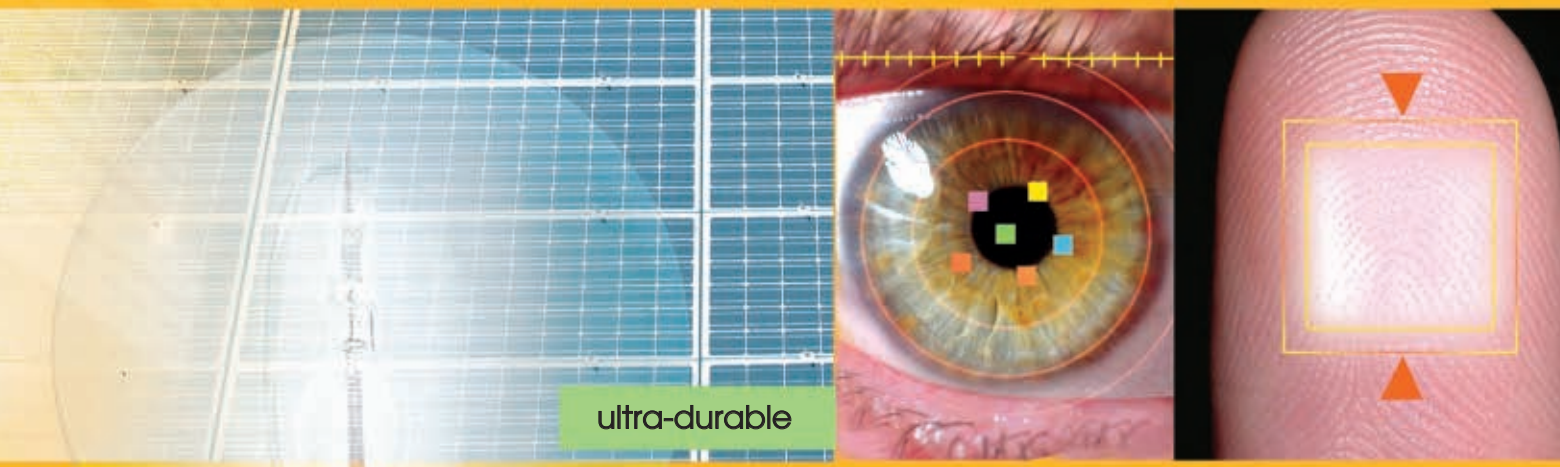

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