PHOTONICS spectra

June / 2010

Dual-Mirror Adaptive Optics

Lasers for LED Manufacturing

LASERS AT 50
page 54

# Photonics in Solar Cell Production


Inside this issue, starting opposite page 90

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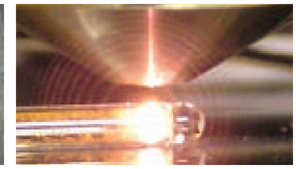


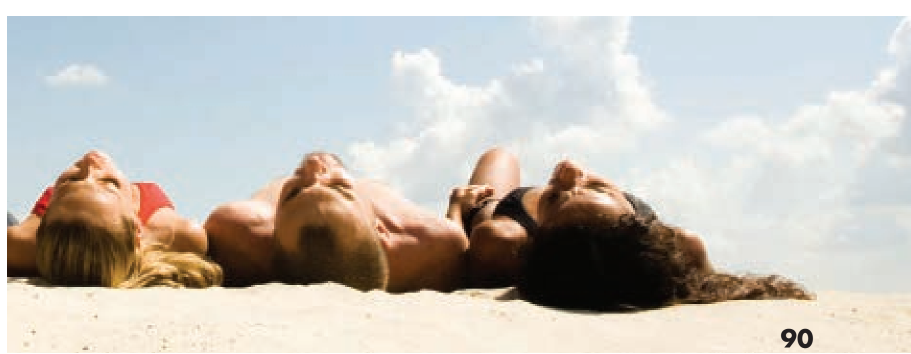
NEWS & ANALYSIS




DEPARTMENTS



**THE COVER**
The ramp-up of solar cell productions means more attention must be paid toward swift, efficient quality control. See articles starting on p. 39. Photo courtesy of iStockphoto. Cover design by Lisa N. Comstock.



## FEATURES





LASERS AT 50



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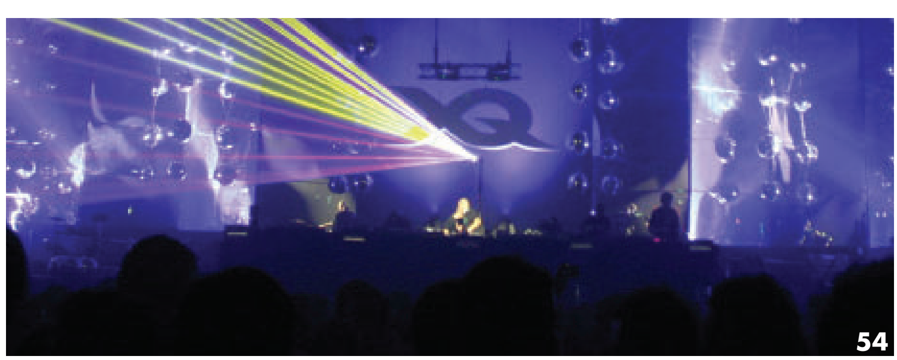



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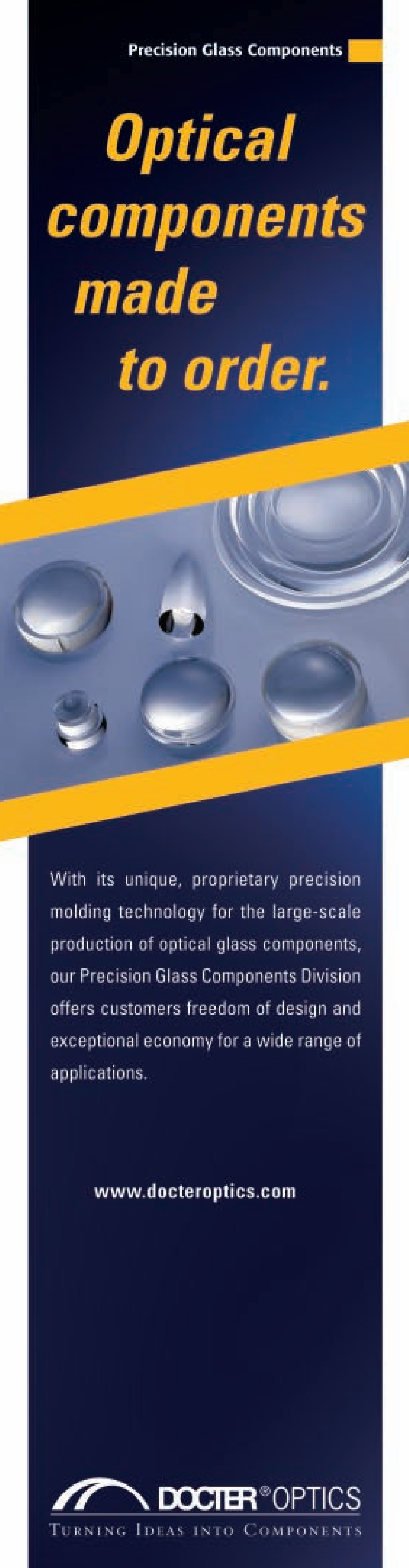
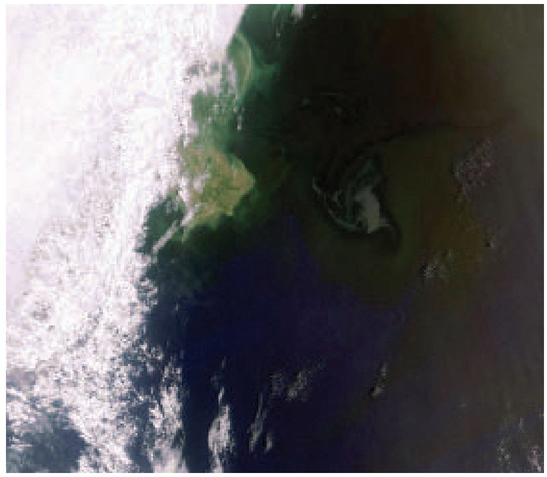





# Photonics and the environment



This is an Envisat optical image of the oil spill (visible as a white whirl on the right) in the Gulf of Mexico, acquired from the Medium Resolution Imaging Spectrometer (MERIS) on April 25, 2010, at 16:28 UTC (universal time corrected). Courtesy of European Space Agency.

As this issue goes to press, a dark black cloud of crude oil is still swirling and spreading throughout the Gulf of Mexico, as anywhere from 5000 to 80,000 barrels a day (various government, corporate and scientific sources are not in agreement on the number) escape from a damaged well, weeks after the initial explosion and fire on Transocean Ltd.'s drilling rig, Deepwater Horizon, which was licensed to BP.

And while crews race to monitor and contain the spill – and try to mitigate the damage as much as possible – photonics technologies are lending a hand.

BP has been using submarine-mounted cameras to keep an eye on the spill, and NASA's eyes in the sky, including the Moderate Imaging Spectroradiometer, have been watching from above. Satellite images, both radar and optical, of the area from the European Space Agency's Envisat are helping officials use the remote sensing technologies to formulate a response.

Those of us in the industry know the often-unsung advantages of photonics for situations exactly like this, and we thank the developers, manufacturers and researchers who have brought these and other useful light-based technologies to life to enhance not only pollution disaster recovery efforts but also other applications that affect the environment.

We all know that photonics has great potential to affect the planet. But, sometimes, the planet affects the photonics community, too. Although the World Health Organization reported that the volcanic eruption in Iceland has not caused significant changes in ground-level air quality in Europe and is not expected to cause health risks, the billowing plume snarled air and ground traffic throughout the world.

Among those affected were attendees of the European Machine Vision Association Business Conference in Istanbul, Turkey. Photonics Media's own European sales manager, Penny Pretty, recounts her epic journey across Europe to get home from the event – sharing all the highs and lows, all the humor and frustration – at www.photonics.com. How did the eruption affect your travels? Leave a comment on our Web site and tell your tale.

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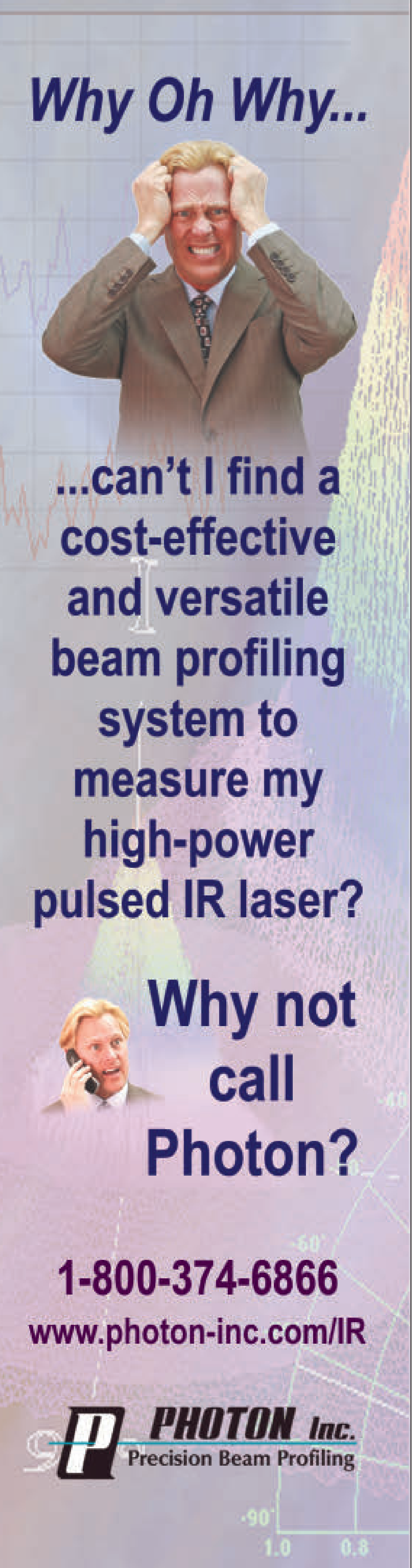


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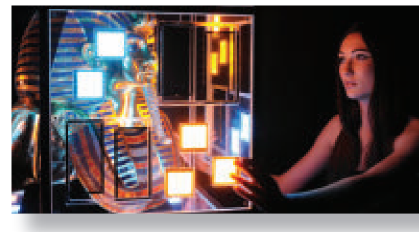
*WEB EXCLUSIVE:*
**Could It Be Lights Out for the Traditional Bulb?**



Marie Freebody, contributing editor for Photonics Media, takes a look at the global trend toward more energy-efficient lighting, in particular LEDs and OLEDs, and the fate of the traditional incandescent bulb.

To see the full version of this article, found this month on page E4, visit www.photonics.com/webexclusives.

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## In the July issue of Photonics Spectra . . .

**Inspection of Optical Lenses: Spectroscopy vs. Interferometry**
The increasing requirements being placed on customized lenses makes easy, accurate, reportable inspection of such lenses more critical than ever. What are the best spectroscopy and interferometry technologies for this purpose? What are the trade-offs?

**The Latest in Displays**
Senior editor Melinda Rose will report from the Society for Information Display's annual conference on the most exciting trends in display technology.

**Thermal Imaging for the Solar Contractor**
Thermal imaging cameras allow precise diagnosis of problem areas, save valuable time, and empower solar contractors to create reports showing clients exactly where the problem is.

**Error Sources in Precision Positioning Applications**
In positioning applications, consideration must be made of the effect of the flatness of mounting surfaces and overhanging loads on the performance of precision positioning systems.


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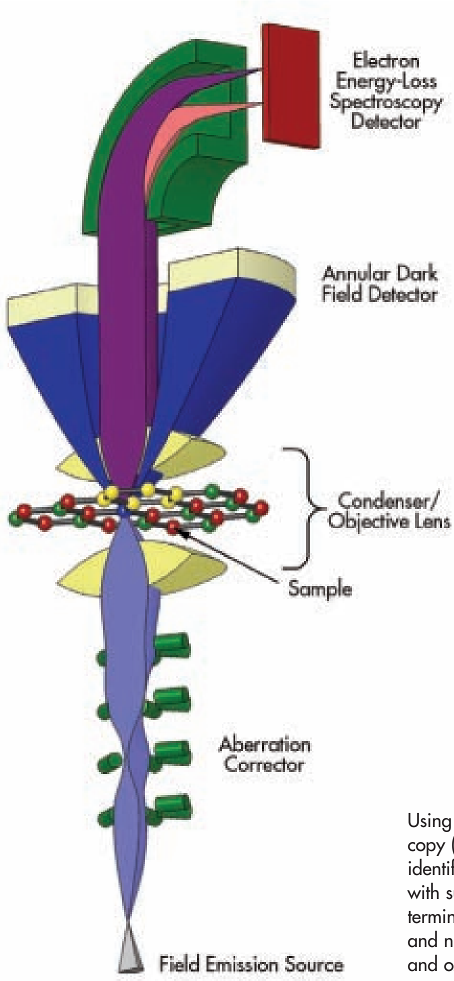
# STEM technique maps all the atoms in any molecule

OAK RIDGE, Tenn. – Transmission electron microscopy (TEM) is a technique that should, in theory, facilitate direct imaging and chemical identification of each and every atom in a material that has an unspecified three-dimensional structure. This is especially true given the recent introduction of aberration-corrected optics. Until recently, however, neither TEM nor any other method has proved up to the task in nonperiodic materials.

Now, however, a group of researchers has devised a technique for imaging and identifying atoms in almost any solid or molecule. The team recently used its creation to resolve and directly identify every atom in a monolayer of boron nitride, a feat never before performed.



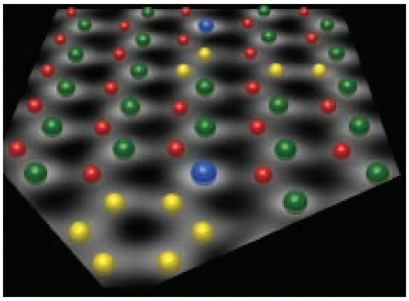

The researchers, who included those affiliated with Nion Co. of Kirkland, Wash., Vanderbilt University in Nashville, Oak Ridge National Laboratory and the University of Oxford in the UK, reported in the March 25, 2010, issue of *Nature* that they had used annular dark-field imaging in an aberration-corrected scanning transmission electron microscope (STEM) in their study.

This type of atom-by-atom analysis could be performed on organic and other molecules that do not crystallize into an ordered array, said Ondrej L. Krivanek, president of Nion Co. and lead author.

"With the 1-Å – or 100-pm – resolution we now roughly have for light atoms, all the atoms should be identifiable, except probably hydrogen, and the atomic structure of any general molecule should therefore be analyzable in principle," said Krivanek.

Because electrons are one-fiftieth the size of an atom, they have long been considered prime candidates for direct atomic imaging and identification. However, this has been done only for crystals, which have a regular structure. That has now changed, thanks to various enabling technologies.

One such technology is aberration correction of electron beam imaging, an area that Krivanek said Nion pioneered and in which it is a leader. This has improved imaging resolution by a factor of three.



Using aberration-corrected annular dark-field electron microscopy (left), researchers for the first time have located and identified all atoms in a nonperiodic sample of boron nitride with substitutional impurities. Shown is an experimentally determined model superimposed on the image, with boron (red) and nitrogen (green), along with impurities carbon (yellow) and oxygen (blue). Courtesy of Ondrej L. Krivanek, Nion Co.

Another advance was the development of very stable electron beams, achieved by eliminating all sources of noise. The result is that the beam used in the current experiments is still to 5 pm rms – 10 times better than is typical.

Other enabling technologies were the aforementioned annular dark-field detection, as well as cold-field emission and ultrahigh-vacuum processing. The first technique, which recently was extended to light atoms, allows chemical identification because the signal is strongly dependent upon atomic number. The second one optimizes resolution when using a lower-energy electron beam, a necessity because these beams minimize radiation damage to structures with light atoms such as boron, carbon, nitrogen and oxygen. Ultrahigh vacuum around the sample prevented stray contaminants from being picked up during the analysis.

Imaging in the study was performed using a Z-contrast UltraSTEM scanning transmission electron microscope made by Nion, with a corrector of third- and fifth-order aberrations and a cold-field emission electron source, which helped to minimize beam blurring.

The aberration corrector and the cold-field electron source gave the researchers excellent resolution at 60 kV. This was important, according to Stephen J. Pennycook, a materials science and technology researcher at Oak Ridge, because operating at this low voltage allowed them to avoid atom displacement damage to the sample.

The use of Z-contrast STEM was integral to the experiment. "The Z-contrast mode is the only way to distinguish the elements based on their intensity in the image," Pennycook said. Phase contrast imaging is the other common high-resolution TEM mode. Here, however, the atoms are very close in intensity and impossible to distinguish one after the other. Z-contrast imaging uses electrons scattered through larger angles, scattering off the nucleus or Rutherford scattering, and thus is much more sensitive to the species of atom.

"The other big advantage of a Z-contrast microscope," Pennycook added, "is that it also allows electron energy loss spectroscopy, when transmitted electrons are analyzed for their loss of energy. Although this is a lower-level signal, it is element-specific, so we knew for certain that there was a lot of carbon on the specimen."

After building and tuning the microscope, the researchers examined boron nitride monolayers. They did this for two reasons, Krivanek explained. One is as a proof of principle of the elemental analysis technique. The second was that boron nitride sheets are potentially useful because the material is related to graphene, which could form the basis for future electronics. Devices could someday be built out of graphene, with nonconducting boron nitride separators.

In their study, the researchers corrected the aberration in an electron beam, swept it across the boron nitride monolayer sample and collected the resulting dark-field image. This revealed individual atoms.

By analyzing the molecular structure of experimental materials, atom by atom, researchers can identify structural defects in those materials. This is significant because defects, including the presence of an impurity atom or molecule, often determine the material's properties.

They also found atomic substitutions in the monolayer. For example, there was carbon in the place of boron at some locations, carbon in the place of nitrogen at others and oxygen in the place of nitrogen elsewhere. These atoms, which differed in size from the ones they replaced, caused distortions in the monolayer of about one-tenth of an angstrom, or about 10 pm. These observations were in agreement with calculated values.

Although this proves that the technique works, Krivanek noted that there are limitations to keep in mind. The most important is that major radiation damage can occur in a sample, arising from the impact of the electrons in the beam. There are ways around this, particularly if many identical copies of a molecule are present. As that is often the case in biology, the approach could be applicable to the study of organic molecules.

The researchers plan to explore the electron energy loss spectroscopy signal in more detail and hope to correlate the defects observed with electronic changes in the material. This also is very important for graphene, a potential replacement for silicon (which is nearing the famous "end-of-the-road map," Pennycook said, so next-generation devices will have to use a different material). Graphene offers the right characteristics, but developers have not yet come up with a reliable means to make repeatable devices with it.

"The key is to have the right impurities in the right places and not the wrong ones," Pennycook said. "So seeing and identifying the impurity atoms is the key to understanding electrical properties and, ultimately, to new devices."

As for the future, Krivanek said of the technique, "We can now see individual atoms more clearly than we ever could before. Since the entire world is made of atoms, the potential range of applications is very wide indeed."

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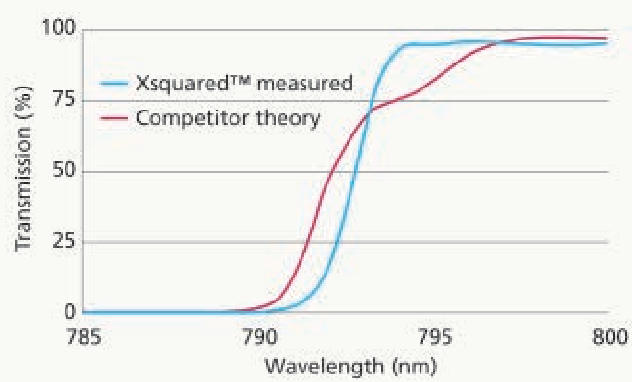


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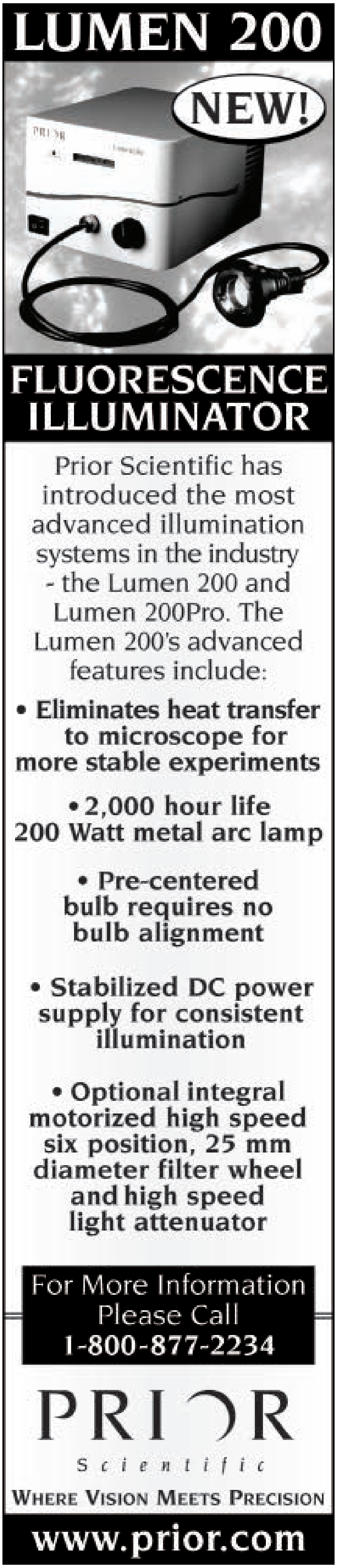





# Quantum dot-based image sensors: A picture of the future?

MENLO PARK, Calif. – After operating in complete secrecy for the past three years, InVisage Technologies Inc. has revealed the reason behind its clandestine behavior: the development of a new type of image sensor material that promises to deliver four times better image quality than traditional silicon-based sensors.

Edward "Ted" Sargent, chief technology officer and lead researcher behind the project, said that the company's QuantumFilm technology will be the first to combine "great imaging" and portability in one system. The Silicon Valley startup plans to provide it to select customers toward the end of the year and expects to see the material adopted into commercial devices by the end of 2011 or early 2012.

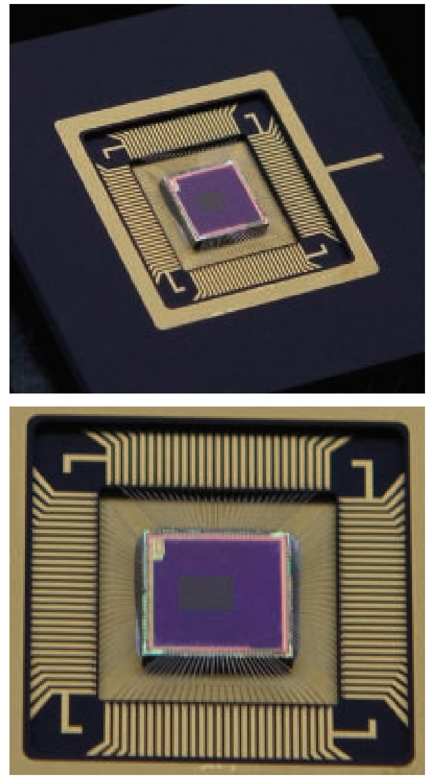
"Our aim was to create image sensors that go beyond the inherent limitations of today's silicon-based sensors and to ultimately deliver cameras that provide dramatically enhanced sensitivity and resolution combined," Sargent said. "For the last three years, we have kept quiet – not even had a Web site – keeping our heads down to focus on engineering great products. Now that we have succeeded, we are telling the world."

The new sensor material uses quantum dot technology and a simple method of integration that will enable about 95 percent of an image to be captured. Applications include digital photography and video, with the first products expected to be incorporated into camera phones.

Today's digital cameras use CMOS image sensors, with silicon as the light sensor. The problem is that silicon image sensors exhibit light-sensing efficiencies of only about 25 percent; i.e., for every four photons incident on the sensor, only about one is converted into a photoelectron.

The losses result from the fact that silicon is not only a weak absorber of light, but it is also buried beneath layers of metal interconnect wires that serve to obscure half of the pixel area. This is known as the fill factor problem and accounts for an optical loss of ~50 percent.

Such losses mean that it is difficult to take a high-quality image using small devices such as a cell phone camera. To compensate for the lost data, you would need a large piece of silicon.



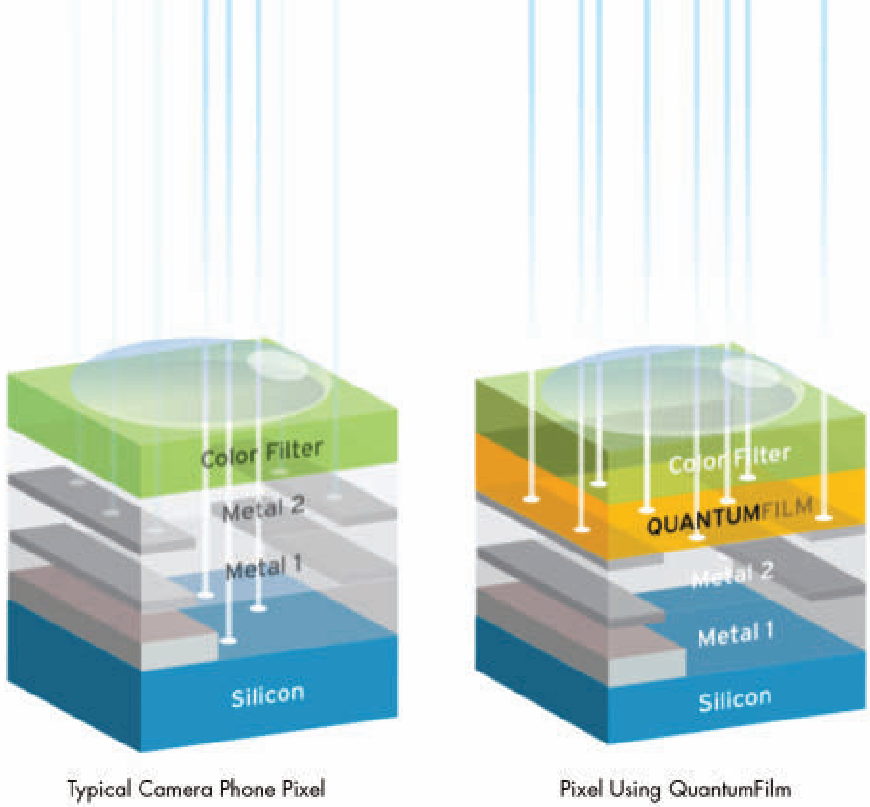
InVisage Technologies' QuantumFilm image sensor, the first using quantum dots, is expected to bring high-quality images to camera phones.

QuantumFilm, however, is spin-coated on top of the silicon wafer so that no lines obscure the pixel area. It also is engineered from the bottom up to be highly light-absorbing (black). Sargent said that all of these properties combined lead to complete conversion of photons to electrons, 100 percent fill factor and an increase in sensitivity by a factor of four.

"Today there are two classes of cameras, those that take great pictures, like digital SLRs, and those that are portable and that we therefore always have with us, like camera phones," he said. "Great photography and superb portability urgently need to be merged into a single solution, and this is what InVisage has enabled."

Because all of InVisage's light conversion is performed using QuantumFilm and not silicon, Sargent said that image quality is only enhanced as pixels shrink in size to accommodate larger megapixel counts.

"The design also means that InVisage can continue to take advantage of silicon's




On the left: Today's pixels capture only about 25 percent of light. InVisage Technologies' QuantumFilm image sensor captures nearly all of the light.

superb electronic properties for all circuit engineering – the crucial analog, analog-to-digital and digital functions our customers expect," he said.

With total worldwide image sensor sales reaching nearly $6 billion in 2009, some believe that QuantumFilm has the potential to capture a significant share of the market as well as to aid market growth through new applications.

"This is an extremely innovative technology. It overcomes a limit imposed by physics that was thought to be impossible to overcome," said Morry Marshall, vice president of strategic technologies at semiconductor marketing and research firm Semico Research Corp. of Phoenix.

"QuantumFilm technology allows a smaller image sensor for a given number of pixels, or more resolution for the same image sensor size. This is particularly valuable for small, handheld devices such as smart phones. It could also increase resolution in digital still cameras."

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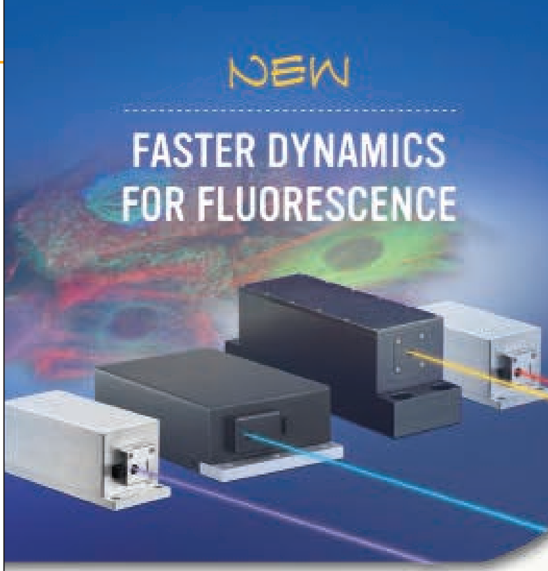
# Quantum sensor sets new limits

BATON ROUGE, La. – Researchers at Louisiana State University (LSU) are taking advantage of the quantum properties of light to design the world's most sensitive optical interferometer. Optical interferometers are used in a vast range of applications, including metrology, surface profiling, microfluidics, mechanical stress/strain measurement and velocimetry.

These instruments operate by combining two or more light sources (typically laser light) so that interference fringe patterns are produced. Information derived from such fringe measurements is used to determine precise wavelength and to measure very small distances and thicknesses.

But rather than using laser sources, which adhere to the general laws of classical physics, the LSU team speculated that using quantum sources would introduce a different set of laws and lead to a

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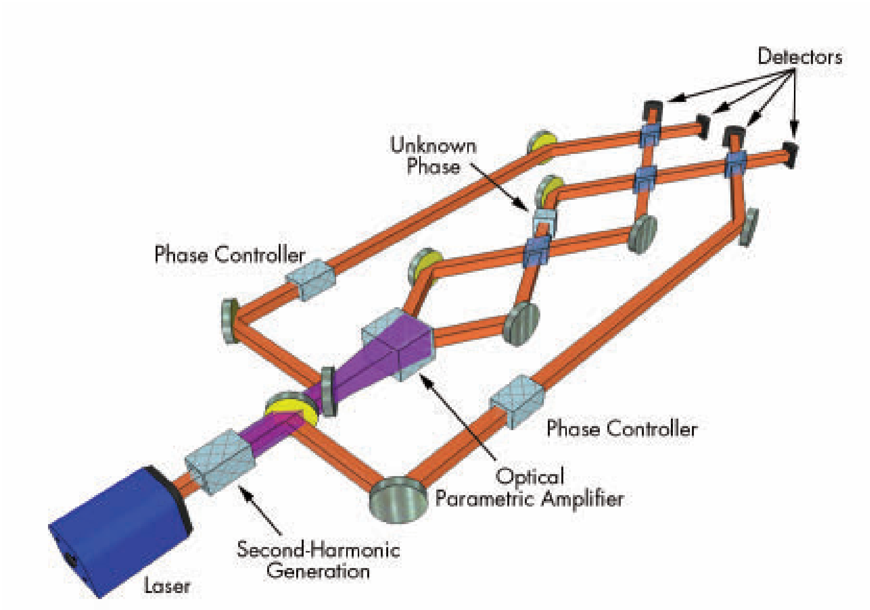
breakthrough in sensitivity.

"It used to be thought that the ultimate limit on sensitivity was set by a scaling law inversely proportional to the square root of the laser power – the so-called shot noise limit," said Dr. Jonathan P. Dowling, Hearne professor of theoretical physics at LSU and lead researcher on the project. "From the 1980s until now, it had become clear that, by exploiting the quantum nature of light, a new limit might be proposed where the sensitivity scales inversely as the laser power – the Heisenberg limit."

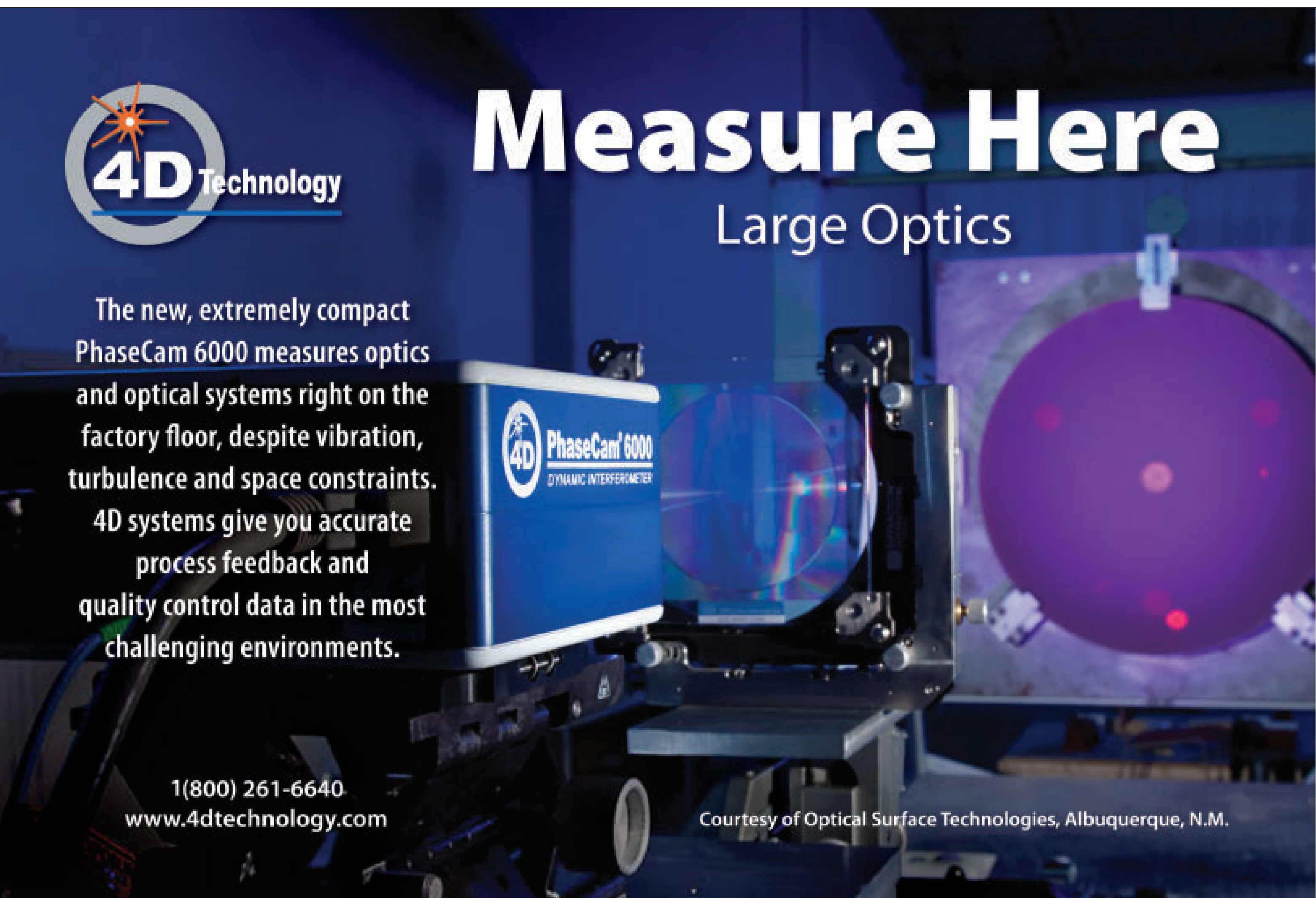
Dowling and colleagues show that a nonclassical light source (two mode-squeezed light sources) combined with a parity detection scheme actually could beat this Heisenberg limit.

"We do not violate the Heisenberg uncertainty principle, but show the connection between the principle and the limit was a bit tenuous and the limit has a little more wiggle room in it to do better than previously thought," Dowling said.

The quantum sensor design is a conventional Mach-Zehnder interferometer but with the classical laser light source replaced with a quantum squeezed light source. Details of the design are reported in a paper published in *Physical Review Letters* in March 2010. In the proposed setup, the classical intensity difference counting is replaced with a more elaborate photon counting scheme. So, although the optics remains the same, the photon source and detection scheme are quantum.




This setup is based on two mode-squeezed vacuum generated in an optical parametric amplifier with parity measurement achieved through coincidence homodyne measurement, thus avoiding photon counting. A Mach-Zehnder interferometer fed with specially prepared squeezed light, with a detection scheme based on a novel double homodyne – which performs parity detection by proxy of intensity-intensity correlations. This device has the ability to beat the Heisenberg limit on phase sensitivity and saturates the Cramer-Rao bound. Courtesy of Petr Anisimov.



The LSU group is already privileged to have access to one of the most sensitive measuring devices on Earth – the large LIGO optical interferometer. The LIGO, or Laser Interferometer Gravitational-Wave Observatory, was set up in 1992 to attempt to directly detect gravitational waves. When a gravitational wave passes through the device, the space time in the local area is altered, resulting in a very slight phase change.

Dowling hopes that the breakthrough quantum sensor could have an array of applications ranging from enhanced gravity wave observations to optical gyroscopes and commercial navigation systems.

Researchers at Louisiana State University are exploiting the quantum nature of light to design the world's most sensitive optical interferometer. Courtesy of Louisiana State University.

"This work is a theoretical design for a quantum sensor," Dowling said. "The first step will be to collaborate with our experimental colleagues at other universities to do an experimental proof of principle. This will be followed by investigations into commercial applications such as magnetometers or gyros."

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## X-ray, meet optical control ...

BERKELEY, Calif. – Researchers have shown that they can control matter directly with intense x-ray beams and can use one beam to control another. The experiments could open the door to new and interesting ways to use x-rays, said Thornton E. "Ernie" Glover of Lawrence Berkeley National Laboratory's Advanced Light Source (ALS), a principal investigator of the study.

The research team – led by Glover, Linda Young of Argonne National Laboratory in Illinois and Ali Belkacem of Berkeley Lab's Chemical Sciences Division – were inspired by previous "optical control" experiments in the visible light regime.

"In those all-optical experiments, a


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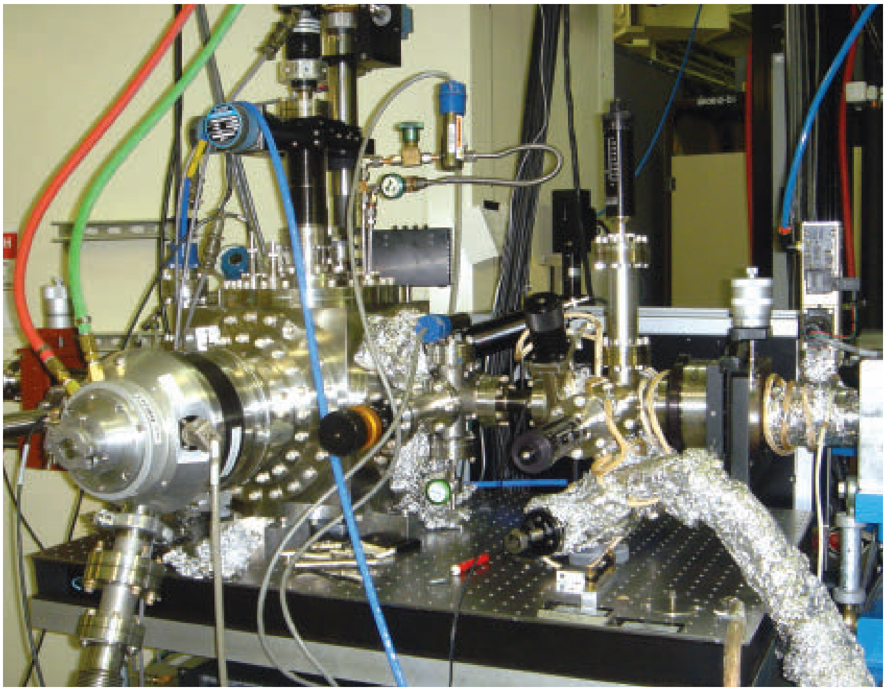
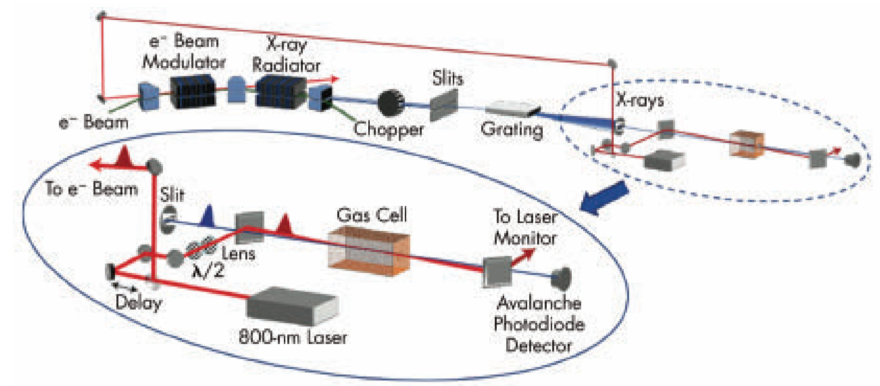


Using the femtosecond spectroscopy beamline 6.0.2 developed at Lawrence Berkeley National Laboratory's Advanced Light Source, investigators have shown that they can control matter directly with intense x-ray beams and can use one beam to control another. These capabilities suggest a range of "new and interesting" ways to use x-rays.




Shown is a simplified sketch of the experiment at the femtosecond spectroscopy beamline. A laser oscillator generates femtosecond pulses that follow two paths. One path interacts with the synchrotron's electron beam to generate femtosecond x-ray pulses; the other (after a delay to ensure synchronization) rejoins the x-ray pulses and co-propagates with them through the gas cell. Courtesy of Lawrence Berkeley National Laboratory.

'control' light pulse manipulates a medium and changes how an optical 'probe' pulse experiences that medium," Glover said. "Our goal was to discover whether similar control techniques could be extended to the x-ray regime: Can light be used to tailor how x-rays interact with matter? If so, what are the limits to such 'optical control'?"

He added that, although the optical control method was introduced more than a decade ago, and others may have considered extending similar physics to the x-ray regime, "actually demonstrating this is an altogether different thing." The experiment required femtosecond x-ray pulses easily tunable over a considerable wavelength range as well as high-power, femtosecond optical laser pulses. Also, significantly, the x-ray and optical pulses had to be synchronized on a femtosecond timescale.

The necessary technological capabilities were first reported at the ALS, where a team developed a beam-slicing technique enabling generation of femtosecond x-ray pulses at a synchrotron. (To date, only two other light sources – one in Switzerland and one in Germany – have implemented the beam-slicing approach to generating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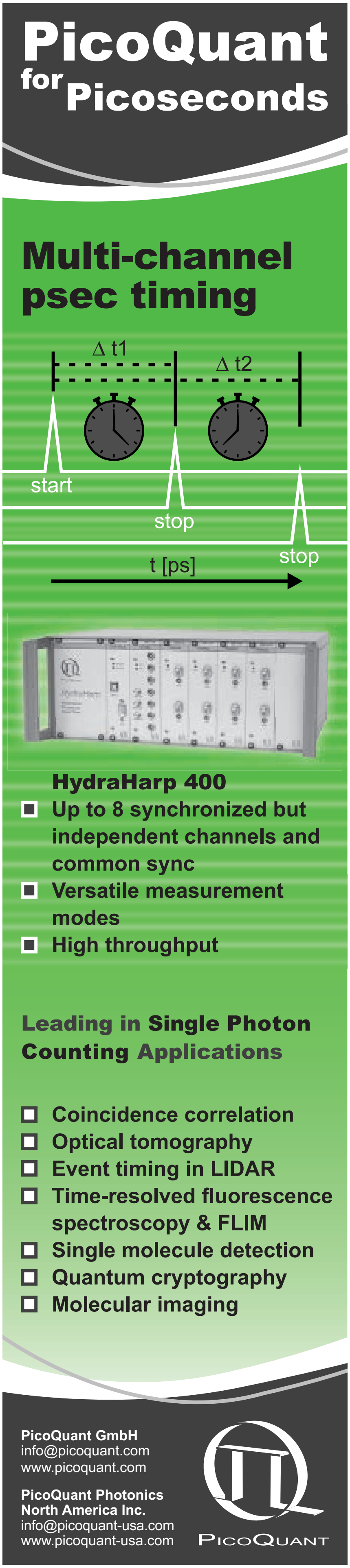


femtosecond x-rays.) Intrinsic to this technique is the availability of high-power optical pulses synchronized to the x-rays on a femtosecond timescale.

Using the ALS' femtosecond spectroscopy beamline 6.0.2, the researchers sent ultrashort laser pulses and higher-frequency x-rays through a gas cell containing pressurized neon. The neon, which normally would absorb the x-rays, became transparent to them when excited by the laser pulses.

Glover – whose group studies ultrafast x-ray science (UXS), the effort to understand and ultimately control the ways in which matter evolves at the atomic and molecular levels – explained why this is significant. First, he said, "both UXS and optical control are relatively new fields and, viewed broadly, the novelty of our study is finding a useful nexus of these two fields."

### Controlling interactions

From the ultrafast x-ray science perspective, the experiment was notable because it employed light in a way fundamentally different from previous studies. Prior experiments focused on using light to put a system in an excited state and x-rays to probe how the system changes. The current study used light to control the underlying x-ray/matter interaction cross section for x-rays passing through matter; also, the material was typically in its ground state.

By controlling the underlying interaction cross section, and thus the ways in which x-rays experience the material, the researchers hope to find new ways to use x-rays. In the current experiment, they used x-ray transparency to measure the duration of femtosecond x-ray pulses by recording the x-ray transmission while moving a femtosecond laser pulse through a femtosecond x-ray pulse. Such an approach to measuring ultrashort x-ray pulses is attractive, Glover said, because the instrumentation used is simpler than the photoelectron spectroscopy-based technique currently used.

An important extension of this, he added, is the ability to shape x-ray pulses on a femtosecond timescale. Combining this ability with the next generation of intense x-ray sources could lead to a range of new research areas, including quantum control in the x-ray regime. Indeed, this represents a possible avenue of investigation for Glover and colleagues, albeit down the road.

"We hope to start thinking in earnest about quantum control with x-rays," he said, "but that will probably wait for a couple of years while the new x-ray FELs [free-electron lasers] come online, and researchers learn how to efficiently perform experiments at these new facilities."

In the near-term, the researchers plan to explore whether light can be used to manipulate the phase of an x-ray pulse, and not just the amplitude, which they have already demonstrated.

"This question is of fundamental interest," Glover said. "If such phase control is possible, it may spawn new applications such as new approaches to making x-ray lenses/optics and possibly even new approaches to how we use x-rays to view matter at the microscopic level."

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# Superwicking with silicon

ROCHESTER, N.Y. – Because most computer chips and transistors are made of the semiconductor silicon, the element is key to the microelectronics industry. A serious barrier with silicon, however, is keeping components cool. Until now, computer chips have been air-cooled, but air's limited capacity to absorb heat has been a hurdle in the quest to design ever-faster computer chips.

That obstacle may soon be overcome, thanks to scientists at the University of Rochester's Institute of Optics, whose research on high-intensity laser-treated silicon has strongly suggested a new way to cool components: using water or volatile liquids. By patterning parallel grooves onto small silicon wafers and testing how the liquids flow over them, they discovered that these liquids are propelled upward in a gravity-defying way described as "super-capillary action" and "superwicking."

The laser treatment renders the silicon superhydrophilic; i.e., the liquid molecules become more attracted to the silicon than to each other. In stark contrast, liquids bead up on the surface of silicon in its normal state. Associate professor of optics


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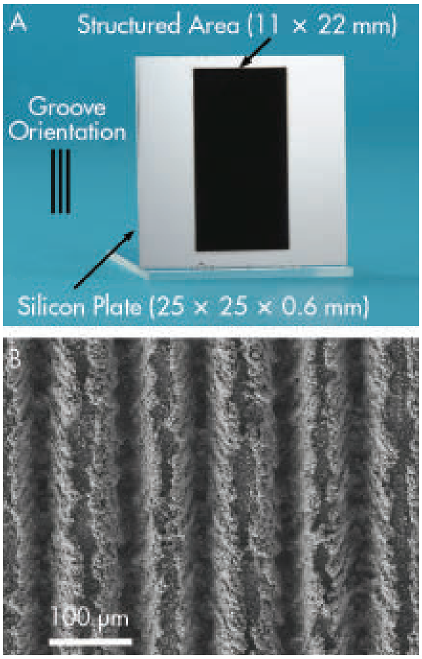


(A) On this silicon wafer, an array of laser-carved parallel grooves appears black. This type of laser treatment would enhance heat absorption and could benefit the solar industry. (B) Shown is a scanning electron microscopy image of microgrooves.

Chunlei Guo and his assistant Anatoliy Y. Vorobyev published their study in the March 15, 2010, issue of *Optics Express*.

## Groovy travels

The researchers used an amplified Ti:sapphire laser to generate 65-fs pulses at a maximum repetition rate of 1 kHz. The beam was focused onto a 25 × 25 × 0.65-mm silicon wafer, creating a 22 × 11-mm array of parallel microgrooves spaced 100 µm apart. Each groove was 22 mm long and approximately 40 µm deep. Magnified microscopy views show that within the microgrooves are nano- and microstructures, and that the nanostructures consist of both nanoprotrusions and nanocavities.

In the pivotal experiment, they placed a wafer on a table at a perpendicular angle and pipetted a droplet of water onto the base of a microgroove. At a top speed of 3.5 cm/s, the water traveled uphill over the groove's 22-mm length, slowing down slightly over time.

Motivating the study was research performed by Guo and Vorobyev a year earlier, using a similar laser patterning technique but with metals – platinum and gold. The outcome at that time was that the patterned surface pumped liquids uphill. Testing the metals for wettability, the investigators found that laser treatment renders the surfaces hydrophilic. The article, titled "Metal pumps liquid uphill," was published in the June 1, 2009, issue of *Applied Physics Letters*.

The results of the 2009 study were a bit of a surprise but a fortunate outcome in terms of silicon development. "Our 2009 study in turning metals superphilic was a bit unexpected, but we were determined to work on silicon afterwards," Guo said.

He anticipates that the superwicking technique may find numerous applications, including nano-/microfluidics, lab-on-a-chip technology, chemical and biological sensors, and solar cells.

As for the future, Guo said, "We plan to further study the fundamental mechanisms behind our observation. We also would like to look into applying our technique in real-life applications."

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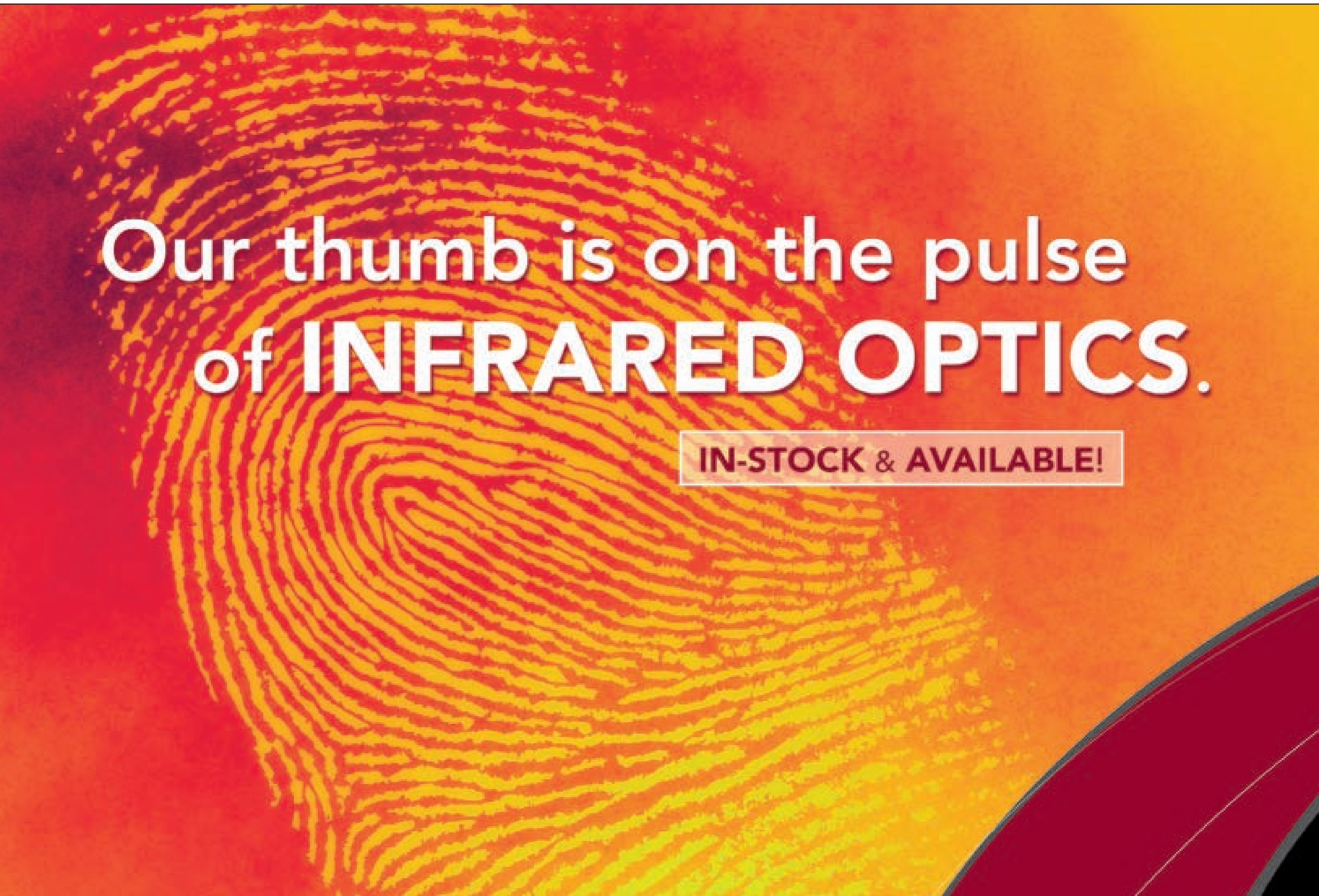


# A new twist on moving matter with light

ANN ARBOR, Mich. – Light can bend rigid structures, at least on a microscopic scale, researchers report. Light-driven twisting of tiny ribbons could someday be used for negative refractive index materials, in microelectromechanical systems (MEMS), or for lithography on a scale between the macro- and the micro-worlds.

"Twisting changes the physical dimensions of the ribbons, such as their length," said lead investigator Nicholas A. Kotov, a chemical engineering professor at the University of Michigan. "This gives a possibility for changing the topology of the surface and a lithographic pattern similar to the Braille font."

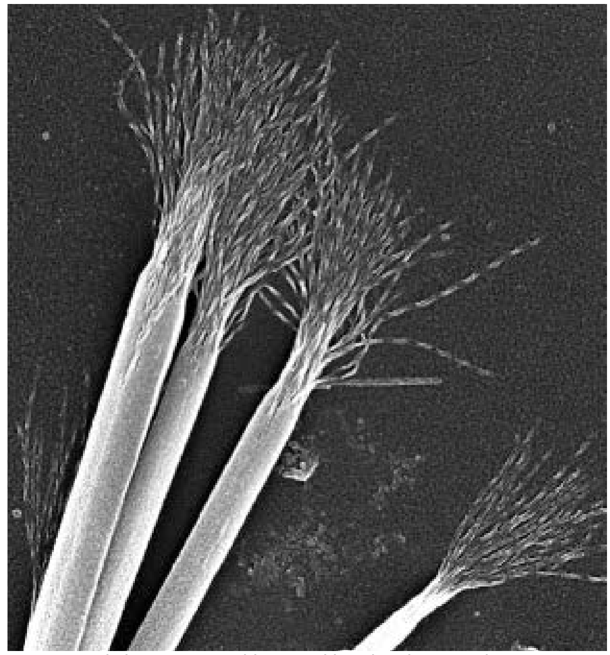
Previously, the largest objects known to be physically affected by light were molecules. The new research showed light twisting ribbons thousands of times bigger.

According to Kotov, the discovery was accidental. The researchers were examining the self-assembly of nanoparticles, with the idea that this might be a way to produce metamaterials with a negative refractive index or other unusual properties.

## Tangling

To this end, they put cadmium telluride nanoparticles, which have an emission maximum of 550 nm, in water. They selected these particles as a research vehicle in part because they have permanent dipoles, or pairs of equally strong charges. They created the nanoparticles in such a way as to have a higher than average dipole and chemical reactivity, both of which affect interparticle forces.

The slow oxidation of



Exposure to light twists nanoribbons and bunches them together. Courtesy of Nicholas Kotov, University of Michigan.

the tellurium ions led to the formation of cadmium sulfide/cadmium telluride nanocrystals. Within three days, the orange color of the original solution turned a dark green, indicating the completion of nanoparticle self-assembly.

The resulting structures, the researchers found when they examined them using electron microscopes, were helical ribbons. While typically from 0.8 to 2 μm long, some were as long as 8 μm. Atomic force microscopy showed that the ribbons were only 10 to 12 nm thick and composed of three to four nanoparticle layers stacked atop one another.

When the group started to unravel why the twisting occurred, they found something unexpected. Self-assembly that took place in the dark resulted in long, flat ribbons, not twisted ones. When those straight ribbons were exposed to ambient light, however, they formed dog-bone shapes and other complex structures. With enough exposure, they curled into either a right- or left-handed helix, with an equal chance of transforming into one or the other. No matter the handedness of the helix, increasing the intensity of the light increased the twist.

This result was very surprising, Kotov said. It took several years, extensive experiments and painstaking computer simulations by his collaborator Sharon Glotzer to understand how light can twist such a relatively large rigid structure.

### Unravelling?

The key is the effect of the photons on the forces acting between the nanoparticles. During the initial phase of the self-assembly, the attraction between nanoparticles is weak, and the results are spherically shaped aggregates. Light increases the dipole interaction between the nanoparticles, effectively boosting the repulsion between them. Relieving this strain leads to the intermediate shapes and, finally, to a twisted ribbon.

At the moment, the induced twist is permanent. However, it should be possible to create dynamic constructs, given the right combination of nanoparticles and the appropriate media.

Indeed, Kotov reported that one of his group's research objectives now is the creation of structures that twist and untwist with light. That could then lead to MEMS devices that turn like propellers, do other mechanical work or act like motors under the right lighting conditions. This physical change also could be used in lithography.

Another important point is that this work shows that particles can form structures as complex and intricate as those formed by biomolecules, something that could be of research interest. "Some proteins can form these helical structures, and we are investigating this analogy," Kotov said.

Kotov's group included investigators from the University of Leeds in the UK, Chungju National University and Pusan National University in South Korea, Argonne National Laboratory in Argonne, Ill., and Jiangnan University in China. They reported on their work in the March 12, 2010, issue of *Science*.

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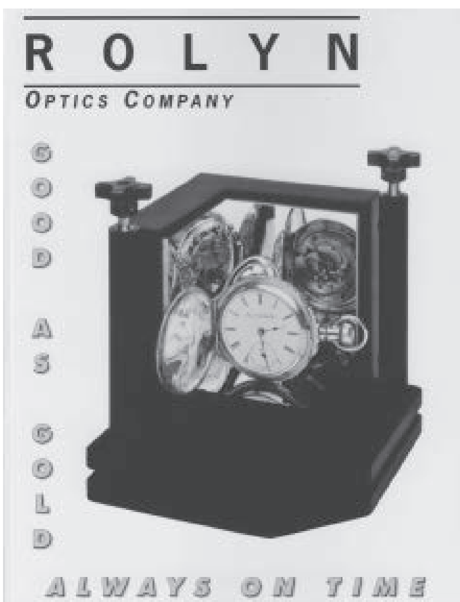


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# Igniting a few good ideas with fullerenes

GAINESVILLE, Fla. – A standard TV trope is the fuse made of a strand of gunpowder slowly burning while heading toward a pile of powder kegs and bundles of dynamite. This fire-starting scenario does, in fact, work, although nobody really does it that way. However, researchers at the University of Florida recently demonstrated a new laser-based technique that could take this principle to a different – and much tinier – level.

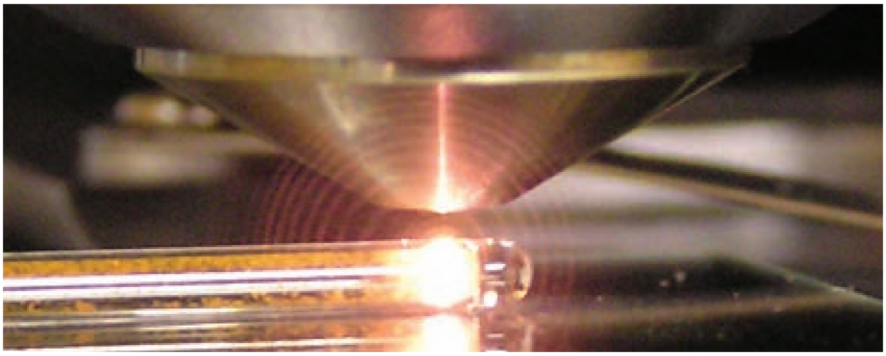
Vijay Krishna, a postdoctoral associate at the university, and his colleagues knew that one could heat carbon nanostructures to the point of ignition by irradiating them with laser light. Causing carbon nanoparticles to ignite might offer useful medical, chemical and mechanical applications, but the particles by themselves have raised questions regarding their biological and environmental safety. Krishna and his team – Nathanael Stevens, Ben Koopman and Brij Moudgil – decided to explore how carbon fullerenes combined with hydroxyl and carboxyl functional groups – which are known to be safer – would react to similar heating.

As they report in the online edition of *Nature Nanotechnology*, functionalized carbon nanoparticles perform very well as ignition materials, using surprisingly low laser intensity.

Using a 785-nm laser made by B&W Tek Inc. of Newark, Del., the investigators trained a diffuse beam at several forms of the nanoparticles, including unadulterated fullerene, fullerene bromide, fullerene hydride, polyhydroxy fullerene and carboxy fullerene, as well as plain granular activated carbon. The nonfunctionalized nanoparticles and the macroscale carbon failed to ignite at laser intensities up to 90 kW/cm$^2$. In contrast, the functionalized particles reached their ignition points with intensities in the 0.3- to 15-kW range.

Pristine fullerenes are symmetrical carbon cages that are difficult to alter using low-power irradiation. According to Krishna, adding functional carboxyl and hydroxyl groups distorts the cages, straining the structures. Irradiation by laser cleaves these functional groups and releases the stored energy inside the strained portions, he said.

The released energy comes in the form of heat and light. When irradiated in a vacuum, the fullerene bromide in particular exhibited impressive light emission for up to 10 seconds before turning into a black residue. With all of the functionalized materials, the gap between the start of the beam and the emission of light from the irradiated particles was less than 10 ms, indicating that the cleavage of the functional groups is an ultrafast process that may be exploited in the future.



Irradiating functionalized fullerenes with a 785-nm laser produces heat and light emissions. Photos courtesy of Vijay Krishna, University of Florida.

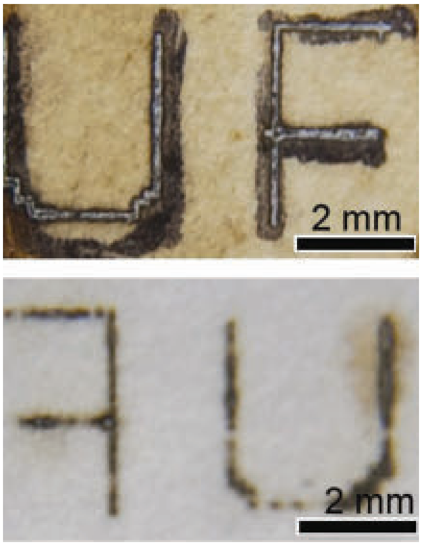
Thus far, Krishna and his colleagues have tested the utility of the functionalized nanoparticles in igniting explosive materials, in treating cancer cells and in lithography.

Using the same 785-nm beam, they ignited carboxy fullerenes that were in contact with the same explosive used in blasting caps. They could instantaneously set off the traditional blasting material using a 1-W beam, which provided an intensity of less than 10 W/cm$^2$. In total, using the low-power laser requires less energy than using a traditional electrical charge for detonations performed in tunneling or demolition.

For cancer treatments, the technique shows promise because functionalized fullerenes can be readily taken up by tumor cells. Once heated via laser, the nanoparticles explode, ripping the cells apart.

"The photothermal and photoacoustic properties of polyhydroxy fullerenes make them attractive for cancer therapy," Krishna said. "Furthermore, these molecules are biocompatible and are rapidly eliminated from the body."

The group also believes that the ignition process could be used in finely detailed lithography. They tested this by coating paper samples with hydroxy fullerenes, then scanned them with the laser, thereby "writing" on them with the resulting residue. Because the particles are about 1.3 nm in size, lithographical features likely would be restricted only by the beam width.




Optical micrographs show the initials "UF" inscribed with a 785-nm laser on paper that has been coated with polyhydroxy-functionalized fullerenes.

According to Krishna, his group envisions a multitude of other possible applications for functionalized fullerenes, including high-density data storage, laser-based spark plugs, room temperature hydrogen storage and release, and low-energy, catalyst-free synthesis of carbon nanoparticles.

The next step is to verify and improve the process, Krishna said. The group will expand from there.

"Further challenges are to explore the complete spectrum of electromagnetic radiation to find which bands interact with functionalized fullerenes and [to] optimize the molecular structure for various applications."

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# Laser cutting machine industry: Versatility is key

HAMBURG, Germany – The world market for laser cutting machines is expected to exceed \$3.8 billion by the year 2015, according to a report from Global Industry Analysts Inc., based in San Jose, Calif. Released in February 2010, the publication is titled *Laser Cutting Machines: A Global Strategic Business Report*. Manufacturers of the machines are under pressure to increase productivity because of growing globalization, according to the company. Integrating computer-aided design and manufacturing software is viewed as key to international competitiveness.

The report notes that manufacturers have focused on developing lasers that deliver more power at lower cost, resulting in the 200- and 400-W models that are now widely available and that enable faster cutting in select applications. The laser beams produced by the laser cutting systems are now better shaped, enabling galvo cutting machines to steer beams at faster rates while providing suitable cutting quality.

Laser cutting machine manufacturers are working toward making their machines adaptable to materials of various thicknesses for niche jobs, where lot sizes differ according to job order, according to the report.


The TruLaser 1030 laser cutting machine from Trumpf is suitable for use by entry-level fabricators and OEMS that manufacture in small batches. Photo courtesy of Trumpf.

## Fiber and $CO_2$ lasers

Founded in 1975, Rofin-Sinar Laser GmbH of Hamburg has delivered lasers for the cutting industry since 1982. “We offer $CO_2$ and fiber laser sources to our OEM partners, integrating them into their machines,” said Markus Rütering, product manager of laser sources at the company. The amount of laser power used has been up to 5 kW in recent years, he said, adding that customers are getting more specific in their choice of lasers and that it is important for them to ask the right questions to make sure that they obtain the best laser for their jobs.

“All in all, the $CO_2$ lasers are dominant in the market in terms of numbers, even with fiber lasers winning some market share,” Rütering said. He commented that fiber lasers would likely gain a 25 percent share of the market. “As long as fiber lasers are priced as they are today, and as long as they are limited in stainless steel cutting to approximately 3 mm or 8 mm (high- and standard-quality cuts, respectively), they will not overtake the cutting market. Fiber lasers are also used for cutting brass and copper, but the number of jobs involving these materials is small,” he said.

Fiber lasers are well accepted for jobs cutting thinner metals, and they have the advantage of easier beam delivery. They have some limits in cutting thicker materials, need a more sophisticated approach for safety enclosures and are still more expensive compared to $CO_2$ lasers, Rütering added.

The $CO_2$ laser will likely remain the technology for cutting all thicknesses in steel and aluminum, as well. The DC series diffusion-cooled $CO_2$ slab lasers from Rofin’s Hamburg factory are offered from 1 to 5 kW for cutting applications. Approximately 5000 of the DC lasers are installed in cutting systems on a global scale, Rütering said.

They are complemented by the SC series 100- to 600-W lasers from the company’s UK-based factory. These are also showing a record 5000 shipped units, most in cutting as well. The lasers are used in all sheet metal applications, dieboard as well as the transparent thermoplastic, poly(methyl methacrylate) and other plastics.

Overall, Rütering predicts that laser cutting systems will become more dynamic and the linear axis will be used more often. “As for challenges, the market share can be improved if performance is increased for the same price. Basically, it is price vs. performance, compared with other established technologies such as plasma and flame cutting,” he said.

## Application-specific machinery

“In terms of major trends in the industry, flexibility and efficiency are going to be the determining factors for success in any business field,” said Stefan Schreiber, product manager at TruLaser Group, Trumpf Inc., headquartered in Farmington, Conn.

“For laser cutting, this means the cost-per-part is what users are really looking at, and this will drive technology and applications. A producer of $CO_2$ laser, disk laser and fiber laser sources, Trumpf has positioned itself to serve this market demand,” Schreiber said. He explained that the field of applications for disk and fiber lasers is similar; they both use a 1-μm wavelength.

Schreiber predicts a trend toward new

machines that will meet specific requirements for specific applications – and that there will be less emphasis on developing a single machine with many capabilities, as has been the practice in the past.

"The primary challenge has been, and remains, the ongoing quest to develop ever more innovative technology and machines, including supportive CAD/CAM systems and calculation modules to help fabricators create cost-efficient parts."

### Technical developments

"Getting from a drawing to a cost-effective finished part in as little time as possible is the challenge for every fabricator," said Schreiber, adding that integrated software functions such as Trumpf's TruTops Unfold are used to convert complex 3-D sheet metal designs into production-ready 2-D views. "In addition, single-cutting-head technology in a machine eliminates head changes and reduces the potential for operator error. Automatic nozzle changers support that even more. Higher levels of automation reduce manual intervention during the production process, allow for cost savings and lights-out fabricating – resulting in a more streamlined and efficient operation."

With its single-cutting-head strategy and a 5-kW $CO_2$ laser, Trumpf's "workhorse" TruLaser 3030 is designed to increase productivity and flexibility when cutting sheet thicknesses up to 25.4 mm. The machine's long X-axis works with a maintenance-free gearless torque motor, while the Y- and Z-axes are driven by linear axis motors, which increase the simultaneous axis speeds from 8499 cm/min to 14,001 cm/min, according to the company. The FastLine process, now a standard feature, generates a flow transition between the piercing and cutting processes, reducing processing times by an average of 20 percent in thin sheets, Schreiber said.

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**Scholarship Grant** Piezosystem Jena Inc. of Hopedale, Mass., has awarded a $1500 scholarship to Andre Denio of California State University, Northridge, to support his research into developing computer algorithms that control piezoelectrically driven mirrors. The mirrors are part of an adaptive optical system being developed for ground-based telescopes.

**Sensor Business Acquisition** Pepperl+Fuchs of Mannheim, Germany, has agreed to acquire the binary proximity sensor business of Siemens Industry Automation Div. of Nuremburg, Germany. The agreement is expected to be finalized June 30, 2010, and Siemens will continue to accept, support and execute all orders for proximity sensors until the transfer is completed.

**Systems Order** Dionex Corp. of Sunnyvale, Calif., has announced that it has won a tender order for 42 units of its ICS-1100 system from the Polish Environmental Inspectorate. The new units will be used in environmental labs throughout Poland for analysis of inorganic anions in water and air samples. The inspectorate will now own 76 of Dionex's integrated circuit instruments.

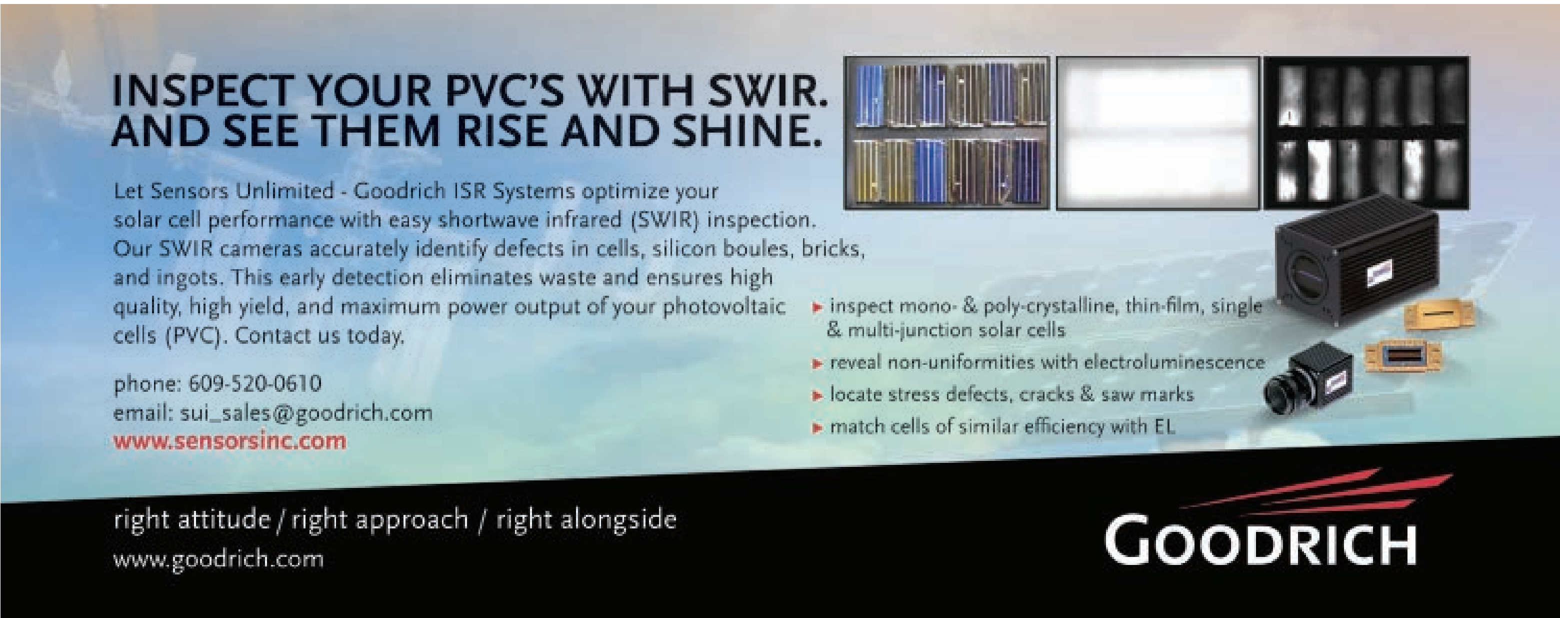
**Support Network** San Diego-based Filmetrics Inc. has announced the opening of film thickness measurement application labs in Tainan, Taiwan and Munich, Germany. Providing headquarters for film thickness support in Asia and Europe, each lab is tied into the company's support network to provide immediate Internet and voice response for its customers. The two labs complete its 24-hour worldwide support network, which combines real-time video, remote diagnostics and online "hands-on" capabilities.

**Wafer Manufacturing** Schott AG of Mainz, Germany, has announced that its electronics and biotechnology center is setting up a wafer line at its plant in Penang, Malaysia, to meet the demands of the market and to better serve its Asian customers. The line is expected to be in operation by summer.

**European Group Formed** At the fourth Photovoltaic Fab Managers Forum, Semi PV Group Europe, a special-interest organization that serves the photovoltaic (PV) supply chain, announced the formation of the European Crystalline Cell Technology and Manufacturing Group. Consisting of eight crystalline solar cell manufacturers – Q-Cells, Deutsche Cell, Bosch Solar Energy, Schott Solar, Sovello, Sunways, SolarWatt/Systaic Cells and Solland – the group plans to address the technology challenges facing the PV industry. It has established a crystalline solar cell technology road map up to the year 2020.

**Metrology System Implementation** QED Technologies of Rochester, N.Y., an exclusive provider of magnetorheological finishing and subaperture stitching interferometry, has announced implementation of one of its aspheric stitching interferometers at Leibniz Institute for Surface Modification (IOM) in Leipzig, Germany. The new interferometer will enable IOM to develop surface figuring and finishing steps that produce surfaces with accuracies in the nanometer range. The instrument will be used specifically for precision fabrication and measurement of aspheres.

**$16 M Order** Following a large traffic safety order announced at the beginning of March, Jenoptik AG of Jena, Germany, has received another major order to deliver lasers for medical use to a US-based client. The $16 million



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order covers a period of three years and will be fulfilled by Jenoptik's Lasers & Material Processing Div., one of five operated by the optoelectronics group.

**Distribution Partnership** Rudolph Technologies Inc. of Flanders, N.J., has selected the John P. Kummer Group to distribute its probe card test and analysis products in Europe. The partnership was established in anticipation of growing demand as the semiconductor manufacturing industry continues its recovery and manufacturers look for new methods to reduce cost and optimize test process performance.

**Satellite Launched** CCD imaging sensors manufactured by e2v were launched into space by NASA from Cape Canaveral, Fla. in early March 2010 onboard a Delta IV rocket, which carried the National Oceanic and Atmospheric Administration's Geostationary Operational Environmental Satellite-P (GOES-P). It supplied 20 flight model and 20 engineering model CCDs for the SXI instruments on GOES-N, O and P. Designed and built at the Lockheed Martin Space Systems Advanced Technology Center, e2v worked with University College London's Mullard Space Science Laboratory and Lockheed on the design, characterization and supply of the sensors for the program.

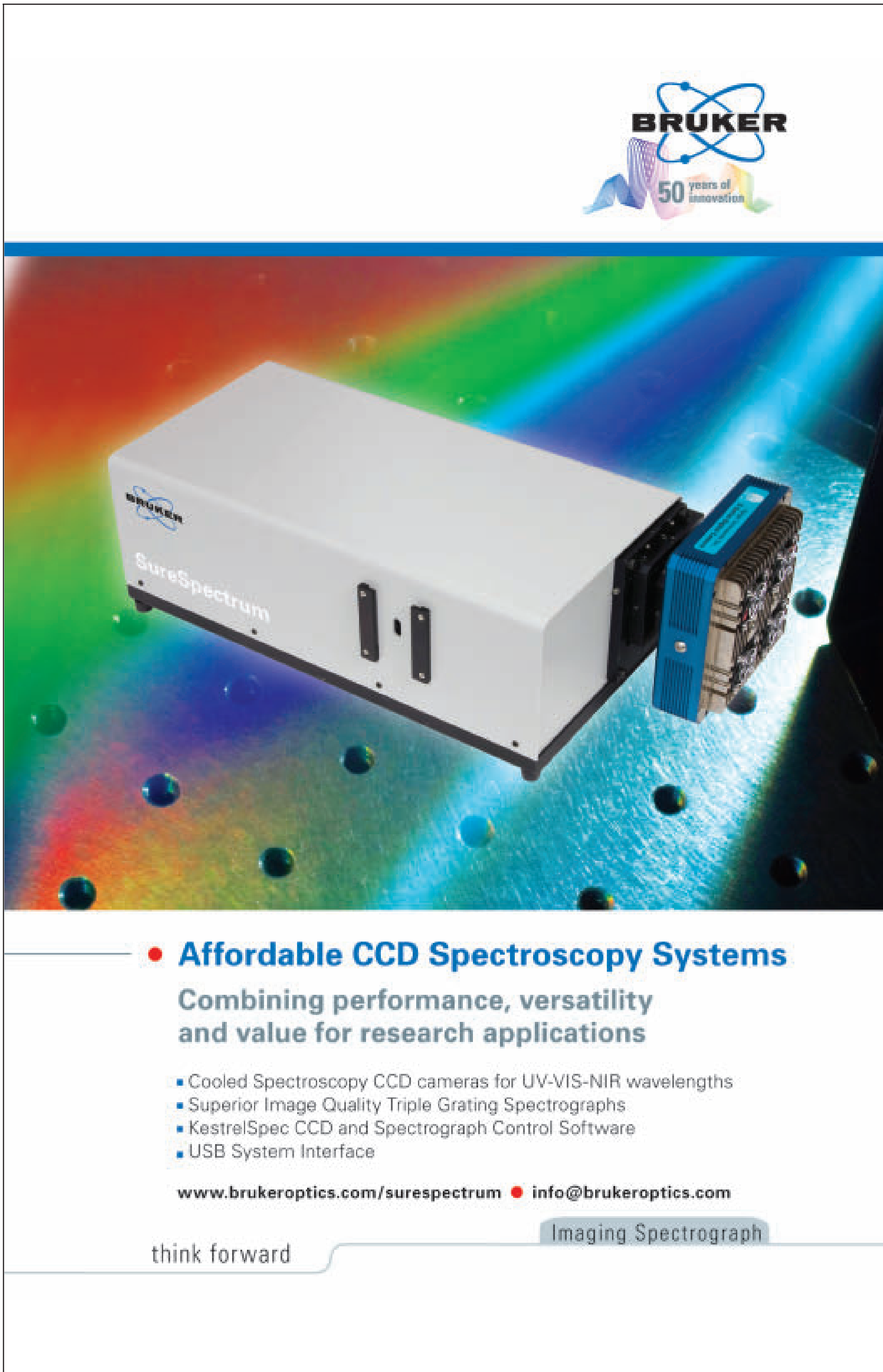
**West Coast Partnership** Hexagon Metrology Inc. of North Kingstown, R.I., a metrology equipment and software provider, has entered into a strategic distribution partnership with Ellison Technologies Inc., a computer numeric control machine tools and metal cutting solutions distributor. The latter company of Santa Fe Springs and Berkeley, Calif., has become the authorized distributor of the former company's products used in quality control applications for manufacturing. The partnership will allow both companies to more effectively serve the requirements of the manufacturing community throughout the western US, particularly in the aerospace, defense, automotive, energy, wind power and heavy machinery markets.

**Lithography System Selected** Yale University of New Haven, Conn. has selected Vistec Lithography Inc.'s EBPG5000plus electron-beam lithography system for its future nanotechnology research programs. As part of the Yale Institute for Nanoscience and Quantum Engineering, it will encourage multidisciplinary research involving the university's faculty, students and worldwide research partners. The company, of Watervliet, N.Y., is a provider of electron-beam lithography equipment based on shaped beam technology.

**$9 M Funding** APIC Corp. of Los Angeles, an integrated silicon photonics components developer, has announced that the Naval Air Systems Command (NAVAIR) has released $9 million in funding for Phase IIC development of Network Enabled by WDM Highly Integrated Photonics, a program jointly funded and managed by DARPA and NAVAIR. The program's focus is to research and develop advanced integrated electro-photonic components for the introduction of fiber-optic local area networks aboard tactical military aircraft.

**Follow-On Order** St. Florian, Austria-based EV Group, a wafer bonding and lithography equipment supplier, has announced that Morocco-based wafer-level camera manufacturer Nemotek Technologie has placed a repeat order for its bonding and UV nanoimprint lithography systems – the EVG520IS and IQ Aligner. The latter company will use the systems to address its production demands for CMOS imaging sensors and wafer-level optics deployed in wafer-level cameras for mobile applications.

**Telescope Donation** To educate students about science, optics and astronomy, the OSA Foundation has established a program to donate hundreds of telescopes to students in the Milwaukee area. Through a partnership with the Institute for the Transformation of Learning and a grant from the Greater Milwaukee Foundation, the foundation will donate nearly 500 "Galileoscopes" as well as books and DVDs about Galileo Galilei and astronomy to six local middle, junior high and high schools as part of its program called the Galileoscope Challenge.



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# Frog's foam fashions fuel

BY KRISTA D. ZANOLLI
CONTRIBUTING EDITOR

With the inevitable decline of fossil fuels, the race is on to discover renewable energy solutions. As an alternative, researchers from the University of Cincinnati have found a way to convert solar energy and carbon dioxide into sugars to create new forms of biofuel.

The natural process of photosynthesis involves plants taking energy from the sun and carbon from the air and converting them into sugars. It's those converted sugars that make biofuels like ethanol and bioethanol viable alternatives to fossil fuels. The problem is that the cost of growing and processing crops for biofuel production reduces efficiency rates to as low as 5 percent.

The researchers now say that they have fashioned an artificial photosynthetic material that can convert solar energy and carbon dioxide into sugars with an efficiency rate approaching 96 percent. And, oddly enough, they owe their inspiration to the nesting habits of a subtropical frog – the Tungara.

The female Tungara generates a resistant biofoam nest to protect her fertilized eggs from sunlight, temperature and pathogens until the eggs hatch. The foam is effective because it allows light and air to penetrate while still concentrating the reactants. The foam nests are also resistant to bacteria and fungus and can last up to two weeks. Similarly, the artificial photosynthetic material, which uses plant, bacterial, frog and fungal enzymes trapped within a foam housing, produces sugars from sunlight and carbon dioxide.

The artificial material's major foam-forming ingredient is the Tungara frog's surfactant protein Ranaspumin-2. Unlike chemical detergents, the Rsn-2 protein surfactant enables foam formation in low concentrations without disrupting cell membranes.

According to the study published online in *Nano Letters*, the foam converts light into adenosine triphosphate or ATP (considered the major energy currency of a cell) and then carbon dioxide into sugar using the Calvin-Benson-Bassham cycle. The ATP synthesis is initiated by the lipid vesicles' exposure to green light.

University of Cincinnati researchers are finding ways to take energy from the sun and carbon from the air to create new forms of biofuel, thanks to a semitropical frog species. Courtesy of the University of Cincinnati.

"The advantage for our system compared to plants and algae is that all of the captured solar energy is converted to sugars, whereas these organisms must divert a great deal of energy to other functions to maintain life and reproduce," said David Wendell, research assistant professor and co-author of the study, along with Carlo Montemagno, dean of the college of engineering and applied science, and student Jacob Todd. "Our foam also uses no soil, so food production would not be interrupted, and it can be used in highly enriched carbon dioxide environments, like the exhaust from coal-burning power plants, unlike many natural photosynthetic systems."

Wendell added that too much carbon dioxide shuts down photosynthesis in natural plant systems, "but ours does not have this limitation due to the bacterial-based photocapture strategy."

"The system that we have takes carbon out of the atmosphere and uses the sunlight to go and remold the molecules into a fuel – so it's carbon neutral," said Montemagno in an interview with Cincinnati public radio station WVXU. "I think the features of what we've done allow it to be scalable and commercially deployed. For me the real underlying advantage of this is that we're demonstrating that we are able to incorporate life processes and make it intrinsic, and that's what is really magical about this."

"You can convert the sugars into many different things, including ethanol and other biofuels," Wendell said. "And it removes carbon dioxide from the air but maintains current arable land for food production."

"This new technology establishes an economical way of harnessing the physiology of living systems by creating a new generation of functional materials that intrinsically incorporates life processes into its structure," Montemagno said. "Specifically, in this work it presents a new pathway of harvesting solar energy to produce either oil or food with efficiencies that exceed other biosolar production methodologies. More broadly, it establishes a mechanism for incorporating the functionality found in living systems into systems that we engineer and build."

The team says the next step will be to try to make the technology feasible for large-scale applications like carbon capture and coal-burning power plants.

"This involves developing a strategy to extract both the lipid shell of the algae (used for biodiesel) and the cytoplasmic contents (the guts), and reusing these proteins in foam," Wendell said. "We are also looking into other short carbon molecules we can make by altering the enzyme cocktail in the foam."

"It is a significant step in delivering the promise of nanotechnology," Montemagno added.

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# Leaves teach technical lessons

BY CAREN B. LES
NEWS EDITOR

Scientists have introduced a design for an artificial inorganic leaf that can capture solar energy and use it efficiently to change water into hydrogen fuel, an environmentally friendly alternative to nonrenewable fossil fuels such as coal, oil and natural gas. Some predict a "hydrogen economy," perhaps beginning with a broader acceptance of hydrogen-fueled cars – if a cost-effective way to produce hydrogen is devised. Hydrogen, when burned, emits water vapor. In contrast, fossil fuels, when burned, emit carbon dioxide, a greenhouse gas associated with climate change and other environmental concerns.

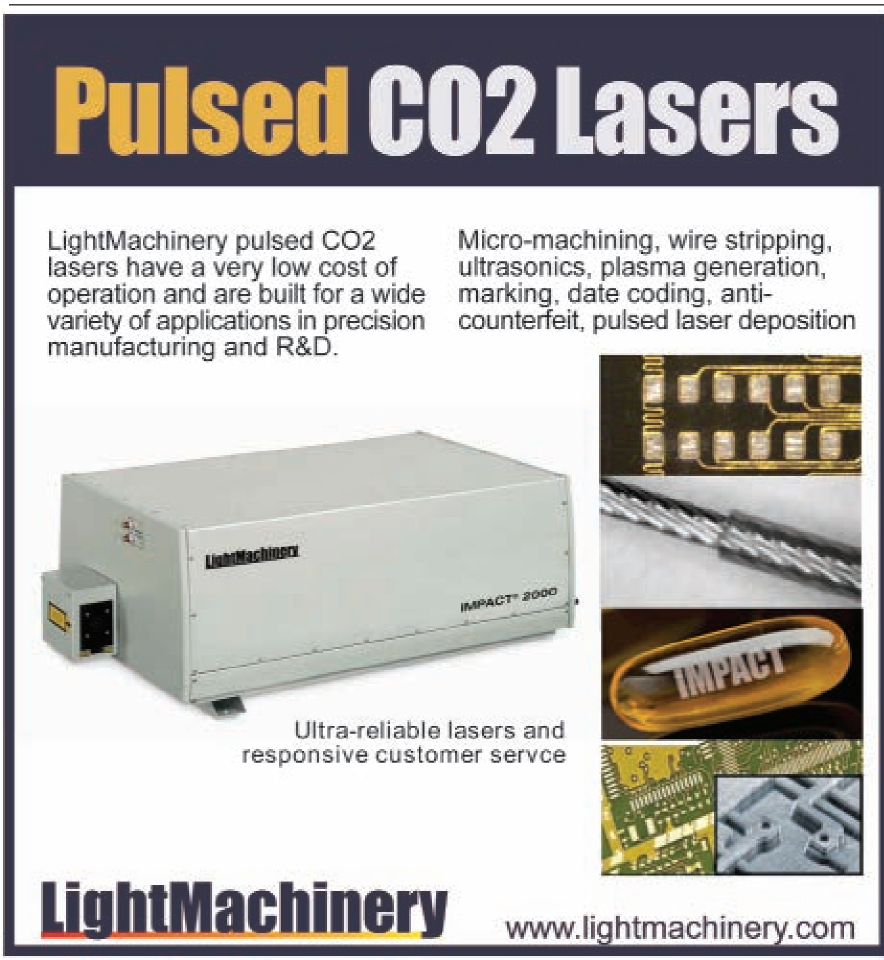
With their high light-harvesting efficiency, leaves use sunlight to split water into its components, hydrogen and oxygen, in the photosynthetic process. The green plant will produce biohydrogen (NADP, a kind of compound of hydrogen) and oxygen, not a pure hydrogen.

Dr. Tongxiang Fan and his colleagues at State Key Lab of Metal Matrix Composites at Shanghai Jiaotong University have closely observed the natural structure and function of leaves and applied their knowledge to design artificial leaves with enhanced light-harvesting functions to take advantage of the renewable resource of solar energy.

"Using natural leaves as biotemplates, we developed an artificial inorganic leaf by organizing light-harvesting, photo-induced charge separation and catalysis modules (platinum/nitrogen-titanium dioxide) into leaf-shaped hierarchical structures. The enhanced light-harvesting and photocatalytic water-splitting activities are due to the reproduction of the leaf's elaborated structures and self-doping of nitrogen during synthesis," Fan said.

Using titanium dioxide, a single component catalyst, as a prototype, the researchers demonstrated the successful structural design for improved photocatalytic activity based on the structures of biological systems. Titanium dioxide is a photocatalyst for hydrogen production.

They found that the absorbance intensi-



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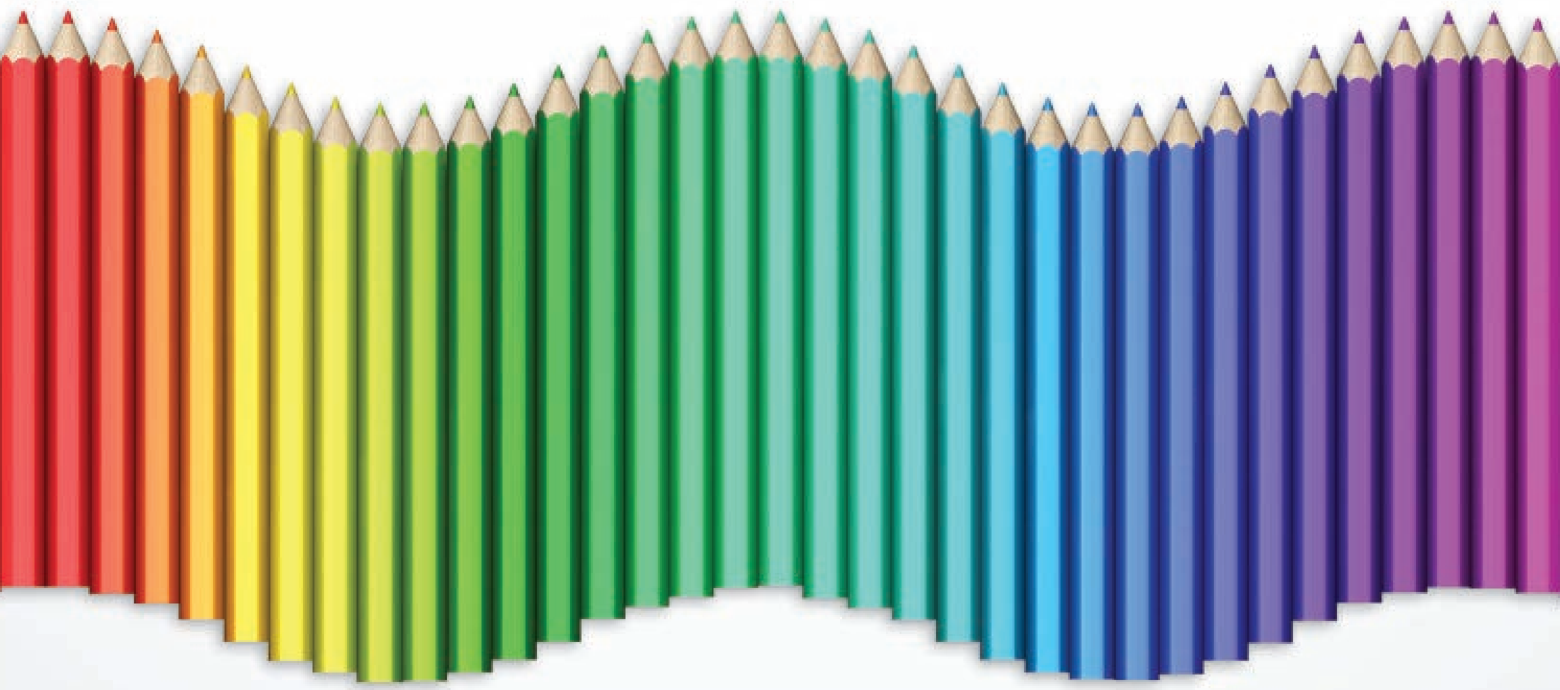

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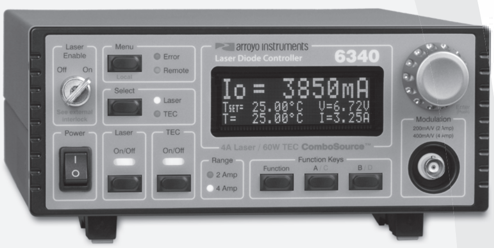


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ties within the visible light range of artificial inorganic leaf and titanium dioxide increased by 200 to 234 percent, and that the bandgap-absorption onsets at the edge of the UV and visible ranges showed a redshift of 25 to 100 nm, compared with those in titanium dioxide without the biotemplate. Activities of artificial inorganic leaf/titanium dioxide are eight times higher than titanium dioxide synthesized without templates and 3.3 times higher than P25, a commercial catalyst with high activity, Fan said.

"The research may represent an important first step towards the design of novel artificial solar energy transduction systems based on natural paradigms, particularly on mimicking the structural design. The work could be a real breakthrough suggesting an important – and uncommon – preparation strategy to obtain an active photocatalyst for water splitting, and opening new perspectives in this strategic area of modern research," he added.

Actually, all biomass, such as agricultural and algae wastes, could be used as resources for the fabrication of functional materials with photocatalytic water splitting and photocatalytic degradation activities such as artificial leaves, Fan said.

### Form and function

Artificial inorganic leaves have structures similar to the natural leaf from the macro- to the micro- and nanoscales. They have the appearance of leaf-shaped inorganic films, with the thickness of tens of micrometers, he said.

For micro- and nanostructures, the artificial leaves replicate the hierarchical structures of natural leaves, including the lenslike epidermal cells, the veins' porous architectures, the differentiation of leaf mesophyll into palisade and spongy layers, and the three-dimensional constructions of interconnected nanolayered thylakoid cylindrical stacks (granum) in chloroplast.

For functions, the artificial inorganic leaves could harvest UV and part of visible light. They could split water into hydrogen and oxygen in the presence of sacrificial reagents efficiently under UV and visible light irradiation.

Two main challenges facing research in this area are the limited solar energy harvesting, particularly visible light, and the insufficient energy conversion, particularly in the absence of sacrificial reagents, Fan said.

### Applications

"The advantage the technique would have over conventional technologies is that it makes full use of solar energy and biomass," he noted. "Solar energy is inexhaustible and free. So using sunlight to split water molecules and form hydrogen fuel is one of the most promising tactics for kicking our carbon habit. Biomass also is inexhaustible and cheap. Making full use of solar energy and biomass to generate sustainable energy such as hydrogen and to relieve environmental pollution would be of great significance for the global energy crisis and environment pollution."

One application of the technique is converting solar energy into chemical fuels. This can be divided into two parts: photocatalytic water splitting for hydrogen production and photocatalytic reduction of carbon dioxide into organic fuels. Fan said this is one of the most promising tactics for kicking our carbon habit and could be significant for the global energy crisis and global climate warming.

The other important application is converting solar energy into electricity. The strategy could be used for the production of cost-effective solar cells, of photovoltaics and of photoelectrochemical cells based on the leaf model.

Renewable hydrogen and organic fuels, such as methanol and ethanol, could be a huge industry in the future. They could be used in cars and mechanical machines – even in homes for daily use, Fan said.

### Photonic tools

In the study, several advanced spectroscopic techniques were used for measurement: UV-visible absorption spectroscopy, for the quantitative comparison of overall visible light absorbance intensity and bandgap absorption onsets of samples; electron paramagnetic resonance spectroscopy, for the detection and identification of free radicals and paramagnetic centers, which was used as a preliminary study on the catalytic activity; and x-ray photoelectron spectroscopy, for the confirmation of elemental composition and the chemical state.

Several optics-based tools were used for the characterization: a digital microscope for characterization of surface details such as morphologies and colors of leaves under high magnification; an optical microscope for the observation of the interior structures and colors of leaves; and confocal laser scanning microscopy for the identification of tissues of natural leaves, including cuticles, mesophyll cells, bundle sheath cells and vascular bundles. The latter also was used for the quantitative measurement of fluorescence intensities, which could provide some indications for the chemical procedures. Transmission electron, field-emission and scanning electron microscopes were important for the characterization of the micro-/nanostructures of the natural/artificial leaves.

### Further research

"For the next step, we are planning to use a single chloroplast as a biotemplate. The synthesis of artificial chloroplasts with similar structures and analogous functions would be very attractive and interesting," Fan said.

The production of other series of artificial leaves, including titanates, niobates, tantalates, metal nitrides and phosphides, metal sulfides and other transition metal oxides for higher photocatalytic efficiency, is of interest to the researchers, as is the construction of multicomponent systems for overall water splitting.

The design and construction of a photocatalyst system for the reduction of carbon dioxide into organic fuels by mimicking the dark reaction of photosynthesis would be of great significance for the energy crisis and global climate warming, Fan said.

Finally, the method could be extended to artificial polymeric or supermolecular leaves, which could respond to visible light and which are much closer to natural systems, he added.

### Waste not

The investigators also are researching the synthesis of other photocatalysts with good photocatalytic water splitting and photocatalytic degradation activities by using biomass, including agricultural wastes – straws, rice hulls – and ocean algae wastes as the resources.

"This could relieve the increasing energy shortage and environmental pollution. The core idea is 'governing wastes with wastes.' This means that the development of novel materials fabrication techniques with agricultural wastes as the resources could be used to relieve the problems of energy shortage and environmental pollution," Fan said.

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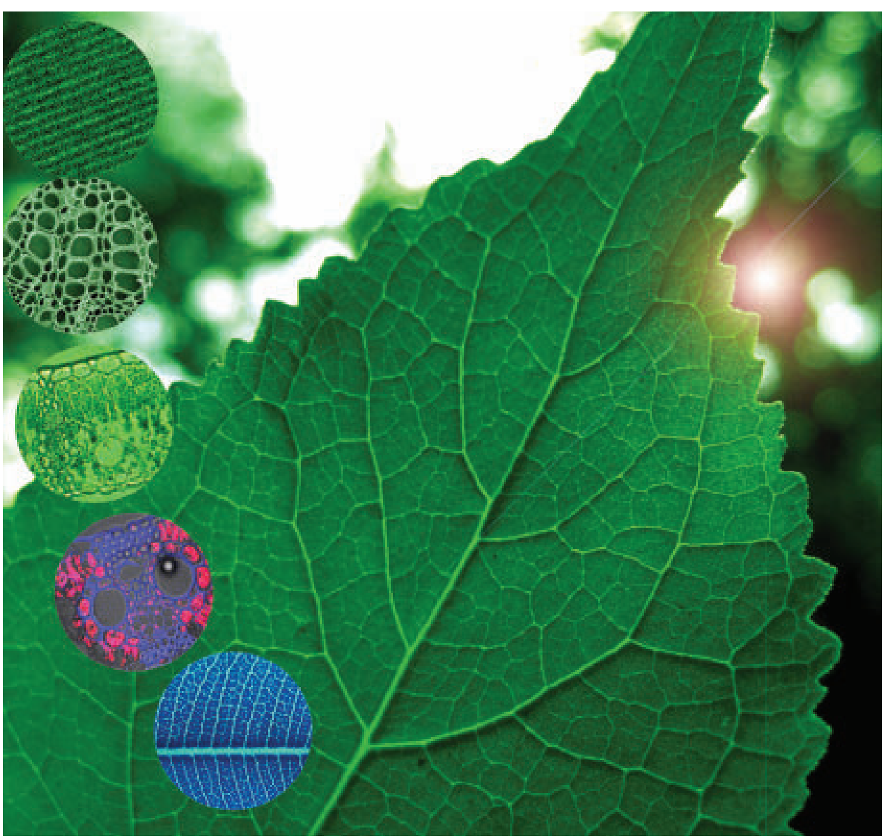

A natural leaf and its hierarchical structures (insets) are pictured. Scientists have reported the design for an artificial inorganic leaf. Courtesy of Tongxiang Fan, Shanghai Jiaotong University.

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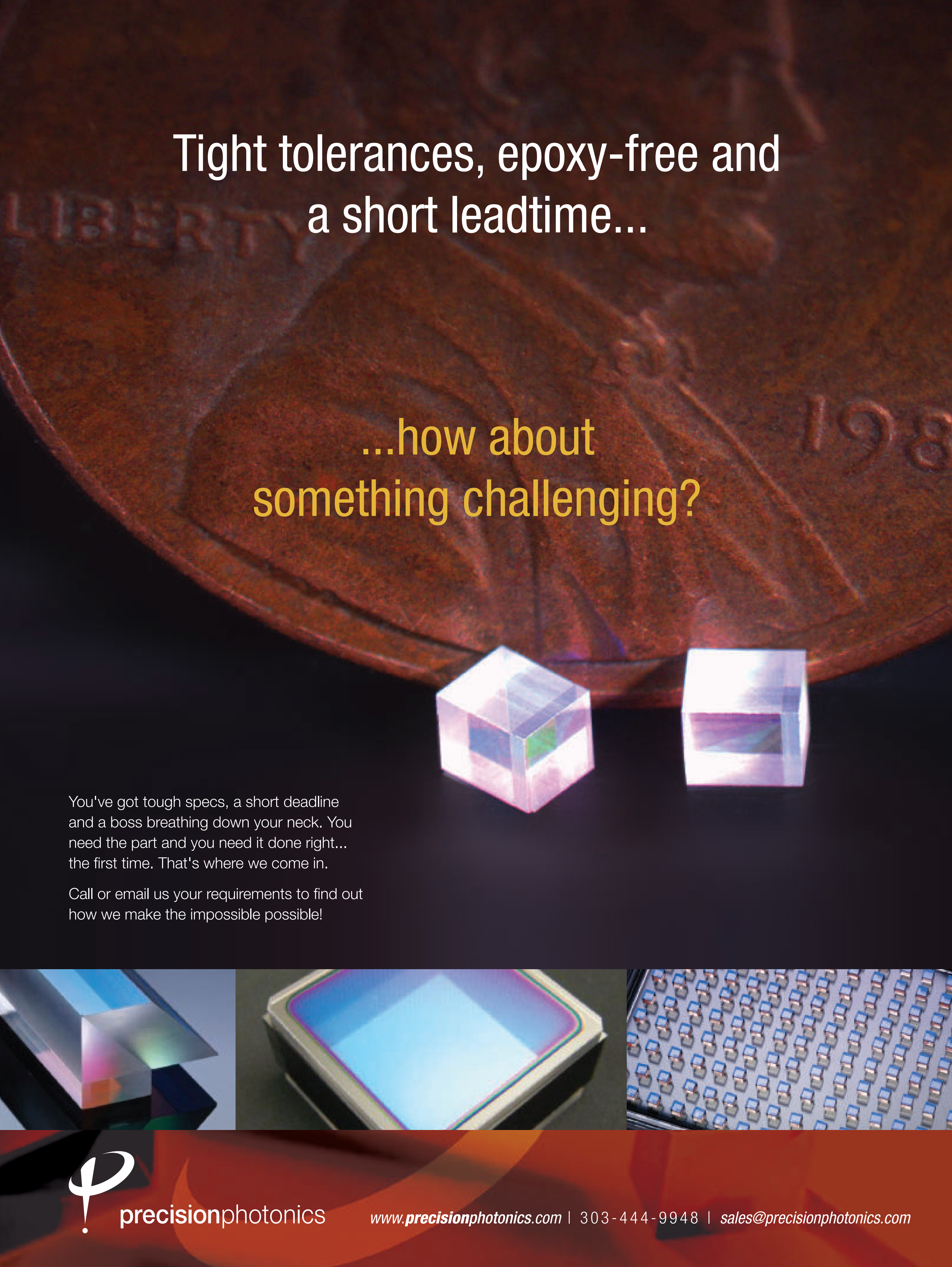
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# Solar Cell Inspection

BY DANIEL SEILER
IDS IMAGING

Worldwide energy demand is rising, and so is the price of that energy as fossil fuel resources are consumed. These trends have led to growing worldwide interest in alternative energy sources such as solar photovoltaic (PV) cells. The key to success in the solar cell market, however, is lowering their cost to manufacture by increasing production volume – and machine vision systems are key to increased production.

A combination of technology advancements and governmental stimulus has done just that, creating a tremendous opportunity for solar cell manufacturers. The advancements have indeed helped lower the cost of solar PV systems while government-funded initiatives have provided the capital for increased research and production investment. The result is a rapidly growing market for solar cells and increased competition to serve that market.

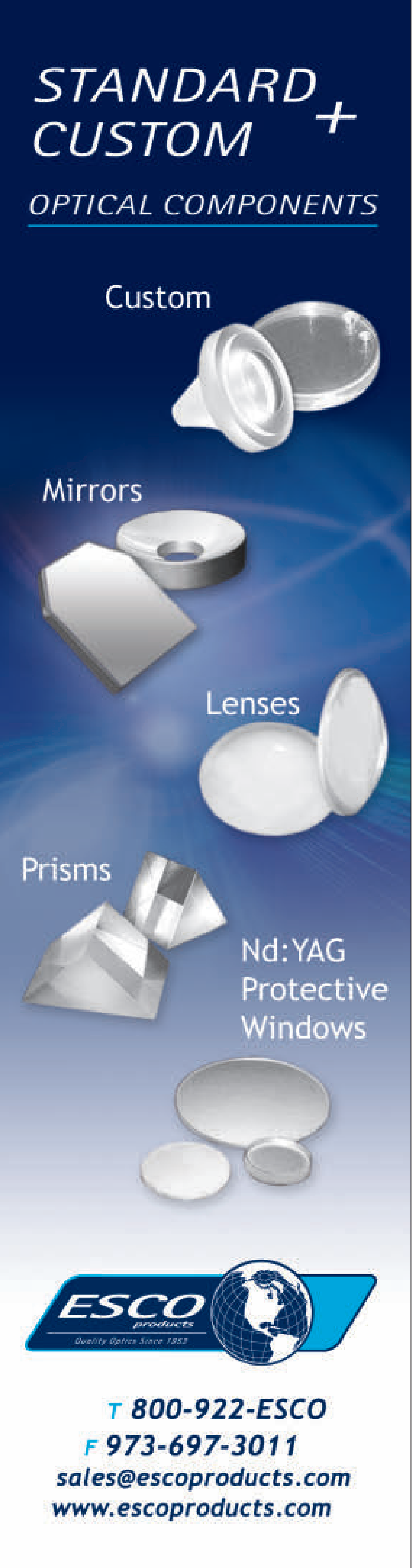
The appeal of solar PV systems is the abundant availability of solar energy. Extrapolated to the whole of the Earth, this energy is equivalent to more than 10,000 times the global annual demand for primary energy. The challenge, of course, is to make the best possible use of this potential. The efficiency – the amount of solar energy converted to electric power – must be as high as possible. However, the theoretical maximum of 30 percent is far from being reached, even under laboratory conditions, forcing the use of large solar cell arrays to gather sufficient amounts of energy. For these large arrays to be cost-effective energy sources, therefore, the solar cells must be as inexpensive as possible.

Solar cells usually are made of polycrystalline silicon and require many of the same manufacturing processes as integrated circuits. There are significant differences in their production, however. One is size: Solar cells are typically 150 × 150 mm or larger, which only high-end processor integrated chips (ICs) approach in scale. To get acceptable fabrication yields with such large cells, the raw silicon wafers must meet exacting demands on purity and freedom from defects.

## Early detection essential

Solar cell wafers also are subject to different handling stresses than IC wafers. The front metallization layer that forms the conductor grid on a solar cell is applied using a silk-screen process that creates pressure stresses on the 0.2-mm-thick wafer. This can create defects in the finished cell that can adversely affect power production, including chipping, cracks and broken edges. Because solar panels require many cells to work together efficiently, defects in individual cells must be reliably identified before assembly into the panel, where they would compromise overall panel performance.


Figure 1. Machine vision systems are becoming essential tools for lowering the manufacturing cost of solar photovoltaic power panels.





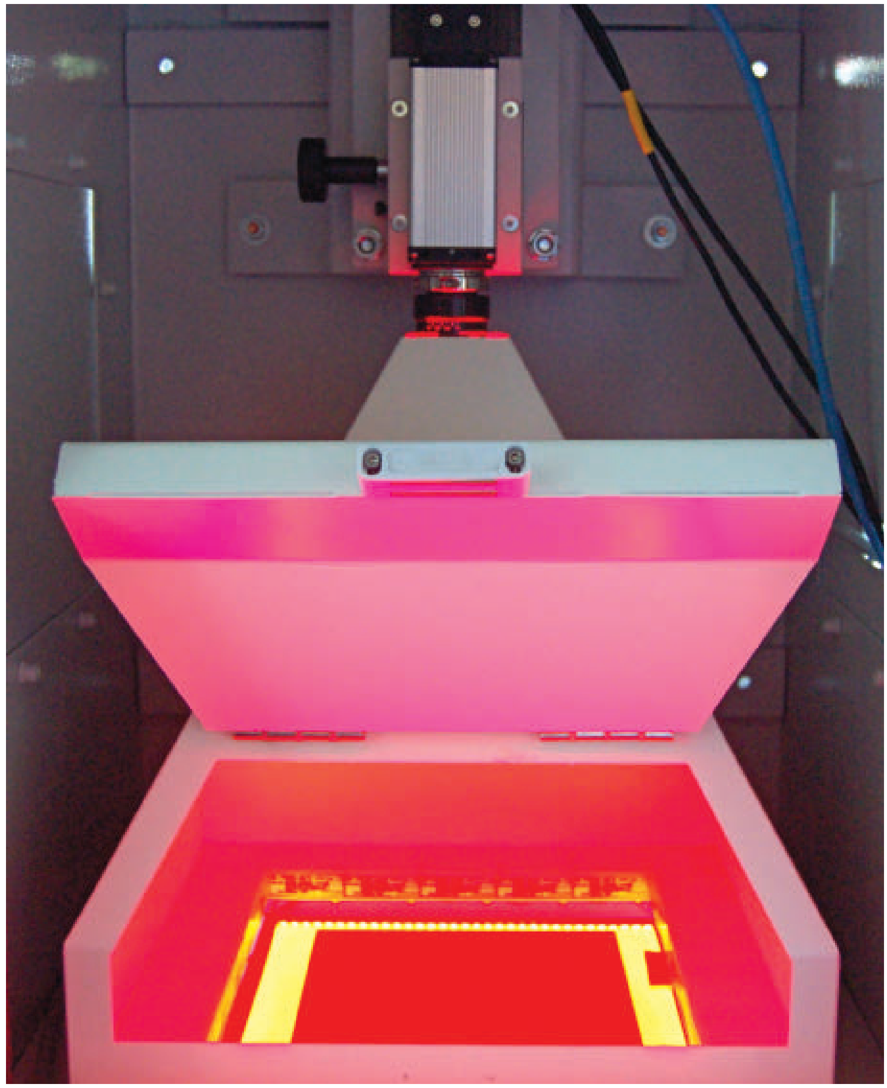



Figure 2. Dual lighting systems allow this solar cell wafer inspection system to work with images optimized for different inspection tasks.

Machine vision using high-resolution cameras is proving to be the only viable way to ensure early detection of these defects (Figure 1). Manual quality assurance is next to impossible because the fragile wafers are difficult to handle. High resolution is needed because cracks as small as 120 µm long are enough to compromise performance. The challenge is to provide such resolution at the high throughput rate required to achieve the production efficiencies needed to keep cell costs down.

The Image Processing and Intralogistics department at Eckelmann AG of Wiesbaden, Germany, is currently developing such an inspection station – the E.SEE-Waferinspect – for a customer who wants to equip several wafer production lines with the system. The system not only looks for flaws such as chips and edge defects, but also must examine the wafer surface for contaminants, measure the wafer dimensions to an accuracy of 50 µm and measure the angle of chamfered corners. The production lines have a throughput of 3600 wafers per hour, leaving the machine vision system with just under a second to complete each inspection.

To achieve the required 50-µm measurement accuracy on a 150 × 150-mm wafer, the camera needed a resolution of ~5 million pixels. Handling that much data at the production speed required a high-speed output port on the camera that allowed it to be positioned a large distance from the host image-processing computer. Based on previous good experiences with camera integration, product quality, service and support from IDS, Eckelmann decided on the UI-5480-C from IDS' uEye series.

## One camera, dual imaging

The UI-5480-C has a high-speed CMOS

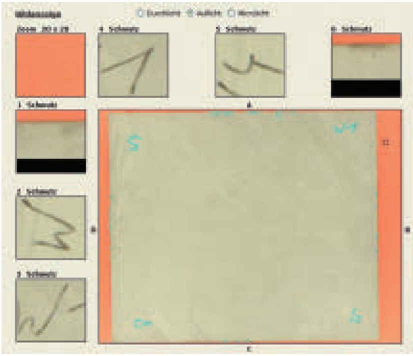


Figure 3. The red backlighting helps through-cracks to appear in high contrast to the wafer surface, simplifying their detection using only monochrome processing.

color sensor with 2560 × 1920 pixels and can capture and deliver full-resolution images at a rate of 15 fps. It also offers an area-of-interest function for limiting the field of view the camera sends to the image processor, enabling the image processor to work with a square partial image that matches the wafer shape and eliminates distracting background. The camera provides a Gigabit Ethernet port, supporting cable lengths up to 100 m to allow flexibility in camera positioning.

To detect defects and make the needed measurements in the time available, the inspection station takes a divide-and-conquer approach by breaking the task into two parts. The camera is installed in a metal housing that is open at the bottom and equipped with built-in lighting. During production, a rotary table positions the sawn silicon wafers below the camera for in-line inspection (Figure 2). The camera acquires two successive images, each with different lighting. While the camera is taking the second image, the image processor analyzes the first one. The second image's processing takes place while the station sets up for and captures the first image of the next wafer to be inspected. Because the image capture and analysis are performed in parallel, this solution saves valuable inspection time.

The two types of lighting allow the processing software to work with images optimized for different types of inspection. The first image is acquired using diffuse red LED backlighting, which makes through-cracks readily visible. The colored light also helps simplify the image processing used to detect and measure the cracks. Red hides the grain boundaries on the polycrystalline silicon to prevent the vision system from confusing them with defects. Despite the color, however, image processing uses only gray-scale operations for speedier computation (Figure 3).

The second image is taken using diffuse incident white LED lighting, which provides good contrast between the normal wafer surface and any impurities or defects. Cracks that do not pass completely through show up clearly under the diffuse lighting. Besides detecting surface defects and contamination, the system uses the white-light image for measuring wafer size and the chamfers at the corners.

## Design for flexibility

Eckelmann's corporate philosophy is to flexibly customize standard components to meet the individual customer's needs. As a result, the E.SEE-Waferinspect system is designed to be modular so that solar cell manufacturers can readily add other measurement functions such as grain size and wafer thickness. An additional software module working with the white-light image measures grain size. The addition of another camera expands on the divide-and-conquer approach to support measurement of wafer thickness.

When the inspection station is completed, the company will have put more than two man-years of development into camera control and image processing. Thus, a key element supporting Eckelmann's development of the inspection system was the software support that came with the IDS uEye camera. The camera's software development kit (SDK) provided a ready-to-go interface for the image-processing software library used in the wafer inspection system, greatly facilitating the integration of the camera with the analysis program. Besides providing interfaces for ActiveX, DirectShow and various libraries, the uEye SDK also features a direct programming interface (API) for accessing drivers in C++, C# and VB.

Eckelmann's E.SEE-Waferinspect system demonstrates only one role for machine vision in solar cell manufacture: finished wafer inspection. Many other opportunities exist. Machine vision can speed incoming wafer inspection, surface treatment during processing, application of metallization and final test of assembled panels. By speeding production and catching defects early to avoid waste and rework, machine vision is helping solar PV systems fulfill their promise of providing a cost-effective, renewable energy resource.

## Meet the author

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# Robotic Automation for Solar Cell Manufacturing

BY RUSH LASELLE
ADEPT TECHNOLOGY INC.

The global photovoltaic (PV) manufacturing community is on the cusp of a resurgence in investment, development and innovation, a revolution that largely will be driven by technology. It is vital to find the most effective – and most cost-effective – tools and processes to increase productivity and decrease costs within a set capital plan. Robotic automation is a significant part of solar cell manufacturing, but it is important to consider which robot types and kinematics are best for each unique process, looking at the solar manufacturing areas where there are the greatest return opportunities for robotic automation as well as investigating which robot type is best for a particular solar application task and where vision fits.

In this article, I will provide a primer targeting these issues and discuss how the solar industry can best maximize factory throughput, reduce costs and improve efficiencies with robotic automation.

## Flexibility through vision

Vision has become a highly adopted tool to improve the productivity of robotic automation in all industries and all facets of placement. Vision systems offer tremendous flexibility for applications that don't require fixtures or trays for part location. Vision guidance enables the system to take a picture, compute a part's location and orientation, and guide the robot to the part using a computed robot-to-camera transformation obtained through an automated calibration process. Tremendous flexibility and cost savings are realized because parts don't have to be fixtured.

Vision systems allow parts to be randomly presented to the robot without orientation or alignment, or without being placed in a tray, which also reduces cost. These systems frequently incorporate line tracking, enabling the robot to pick these parts from a moving belt, further optimizing the process.

Robot-integrated vision allows inspection to be incorporated right into the handling process, placing it in parallel with handling, further reducing the overall cycle time and increasing throughput. Various part geometries require only vision retraining or the selection of a recipe instead of manual changes in fixtures and tooling. This increases the overall lifetime profit of the equipment by virtue of its

Figure 1. Cartesian solutions are typically called upon to serve applications where the substrate remains in the same plane. Images courtesy of Adept Technology.

optimization and improved throughput. Most robot manufacturers offer packages with multiple cameras and tracking solutions for integration into a single cell. This offers tremendous power and flexibility for solar manufacturing.

## The right kinematic solution

How do you select the right robot for the task? First, you must consider the payload requirement for the robot. People often consider only the products being handled. But it is also important to consider the tooling solution or end-of-arm tooling (EOAT).

Evaluating the motion requirements also is critical. Not only the simple motion of picking and placing but also what interferences exist between the robot and its linkages as well as other items that may be in dynamic motion within the cell must be considered.

How repeatable must the robot be? Robot manufacturers speak in terms of repeatability, while engineers and designers look at accuracy. A robot's repeatability outlines the machine's ability, once programmed, to return to the taught position. Accuracy refers to the ability to input a given location digitally and to have the robot move to that point in space "accurately." This encompasses offsets and other digitally input motion parameters, often varying within a given mechanical unit's work envelope. Thus, you must make sure you carefully evaluate these factors to gain a good understanding of the requirements of a process plus the capabilities of a given robotic solution.

Do your processes require special environmental considerations? Do you need a robot designed to eliminate the generation of particulates that might degrade the product? Or must the robot be protected from process-specific elements such as those in slurry ingot processing?

## Robot kinematics

The four major categories of robot kinematics are Cartesian, SCARA (selective compliant assembly robot arm), articulated and delta/parallel.

The Cartesian kinematic solution is simple and highly configurable (Figure 1). The platform includes everything from a single degree of freedom or unidirectional travel to numerous axes of motion. Adjusting strokes or lengths and configuration is relatively easy with Cartesian kinematic solutions as compared with the other types. Multiple drivetrains exist, optimized to provide high throughput or precise motion as characterized by whether the drive might be a ball screw or a belt-driven mechanism.

Platforms exist to accommodate small-part assembly up to extremely large part transfer such as overhead cranes that might be observed in a manufacturing facility. In the photovoltaics industry, Cartesian solutions can be applied to both small and large work spaces. They typically serve applications where the substrate remains in the same plane and does not have to be flipped or have its configuration changed, other than a rotation in the same plane as the table or conveyor (X-Y plane).

The next robot is the SCARA, which offers a cylindrical work envelope and typically provides higher speeds for picking, placing and handling processes than do Cartesian or articulated robotic solutions (Figure 3). It also delivers greater repeatability by offering positional capabilities superior in many cases to articulated arms. This class of robot usually is used for lighter payloads in the sub-10-kg category for
assembly, packaging and materials handling. For solar manufacturing processes, it is best suited for handling of cells in smaller work spaces with high speed and repeatability.

Articulated robots, the third group, have a spherical work envelope, and their arms offer the greatest level of flexibility because of their articulation and higher degrees of freedom (Figure 4). Because they make up the largest segment of robots available, you can find a wide range of solutions, from tabletops to large 1000-kg-plus solutions. Articulated robots are applied to a variety of solar applications, including the handling of heavy silicon ingots or glass, or the handling of

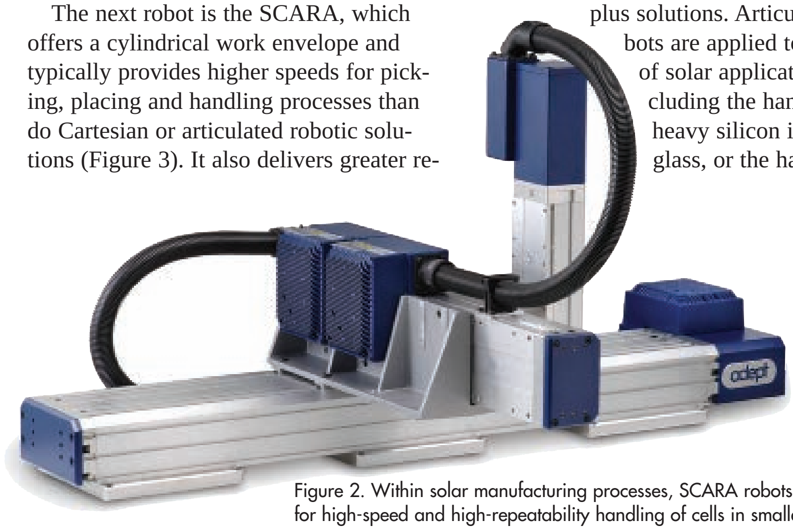


Figure 2. Within solar manufacturing processes, SCARA robots are best suited for high-speed and high-repeatability handling of cells in smaller work spaces.

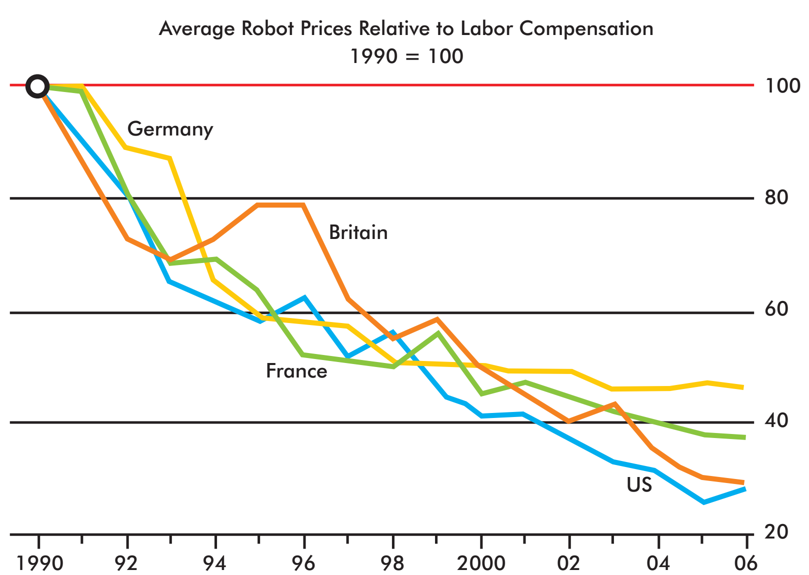


Figure 3. With more automation, the solar industry can potentially realize a 75 percent savings in direct labor costs alone. Courtesy of International Federation of Robotics.


Figure 4. Articulated robots are frequently applied to process intensive applications where they can use their full articulation and dexterity for solar applications such as handling silicon ingots, glass, subassemblies and assemblies.

subassemblies or assemblies where the products are introduced to the cell in a configuration different from the way in which they are presented to the system.

Delta/parallel robots make up the fourth category (Figure 5). This kinematic solution provides a cylindrical work envelope and is most frequently applied to applications where the product again remains in the same plane from pick to place. The design uses a parallelogram and produces three purely translational degrees of freedom, so work must be done within the same plane. Base-mounted motors and low mass links allow for exceptionally fast acceleration and, therefore, greater throughput over the other groups. An overhead-mounted solution, it maximizes access but also minimizes footprint. These units are designed for high-speed handling of lightweight products and offer lower maintenance because of the elimination of cable harnesses and cyclical loading.

Parallel robots are deployed into many solar cell processing steps because they offer high-speed transfer of solar cells through manufacturer lines and a multitude of processes, including diffusion of process equipment, wet benches and PECVD (plasma-enhanced chemical vapor deposition) antireflection coating machines. The Quattro parallel-linked product from Adept Technology Inc. recently achieved 300 cycles per minute, illustrating the capabilities for this class of machine to handle products at high rates.

### Deployment within the solar process

Typical PV process steps can be seen in Figure 6. The steps are broken into four basic groups where high concentrations of robots are deployed. The ingot processing step predominantly uses Cartesian gantries and large articulated arms because of the requirement for heavier payloads and large work-space optimization. Wafer manufacturing uses a variety of arm types, depending upon volume and process requirements. Cell processing tends to use gantries, SCARAs and parallel linked robots. Reach and repeatability considerations usually are the deciding factors. Module building uses a variety of arms – often articulated and Cartesian arms for reach and flexibility, although some specific tasks use the services of SCARAs and parallel robots.

### Antireflection coating process

Comparing the four robot categories, we consider their usefulness for an antireflection coating load/unload process. A Cartesian robot is optimized from a reach standpoint. However, the majority of solutions here would prove too slow and would require in excess of a single-head EOAT tooling. Because this complication would drive the need for prealignment and could result in further complications in preconditioning the product, a Cartesian solution could be considered less flexible.

### Cartesian robots

- Optimized for reach
- Too slow for loading/unloading using a single-head EOAT
- Because multihead EOAT often is used, cells require prealignment.
- Less flexible when reconfiguring for different size wafers is required

SCARA robots enable increased speeds and are more flexible than Cartesians. However, in a traditional tabletop version, the work space is limited, so SCARA may not be optimal in reaching all points on the load and unload areas.

### SCARA robots

- Faster and more flexible than Cartesian


Figure 5. Parallel robots offer high-speed transfer of solar cells through manufacturer lines and a multitude of processes.

robots when used with vision guidance
- Table-mounted versions could limit work space, and multiple robots may be required to cover pallet/matrix.

Articulated robots would be pedestal-mounted and could prove too slow in increasing the complexity of the installation.

### Articulated robots

- Too slow for loading/unloading with single-head EOAT
- Spherical work envelope isn't ideal for covering pallet/matrix.

The optimal choice might be a delta or parallel-style robot, for a number of reasons. The overhead mount is ideal for reducing the footprint of the automation cell. It can reach all places on the PECVD pallets. And when the benefits of the delta are combined with vision, it provides an exceedingly flexible solution that will meet the throughput requirements. Note: Vision is an enabler not only for parallel linked robots but for all categories of robots.

### Delta/parallel robots

- Overhead mount design is ideal for loading/unloading equipment.
- Larger delta robots can cover the width of most PECVD pallets.
- When used with vision guidance, they enable extremely good positioning.
- Excellent flexibility and quickly reconfigurable
- Robot design is optimal for handling cells (lightweight) at high speeds.

### Conclusion

The common goal for solar manufacturers is to drive down the cost per watt. As the solar industry strives to achieve grid parity, manufacturers must be knowledgeable about modern robotics as well as about automation and vision technologies – and the value they contribute to helping reduce the cost of solar cells.

History has shown that automation plays a significant role in reducing manufacturing costs in many industries, and when the costs associated with higher quality and yields are considered, its benefits offer an even more appealing value proposition. Although robotics and automation may be viewed by some industries as mature technologies, industry leaders are continuing to develop innovative products and new technologies that are ideal for solar manufacturing processes.

It would be prudent for solar manufacturers to look outside of their industry for the best practices in high-volume manufacturing with automation, robotics and vision to achieve cost-reduction goals.


Figure 6. High concentrations of robots are being deployed into the four basic photovoltaic process steps.

### Meet the author

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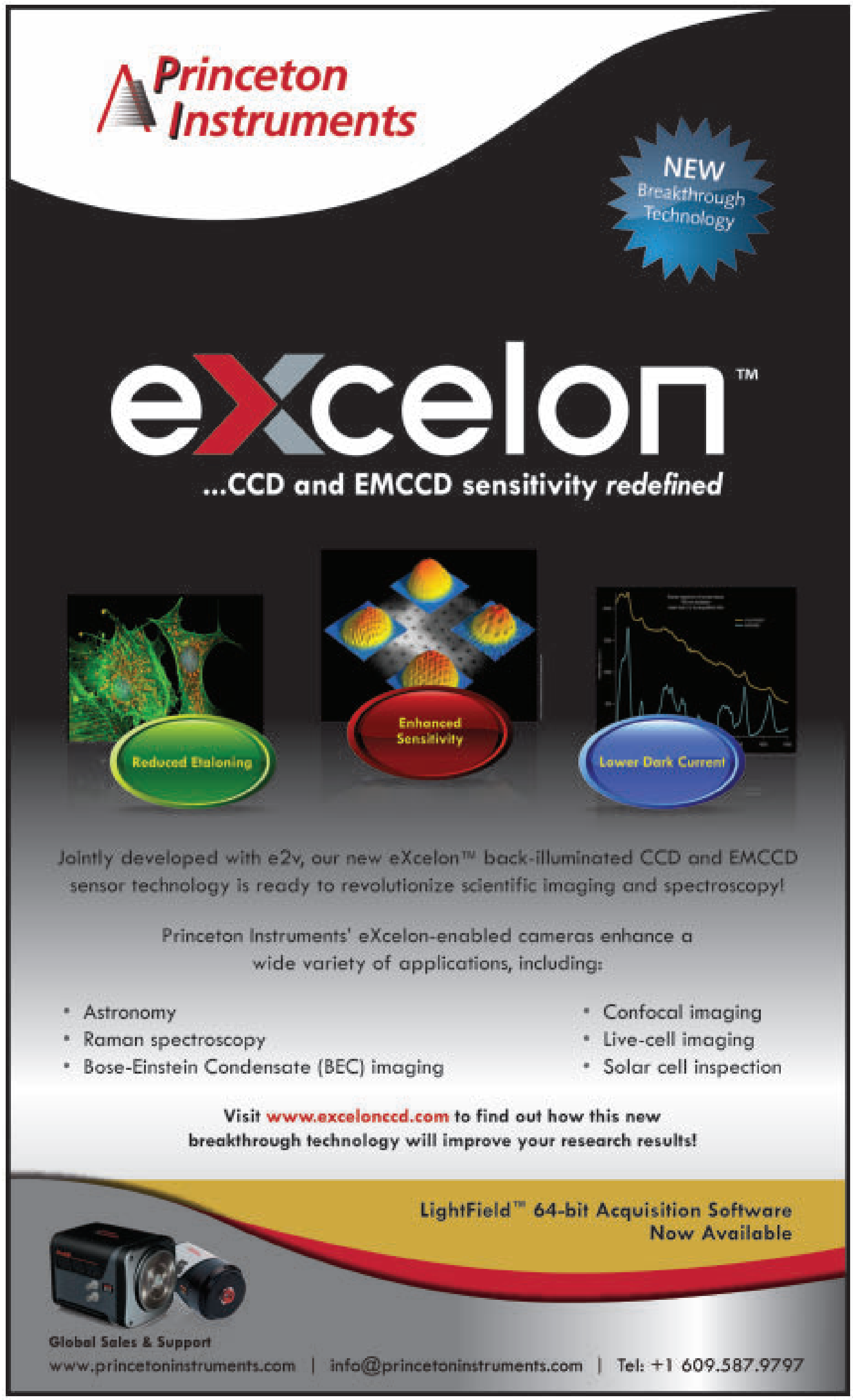

# Dual-Mirror Adaptive Optics Systems

## Take the Low and High Roads to Imaging Success

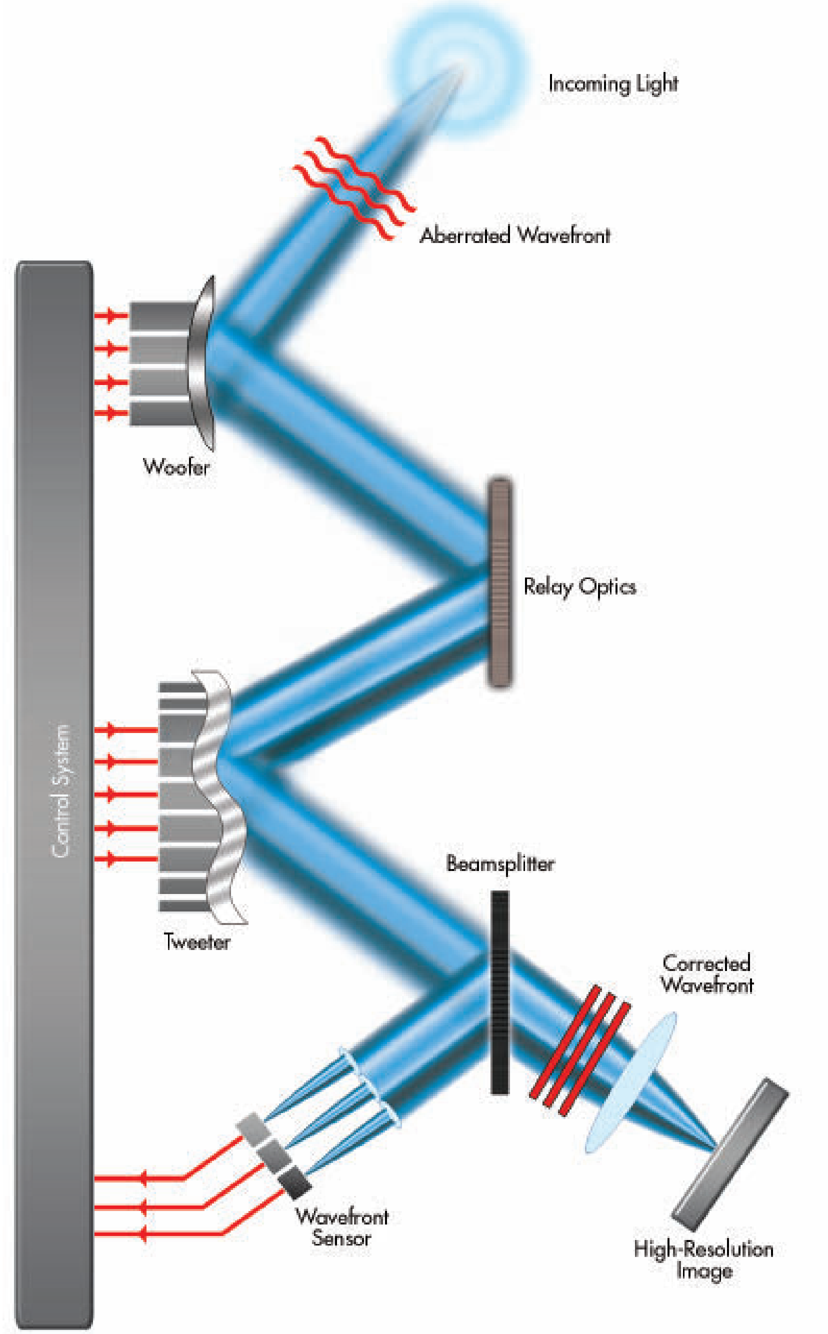


Figure 1. Shown is a simplified layout of a typical woofer/tweeter adaptive optics system. In this configuration, incoming light is reflected off the woofer and tweeter mirrors, which are managed by a single control system. The deflection of each mirror is determined by an algorithm that calculates the optimal mirror shapes to compensate for aberrations as measured by a wavefront sensor.


BY MICHAEL R. FEINBERG AND PAUL BIERDEN, BOSTON MICROMACHINES CORP.


Researchers worldwide have leveraged advances in microelectromechanical systems (MEMS) mirror technology by using adaptive optics to correct for wavefront aberrations caused by distortion. Now, the next generation of adaptive optics systems is using dual deformable mirror configurations to effectively compensate for a variety of wavefront aberrations. Researchers have opened possibilities in ground-based astronomy and biological imaging that previously were unimaginable.

### The right mirror for the job

Deformable mirrors are advanced wavefront control devices that can change shape to correct a distorted incident wavefront. The fundamental specifications for deformable mirror systems are resolution, spatial frequency, speed, stroke and surface finish.

The resolution is determined by the number of actuators in the mirror array, which ranges from 19 for an entry-level membrane-based device to more than 4000 for a MEMS deformable mirror. Spatial resolution is a measure of how complex a wavefront the deformable mirror can correct. This is determined by the number of actuators that control the shape of the mirror and by the mechanical coupling between adjacent actuators. Speed is based on the architecture and material

| | Woofer | Tweeter |
|---|---|---|
| **Resolution** | Low | High |
| **Speed** | Low | High |
| **Stroke** | High | Low |

Above are properties of the major classifications of deformable mirrors (woofer and tweeter).

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properties of the deformable mirror. Finally, stroke is a measure of maximum actuator deflection.

As the technology stands today, mirrors are most proficient at either low-resolution, low-speed and high-stroke operation, or high-resolution, high-speed and low-stroke operation, identified as "woofer" and "tweeter," respectively (see table). It is this tradeoff that necessitates a next-generation approach to adaptive optics wavefront correction.

To achieve a higher degree of wavefront correction, newer adaptive optics systems are using both a woofer and tweeter style of deformable mirror. The woofer/tweeter dual-mirror configuration allows for better compensation of large-variance, high-spatial-frequency phase distortion. A simplified layout of such a system is shown in Figure 1.

Low-order optical aberrations are the most common and are corrected using a high-stroke, low-resolution mirror (the woofer). This can be accomplished using a membrane-type mirror with a limited number of actuators. High-order aberrations are more complex and require more precision. Most microscopy, vision science and laser shaping applications require 1 to 4 μm of stroke to correct for these aberrations, which is achievable with a high-resolution mirror (the tweeter).

One mirror that can fill the role of the tweeter is a MEMS deformable, which consists of a mirror membrane – either continuous or segmented – supported by an underlying actuator array. Each actuator in the array can be deflected by electrostatic actuation to achieve the desired pattern of deformation.

Scientists have been developing dual deformable mirror woofer/tweeter systems to deploy in adaptive optics applications for retinal imaging and astronomy.

## Vision science applications

Leading vision scientists and ophthalmologists believe that the human retina will be a window into human health. Being able to visualize the retina at a cellular level gives researchers the ability to study vasculature and photoreceptor properties and holds promise for earlier diagnosis of the "big three" eye diseases: glaucoma, diabetic retinopathy and age-related macular degeneration.

Wavefront distortions generated in the eye itself prevent generation of useful high-resolution images without the use of adaptive optics, which corrects distortions introduced by the cornea, crystalline lens and vitreous humor. Adaptive optics enables increased contrast levels and unprecedented retinal resolution levels.

In retinal imaging with an adaptive optics scanning laser ophthalmoscope (AOSLO), a dual deformable mirror approach could be used because of the large individual differences in defocus and astigmatism in humans. For the first time, researchers can see critical detail within the retina and can detect changes in the eye significantly earlier than with current diagnostic tools. Earlier detection can enable early treatment that could slow the progression of eye disease – or even prevent it.

Steps are being taken to detect disease through the use of an AOSLO system at Indiana University Bloomington, where researchers Stephen A. Burns, Weiyao Zou and Xiaofeng Qi have developed a real-time zonal control algorithm that uses wavefront slope measurements from a single Shack-Hartmann wavefront sensor to generate control signals for two deformable mirrors.

The procedure will be used to implement a woofer/tweeter dual deformable mirror AOSLO system for in vivo human retinal imaging with a 140-actuator deformable mirror (maximum stroke, 3.5 μm) and a 52-actuator magnetic deformable mirror (maximum stroke, 50 μm). The low-stroke deformable mirror is the tweeter, for correcting the high-order aberrations; the high-stroke deformable mirror is the woofer, for correcting the low-order aberrations. The dual-mirror system effectively removed aberrations in the eye, thereby generating clear images that will be used to study the progression of eye disease in live patients.

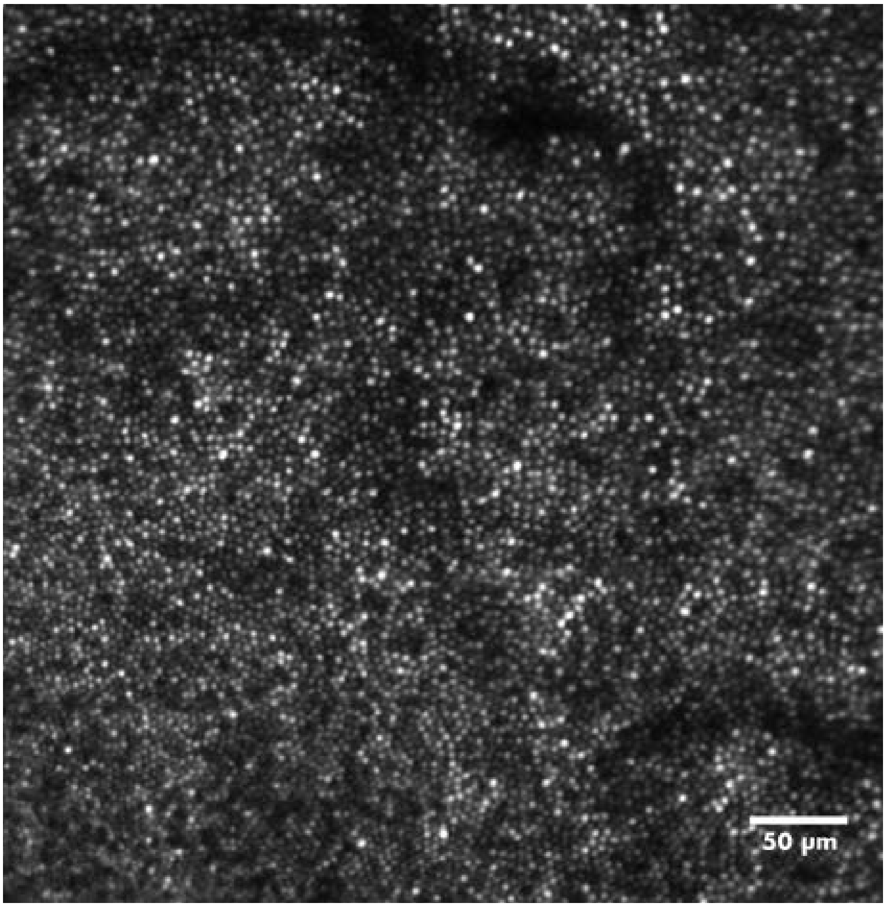


Figure 2. This image shows individual photoreceptors in the retina using an adaptive optics scanning laser ophthalmoscope with woofer/tweeter optical architecture. Courtesy of Kevin M. Ivers, Chaohong Li and Jason Porter, University of Houston College of Optometry.

## Astronomy applications

Adaptive optics also is commonly used on telescopes to remove the effects of atmospheric distortion. When light from a star or another astronomical object enters the Earth's atmosphere, turbulence distorts the light in various ways, including blurring images. An adaptive optics system tries to correct this by using a wavefront sensor that takes some of the astronomical light for analysis, a deformable mirror that lies in the optical path and a computer that receives input from the sensor. The sensor measures the distortions that the atmosphere has introduced on the timescale of a few milliseconds, and the computer calculates the optimal mirror shape to correct them. The surface of the deformable mirror is reshaped accordingly.

One system under construction that will use a woofer/tweeter design is the Gemini Planet Imager, a next-generation adaptive optics instrument being built for the Gemini telescope by a consortium of US and Canadian institutions. Funded by the Gemini Observatory, a partnership of seven nations, the group's goal is to image extrasolar planets orbiting nearby stars using a dual deformable mirror system. The Gemini system's low-actuator-count woofer reduces the residual wavefront error to a level controllable by the finer tweeter, a MEMS deformable mirror with 4096 active elements. First light is projected to be recorded in early 2011.

A second example is the PALM-3000, a high-precision upgrade to the Palomar Adaptive Optics System on the 5.1-m Hale Telescope at Palomar Observatory in Palomar Mountain, Calif. It will use its existing deformable mirror (241 active actuators) as the woofer and a new high-actuator-count deformable mirror (3388 active actuators) as its tweeter. As with the Gemini Planet Imager, first light is projected to be in early 2011.

### Dual-mirror control

Two distinct methods for control of dual deformable mirror woofer/tweeter systems have been developed – serial and parallel. Using a serial approach, the aberration is corrected by the woofer first, and the resulting image is sequentially corrected by the tweeter. This is a "best effort" approach and is currently taking a backseat to a more real-time parallel approach. With improved algorithms and faster processing speeds, most applications now take advantage of parallel correction methods. To do this, the algorithm sorts the wavefront aberrations into two groups – one for the woofer correction and one for the tweeter correction – in real time.

A recent algorithm developed for vision science has come from Chaohong Li, Nripun Sredar, Hope Queener, Kevin M. Ivers and Jason Porter at the University of Houston's College of Optometry in Texas. The success of this technique is shown in Figure 2, which depicts a high-resolution image of photoreceptors in the retina.

For astronomical applications, previous work has been done as part of the "Woofer Tweeter Experiment" at the University of Victoria in British Columbia, Canada, and is currently proceeding for the Palomar Observatory's PALM-3000 adaptive optics upgrade.

Adaptive optics continues to evolve to provide clarity. Using dual deformable mirror devices, biological imaging researchers can look deeper in vivo and astronomers can obtain higher-resolution images of celestial objects, enabling further research into the behavior of other solar systems. The woofer/tweeter optical architecture provides continuous improvement to correct wavefront aberrations and promises to lead to new discoveries in all types of imaging applications.

### Meet the authors

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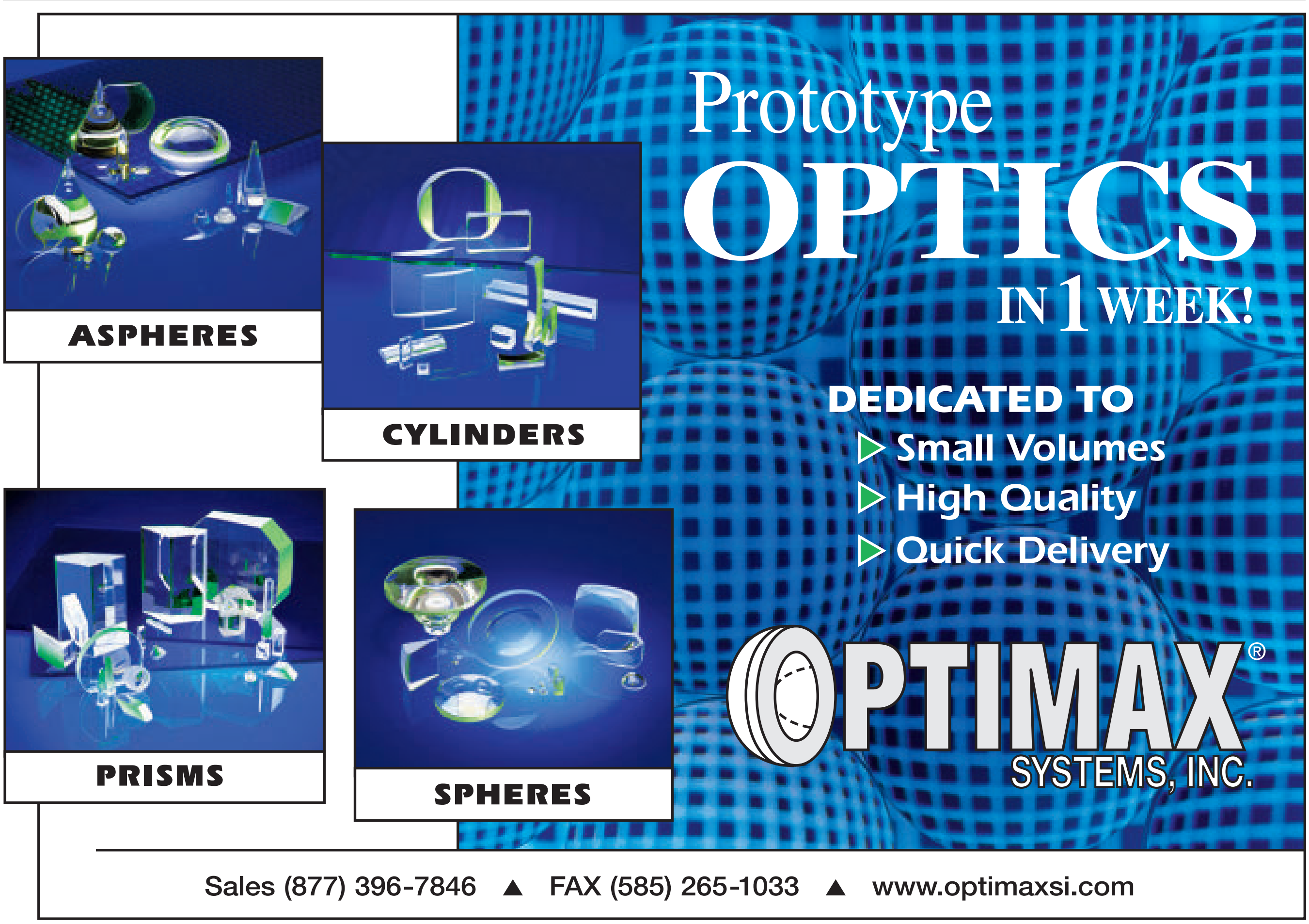


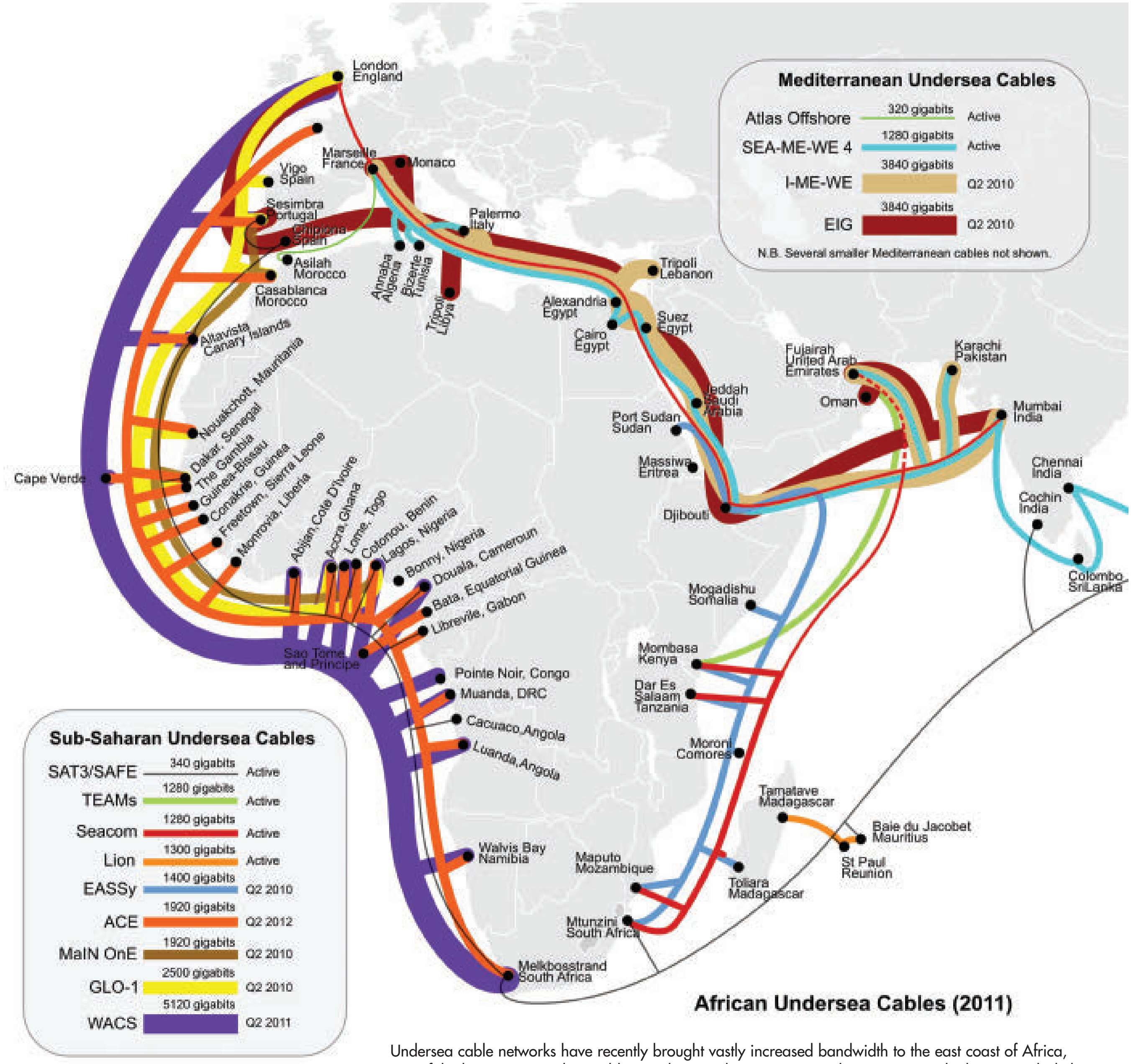
In shallow waters, cable is buried using remotely operated sea plows. Here, a sea plow is loaded into the sea. In the background is Ras Sidr, Egypt. Courtesy of Tyco Telecommunications.

# Fiber Optics off the Coast of Africa

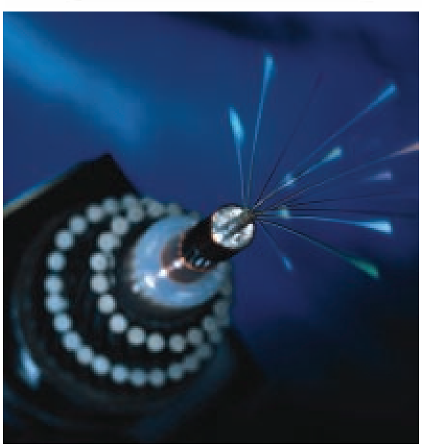
## Submarine cable systems bring increased connectivity to the continent

BY GARY BOAS
CONTRIBUTING EDITOR

Tuesday night, April 6, 2010: The *Ile de Batz* slowed to a stop in the waters of Dar es Salaam Bay, just off the Msasani Peninsula in the east African nation of Tanzania. The ship had been traveling south from Kenya, laying cable for the Eastern Africa Submarine Cable System (EASSy), a 10,000-km undersea network




Undersea cable networks have recently brought vastly increased bandwidth to the east coast of Africa, one of the last regions in the world not to have such a connection. These join several other networks linking North Africa and the west coast of the continent to the rest of the world. Courtesy of Steve Song / http://manypossibilities.net/african-undersea-cables.



A number of submarine fiber optic cable systems are helping to bring increased bandwidth and improved connectivity to Africa. Shown here is a cross section of steel-armored cable from Tyco Telecommunications. This specific type of cable is installed on the ocean floor, usually in shallow waters. Courtesy of SEACOM.

that will connect with nine African countries along the east coast of the continent and serve an additional 12 landlocked nations through backhaul networks.

The cable reached shore the following morning at about 11 a.m. From there it would travel inland, connecting Tanzania and other African nations to networks throughout the world. Chris Wood, CEO of the West Indian Ocean Cable Company, the largest shareholder in the project, was on hand to observe the event.

"Interconnection with other undersea international cable systems will enable traffic on EASSy to seamlessly connect to Europe, North and South America, the Middle East and Asia," he said, according to an article in the *Tanzania Daily News*, "thereby enhancing the east coast of Africa's connectivity to the global telecommunications network."

Just shy of two weeks later, on Monday, April 19, the EASSy cable system was completed; testing was set to begin almost immediately, Wood said in a statement. Soon, the fibers snaking across the floor of the Indian Ocean would go online, bringing businesses and individuals throughout Africa ever closer to the rest of the world.

## Dramatic changes on the continent

The EASSy system, with a 1.4-Tb/s capacity, is only one of several such initiatives. The 4500-km TEAMS (The East African Marine Systems) offers a capacity

The submarine cable systems reach shore at points along the coast of Africa, bringing service through backhaul networks to countries such as South Africa and Kenya as well as to landlocked nations in the interior. Courtesy of SEACOM.

of 120 Gb/s to 1.4 Tb/s, while the 13,700-km cable system by the SEACOM company provides a capacity of 1.28 Tb/s.

These submarine cable systems could lead to important changes on the continent. "East Africa was the last region in the world not to have a fiber connection to the rest of the world," SEACOM CEO Brian Herlihy said recently in an e-mail. "African retail carriers can now enjoy equal and open access to inexpensive bandwidth, removing the international infrastructure bottleneck and supporting economic growth."

This is important, as demand for bandwidth has increased considerably in recent years. Africa is one of the fastest growing markets for information and communications technology services. In many countries, especially outside South Africa, this growth is spurred by demand for IP phones, which offer a less expensive, more efficient means of making calls. South Africa more closely resembles Europe and the US in its communications needs, seeking instant messaging, video calls and other features that will aid in accelerating business.

Telephony is only one part of the picture, though. The introduction of broadband Internet to the continent will contribute to development in a variety of ways. "Africa can now launch itself as a major competitor for call centers/business process outsourcing," Herlihy said. The financial and manufacturing sectors, among others, can lower costs even while increasing productivity. Hospitals performing clinical studies can share data in real time with collaborating sites around the world. And science, education and other research can be conducted in east or southern Africa "as easily as it could be conducted in Cambridge, Massachusetts."

The list of potential applications goes on. Using the Internet, farmers in Tanzania will be able to access both the local and international markets for their products without having to rely on middlemen and cooperatives. Schools in South Africa can take advantage of resources available through the Tertiary Education and Research Network of South Africa. And surgeons at the Regency Medical Centre in Dar es Salaam, also in Tanzania, may be able to perform complicated procedures in real time using telemedicine, working with major medical centers in India. Currently, many patients find that they have to travel abroad to receive necessary treatment. Many of these would not be possible without the vastly increased capacity provided by the submarine cable systems.

Less critical, perhaps, but just as significant: The increased capacity will help to facilitate faultless content delivery from the World Cup, to be held in South Africa this month.

Notably, not everyone in Africa is demanding increased capacity and improved

connectivity. At the annual Digital Sense Africa Forum held in Lagos, Nigeria, April 17 and 18, 2010, participants noted that the nation has only 1 percent broadband penetration out of an estimated 7 percent Internet access, in part due to an increase in cyber crimes. "We are not Internet hungry," said 2010 forum chairman Samuel Adeleke, according to *IT News Africa*. Adeleke is also president of the Internet Service Providers Association. "There is need for active participation both as a nation and as individuals to change the perception from the negative use of the Internet to the positive."

### In it for the long haul

In addition to supporting education and medicine, for example, the laying of the submarine cable systems has encouraged significant investment in backhaul, an industry term for the portion of a telecommunications network linking the core network to smaller subnetworks at the outer reaches. Businesses throughout eastern and southern Africa are currently rolling out national backhaul infrastructure, including several national operators in South Africa. In Rwanda, the national government has laid extensive fiber networks connecting both urban and rural areas to the rest of the world.

"All of these investments are now economically feasible due to the substantially lower bandwidth prices brought by cables like SEACOM," Herlihy said, adding that retail carriers also benefit from the equal and open access to inexpensive bandwidth. He noted, for example, that in South Africa the monthly lease cost for an STM-1 circuit has declined by more than 50 percent since 2006, from 2.1 million rand that year to only 0.8 million rand today. In Mozambique, many Internet service providers are now able to offer end users the choice of either double the bandwidth for the same price as before, or the same bandwidth for half the price.

Until recently, satellite was the only means to extend information and communications technology services to the vast majority of the continent, and it is still likely the better option for reaching countries that have scattered populations (Sudan and Algeria, for example) or that have recently been at war, whose infrastructures have largely been destroyed (Congo, Sierra Leone, Liberia, Sudan).

With the landing of the submarine cable systems, the continent will see more and faster connections. But fiber is not likely to replace satellite entirely. Rather, the two will prove complementary in bringing advanced information and communications technology to Africans across the continent, thus connecting them to the rest of the world in ways unimaginable even just a few years ago.

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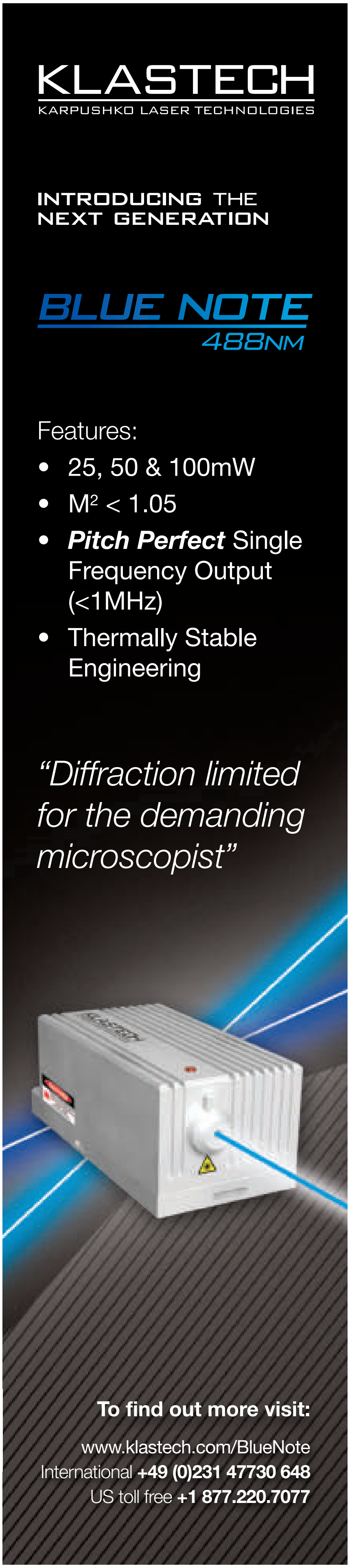

# 50 YEARS of the Laser Industry

## Same Innovation, Different Motivation

BY PAUL SECHRIST
COHERENT INC.

**The relentless innovation that has always characterized the laser industry is now driven and firmly controlled by the needs of applications.**

In the technology's infancy, the main goals were the discovery of new laser materials and the development of different operating regimes. Then came a period, particularly in scientific lasers, where achieving benchmark performance (e.g., shortest pulse width or highest peak power) was the main objective. Next came a slow migration of lasers into industrial/OEM applications and, later, the telecom boom, where the focus became fiber related and brought us a new material – doped ytterbium fiber – and a renewed emphasis on pump (diode) technology.

Today, innovation is driven primarily by the need to satisfy the requirements of specific applications. For example, in solar cell and flat panel display production, development is focused on delivering better results from laser-enabled processes (e.g., increased throughput, lower cost, higher yield). Laser innovation for microscopy applications is targeted at faster imaging and higher spatial resolution. Lower cost of ownership, critical in many industrial applications, is driving developments to improve the reliability and efficiency of existing laser technology. This article will illustrate these trends by examining a few key laser technologies and the applications they enable.

### Multiwatt visible lasers

Perhaps no single area epitomizes the evolution of our industry like the CW multiwatt visible laser. The first generation of this technology was the argon-ion laser, which could produce output at several visible and UV wavelengths, the most intense being 488 and 514.5 nm. When introduced in the late 1960s, these lasers generated tremendous interest and market demand. At first, this was as much about how the laser worked as

Figure 1 (Opposite). Both yellow and blue OPSL lasers are used in high-impact light shows. Photo courtesy of Lightline Lasertechnik, Osnabrück, Germany.

about how it could be used. This focus characterizes the first decade of the laser industry. Later uses include holography, inspection and trabeculoplasty, a treatment for glaucoma that was the world's first medical laser application. And in scientific applications, these lasers were used as pump sources for dye lasers, which were the next very diverse technological development.

Unfortunately, ion lasers were inefficient, bulky and much less reliable than the lasers of today. Their optics required frequent tweaking, and water cooling was essential for multiwatt operation. The early plasma tubes had a lifetime of a year, making them expensive consumables. Some of these limitations were mitigated by very creative engineering and a switch to ceramic discharge tubes, but these lasers remained user-unfriendly (by today's standards), and few true OEM applications developed. In contrast, their lower-power, lower-cost, air-cooled cousins became the workhorses for a generation of biomedical instruments and disc mastering machines.

Multiwatt, CW, visible technology was revolutionized by the introduction of diode-pumped solid-state (DPSS) lasers. Unlike ion lasers, these DPSS lasers could emit only one wavelength, 1064 nm, which was then intracavity doubled to produce 532 nm. But this single-wavelength functionality was considered a small price to pay for the massive gain in efficiency, longer lifetime, lower cost of ownership, a ten times reduction in size and the fact that these lasers could be factory-sealed with no subsequent use tweaking required. Needless to say, applications for these solid-state lasers expanded overnight. And existing scientific applications, such as pumping for both CW Ti:sapphire and ultrafast laser systems, switched from ion to DPSS. Other important uses for these lasers included forensics, inspection and holography.

Despite the advantages of DPSS, commercial and scientific applications continued to demand even lower cost of ownership and greater flexibility and reliability, but without any sacrifice in output characteristics. A third generation of visible lasers based on optically pumped semiconductor laser (OPSL) technology arose to meet this need. Here a laser diode pumps a semiconductor chip rather than a doped crystal. This eliminates the thermal lensing issues that plagued DPSS lasers. OPSL also enabled automated "pick and place" manufacturing methods and economies of scale.

And today this technology can be tailored to output specific wavelengths over a near-IR range that, when intracavity doubled, provides a selection of visible wavelengths.

The result is that OPSL technology exceeds the best of ion and DPSS characteristics: It is wavelength-flexible and power-scalable, yet inherently compact and efficient. As a result, we are now at a point where laser output can be defined by the application, rather than vice versa. So while these lasers are available at legacy wavelengths, such as 488 and 514 nm, they are also offered at completely new wavelengths to optimize targeted applications. A standout example is the 577-nm yellow laser that is matched to oxyhemoglobin absorption. This wavelength provides superior results in the

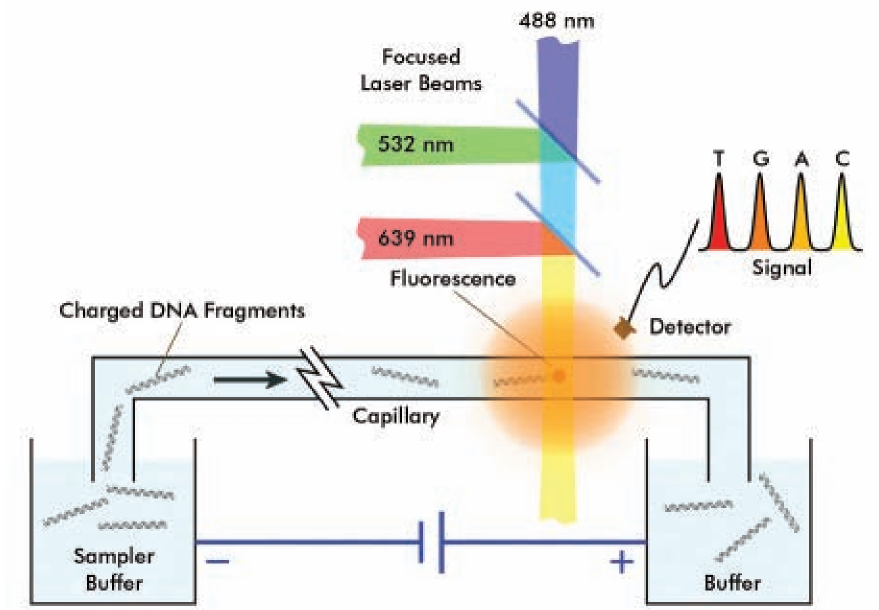


Figure 2. Fast-automated DNA sequencing relies on laser-excited fluorescence. The use of multiple laser wavelengths is critical, as instrument builders close in on the holy grail of "the thousand-dollar genome," a price point predicted to cause massive clinical diagnostic market uptake. Courtesy of Coherent Inc.

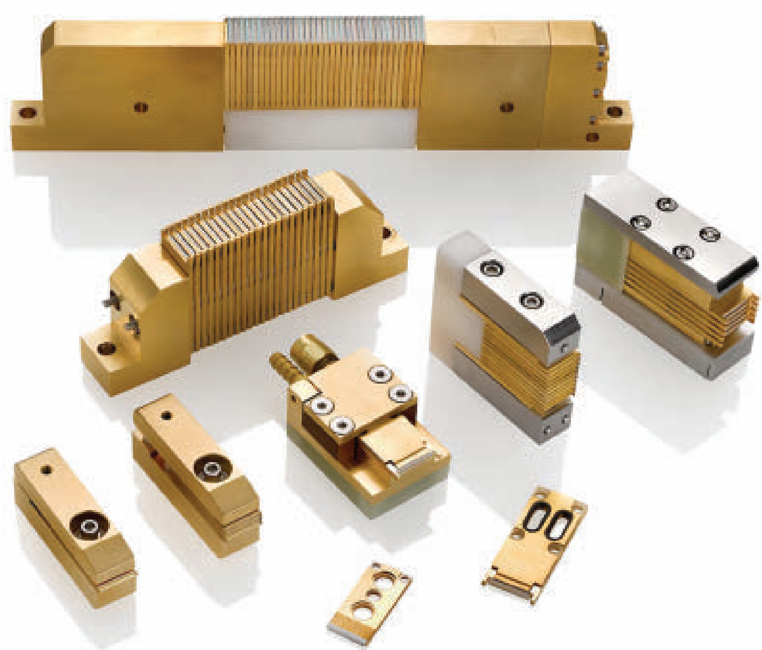

Figure 3. Laser diodes and diode arrays are key building blocks of both materials processing systems and other lasers. They are the most mature of all lasers in terms of volume manufacturing. This is reflected in their closer resemblance to integrated electronic components than to other laser technology. Courtesy of Coherent Inc.

photocoagulation used to treat wet-form macular degeneration. This has also turned out to be a useful and popular wavelength for use in laser light shows (Figure 1).

Most recently, multiwatt OPSLs in the red have become available. These wavelengths were developed to provide brighter images and a wider color gamut in entertainment applications as well as to support faster DNA sequencers, which now use a combination of 488-, 532- and 639-nm laser wavelengths (Figure 2).

**The diode laser revolution**

Many of the advances in laser technology over the past two decades have been enabled through the use of diode lasers as pump light sources. However, just as with other laser types, the diode laser itself started out as a low-power lab novelty with limited reliability. But the need for compact, long-lived sources in data storage and telecommunications drove these devices to higher output powers, narrow linewidths and increased reliability.

Producing even higher power diode lasers and arrays with increased brightness remained a challenge. The principal problems were heat load management and facet failure, since a large amount of optical power is channeled through a facet measuring, at most, tens of microns. In addition, many applications needed a system design that could withstand repeated on/off cycling.

The laser industry met this need by incremental improvements in power, lifetime and brightness.  Key technical innovations were the introduction of aluminum-free active region devices to address facet lifetime and indium soldering to address the mounting/cooling interface issues. Market success followed suit, with applications such as optically pumping solid-state lasers in tasks such as chemistry, holography, materials science, biology and industrial micromachining, and materials processing using the direct diode output in tasks such as welding, cladding and hardening. Today, few would argue with the fact that laser diodes (individually or aggregated) are the single most important technology in the laser industry (Figure 3).

**$CO_2$ lasers**

The solid-state laser revolution has not been completely universal in its reach. When it comes to industrial applications, the $CO_2$ gas laser (first commercialized by Coherent in 1966) has long reigned as the lowest-cost-per-watt champion. No other technology can come close to the high power or low cost in

Figure 4. Sealed carbon dioxide lasers are now widely used for engraving and marking of a wide range of organic materials, with possibly no application more eye-catching than the production of images, cutouts and fake 3-D effects on high-end denim jeans. Courtesy of Coherent Inc.

the mid-IR. Initially, $CO_2$ lasers were flowing gas type, with the $CO_2$ lasing in a long plasma discharge tube. These lasers were eventually scaled up to multiple kilowatts for brute force applications such as cutting steel for automobiles and drilling holes for the aerospace industry.

Materials processing engineers soon realized that the mid-IR was a perfect wavelength for processing a host of organic materials in applications such as cutting and perforating paper, as well as cutting plastics, leathers, metal foils and carbon fiber laminates used in automotive interiors. In addition, emerging applications such as via drilling in the electronics industry needed lower initial and operating costs, flexibility in power and, in some cases, optimization of wavelengths and a quantum leap in miniaturization and operational simplicity compared with the massive water-cooled flowing gas lasers with their fast pumps and expensive bottles of laser gas. These changes to $CO_2$ lasers ultimately enabled the transition from conventional mechanical processes (drills in the case of microvias) to enhanced laser-based processes. Many applications also needed pulsed operation with fast rise times to avoid charring and damaging the cut edges in these relatively delicate materials.

At low power levels of less than 100 W, this need was met with the development of sealed waveguide lasers using radio-frequency excitation. The low cost and simplicity of these compact lasers continue to feed a healthy and diverse materials processing market, headlined by marking and engraving (Figure 4) as well as surgical and aesthetic applications. At higher powers – i.e., up to a kilowatt – the goals of compact simplicity and high reliability were met with the introduction of sealed slab discharge lasers (Figure 5), where the power scales as the area of the electrodes rather than the length of a waveguide.

These novel lasers enabled a host of new materials processing applications, most notably using robotic and flatbed mounting, in organics, thin metals and particularly in mixed (laminated) materials for electronics and automotive interiors. The sealed $CO_2$ laser thus became a very mature tool used in many industries and applications. As a result, size, reliability and cost of ownership drive today's decision making in applications ranging from microvia creation (think mobile phones) to flat panel display manufacturing and other high-volume cutting and drilling applications.

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Figure 5. Carbon dioxide lasers have undergone tremendous innovation over the years. The biggest step forward was arguably the development of compact sealed lasers at powers of up to a kilowatt (foreground, Coherent Diamond 500W series) in a platform that bears little resemblance to their large, cumbersome and less reliable forebears (background, Coherent Everlase 500W series, circa 1980). Courtesy of Coherent Inc.

**Fiber lasers**

Fiber lasers represent another example of innovation where a completely new laser type is pioneered for one application but later modified or upgraded to address the needs of others. Born from the telecom boom, these lasers initially saw life as amplifiers for ultralong-haul communications networks.

These fiber amplifiers used laser diodes to pump light into a doped optical fiber. When married with fiber Bragg gratings, they emitted laser light at about 1.1 µm. First produced as a low-power laboratory novelty, they underwent a rapid acceleration during the telecom bubble. However, when that imploded, the specialty manufacturers of these telecom novelties began to look for other potential applications. It became clear that if fiber lasers could be scaled to higher powers, they could become viable and successful sources for certain materials processing tasks at kilowatt levels.

The first generation of high-power fiber lasers relied on a large number of laser diodes for pumping and on long lengths of doped fiber for distributing the gain and thus minimizing thermal strain effects. This approach has enabled powers ranging from tens of watts up to tens of kilowatts with operating modes from CW and modulated, to even some low-power mode-locked (picosecond/femtosecond) models. The power and optical characteristics of these fiber lasers have enabled them to be quite successful in certain materials processing segments – marking, micromachining and cutting thin materials. Specifically, lower-power (e.g., 20- to 200-W) CW fiber lasers are used to engrave metals and coated metals.

The other sweet spot for fiber lasers has proved to be in the 1- to 2-kW window, where, depending on the material and the application specifics, they share the limelight with $CO_2$ lasers. Their 1-µm wavelength makes them particularly attractive for cutting metals since their main competitor – the $CO_2$ laser – is not an ideal wavelength match. But for cutting nonmetals and mixed materials, the lower cost of ownership of sealed $CO_2$ lasers means this is a very competitive area for the two laser technologies.

Fiber lasers remain a relatively new commercial deployment, and it remains to be seen what the future holds. But reliability and cost of ownership as well as serviceability will play a role. By applying more effective aggregation of diodes and reducing the total part count, a next-generation fiber architecture would enable more applications. In addition, there is a strong trend to produce more specialized fiber laser products, highly optimized for target applications, reflecting the growing maturity of fiber lasers for use in materials processing, scientific research and medical procedures.

The laser industry has always been powered by technology and innovation. In the early years, these were pursued as an end in and of themselves. Applications were almost an afterthought, mirroring the original skepticism that the laser was indeed a solution looking for a problem. However, over the past two decades, this has completely changed. With an explosion of diverse applications, the laser has become arguably the key tool in ushering in the age of the photon. So while technology and innovation are still the watchwords of our industry, these efforts are now focused on developing products demanded by, and defined by, the applications themselves.

**Meet the author**

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II-VI INFRARED ...the world leader in $CO_2$ laser optics

# YOUR OPTICS FOUNDRY

From the very beginning of commercial $CO_2$ lasers in the 1970s to today, II-VI Infrared has been the premiere supplier of $CO_2$ laser optics worldwide. The **enabler** to the entire $CO_2$ laser industry –– producing commercial quantities of built-to-spec optics that gave OEMs the ability to push $CO_2$ laser designs and output powers forward –– II-VI's winning combination of consistent quality, low absorption, and high volume production have made us the #1 choice for optics across the entire wavelength spectrum –– from 9.0 to 11.6μm –– of $CO_2$ lasers and applications.

A pioneer in infrared (IR) optical materials, II-VI was founded in 1971, initially producing cadmium telluride (CdTe). By 1973 we were producing the world's first AR and HR $CO_2$ laser optics. In 1975, we began developing zinc selenide (ZnSe) –– what would become the leading transmissive IR optical material. In 1977, we began offering silicon (Si) reflective optics. Three years later, we introduced our reflective phase retarder (RPR), which enabled circular beam polarization and a clean cutting kerf, and led to rapid worldwide growth in $CO_2$ laser cutting systems. That same year, we began offering optics made from gallium arsenide (GaAs) and germanium (Ge).

Always striving to reduce coating absorption, we significantly increased reflectivity in our silicon (Si) and copper (Cu) mirrors in 1981. By 1982, we had done the same for transmissive optics when we developed our low absorbing AR coating for ZnSe. We began full-scale production of ZnSe in 1984, and remain the world's largest ZnSe producer to this day.

The optics foundry for $CO_2$ laser OEMs throughout our history, II-VI produced the world's first commercial resonator optics for slab lasers and coaxial lasers, and was the first $CO_2$ laser optics supplier of production optics in both Japan and Germany. Today, our worldwide presence and vertical integration –– from growing our own IR optical materials to delivering finished coated optics –– make us the #1 choice whenever OEMs need built-to-spec optics produced in commercial quantities with consistent quality.

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# LASERS in the manufacturing of LEDs

BY MARCO MENDES AND JEFFREY P. SERCEL, J.P. SERCEL ASSOCIATES INC.

In today's society, there is a continuous need for devices with lower energy consumption and higher efficiency. Light-emitting diodes (LEDs) are expected to see a 61 percent rise in worldwide demand in 2010, according to Barry Young of IMS Research, due in large part to the mobile handset. The market for large backlit LED TVs is rapidly expanding, and LEDs also are used in a large number of other applications, from projectors and flashlights to car tail- and headlights and general illumination. Solid-state white-light sources can be realized either by mixing different LEDs emitting red, green or blue light, or by using a phosphor material to convert monochromatic light from a blue or UV LED to broad-spectrum white light.

With the increase in LED production, manufacturers are looking for new process developments to optimize scribe width, speed and production throughput. New advances in laser liftoff (LLO) and laser wafer scribing for LEDs provide manufacturers with cost-effective industrial tools that are ready to meet increased demands.

**High-brightness LEDs with vertical structure**

Typically, blue/green LEDs are composed of a GaN film a few microns thick, grown epitaxially on a sapphire substrate. Some of the major costs of LED fabrication are the sapphire substrate itself and the scribe-and-break processes. For the traditional LED configuration, the sapphire is not removed, so both cathode and anode are installed on the same side of the GaN epitaxial (epi) layer (Figure 1).

There are several drawbacks to this configuration. For high-brightness LEDs, disadvantages include a high current density inside the material, current crowding, reduced reliability and shorter lifetimes. Also, there is significant light loss through the sapphire.

By using an LLO process, LED designers can create a vertical LED, which overcomes many of the limitations of the traditional horizontal configuration. Vertical configuration provides the possibility of pumping an LED with more current, eliminating the undesired current crowding and bottleneck inside the device and significantly increasing the maximum light output and efficiency of the LED (Figure 2).

The vertical LED structure requires removing the sapphire before attaching the electrical contacts. Excimer lasers have proved to be valuable tools for separating the sapphire and GaN thin film. LED laser liftoff dramatically reduces the time and

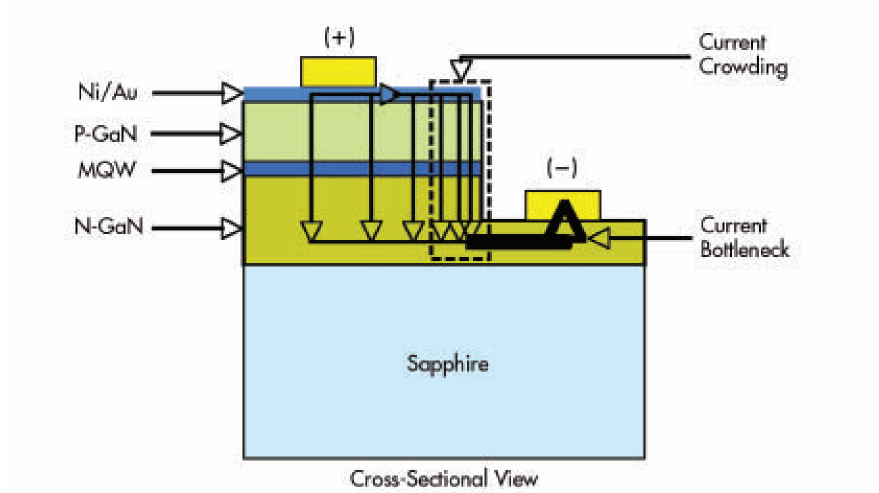



Figure 1. This diagram shows the traditional horizontal configuration for a blue LED. MQW = multiple quantum well.

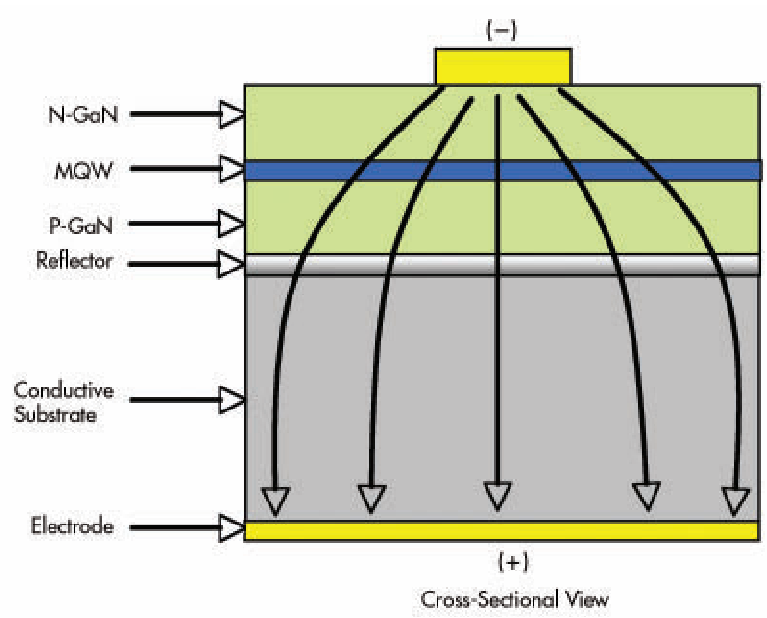



Figure 2. A model of a vertical configuration for a blue LED is shown.

cost of the LED fabrication process, enabling the manufacturer to grow GaN LED film devices on the sapphire wafer and to transfer the thin-film device to a heat sink electrical interconnect. The process allows for creation of freestanding GaN films and integration of GaN LEDs onto virtually any carrier substrate.

**Laser liftoff principle**

The basic concept behind UV LLO is to use the different absorptions of UV laser light in the epi material and the sapphire. With a high (9.9-eV) bandgap energy, sapphire is transparent to 248-nm KrF excimer laser radiation (5 eV), whereas GaN (approximately 3.3-eV bandgap) strongly absorbs the 248-nm laser light. As shown in Figure 3, the laser light travels through the sapphire and couples with the GaN, causing ablation at the GaN-sapphire interface. This creates a localized explosive shockwave and debonds the GaN from the sapphire at that location. The same principle applies to AlN on sapphire when using 193-nm ArF excimer laser radiation. Aluminum nitride with a bandgap of 6.3 eV can absorb the 6.4-eV ArF radiation, but AlN is still transparent to sapphire with a 9.9-eV bandgap.

To achieve successful liftoff, both beam homogeneity and wafer preparation are important. At J.P. Sercel Associates (JPSA) Inc., innovative and patented beam homogenization techniques with excimer lasers create a flattop beam on the wafer with uniform energy density distribution across an area as large as 5 × 5 mm.

Correct wafer preparation is crucial for successful LLO. It minimizes the residual stress from the high-temperature epi layer growth on sapphire, and it ensures adequate bonding between the epi layer and the carrier substrate to avoid fractures along the epi during liftoff. Figure 4 shows a typical liftoff result.

Using LLO systems leads to high-speed, high-yield production at ambient temperature. Well-designed systems allow exposure of multiple die simultaneously with a single shot and permit accurate placement of each shot across the wafer using a novel "fire on the fly" technique.

**Blue LED wafer scribing**

There are traditional manufacturers who continue to supply horizontal-structure blue LEDs, and laser scribing is ideal for processing this wafer configuration. The extreme hardness of the sapphire causes significant problems for both saw dicing and diamond scribing, including low die yield, low throughput and high operating costs.

The use of UV diode-pumped solid-state (DPSS) lasers has proved to dramatically increase die yields and wafer throughput as compared to traditional diamond scribing methods, without appreciable loss of brightness in LED wafers. The short wavelength enhances optical absorption at both the GaN and sapphire layers, lowering the irradiance required for ablation while simultaneously allowing for reduced cut width.

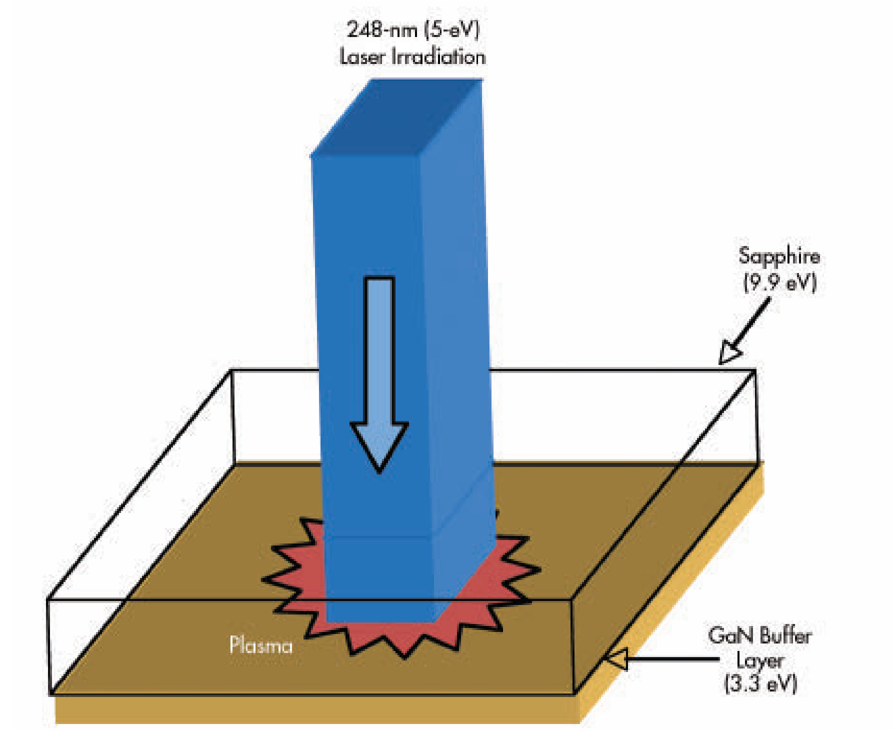



Figure 3. This is a schematic representation of laser liftoff at 248 nm.

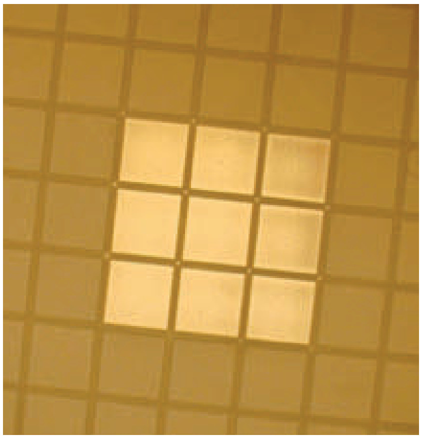


Figure 4. This diagram illustrates single-pulse laser liftoff of GaN from sapphire at 248 nm (one pulse covers nine die).

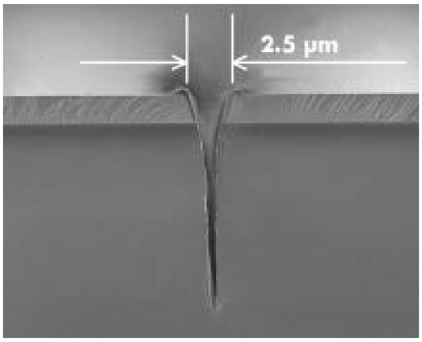



Figure 5. Shown here is the kerf width in a GaN-on-sapphire wafer.

Scribe width, speeds and production throughput are essential to keeping manufacturing costs low and wafer yields high. JPSA has developed a patented beam delivery system that allows for a very narrow kerf of 2.5 µm wide (Figure 5) and offers proprietary surface protection that minimizes debris. Moving the wafer under a tightly focused laser beam produces an extremely narrow V-shape cut; starting at the epi side and extending into the sapphire, it is typically 20 to 30 µm deep. After laser scribing, V-shape laser cuts act as stress concentrators for the process of breaking with standard cleaving equipment.

The narrower kerf width generated by 266-nm front-side scribing increases the number of usable die produced per wafer,

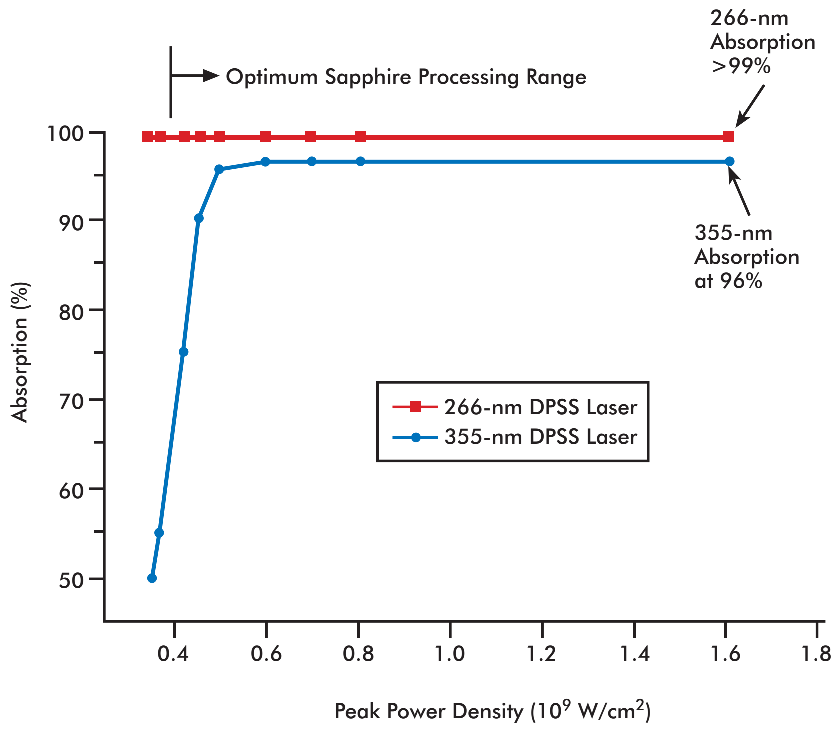



Figure 6. This graph represents UV absorption in LED sapphire.

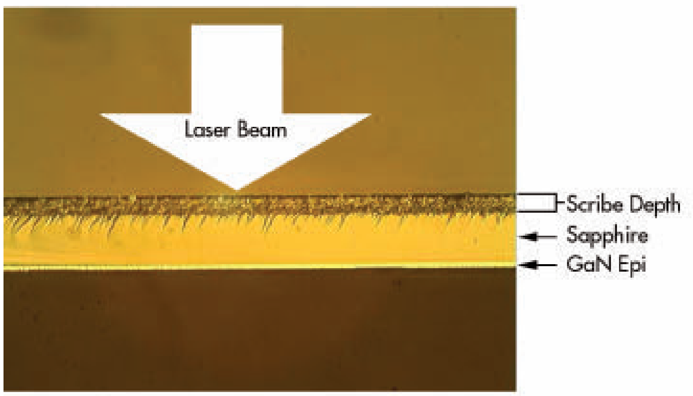



Figure 7. Shown here is a cross section of a GaN wafer scribed from the sapphire (back) side by a 355-nm diode-pumped solid-state laser.

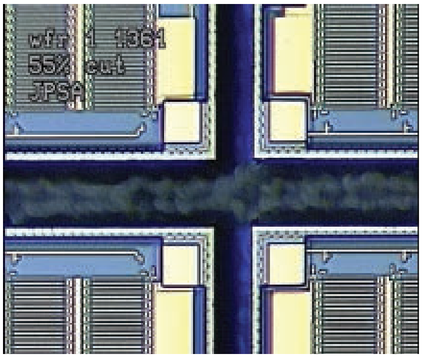



Figure 8. Clean, well-defined edges are highlighted in this scribed and expanded GaAs wafer.

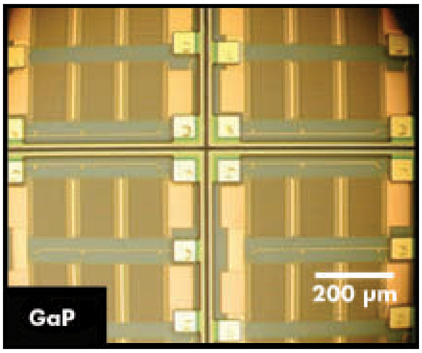



Figure 9. Pictured is GaP scribing at 300 mm/s for a 30-m cut, which is deep enough to break wafers up to about 250 µm thick.

potentially boosting the entire fab operation.

An easy comparison involves a typical 2-in. blue LED wafer on sapphire, with 250 × 250-µm devices. Using traditional diamond scribing with typical 50-µm streets (300-µm die pitch), there will be approximately 22,500 die on the wafer. The typical breaking yield is 90 percent for traditional diamond scribing and results in 20,250 usable die per wafer.

By using UV laser scribing, the street width can be reduced to 20 µm (a 270-µm pitch), increasing the number of die on the wafer to approximately 27,800 (a 23 percent increase). With increased breaking yields, the method produces about 27,500 usable die – a 35 percent total increase in usable die per wafer.

Since 1996, JPSA has been using 266-nm DPSS lasers to scribe blue LED sapphire wafers from the GaN front side at speeds of 150 mm/s, leading to a throughput of about 15 wafers per hour (for standard 2-in.-diameter wafers with a die size of 350 × 350 µm). With its high throughput and minimal impact on LED performance, the process is tolerant of wafer warp and bow, delivering much faster scribing speeds than traditional mechanical methods.

**Scribing silicon carbide**

In addition to sapphire, silicon carbide can be used as an epitaxial growth substrate for thin blue LEDs. Ultraviolet DPSS lasers at 266 and 355 nm (4.6 and 3.5 eV, respectively) excel at scribing silicon carbide, which has a large bandgap of around 2.8 eV. Because of the high photon energy, enhanced coupling is achieved, allowing for high-speed scribing and easy breaking. Thick III-nitrides such as GaN and AlN also can be scribed using UV DPSS lasers. While the scribing speed for 200- to 400-µm-thick GaN or AlN is significantly reduced compared with the speed for thin epi films on sapphire or silicon carbide, the cut quality is excellent and allows for a clean breaking step.

For vertical high-power LEDs, LLO detaches the sapphire while the epi film remains bonded, typically to a high-conductivity carrier substrate such as copper, copper-tungsten, molybdenum or silicon. For wafer-based silicon, cutting depths of 100, 150 and 200 µm can be achieved at 300, 150 and 100 mm/s, respectively. Beam delivery techniques allow these scribing speeds/depths while requiring only limited laser power and, consequently, minimizing thermal affectation. Scribing of metal-based wafers is challenging because of high thermal conduction that typically leads to a weld back effect. In addition, a full cut often is required for separation because the material is extremely ductile. At JPSA, we have developed advanced techniques that allow for successful scribing of these substrates up to 200 µm thick and that could prove extremely important for the high-brightness LED industry.

**Dual scribing capability**

Back-side scribing by 355-nm DPSS lasers allows scribing from the sapphire side of the LED. Wafer alignment can be performed from the front or back side using multiple inspection cameras, which is important if the sapphire has a metallic reflective layer. Also, the epi is not directly exposed to laser radiation, which may minimize light loss. When compared to a 266-nm laser, the longer 355-nm wavelength leads to reduced absorption in the sapphire (Figure 6). As a consequence, higher power typically is required, which leads to wider kerfs and streets. Additionally, back-side scribing is applicable only for sapphire wafers <150 µm thick, while front-side scribing allows for thicker wafers that may be lapped down to the final thickness required for breaking after processing.

With continued research and development in back-side scribing, such as new laser absorption enhancement techniques, JPSA has achieved high-throughput back-side scribing at speeds of up to 150 mm/s with no debris or damage to the epi layer (Figure 7).

**Wafer scribing III-V semiconductors**

An alternative method for separating brittle compound semiconductor wafer materials in GaAs, InP and GaP wafers is scribing with UV DPSS lasers that rapidly process wafers with kerfs around 3 µm with no edge chipping in any of the III-V materials, making straight, accurate and clean cuts (Figure 8). Typically, wafers up to 250 µm thick are scribed at 300 mm/s, allowing for easy breaking (Figure 9). The III-IV wafers are expensive, so wafer real estate is valuable. The tighter, narrower and cleaner cuts achieved using UV lasers provide a better die count per wafer as well as higher yields, due to fewer damaged die than with conventional saw scribing methods.

**Outlook**

LED technology is advancing rapidly as it strives for higher efficiency and lower manufacturing costs. This "green" technology undoubtedly has a bright future; however, it also faces considerable challenges.

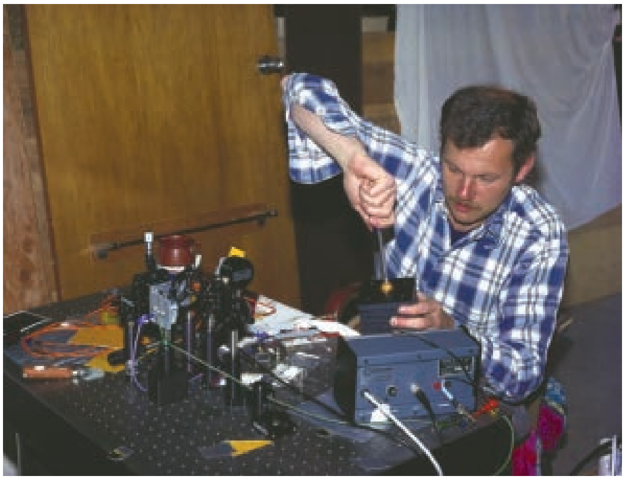
The current explosion of worldwide demand for LEDs requires the development of new laser processes and technologies to produce even higher quality, yield and throughput. In addition to the ongoing development of laser systems, new machining techniques and applications, improved beam delivery and optical systems, and an enhanced knowledge of the interactions between laser beams and materials will be required to sustain the progress of this green revolution.

Equipment engineers are challenged to build flexible tools. Options, such as the capability for automated cassette loading and unloading, edge detection and autofocus systems, define the state-of-the-art laser scribing solution. Companies such as JPSA continue to explore the forefront of laser technology to meet the demands of the LED manufacturing market.

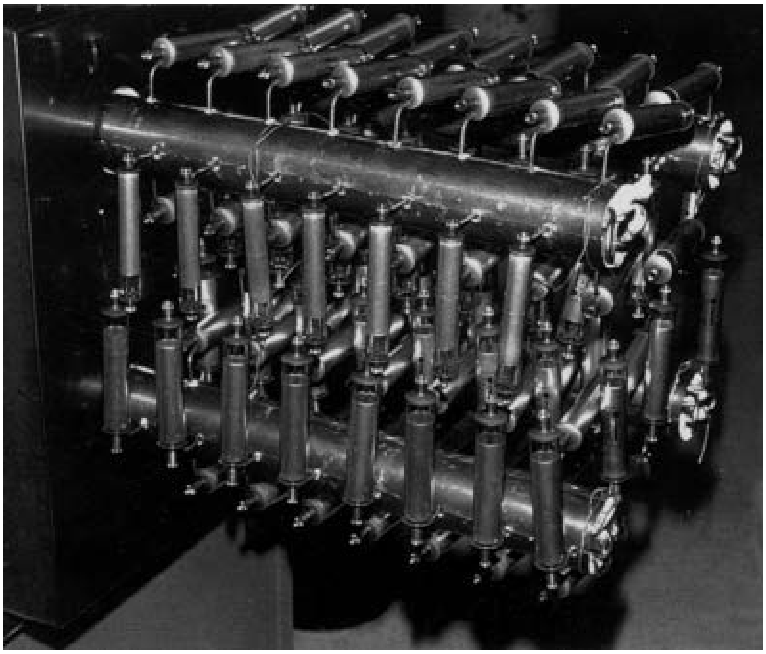
**Meet the authors**

Jeffrey P. Sercel is chairman and chief technology officer of JPSA in Manchester, N.H.; e-mail: jsercel@jpsalaser.com. Marco Mendes is director of JPSA's applications lab; e-mail: mmendes@jpsalaser.com.

# THE GOOD OL' DAYS OF
# Laser Entrepreneurship



David M. Buzawa, vice president of engineering at Iris (now Iridex), puts together a prototype in the garage of Theodore A. "Ted" Boutacoff, the company's president. Courtesy of Iridex.



HeNe lasers from Uniphase became the gold standard, thanks to the company's focus on continuous improvements to manufacturing processes. Courtesy of Dale Crane, founder of Uniphase (JDSU).

BY DR. MILTON M.T. CHANG
INCUBIC MANAGEMENT LLC

History is useful only if we can draw useful generalizations from it. And there was a lot to learn from building companies in our industry, especially in the early days.

My laser career began in 1963, in my senior year at the University of Illinois, when, while working as a part-time student lab technician, I took on the assignment to build a ruby laser to study laser cavity modes. After receiving my graduate degrees, I began my entrepreneurial career in 1971, joining Newport Corp. as its seventh employee. And I was an active angel investor when I was running Newport and New Focus Inc.

**Starting a company way back when**

In the early days of the laser industry, before the word "photonics" was made popular by Laurin Publishing Chairman and CEO Teddi C. Laurin, a technical person like me could successfully start a company without any business experience simply by using common sense and capitalizing on his or her expertise. All you had to do was identify a need in your area of specialization and work hard at it. You didn't even have to worry much about established companies breathing down your neck because there were only a handful of them, and they had plenty of opportunities without bothering to lock horns with you on your niche technical turf. And there were plenty of investors wanting to jump on the glamorous laser bandwagon who were willing to provide capital.

Against that backdrop, opportunities were abundant. I was fortunate to have caught the wave for a very long ride: I was involved in founding, running or serving on the boards of several companies – Newport, Uniphase and Cyonics (later JDSU), Iridex, Lightwave Electron-

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ics, CyberOptics, NEOS, Laser Power Optics, Questek, Cleveland Crystals and Rochester Photonics – before I started New Focus.

**Uniphase**

Once upon a time, HeNe lasers made by Optics Technology Inc. were the ones to buy. They had a "compact" functional design, with the laser mounted on top of the power supply. The lasers looked nice, but output power would drift as the power supply heated up the laser tube. The company soon came to an end when Spectra-Physics introduced its beautifully engineered line of HeNe lasers supported by its professional sales force.

Then, in 1979, came Uniphase, with Dale Crane at the helm, sweating every detail in manufacturing. It was the only company that could respond to Symbol Technology's demand for a rugged, reliable and low-cost laser to make handheld laser scanners.

Uniphase invested in a new manufacturing facility to increase capacity, and it improved quality and lowered costs by making continuous improvements in its manufacturing processes. With Dale on top of every aspect of the business, the company reduced the rate of reject and rework from the industry norm of something like 8 percent to less than 1 percent.

Spectra-Physics eventually abdicated to buying lasers for its scanner division from Uniphase – and the rest is history. The lesson learned is that the technology is important but that novelty wears off, and every product competes on quality, performance and price.

**Iridex**

This company, originally Iris Medical, set out in 1989 to build ophthalmic therapeutic systems that use semiconductor lasers to replace the cumbersome argon laser systems. The founders, Theodore A. Boutacoff, David M. Buzawa and Eduardo Arias, had little doubt that their product would replace existing systems because theirs would fit so well into doctors' offices – especially if the selling price were comparable to the replacement cost of argon laser tubes.

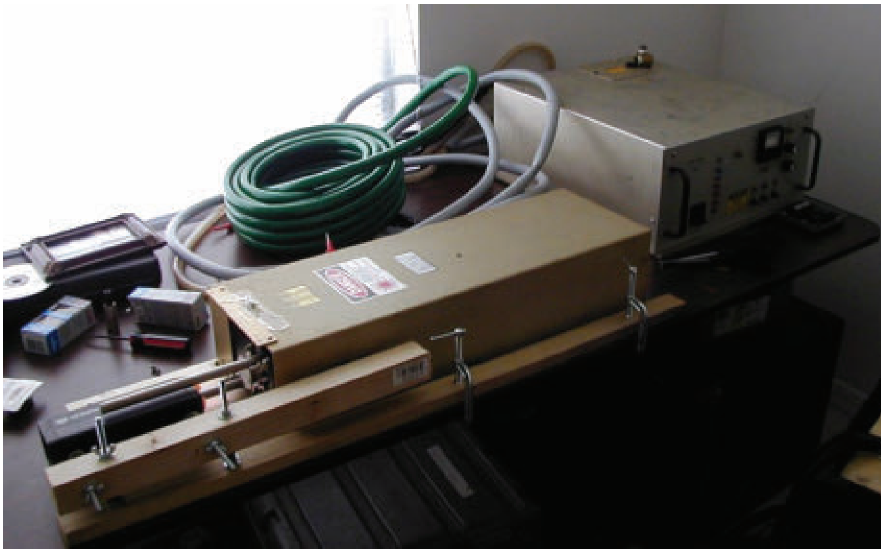
But semiconductor lasers were difficult to produce at the time – and therefore very expensive – and users were placed on allocation. The company knew that all that would change based on the pricing history of DVD lasers and decided to forward-price the system; i.e., they priced the system based on the cost of the laser projected out a few years. That affected early profits but enabled the company to prevail in the long run. The lesson learned is that technology is a necessary but insufficient condition to succeed in business. You also need a sound business strategy.

**Newport**

This company started in 1969 with about a $150,000 investment from the uncle of John Matthews, my California Institute of Technology schoolmate who co-founded it with Dennis Terry. We bootstrapped our way to an initial public offering without additional capital infusion.

We worked hard. John was president, responsible for engineering, Dennis was responsible for manufacturing, and I was responsible for marketing and sales. Our average workweek was more than 14 hours a day, six days a week – sometimes more. John and I would brainstorm about every aspect of the business and technol-


At Newport, Milton Chang learned that just having a technical edge is never enough for success. A company must focus on customer service, engineering, manufacturing and more.



Shown is a Uniphase HeNe laser, the Lexel 88 argon-ion, and its power supply. Courtesy of photographer Gregory Maxwell.

ogy long after midnight, not paying attention to how time flew when we were having fun.

We took care of our customers. Everyone at Newport (and, later, at New Focus) knew that the phone had to be picked up within three rings and that customers were not to be kept waiting more than 24 hours to get an answer. Over time, our attitude of service helped, and I made many friends over the years, some of whom have stayed in touch to this day.

We strove to stay ahead of the competition. John had majored in physics but had a knack for engineering. He designed all the mechanical hardware, including manufacturing toolings, but his pride and joy was the innovation he made in the tabletop damping system, which really made a big difference in optics research.

John's uncle, a conservative Chicago banker, taught us how to be fiscally responsible, and all three of us were by our very natures careful spenders. We grew the company rationally, using only cash actually generated by the business, and we increased profitability by investing in manufacturing processes to reduce cost.

For example, we invested in an expensive stamping tooling to make the vibration isolators out of steel plates instead of aluminum castings, which gave us a better product at lower cost. And we designed and built a multispindle head to drill and tap tabletop mounting holes on 1-in. centers to reduce manual labor a hundredfold.

The lesson learned was that a technical edge alone is never a sufficient condition for success. Your team must be able to execute a plan with the right attitude toward customers, and with engineering and manufacturing expertise, adequate capital, business and management acumen, marketing finesse – and the list goes on.

**Starting a photonics business today**

Opportunities in photonics are still in abundance. But given that the laser industry is now 50 years mature, you have to look harder, maybe even using your special photonics expertise to get into an emerging field and find startup opportunities. And when it comes to having to compete with established companies in a mature industry, follow the adage "If you can't beat 'em, join 'em" by working toward an early acquisition instead of trying to take your company all the way to revenue.

**Looking back**

What I miss the most is the pleasure of seeing investors and management working collaboratively as a team. It is a big loss for everyone when the starting point is on opposite sides of the table, as it often is today. You can still find investors who are statesmen. Their hearts are in the right place, and they want to build great companies.

The starting point is you, the entrepreneur, with the intention of serving each customer well. You must see wealth generation as a derivative of having built a great company. I hope you will respond to my call to rejuvenate the entrepreneurial spirit of the good ol' days.

**Meet the author**

Dr. Milton M.T. Chang, who is semi-retired, spends time mentoring entrepreneurs. He has been an investor in the photonics industry and was CEO and president of Newport Corp. and New Focus Inc. prior to forming Incubic Management. He is a fellow of the IEEE, LIA and OSA and was past president of LIA and LEOS; e-mail: miltonchang@incubic.com.

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# Laser Safety Standards
## THROUGH THE YEARS

BY KEN BARAT, LAWRENCE BERKELEY NATIONAL LABORATORY,
AND JEROME E. DENNIS, IEC TC 76

Shortly after the demonstration of the first ruby laser by Theodore Maiman at Hughes Research Laboratories in Malibu, Calif., in 1960, many other laboratories assembled crude laser devices, and the laser's unique hazard characteristics did not take long to become apparent.

For example, researchers at the US Naval Material laboratory at the Brooklyn Boat Yard in New York purchased a ruby rod and vacuum-coated its ends with an aluminum film. They inserted the rod into a xenon flashlamp surrounded by aluminum foil, and sure enough, a red spot appeared on the laboratory wall many feet away. But the light vaporized the coating, and the ruby rod had to be recoated after every shot.

Experts from major corporations and from the government agreed that control measures had to be established in anticipation of the laser's proliferation. Control measures for laser products and for laser users would be needed, they agreed.

Researchers began to determine the levels of wavelength and duration of exposure that would not be expected to cause injury to a person. The levels became known as maximum permissible exposures (MPEs) and are expressed in units of irradiance or radiant exposure (time-integrated irradiance); i.e., power or energy per unit area. Although measurements of irradiance and radiant exposure are relatively straightforward, the researchers also had to determine the area over which the power or energy would be averaged. This is defined by the area of a circular measuring aperture called the "limiting aperture" in the American National Standards Institute (ANSI) standards.

Once the MPEs were established, they had to apply these values to exposures that could be expected from laser products to determine whether the products would be hazardous in use. Initially, up to 10,000 s was considered reasonable for occupational exposure, and an 80-mm diameter was used to simulate a full day of occupational exposure and viewing with a large-aperture optical instrument.

With these measurement specifications, it is possible to determine whether a product is likely to produce exposures that will exceed the MPE. The level of emission from a laser product that equals the MPE (under the specified conditions of measurement) is defined as the accessible emission limit (AEL) of Class 1. Tables of expressions for AELs were drawn up by bioeffects experts – mainly from the military – and from what is now the Center for Devices and Radiological Health (CDRH), as functions of wavelengths and emission durations similar to those for the MPEs. It also was recognized that there are gradations of hazards depending upon the extent to which the AEL of Class 1 or Class I was exceeded.

The experts agreed that the following classes of laser products were appropriate:

**Class 1 or I:** Not recognized to be hazardous.

**Class 2 or II:** Visible wavelengths; only hazardous for staring directly into the beam for longer than 0.25 s.

**Class 3A or IIIa:** Similar to Class 2 or II for unaided viewing, but allowed up to five times higher power in large-diameter beams.

**Class 3B or IIIb:** Hazardous for direct eye exposure and may be a skin hazard at the upper end of the class.

**Class 4 or IV:** Hazardous for direct eye or skin exposure and also may be hazardous by reflection from diffuse surfaces and a fire hazard.

This classification scheme was adopted by both the FDA and the ANSI Z136 community, enabling a cohesive set of requirements to be developed. The Radiation Control for Health and Safety Act of 1968 gave the Bureau of Radiological Health (BRH), part of the FDA, authority to issue mandatory safety standards for products that electrically generate any kind of radiation and to establish reporting and recordkeeping requirements for manufacturers of such products. The BRH later was merged into the CDRH.

### The CDRH/FDA Standard (21 CFR 1040)

With laser manufacturer input, a proposed laser product safety standard was published in the Federal Register (1973). It included product hazard classifications, measurement conditions for classification, controls and indicators based on classification, and warning labels, and it required safety information in operating and service instructions. The proposal also included additional requirements for medical laser products and established class limits for construction laser products and for laser products intended for use in entertainment and display. The proposal was refined in 1974 in response to comments received from the public and then published as a final regulation to become effective on Aug. 2, 1976, as 21 CFR 1040.10 and 1040.11. A number of adjustments were made to the standard in 1978 and 1985 (see Table 1).

In 1992, members of the CDRH laser staff met with representatives of the military, industry and academia to explore ways to harmonize the CDRH standard and the International Electrotechnical Commission (IEC) standard 60825-1. The main differences at the time were that the IEC standard had different tables of AELs and measurement specifications for hazard classification and also included a guide for the safe use of lasers.

It was agreed that both standards provided reasonably similar safety measures, but the differences contributed to unnecessary costs to industry in designing two standards and invited confusion likely to cause noncompliance with both standards. As an interim measure, the CDRH published a guidance document for industry, *Laser Notice 50*, stating that it would not object to conformance to requirements of IEC standards 60825-1 and 60601-2-22 in lieu of a list of requirements of the CDRH standard. The CDRH has issued numerous other statements of policy and interpretation, but *Laser Notice 50* is probably the most significant because it allows the use of IEC labeling on US products in lieu of CDRH labeling, thus removing dual labeling requirements. These, as well as the standards and regulations, are available at no charge at www.fda.gov/radiation-emitting products.

**Horizontal and vertical standards**

The CDRH standard at 21 CFR 1040.10 and 1040.11 contains requirements in §1040.10 (a horizontal standard; meaning it reaches across all the vertical/applications-specific standards) that apply to all laser products, while in §1040.11 (vertical standards that contain additional or modified requirements), the requirements apply to specific-purpose laser products:

**§1040.11(a)** – Medical laser products.
**§1040.11(b)** – Surveying, leveling and alignment laser products.
**§1040.11(c)** – Demonstration (light show or display) laser products.

Similar structuring occurs in the international standards. IEC 60825-1 is the horizontal standard and applies to all laser products, while the following vertical standards apply additional or modified requirements for laser products for specific purposes:

**IEC 60825-2** – Fiber optic communications systems.
**IEC 60825-4** – Laser guards (for high-power industrial laser machines).
**IEC 60825-12** – Free-space optical communications systems.
**IEC 60601-2-22** – Medical laser products.

Also within IEC Technical Committee 76, which is responsible for the 60825 series, is the responsibility for maintaining the 11553 series of standards of the International Organization for Standards (ISO) for laser-based materials processing machines.

**The International Electrotechnical Commission (IEC)**

Experts from several countries met in 1974 to organize a new Technical Committee 76 in the IEC to develop a standard for the safe use of laser products. The first edition of this standard was numbered 825 and consisted of three parts:

**Part 1** – Scope and definitions.
**Part 2** – Equipment, labeling and informational requirements.
**Part 3** – User's guide.

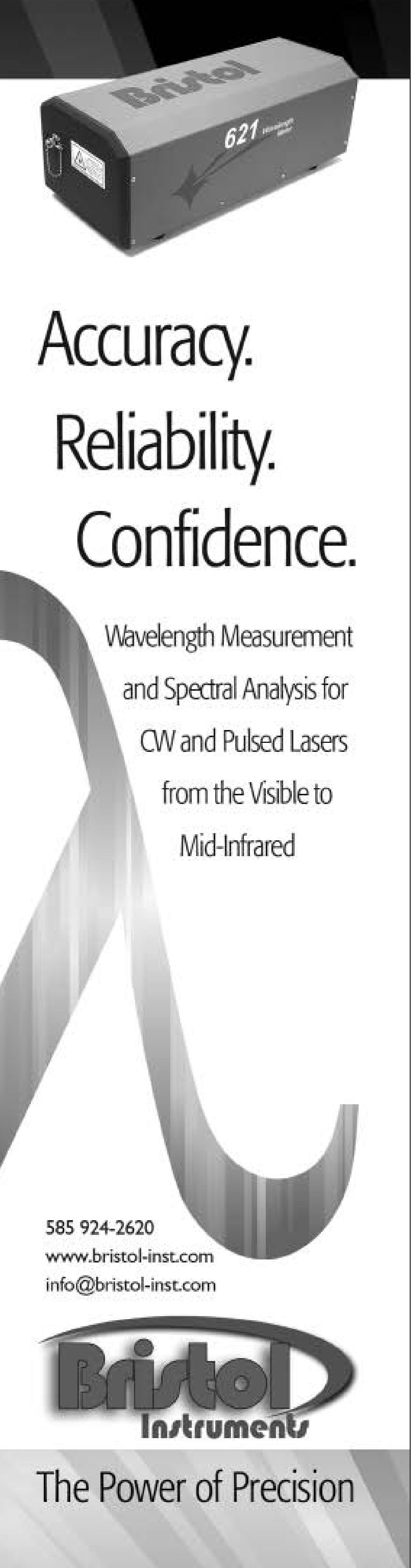
Parts 1 and 2 were normative, or mandatory, in countries that adopted them as their national standard. These parts were very similar to the BRH/CDRH/FDA standard in requirements and in language. Part 3 was informative and contained tables of MPEs and general procedures for safe use. The IEC standards can be adopted by member countries of the IEC in whole or with exceptions. Because the CDRH/FDA standard is mandatory in the US, and because the CDRH/FDA has legal enforcement authority, the US has not adopted the IEC laser standard as its national standard.

When a standard is voted on by the IEC member countries, it is concurrently voted on by the CENELEC, the European Commission for Electrical and Electronic Standards. If approved, the member countries of CENELEC publish the standard as a CENELEC standard designated with the code EN. However, in the EC, the EN standards are not in themselves mandatory but


**TABLE 1: CFR adjustments**

A number of adjustments were made to the standard in 1978 and 1985 (see Table YY).

- Permitting a separation distance from the laser to the measuring instrument to more realistically take into account peoples' minimum visual accommodation distance.
- Establishing a new Class IIa, with a shorter maximum emission duration for classification for products that emit visible laser radiation that is unlikely to be viewed for extended times.
- Permitting the use of a 7-mm aperture for the measurement of radiant power and energy for classification, unless the product is likely to be used in locales where the use of telescopes or binoculars would be expected.
- Establishing registration, product listing and recordkeeping requirements for uncertified laser products sold as components or repair parts.
- Giving the agency authority to approve alternate means of safety with respect to beam attenuators and labeling without having to resort to the more cumbersome variance procedures.
- Permitting Class IIIa as demonstration laser products.






are used as criteria of conformance with the mandatory European Directives.

The first edition of IEC 60825 was published in 1984. Revisions have been made to the current edition, IEC 60825-1, Edition 2, which was published in 2007.

Although these revisions have been occurring in response to advances in photobiological science and experience, the CDRH standard has remained static because of a lack of resources needed to keep up. In the early 1990s, the scope of 60825-1 was expanded to include LEDs because of their electrical and mechanical similarities to laser diodes. However, the latest edition has dropped LEDs because they do not have the radiance of lasers. IEC adopted the standard of the International Commission on Lighting (CIE) as a joint IEC/CIE standard for the Photobiological Safety of Lamps and Lamp Systems in which the hazards of LEDs are now being addressed.

IEC TC 76 has published the following additional standards, each first published in the years shown:

**60601-2-22** Class 3B and 4 medical laser systems – 1992.
**60825-2** Fiber optic communications systems – 1993.
**60825-4** Guards for industrial laser machines – 1997.
**60825-12** Free-space optical communications systems – 2004.
**62471** Photobiological safety of lamps and lamp systems – 2006.

IEC TC 76 is responsible for the maintenance of the ISO 11553 series standards for laser-based machine tools and has published a number of guides and technical reports dealing with applications, measurements and testing. The IEC standards are available from the US National Committee for the IEC at www.ansi.org, the IEC at www.iec.ch or the Laser Institute of America at www.laserinstitute.org.

Laser radiation safety limits based on the horizontal standard 60825-1 are incorporated into standards of other technical committees, including for electrical toys, home entertainment products and personal computers.

### US laser users standards

The first American National Standards Institute standard for the "Safe Use of Lasers Z136.1" was published in 1973 at the request of the CDRH. As applications of lasers matured, many applications-based laser standards were developed. The goal of these standards is to provide a safety back-

**TABLE 2: Application standards**

**ANSI Z136.1-2007** for Safe Use of Lasers – first edition, 1973.

**Z136.2-1997** for Safe Use of Optical Fiber Communication Systems Utilizing Laser Diode and LED Sources – first edition, 1977.

**ANSI Z136.3-2005** for Safe Use of Lasers in Health Care Facilities – first edition, 1988.

**ANSI Z136.4-2005** RP for Laser Safety Measurements, Hazard Evaluation and Instrumentation.

**ANSI Z136.5-2009** for Safe Use of Lasers in Educational Institutions – first edition, 2000.

**ANSI Z136.6-2005** for Safe Use of Lasers Outdoors – first edition, 2000.

**ANSI Z136.7-2008** for Certification & Testing of Laser Eyewear and Barriers.

**In draft:**

**ANSI Z136.8** – Safe Use of Lasers in Research, Development & Training (maybe late 2010).

**ANSI Z136.9** – Safe Use of Lasers in Manufacturing Environments.

**ANSI Z136.10** – Safe Use of Lasers in Entertainment, Displays and Exhibitions.

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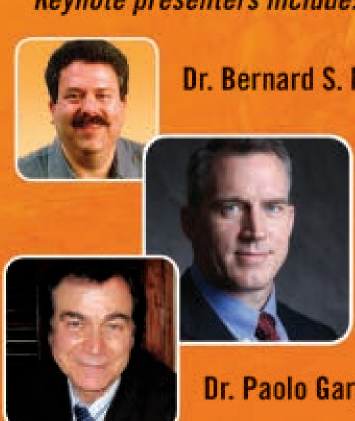

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bone for users and user facilities onto which safety programs can be built.

Z136.1 is a horizontal standard. With each revision of it, biological effect (MPE) information has been refined and page count has grown. Unfortunately, clarity has not been a central concern, which of course allows consultants to make a living. There is now an attempt with the new standards and revisions of existing ANSI Z136 standards to trim Z136.1 and make all the standards user-friendly. One of the first tangible signs of this user-friendliness has been the incorporation of an index in the Z136.1-2000 version. As laser applications have advanced, a number of application standards have come into being (see Table 2).

Although every state has a program regulating ionizing radiation, only a few have a laser regulatory program. The major programs are in Arizona, Texas, New York, Massachusetts and Illinois. The reason for this is reluctance by state government to take on the perceived cost of a laser safety program. This has not stopped 30 states from addressing who can do cosmetic laser surgery (i.e., hair removal) or local municipalities from passing laser pointer rules. The most recent example is the Texas Legislature, which passed legislation that establishes a regulatory program for laser hair removal.

A number of groups also have made forays into laser safety:

- **Federal Aviation Administration, FAA 7400.21** – Outdoor, laser use in airspace.
- **National Fire Protection Association, NFPA 70E** – The National Electric Code has a brief and confusing section on laser labs 330.
- **ANSI B11** – Laser Marking Machines.
- **NFPA 115** – Fire Code for Laser Safety, very much a firefighter-oriented document.
- **Code of Federal Regulation** – Export rules for laser technology are part of this code, which restricts both technology hardware and intellectual contacts.

In conclusion, consider that today you can buy a 1500-mW handheld laser. The goal of standards and regulations is to ensure safety for users and products as well as consistent approaches to safety evaluation. The review process for ANSI and IEC standards allows these documents the opportunity to stay current with – or at least only a few years behind – laser technology, which will continue to advance in areas we can only imagine today.

### Meet the authors

Ken Barat is the laser safety officer for Lawrence Berkeley National Laboratory and the author of *Laser Safety: Tools & Training* and *Laser Safety Management*. He is a member of several ANSI committees; e-mail: kbarat@lbl.gov.

Jerome E. "Jerry" Dennis is in his third term as chairman of IEC TC 76. He retired from the CDRH/FDA in 2008 and has since been active as a consultant in laser product safety. He is past vice chairman of ANSI Z136 and has remained active in Z136 and in its subcommittees. He previously spent 15 years in industry in research and development of laser systems for military, industrial and laboratory applications. He was a member of the US Department of Defense laboratory team in Brooklyn, N.Y., that purchased and coated the ruby rod mentioned above; e-mail: jerodeni2@comcast.net.

### Acknowledgments

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**Paul D. Corkum,** National Research Council of Canada, Canada

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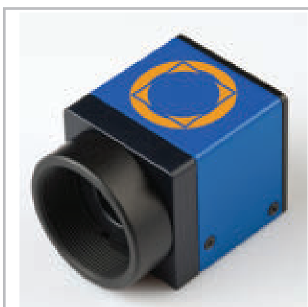

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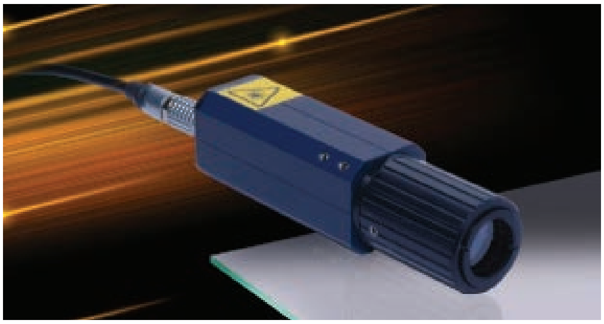


## Diode Laser

StockerYale Inc. has unveiled its InViso laser product line. The series of diode-based laser modules is designed to meet the demanding requirements of high-performance machine vision applications and to complement the company's range of chip-on-board LED systems. The lasers are available at wavelengths ranging from the UV to the infrared and with power levels of up to 100 mW. They are suitable for use in a variety of machine vision and alignment applications, particularly where system integration must be performed quickly and with high repeatability. Applications include high-speed sorting and classification systems in the semiconductor field, food and beverage inspection, and solar panel inspection. They are available in both standard and custom configurations.

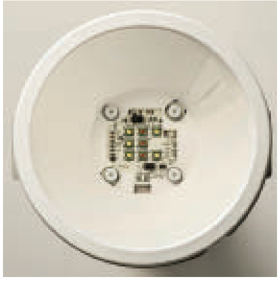
**StockerYale**
**lasers@stockeryale.com**

## Multispectral Camera

JAI's AD-080GE with a GigE vision interface two-CCD camera is capable of imaging visible and near-infrared light spectra simultaneously through a single lens. The camera incorporates two ⅓-in. progressive-scan sensors with 1024 × 768-pixel resolution that are mounted to a custom-designed optical prism. It runs at a rate of 30 fps in continuous operation. It features standard C-mount lenses, partial scanning and vertical binning capabilities, and an analog video output to support autoiris lenses. It is suitable for applications where extended spectral imaging is required, including fruit and vegetable inspection. It is also available for traffic applications, print inspection of banknotes, passports and tickets, electronic board inspection and surface inspection of textiles.

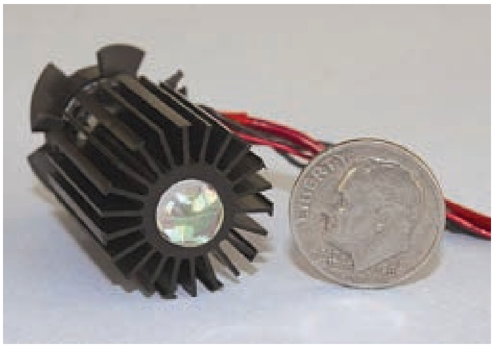
**JAI**
**camerasales.emea@jai.com**

## LED Module



Cree Inc. has introduced a class of products designed to accelerate the adoption of LED lighting by traditional lighting fixture manufacturers and speed time-to-market for their new LED-based fixtures. Customers will now have access to the company's TrueWhite technology, allowing them to deliver efficient, high-quality light in a compact and easy-to-use product. The first product in the new line is the LMR4 LED. It integrates driver electronics, optics and primary thermal management, making it drop-in-ready. Designed to last 35,000 h and consuming just 12 W of power, it delivers 700 lm at a warm-white color temperature of 2700 with a color rendering index of 90. Fixture manufacturers have the option to include a specially designed heat sink to accommodate specific high-heat applications, like downlights for insulated ceilings.

**Cree**
**info@cree.com**



## Laser Engine

SemiNex Corp. announces the Laser Engine, an integrated laser diode system designed for use by manufacturers of high-volume medical and other low-cost handheld applications. Based on proprietary and patented laser diode manufacturing technology, the system includes a high-efficiency laser, a heat spreader, a convection cooling device and an optical lensing element. It is available in 1470-, 1532- and 1550-nm wavelengths and features power conversion efficiency of 45% W/A, offering 3 W of continuous optical power from 6.5 A of input current. A version with greater power output is under development. It is suitable for medical applications such as acne removal, skin wrinkle reduction and skin ablation, and it also can be used in a range of professional applications like medical procedures and surgery, free-space communications and rangefinding.

**SemiNex**
**dbean@seminex.com**

## UV-NIR Spectrometers

The Super Gamut UV-NIR series spectrometers manufactured by BaySpec Inc. use a concave holographic diffraction grating as the dispersion element and an ultrasensitive thermoelectrically cooled CCD array detector as the detection element, thereby providing high-speed parallel processing and continuous spectrum measurements. The detectable wavelength range is 190 to 1080 nm. Resolution is ~1 to 20 nm, slit-dependent, and the signal-to-noise ratio is 6000:1. Stray light is 0.05%, and integration time is from 20 ns to 300 s. The spectrometers measure 94 × 154 × 50 mm and weigh 750 g. The detector array has 2048 × 64 active pixels and is powered through USB. A 16-bit analog-to-digital converter is included. Applications include biochemical, chemical analysis, high-performance liquid chromatography and high-performance gas chromatography engines, color/dyes and environmental.

**BaySpec**
**sales@bayspec.com**

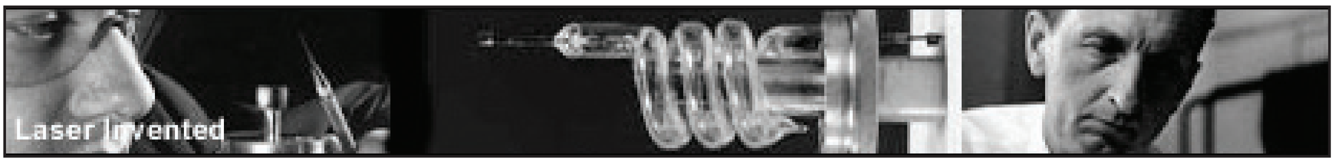
## Vision Measuring System

Vision Engineering Ltd. presents the Falcon three-axis video measuring system for use by quality departments requiring instant noncontact measurement in the X-, Y- and Z-axes. Using a high-resolution camera, it can measure key dimensions and features using video edge detection technology, without deformation, which is critical when measuring small and intricate components. The measuring system incorporates an indexed camera iris control to reduce depth of field, increasing the accuracy and repeatability of Z-axis results. It has two stage options: 150 × 100 mm and 150 × 150 mm, with magnification options of 10× to 50× zoom and 20× to 100× zoom.

**Vision Engineering**
**generalinfo@visioneng.com**

# The Major Events in the First 50 Years of the Laser

A Timeline from *Photonics Spectra* – Now on Photonics.com



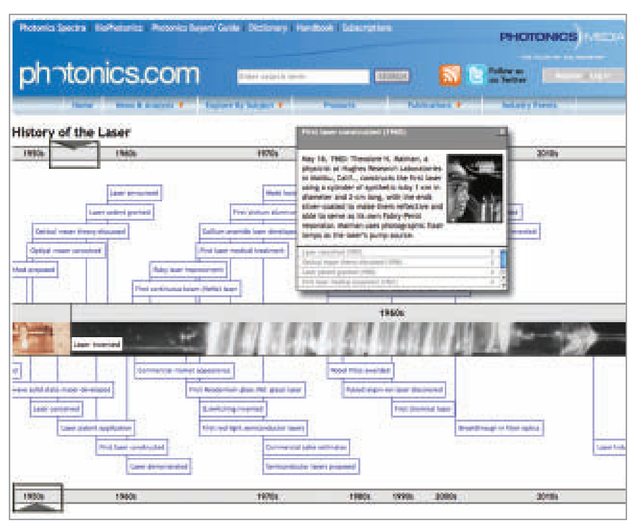

A TRIP THROUGH THE LIGHT FANTASTIC 1951-2010

**You probably know that it all began on May 16, 1960, when Theodore Maiman created the first laser. But what about the other major events surrounding the history of the laser?**

Now you can see them all in a special timeline on Photonics.com. It's part of our celebration of the laser's 50th anniversary.

Just go to Photonics.com and click on the "Lasers at 50" logo. Explore our timeline – with more than 70 major events – and discover all the people and deeds that comprise laser history.

Take a look today!




PHOTONICS spectra

LASERS AT 50

photonics.com

## AFM System

Veeco Instruments Inc. has unveiled the Dimension Edge atomic force microscope (AFM) system for physical and life sciences applications. It features hardware and software advances that reduce the time required to produce expert-level data, providing a seamless path from sample placement through optical identification of the region of interest, and from AFM survey mode to zoomed-in feature identification. The proprietary closed-loop and drift-compensated stage combines productivity, accuracy and sample versatility with acquisition of high-resolution images. With low noise levels, the system enables collection of fine details critical for materials identification, while protecting tips and samples and diminishing tip artifacts. A variety of modes provide the accurate imaging and single-point spectroscopy capabilities required for characterization of solar and semiconductor devices, mapping of heterogeneous polymer-based materials, interrogation of individual nanoparticles and in situ imaging of life sciences samples from single molecules to whole cells.

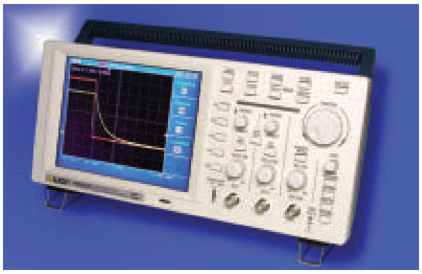
**Veeco**
**sales@veeco.com**

## Zoom Lens

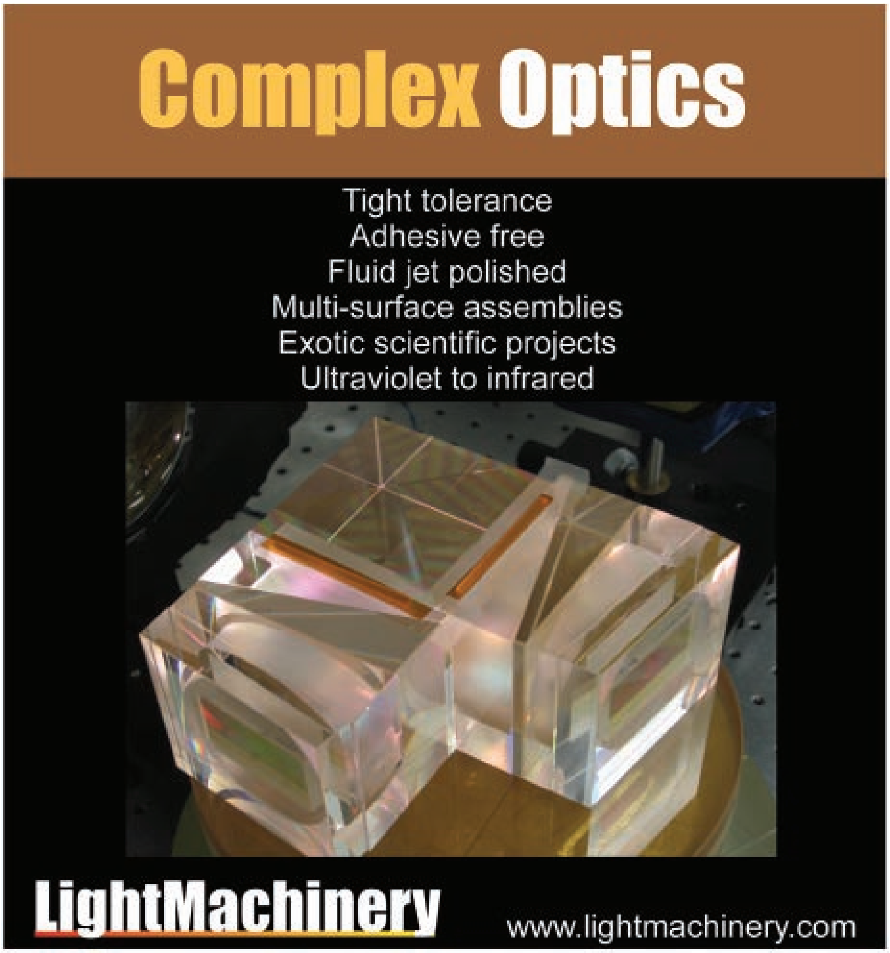
The Model 290 motorized nonbrowning zoom lens from Resolve Optics Ltd. operates in applications subject to radiation, such as nuclear fuel handling, reactor active zones and nuclear waste storage plants. It uses special glass that can withstand long-term exposure to radiation up to a dose of 100 million radians and temperatures to 55 °C without discoloration. The 6× lens features slip clutches and electronic noise suppression. Operating at f/1.8, it provides high image resolution and minimum geometric distortion from 400 to 750 nm, and it can image objects from 800 mm to infinity without using add-on adapters. When focused at infinity, the lens achieves high image resolution on-axis at full aperture throughout the zoom range without refocusing (image tracking). It is designed for use with single-chip ½- and ⅔-in. CCTV cameras and with Newvicon and Chalnicon tubes.

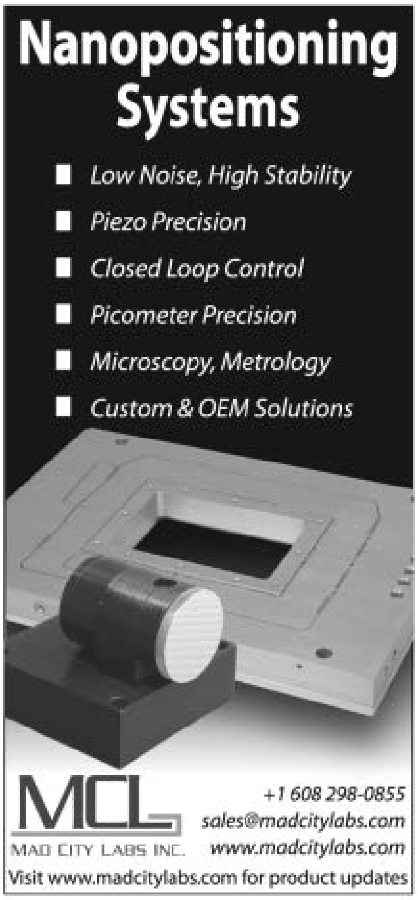
**Resolve Optics**
**sales@resolveoptics.com**

## Oscilloscope Upgrade



Saelig Co. Inc. has announced enhancements for its portable PDS5022S two-channel 25-MHz benchtop oscilloscope. Autoscale can be set to automatically adjust vertical gain or horizontal time base, or both, for circuit probing. As the probe is moved from point to point on a circuit board, the display adjusts for best trace presen-



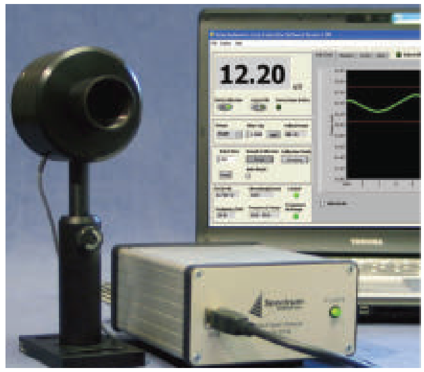



tation. Fast Fourier transform allows the operator to instantly see the frequency spectrum of the signal under test, and trigger hold enables introduction of a delay relative to the trigger point so that a different part of the signal can be seen. Features include video trigger, automatic measurements, an 8-in. full-color 640 × 480-pixel LCD, X-Y mode, averaging, math functions, USB output and onboard waveform storage. The oscilloscope automatically measures and displays frequency and peak-to-peak/rms/mean values, and cursors can be moved to make individual readings.
**Saelig**
**support@saelig.com**

## Bearing Load Cells

The SS6000 series from Sherborne Sensors is a range of shear strain gauge load cells that directly integrate with new or existing roll bearing systems for high-precision force measurements in web tension applications. The design incorporates precision transducer-quality bonded strain gauges as its primary transduction element to ensure reliability and to facilitate integration with closed-loop tension control systems. The transducers are compensated for the effects of temperature on zero output and sensitivity, with minimal deflection and high resonant frequency, ensuring rapid response to tension changes. Sensors are machined from stainless steel for high resistance to shock, overload and corrosion, and are offered in ranges from ±2000 to ±5000 kg, with 2-mV/V output.
**Sherborne Sensors**
**sales@sherbornesensors.com**

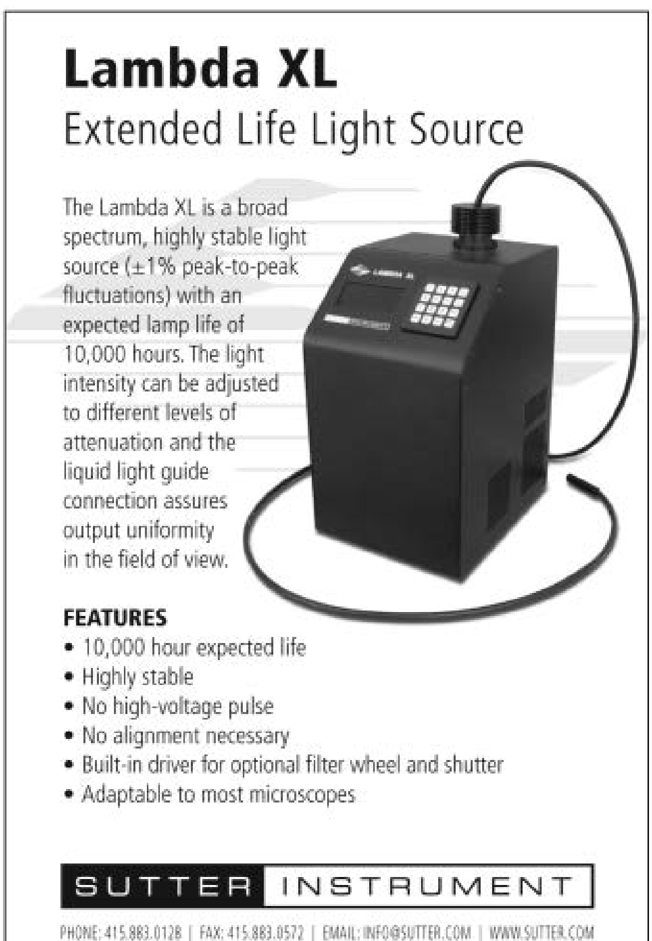
## Broadband Radiometers




Spectrum Detector Inc.'s T.rad series broadband digital radiometers offer sensitivity in the far-IR and the 0.1- to 100-THz regions of the spectrum. The state-of-the-art, thin-film crystalline pyroelectric detector, digital electronics and lock-in amplifier software enable 50-nW measurement with 2-nW resolution. The radiometer probes are available with detector areas of 1.5, 5.0 and 9.0 mm in diameter. The detector and preamplifier are mounted in a metal housing that includes a thermal isolation enclosure that has an SM1 threaded front bezel that takes windows, optics and filters. The only parameters that users have to set are range, filter tau and batch size. The software includes strip chart, statistics, tuning and setup screens.
**Spectrum Detector**
**info@spectrumdetector.com**

## AC/DC Power Systems

UltraVolt Inc. has announced the BT series AC/DC turnkey benchtop power systems that offer flexible output voltages and polarity. Each system houses a high-voltage power supply from the company's microsize/micropower




product line (the XS, US, V, M or D series) and operates in local or remote mode. Features include a clear output voltage display, power grid input, positive or negative polarity, tight line/load regulation, low ripple, good stability, overload protection and an optional shielded output cable. The systems are suitable for use by design engineers in research and in the laboratory, with applications such as photomultiplier tubes, photodiodes, high-voltage testing and avalanche photodiodes.

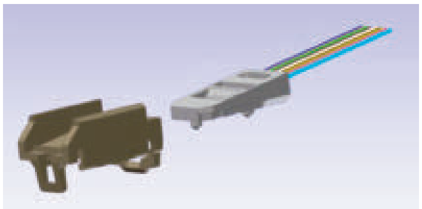
**UltraVolt**
**csd@ultravolt.com**

## High-Speed Video Camera

Photron Inc. has unveiled the Fastcam BC2, a high-definition video camera designed for television broadcast, commercials and motion picture production. With a 12-bit dynamic range and 2000 × 2000-pixel resolution at 1000 fps, the artifact-free electronically cooled CMOS sensor provides resolution of 1920 × 1080 at up to 2000 fps and reduced resolution at more than 86,000 fps. The camera is compatible with the Sony HDVF-C30WR high-definition (HD) viewfinder and with PL, B4 and Nikon F-mount lenses, making it easy to interface with new or existing broadcast equipment. It features instant playback via the dual HD-SDI (serial digital interface) outputs on the back panel, a 2.76-μs shutter and low noise.

**Photron**
**abridges@photron.com**

## Photonic Connector



US Conec has introduced the Prizm LightTurn connector, a next-generation photonic turn parallel optic interconnect solution. Designed as a miniature detachable connector for Avago Technologies' new MicroPOD 120-Gb/s board-mounted parallel optic modules, the connector provides passive alignment and retention features that allow multiple rematings perpendicular to the printed circuit board. The 7.4 × 5.7-mm device consists of a multifiber ferrule with a photonic turn total internal reflection lens array accepting cleaved fibers and a single outer housing. The use of the connector in combination with US Conec's MTP brand multifiber push-on style connector provides an increase in card edge port density compared with using small-form-factor pluggable transceivers, conventional array transceivers or parallel active optical cables on the card edge. The connector is suitable for use in applications including the telecom, datacom and high-speed computercom markets.

**US Conec**
**customerservice@usconec.com**

## Raman Analyzers

Ocean Optics is offering new options for handheld, laboratory and educational Raman applications, and turnkey and application-ready kits are available for 532- and 785-nm Raman laser analysis of aqueous solutions, powders and sur-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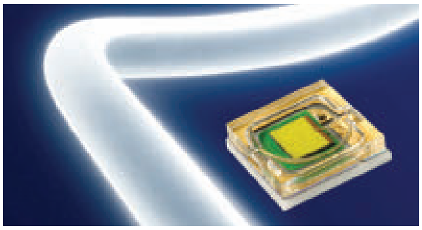
face media. The QE65000 spectrometer offers Bragg grating-stabilized 532- and 785-nm diode lasers, probes for solid or liquid samples, and add-on software modules for data analysis. Software options include a package for chemometric analysis of various substances, a tool for creating and managing spectral libraries and a tool for supporting compliance with the FDA's 21 CFR 11 guideline. Off-the-shelf systems include a spectrometer, a 532- or 785-nm laser, software and sampling accessories for probe- or cuvette-based analysis. The RSL-Plus handheld Raman system includes an onboard mini computer, a fiber optic probe and a sample compartment. Accessories include calibration standards and safety glasses.
**Ocean Optics**
**info@oceanoptics.com**

### SMT LEDs

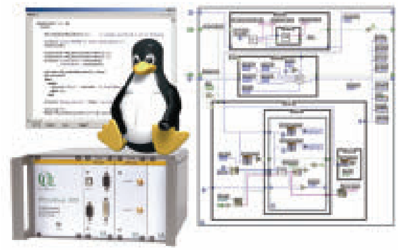


The OSTAR high-power LED from Osram Opto Semiconductors has been developed for use in automotive daytime running light applications based on the use of lightguides. The surface-mount technology (SMT) LEDs' compact dimensions and ability to drive high currents make them suitable for use in both existing and new headlight designs. In addition to the usual point-like LED lighting solutions, linear or 2-D designs can be produced with only a small number of semiconductor light sources. The LEDs are available in the finely graded color groups that meet ECE/SAE color binning requirements. With a power draw of 5 W and an operating current of 1.4 A, the LEDs produce typical brightness of 300 lm, and their 2-mm² chip provides high luminance.
**Osram**
**support@osram-os.com**

### USB Laser Sensor Interface

Introduced by Ophir-Spiricon LLC, Juno is a smart USB sensor-to-PC interface that converts a laptop or desktop PC into a laser power/energy meter. It connects any of the company's smart laser sensors (thermal, pyroelectic, photodiode) to a PC USB port and operates with proprietary StarLab software that logs power and energy, and calculates and displays averages, statistics, line plots, bar charts and histograms. Data can be displayed graphically or saved in text format and exported to an Excel spreadsheet. The system records every energy pulse at up to 10 KHz. Juno is a plug-and-play module that connects several sensors to a PC using one module for each sensor. A USB hub can be used to connect up to eight sensors to one PC. No power source is required. The compact module measures 76 × 55 × 22 mm.
**Ophir-Spiricon**
**sales@ophir-spiricon.com**

### Programmer's Library



A 4-bit programmer's library is available for PicoQuant GmbH's PicoHarp 300 time-correlated single-photon-counting system. Applica-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tion programming interface-compatible with the corresponding 32-bit library version 2.3 for Windows and Linux, it supports all 64-bit Linux versions with 2.6 kernels, offers throughput improvements for the instrument's time-tagged time-resolved mode and supports the latest PicoHarp hardware. Fluorescence lifetime images can be recorded at any resolution and size. The PicoHarp is based on a new time digitizer with 4-ps resolution and a processing rate of up to 10 million counts per second. Two input channels operate independently but with a common crystal time base. Synchronization rates from excitation sources can be up to 85 MHz, and onboard histogramming provides up to 65,536 bins, resulting in a time span of 262 ns.

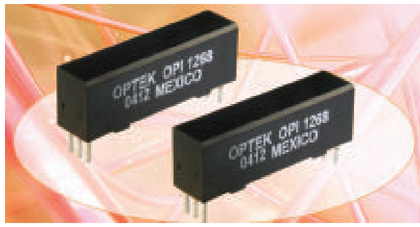
**PicoQuant**
**info@picoquant.com**

## Piezocube


PI (Physik Instrumente) GmbH & Co. KG has introduced a piezocube for 3-D structuring applications. The NanoCube P-611 X-Y-Z nanopositioning system's travel ranges are up to 100 × 100 × 100 μm. It is driven by piezo actuators and achieves resolutions of up to 0.2 nm at millisecond response times and with nanometer repeatability. Vacuum-compatible, it operates over a wide temperature range. Applications include semiconductor manufacturing, optical metrology, micromachining, photonics and manufacturing of minute polymer and protein structures. The cube sides measure 44 mm, facilitating integration.

**PI**
**photonics@pi-usa.us**

## Optical Isolators

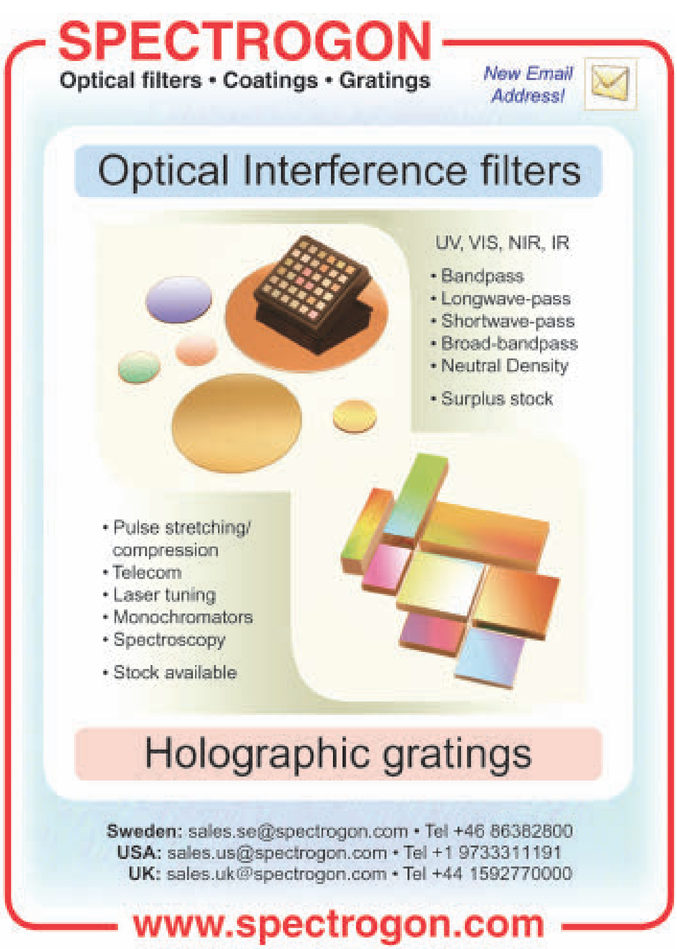


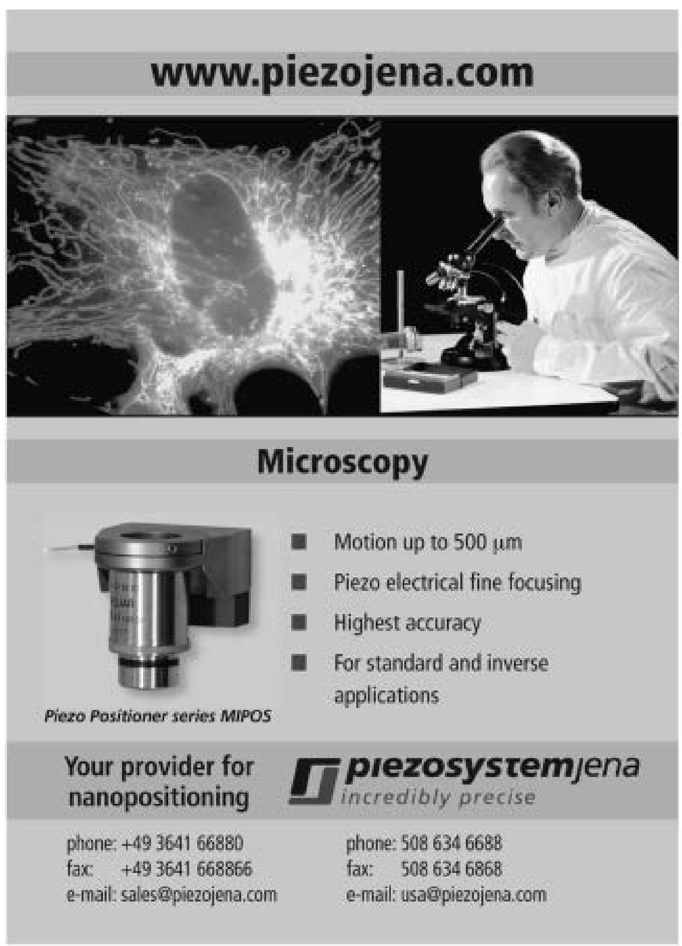

TT electronics Optek Technology's OPI1268 optical isolator delivers AC and DC voltage isolation up to 16 kV while achieving digital data transmission rates of 2 MBd. It is UL-recognized and designed for power isolation in high-voltage PC board circuits in industrial electronics systems, medical electronic equipment and office machines. The output integrated circuit (IC) detects the incoming optical signal and converts it to a proportionate current, which is fed through a linear amplifier and compensated for temperature, current and voltage, resulting in stable digital output with an open collector inverter configuration. The device comprises a GaAlAs LED with a peak wavelength of 850 nm, optically coupled to a Photologic photodiode in the output IC. Packaged in an opaque plastic housing, it measures 27.94 × 6.35 × 8.89 mm and operates from −40 to 100 °C.

**Optek**
**sales@ttelectronics-na.com**

## Medical Imaging Solution

For applications including pathology, surgery, ophthalmology, veterinary surgery, medical diagnostics, dentistry and telemedicine, Toshiba Teli America Inc. has announced a medical imaging solution that can connect and simultaneously receive data from up to four of the com-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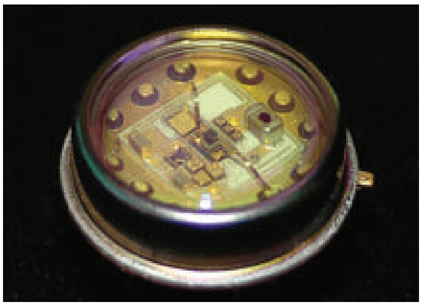
pany's CSFS20CC2 FireDragon color cameras. Based on its iIS-BF4 SmartDragon FireWire-B (IEEE1394.b) processor, the system combines the FireDragon cameras and the SmartDragon processor with TeliDCAM software, which features a viewer, a driver and a software development kit. The software enables users to easily record with or without compression, to capture images, to store and create customer or patient files, to archive files, to create presentations and to download information to servers. Recordings can be compressed 50/1 or 100/1 when recording more than 24 h.
**Toshiba**
**doug.freck@ttai.toshiba.com**

## APD Receivers



Voxtel Inc. has announced the release of a near-infrared avalanche photodiode (APD) receiver with 1-GHz bandwidth and a large 200-μm-diameter optical area. Suitable for laser rangefinder, laser designator, free-space optical communications, optical instrumentation and ladar/lidar applications, it is the latest entry in the company's Siletz line of back-illuminated single-carrier multiplication avalanche photodiode (SCM-APD) products. The receiver integrates the low-excess-noise SCM-APD with a low-noise transimpedance amplifier. The NIR/SWIR (short-wavelength infrared) APDs have an equivalent ionization coefficient (keff) of <0.02 and enable the receiver to operate at high avalanche gain, boosting the optical signal over the amplifier noise level without the degrading effects of avalanche-induced excess noise. The ultralow excess noise and high gain make the photoreceivers highly sensitive, offering a maximum responsivity of >50 A/W at 1550 nm, with operating gain up to 50.
**Voxtel**
**brianb@voxtel-inc.com**

## LSP40 Plug-and-Play Drivers

Laser Components' LSP40 series plug-and-play driver modules are used to accurately control pulsed laser diodes. With just two resistors, the user can regulate both the operating current (and thus the laser power) and the pulse length. The module requires an operating voltage of only 12 VDC and an external trigger signal. The laser current can be set to any value up to a maximum of 40 A, and the pulse length can be set to between 30 and 150 ns at 40 A and, at

12 A, from 30 to 1000 ns. With the LSP40 modules, all 905- and 1550-nm pulsed laser diodes available from the company can be operated immediately, and the modules are interchangeable, guaranteeing maximum flexibility. Applications include medical, rangefinding, laser radar, lidar, burn-in racks, ceilometers and optical triggers.
**Laser Components**
**info@laser-components.com**

## Printed Circuit Board Substrate

Laird Technologies Inc. has released the enhanced Tlam SS LLD for use as a thermally conductive printed circuit board (PCB) substrate. The versatile, thermally enhanced PCB substrate system is designed for heat dissipation in bright and ultrabright LED module applications. The substrate provides eight to10 times the heat dissipation as compared with conventional FR4-based PCBs, a key ability in keeping compo-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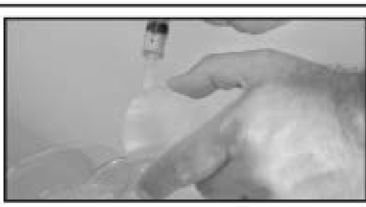

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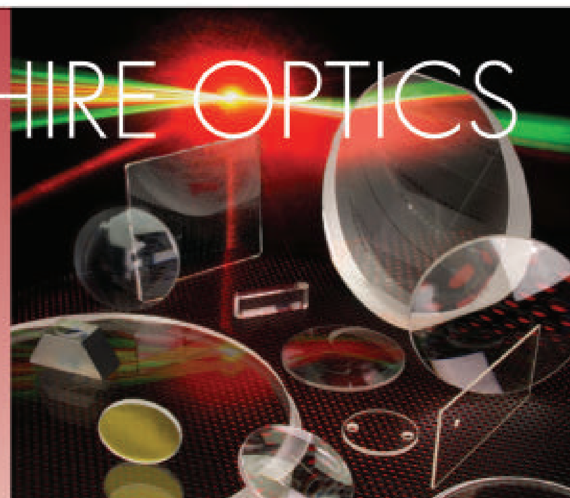

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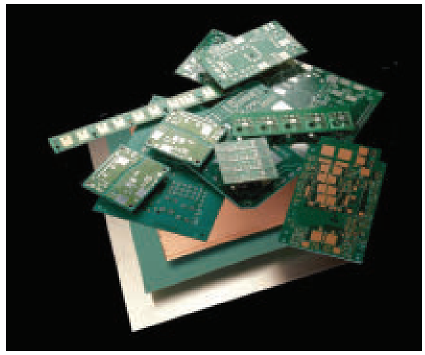

nents cool. The boards are processed through standard pick-and-place surface mount technology and manual wire bond operations. Standard constructions are made with 1- or 2-oz copper and 1- or 1.5-mm-thick aluminum, grade 5052; 1- or 1.6-mm-thick aluminum, grade 6061. A copper base is available.

**Laird Technologies**
**matt.judkins@lairdtech.com**

## Polygonal Scanners

Lincoln Laser Co.'s KW Series polygonal laser scanners feature copper mirrors for materials processing applications using high-energy laser sources. When galvanometer mirrors are enlarged to compensate for high-power lasers, the scan rate slows down. The polygonal scanners dissipate heat more efficiently and produce

faster scan rates because the copper substrate acts as a large heat sink that draws heat away from the mirror facets. Additional heat dissipation occurs as the polygonal mirror rotates, allowing the laser beam to transfer rapidly from facet to facet and minimizing dwell time on any single facet. The scanners accommodate beam power densities of 1000 W/mm$^2$ and produce scan angles of >120° and scan rates of >10 kHz. They can be custom designed to meet thermal, optical, speed and accuracy requirements for lasers of all wavelengths and power levels.

**Lincoln Laser**
**madkins@lincolnlaser.com**

## COB Ceramic Assemblies

Marktech Optoelectronics has expanded its product offerings with the introduction of custom chip-on-board (COB) ceramic LED assem-


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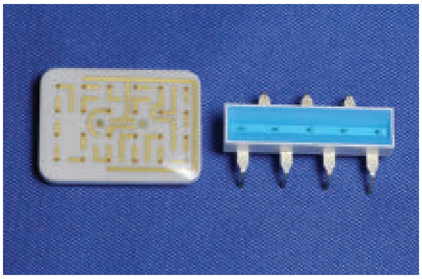
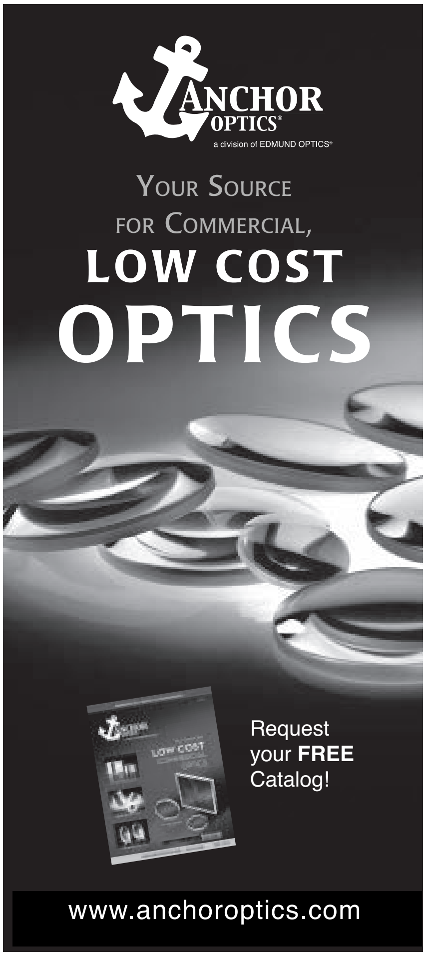


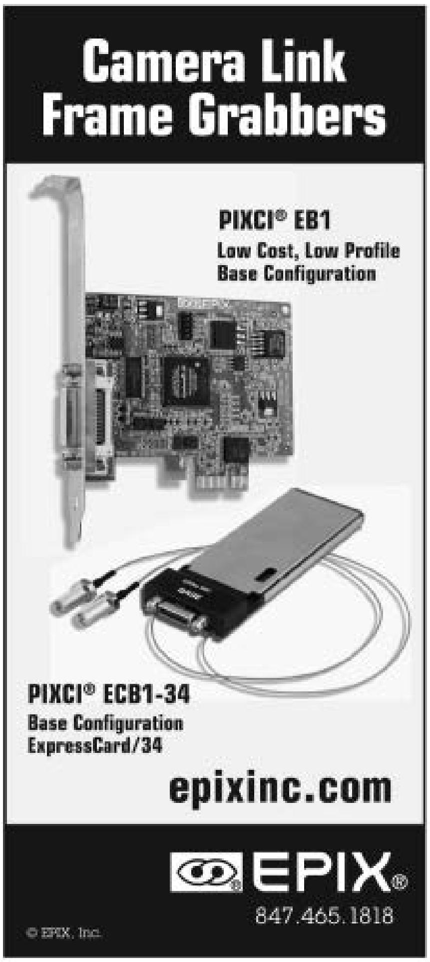
blies and arrays for high-temperature and high-reliability applications. The "chip-on-ceramic" LEDs and LED arrays offer manufacturers and integrators high-efficiency ceramic LED components across a full range of color temperatures. The LEDs are available in configurations from four to hundreds of chips in series or parallel as well as in series/parallel combinations. The company also has expanded its full-service integration and production capabilities and can produce a range of chip-on-ceramic and integrated light engines/modules in volume to support the needs of the medical and military industries.
**Marktech**
**c.daley@marktechopto.com**

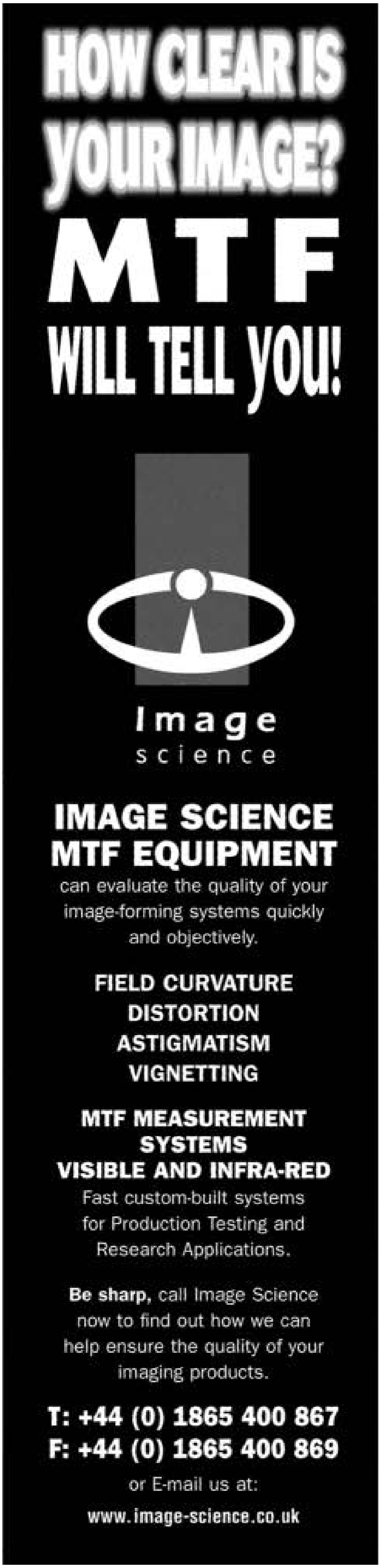
### URB100CC Rotation Stage

Newport Corp. has introduced the URB100CC high-speed rotation stage for motion applications that require fast moves over larger angles

or continuous rotation at high duty cycles. It delivers high-precision performance relative to wobble, angular repeatability and speed stability. Typical applications are lidar, 3-D imaging and film thickness measurements of semiconductor wafers. Instead of a worm gear, it features a belt drive, which provides rotation speeds of up to 720°/s, without sacrificing lifetime. It also includes a proprietary four-point large-diameter contact ball bearing. This two-piece design provides good rigidity and high reliability, while minimizing wobble (50 μrad) and eccentricity (3 μm). For added convenience, position feedback is provided by a motor-mounted 2000-point rotary encoder that produces 0.01° resolution.
**Newport**
**beda.espinoza@newport.com**

### Universal C-Mount Adapter


Craic Technologies has released a universal C-mount adapter for microscope cameras and spectrophotometers that enables a camera or spectrophotometer to be parfocal and parcentral with the eyepieces on the microscope. With the flexibility to be mounted on the open photoports of many microscope models and brands, it features X, Y and Z adjustment as well as a range of photoport flanges.
**Craic**
**sales@microspectra.com**

### Silica Fibers

CeramOptec Industries Inc. has unveiled noncircular core silica optical fibers for use in applications including materials processing and astronomy. The optical fibers are available with square cores with edge lengths from 50 to 1000 μm, with numerical apertures from 0.12 to 0.37 and at wavelengths from the deep-UV to the near-IR. Other shapes are available upon request. Good image scrambling is characteristic of the square core fiber and, together with its low focal ratio degradation, improves image processing. When used with diode lasers, which yield a square-shaped output, the square core fibers offer greater coupling efficiencies and a homogeneous power distribution on the output end. In laser applications such as surface pretreatment, materials can be processed in a more uniform fashion than is possible with a circular beam due to less overlapping. The square output beam reduces the need for beam shaping optics.
**CeramOptec**
**salesengineering@ceramoptec.com**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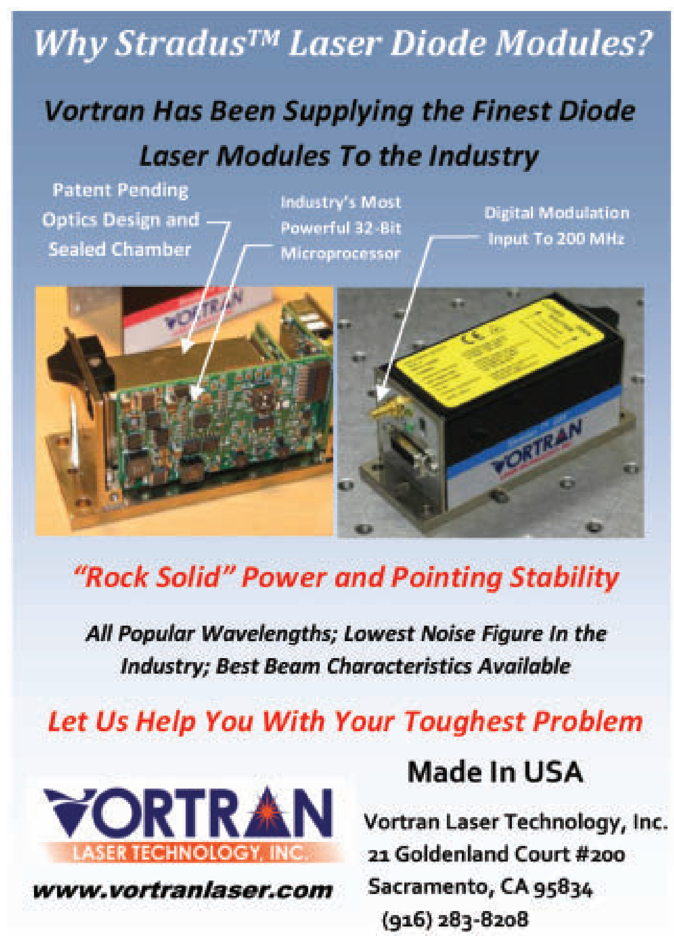

# HAPPENINGS

## JULY

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

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

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

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

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

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

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

## AUGUST

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

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

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

## SEPTEMBER

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

**31st European Conference on Laser Interaction with Matter (ECLIM) (Sept. 6-10)** Budapest, Hungary. Contact István B. Földes, Hungarian Academy of Sciences, fax: +36 1 395 9151; foldes@rmki.kfki.hu; www.top-congress.hu/2010/eclim.

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

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

**SPRC 2010 Annual Symposium (Sept. 13-15)**
Stanford, Calif. Contact Stanford Photonics Research Center, +1 (650) 723-5627; photonics@stanford.edu; photonics.stanford.edu.

**IMTS 2010: International Manufacturing Technology Show (Sept. 13-18)** Chicago. Contact The Association for Manufacturing Technology, +1 (800) 524-0475; amt@amtonline.org; www.amtonline.org.

**Metamaterials 2010: Fourth International Congress on Advanced Electromagnetic Materials in Microwaves and Optics (Sept. 13-18)** Karlsruhe, Germany. Contact S. Linden, Congress Secretary, +49 7247 82 2861; congress2010.metamorphose-vi.org.

**MNE 2010: 36th International Conference on Micro and Nano Engineering (Sept. 19-22)** Genoa, Italy. Contact Corso F.M. Perrone, +39 010 659 8773; secretariat@mne2010.org; www.mne2010.org.

**Remote Sensing (Sept. 20-23)** Toulouse, France. Collocated with Security + Defence. Contact SPIE, +1 (360) 676-3290; customerservice@spie.org; spie.org/x6262.xml.

**ICWMC 2010: Sixth International Conference on Wireless and Mobile Communications (Sept. 20-25)**
Valencia, Spain. Contact IARIA, www.iaria.org.

**LANE 2010: Sixth International Conference and Exhibition on Laser-Assisted Net Shape Engineering (Sept. 21-24)**
Erlangen, Germany. Contact Bayerisches Laserzentrum GmbH, +1 49 9131 852 3239; info@lane-conference.org; www.lane-conference.org.

**SPIE Laser Damage (Sept. 27-29)**
Boulder, Colo. Contact SPIE, +1 (360) 676-3290; spie@spie.org; spie.org.

**OLEDs World Summit 2010 (Sept. 27-29)**
San Francisco. Contact Olga Adamovich, +1 (207) 781-9628; olga.adamovich@pira-international.com.

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

**ALAC 2010: Advanced Laser Applications Conference & Exposition (Sept. 28-29)**
San Jose, Calif. Contact International Laser Users' Council, +1 (734) 418-2365; www.alac-iluc.org.

## OCTOBER

**International Wafer-Level Packaging Conference (Oct. 11-14)**
Santa Clara, Calif. Contact Melissa Serres, Surface Mount Technology Association, +1 (952) 920-7682; melissa@smta.org; www.iwlpc.com.

**Semicon Europa 2010 (Oct. 19-21)**
Dresden, Germany. Contact Kelli Torres, SEMI Global Headquarters, +1 (408) 943-6979; ktorres@semi.org; www.semiconeuropa.org.

## PAPERS

**AIP/ACOFT 2010 (December 5-9) Melbourne, Australia**
**Deadline:** abstract submission, July 9, 04:00 GMT
Papers are encouraged for the 19th Australian Institute of Physics Congress, which incorporates the 35th Australian Conference on Optical Fibre Technology. The Congress provides a forum for discussions within specialist physics topic areas. Contact Kymberlee Senior, Waldronsmith Management, +61 3 9645 6311; aip2010@wsm.com.au; www.aip2010.org.au.

**SPIE Photonics West (January 22-27) San Francisco**
**Deadline:** abstracts, July 12
Organizers of this event seek papers for its collocated conferences: BiOS – Biomedical Optics; LASE – Lasers and Applications; OPTO – Optoelectronic Materials, Devices and Applications; MOEMS-MEMS – Micro- and Nanofabrication; and the new Green Photonics Virtual Symposium. Contact SPIE, +1 (360) 676-3290; customerservice@spie.org; www.spie.org.

**Quantum Optics V (November 15-19) Cozumel, Mexico**
**Deadline:** abstracts, July 16, 04:00 GMT
Abstracts for oral or poster presentations are invited for this conference, which will cover developments in laser physics and quantum optics. Topics to be considered include trapped ions, atom optics, quantum computing and quantum optical realizations of quantum information processing. Contact Héctor Moya-Cessa, Instituto Nacional de Astrofísica, Óptica y Electrónica, +52 222 2663 100; qoii@inaoep.mx; www.speckle.inaoep.mx/qoii/gov.html.

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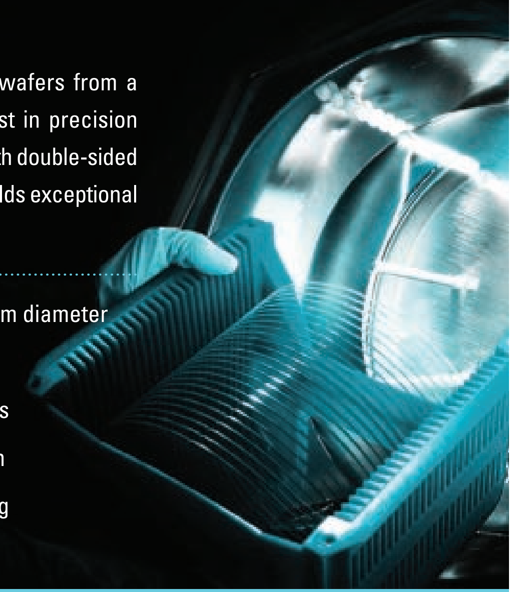

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# HAPPENINGS

**Frontiers in Optics 2010/ Laser Science XXVI (Oct. 24-28)**
Rochester, N.Y. Contact Optical Society of America, +1 (202) 223-8130; info@osa.org; www.frontiersinoptics.com.

**LEDs 2010 (Oct. 25-27)**
San Diego. Contact Brian Santos, IntertechPira, +1 (207) 781-9618; brian.santos@pira-international.com; www.ledsconference.com.

**16th Microoptics Conference (Oct. 31-Nov. 3)**
Hsinchu, Taiwan. Contact Lu Tien-Chang, +888 3 5712 121; timtclu@mail.nctu.edu.tw; www.moc2010.org.tw.

## NOVEMBER

**Electronica 2010 (Nov. 9-12)**
Munich, Germany. Contact Messe München, +49 89 9 492 0720; newsline@messe-muenchen.de; www.messe-muenchen.de.

**PV Tech 2010: International Exhibition & Conference on PV Production Equipment and Manufacturing Technologies (Nov. 17-19)**
Milan, Italy. Collocated will be EnerSolar+, Greenergy Expo and HTE-hi.tech.expo. Contact Artenergy Publishing Srl, +39 0266 306 866; fax: +39 0266 305 510; www.pvtech.eu.


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# The season of sun, sand . . . and nanoparticles?

There is no doubt that natural, unfiltered sunlight is a primal force. It charges ions in the atmosphere, providing iridescent fireworks known as the polar lights. It warms the seas and churns the air, providing weather. It feeds plants via photosynthesis, helps create vitamin D in your body, adds highlights to your hair, and can even improve one's mood and increase one's willingness to buy things. Of course, beachgoers and other outdoor aficionados know that the sun bronzes the skin as well, the risk of melanoma be damned.

But sunlight also affects artificial materials. It strips the color from ink, leaving bluish tones where vibrant greens, yellows and reds once displayed on signs. It also is being found to have a direct effect on the nanoscopic chemicals that are used more and more in personal care products, such as shampoo, makeup and sunscreen lotion.

Because nanoparticles are being used increasingly in consumer products, there is a growing sense of urgency in discovering whether they will have a negative effect on the environment or on human health. After all, once flushed down the drain or tossed into the trash, soap, skin care products and the like enter the ecosystem. Once there, they commence to break down, releasing minute particles and leaving them likely to be taken up by plants, animals and, ultimately, people.

With this nanopollution in mind, researchers globally are examining the mechanisms of product breakdown, how nanoparticles are released and the role light plays in these processes.

One team, composed of scientists from CNRS/Aix-Marseille Université in Aix-en-Provence and from Université d'Aix Marseille, both in France, is looking at the behavior of nanoparticle-infused sunscreens in particular. In a recent paper published in *Environmental Pollution*, the investigators describe the roles played by sunlight, water and the passage of time in breaking down such lotions.

The group studied sunscreen infused with nanoscale composites with cores of $TiO_2$ coated with layers of $Al(OH)_3$ and polydimethylsiloxane (PDMS) – a common additive that reflects UV rays while remaining mostly clear, unlike the opaque white lotions of years past.

The researchers, led by Jean-Yves Bottero, found that sunlight breaks down the PDMS layer, leaving the $TiO_2$ core and $Al(OH)_3$ layer open to degradation from exposure to water, potentially freeing the $TiO_2$ particles into lakes, oceans and the broader world. They also noted that the stability of the PDMS-less composite was affected by organic matter naturally present in the water, leaving open the question of whether tests of nanomaterials in the laboratory can take into account real-world reactions.

Ultimately, research such as that performed by Bottero and his colleagues should inspire others to carefully consider how something as simple yet powerful as sunlight might affect new technologies.

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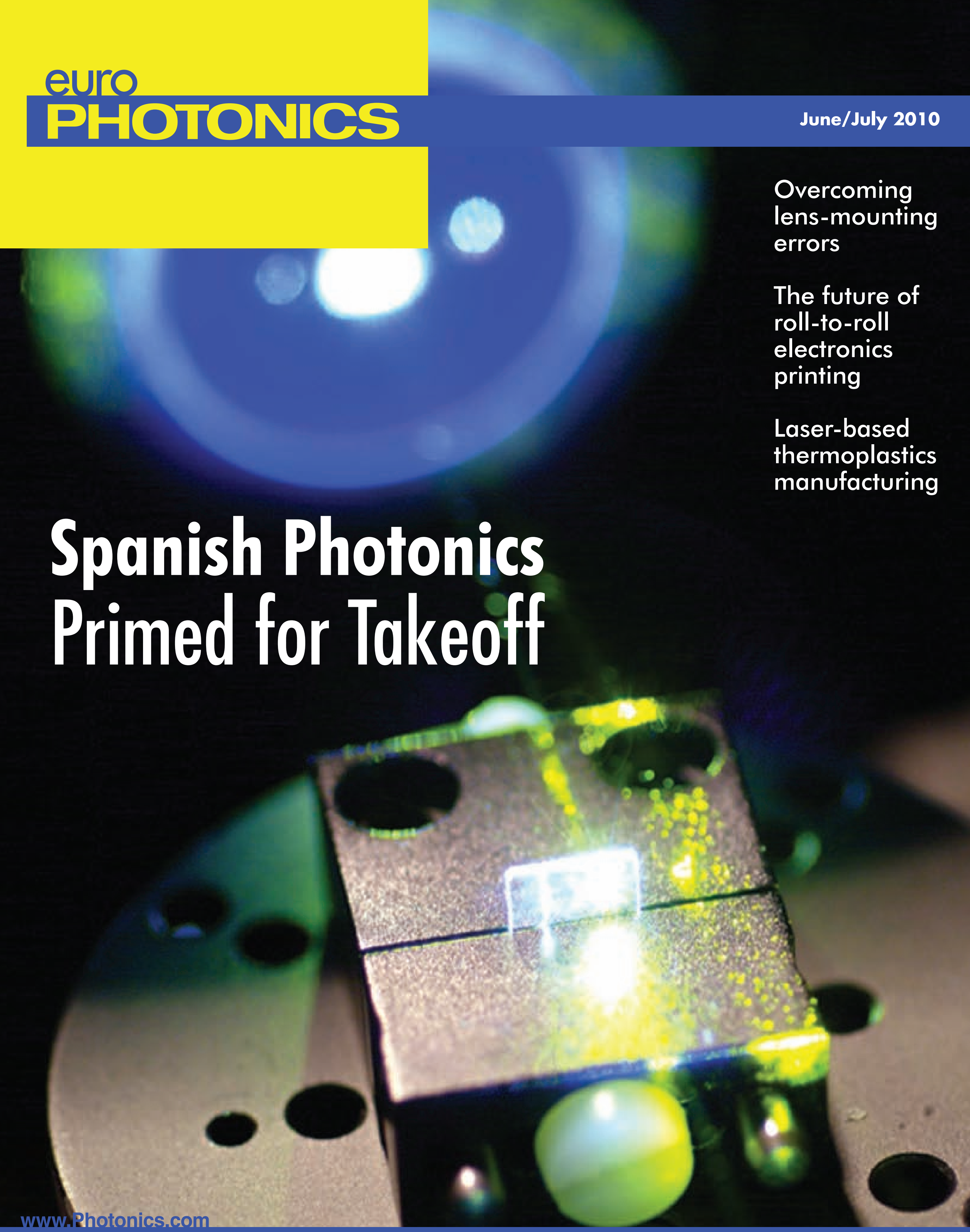
June/July 2010

Overcoming lens-mounting errors

The future of roll-to-roll electronics printing

Laser-based thermoplastics manufacturing

# Spanish Photonics Primed for Takeoff



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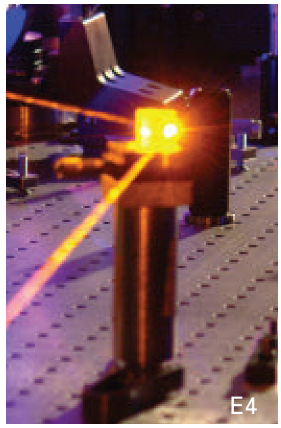




## NEWS



## FEATURES



## DEPARTMENTS



### THE COVER

This month's cover shows the generation of tunable laser light at ICFO – Institute of Photonic Sciences in Spain. An article on the photonics industry in Spain begins on page E6. Photo courtesy of ICFO; photographer, Luis Montesdeoca.

### PHOTONICS

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Special Web report:

# Could it be lights out for the traditional bulb?

REGENSBURG, Germany – After 120 years of faithful service, the incandescent bulb is bowing out in favor of more energy-efficient lighting. All over the world, governments are introducing new rules to phase out the traditional lightbulb.

In September 2009, the European Union banned manufacturers and importers from selling clear incandescent lightbulbs of 100 W or above. This ban will be expanded in September 2011 and 2012 to include lower wattages of clear incandescent bulbs. And in the US, the phasing out of traditional lightbulbs will begin in 2012 when, by law, all bulbs must be 30 percent or more efficient than current incandescent versions.

Solid-state lighting solutions such as LEDs and organic LEDs (OLEDs) seem perfectly positioned to take over where the incandescent bulb leaves off. Today, LEDs already are being used in both functional and decorative light fixtures, where they offer a marked advantage in energy savings. Compared with incandescent lighting, LED-based lighting delivers visible light with reduced heat and, what's more, its solid-state nature provides for greater resistance to wear, shock and vibration, dramatically increasing its life span.

"LEDs offer a lot of benefits compared with classic light sources. From our point of view as a component manufacturer, the most important, in the medium term, is clearly their relatively high efficiency," said Dr. Michael Fiebig, who is head of marketing and business development of LEDs and OLEDs at Osram Opto Semiconductors' solid-state lighting division in Regensburg, Germany. "Whereas a white incandescent lamp converts just 3 percent of the input power into light, the figure for LED components is already around 30 percent."

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An employee of Osram Opto Semiconductors checks the coated OLED panels for regularity. The focus here is on purity as well as the displacement of different coatings. Images courtesy of Osram Opto Semiconductors.

*To read the full report, visit Photonics.com/WebExclusives*

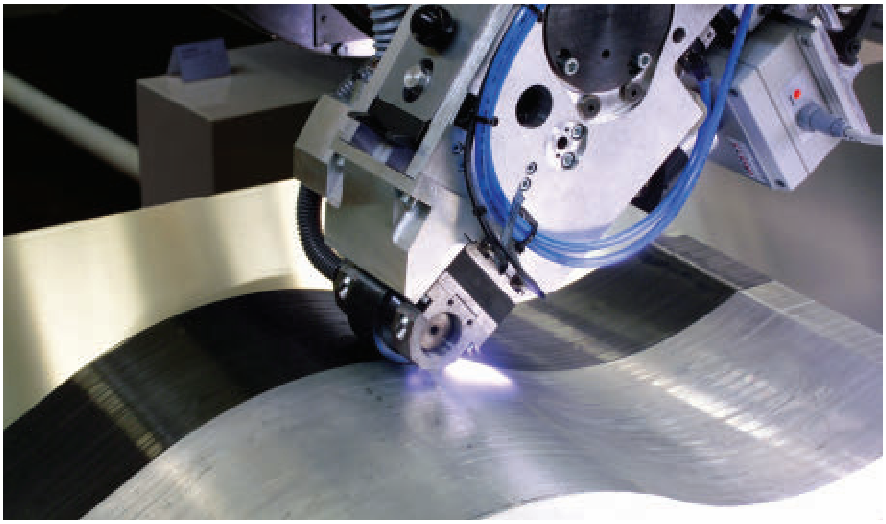
# Lasers reinforce lightweight structures

PARIS and AACHEN, Germany – At the JEC Composites Show in Paris, researchers from Germany's Fraunhofer institutes showed how lasers can make the manufacturing of fiber-reinforced thermoplastic structures more efficient, reliable and automated.

Fiber-reinforced plastics are used in applications including sporting equipment and in the aerospace and automotive industries. Parts using these materials combine impressive stability and breaking strength and are 50 to 70 percent lighter than steel and 15 to 20 percent lighter than aluminum. Nevertheless, there is room for improvement, fueled in part by the trend of using lighter parts to save energy.

When it comes to improving the way these parts are made, "it makes a big difference which kind of polymer material you are using," said Michael Emonts of the Fraunhofer Institute for Production Technology. There are two general classes of polymers that can be used, he said, and each behaves very differently when exposed to heat.

Thermoplastic polymers are normally produced in one step and made into products in a subsequent process. They become soft and formable when heated and, when cooled below their softening point, turn rigid and become usable as formed parts. On the other hand, thermosetting polymers usually are produced and formed in the same step. They also soften somewhat



Lightweight components are manufactured using a new method: combining fiber-reinforced tapes with laser-induced heating. Courtesy of Fraunhofer Institute for Production Technology.

when heated but cannot be shaped or formed to any great extent and will not flow because of their almost crystalline structure.

Most of today's fiber-reinforced materials use thermosetting polymers because they can be processed at room temperature. Making parts involves lining a mold with glass or carbon fiber mats. For high-performance applications, the air is removed before fluid resin is injected so that the matting can become fully saturated, and no air bubbles that would impede stability are generated on the fibers.

Finally, an oven that can accommodate the part is needed to harden the material, which can be gigantic if designed for aircraft, for example. The result is a part that is fully cross-linked by the fiber structure and the almost-crystalline plastic surrounding it. Although this sounds great, it also has a big disadvantage: If damaged, cracks can propagate through the entire part, causing damage or failure far away from the impact – even inside the structure.

Thermoplastic materials avoid this problem as they remain more elastic: Because of their noncrystalline structure, cracks remain local. But the downside is that they cannot be processed at room temperature, which is not compatible with classical production methods.

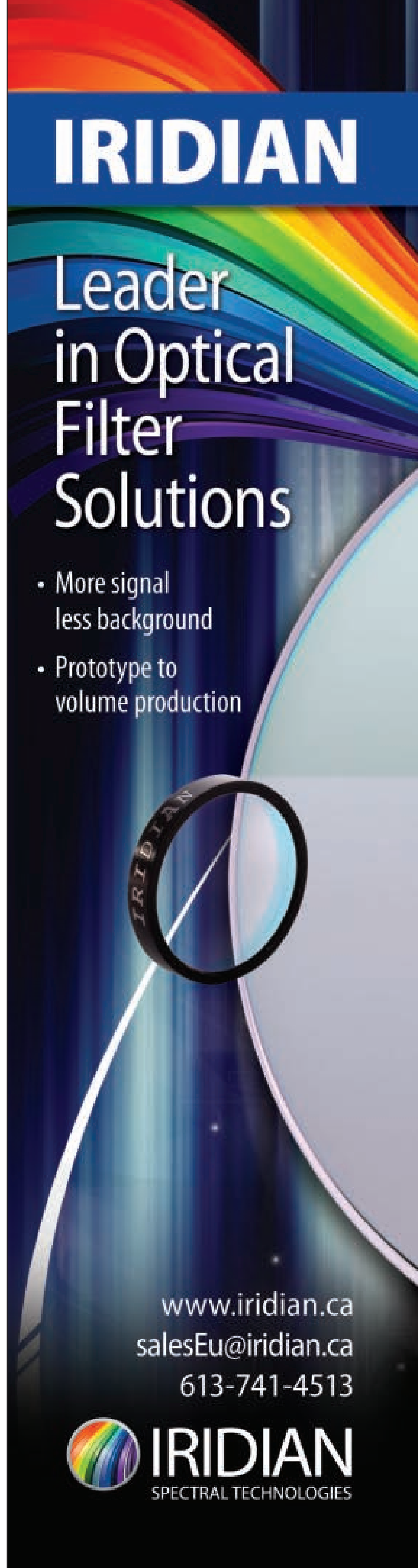
A recently developed alternative uses "tapes" consisting of carbon fibers integrated into kilometer-long strips of meltable thermoplastic resin. To assemble sturdy components from these tapes, multiple layers are stacked on top of each other, partly overlapping, and they are heated locally just before being laid down and pressed together. In this way, highly customized structures can be made and adapted to the application without requiring huge furnaces.

"The big issue with this approach to date, however, has been the availability of suitable sources producing localized heat," Emonts said. Gas flames have been tried, but their capabilities controlling the heat are very limited. Infrared radiation and hot air generators are not very energy efficient. This is where the laser comes in. It heats the material in a localized and efficient manner, enabling the tape strips to fuse with each other and to cool off quickly.

Lasers not only open the path to making single fiber-reinforced parts, but also help make difficult-to-form, bulky components of fiber-reinforced plastic by joining them together.

A new technique presented by researchers from Fraunhofer Institute for Laser Technology ILT offers sturdy connections that satisfy the standards of automotive and aerospace industries, said ILT's Dr. Wolfgang Knapp. "All we need for this is a laser that emits infrared light. The infrared laser melts the surface of the plastic components. If you compress them when they are still fluid and then let them harden, then the result is an extraordinarily stable bond."

Directly applied high-power diode lasers are the first choice for these applications, predominantly for economic reasons. Gaussian beam quality is not really






needed here; in fact, the dispersive beam converts in a homogeneous profile at the workpiece – exactly what is needed. In principle, fiber lasers could be used, especially if they were cheaper or if their better beam quality were needed; e.g., for scanning applications with a long focal distance.

The main challenge when using lasers is the fiber reinforcing the typically transparent polymer material. It induces scattering and (multipath) reflections because of the difference in refractive index between the thermoplastic matrix and the glass, reducing the absorbed power. The lack of absorption in the fiber itself can be the other challenge. Carbon fibers – as widely used in high-cost, high-performance parts – are black and absorb a wide spectrum. Glass fibers, however, do not.

Solving this problem is the next thing the researchers are working on – to address mass uses for glass-reinforced plastic, also known as fiberglass.

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# Photonics in Spain: Open for business

CASTELLDEFELS, Spain – “Several industrial sectors related to photonics are growing in Spain, especially those related to energy efficiency and health,” said Silvia Carrasco, knowledge and technology transfer director at ICFO – The Institute of Photonic Sciences, based in Castelldefels, Spain. The institute arranges collaborations and partnerships with Spanish photonics companies and related customers.

“Biotechnology is one area in which the government and industries in the Barcelona metropolitan area are focusing resources and initiatives. Clean technology is another area that has great potential in Spain, as is reflected by current investments,” Carrasco said.

Founded in 2002, ICFO moved three years later into a fully dedicated building in the metropolitan Barcelona area. At full speed, it is expected to host more than 300 full-time researchers working in some 60 research laboratories. It is conducting wide-scope research in several areas of photonics, including information technologies, nanophotonic devices, optical sensors, ultrafast optics, optoelectronics, integrated optics, and biophotonics and biomedical optics. “We collaborate with all types of industries in these areas, but also in other areas where photonics can make a difference for their business and products,” Carrasco said. The institute runs major focus programs on light for health, energy and information.

In education, it offers PhD degrees in photonics, which attracts international students, while in economic development, it is proactive in establishing partnerships with industrial corporations.

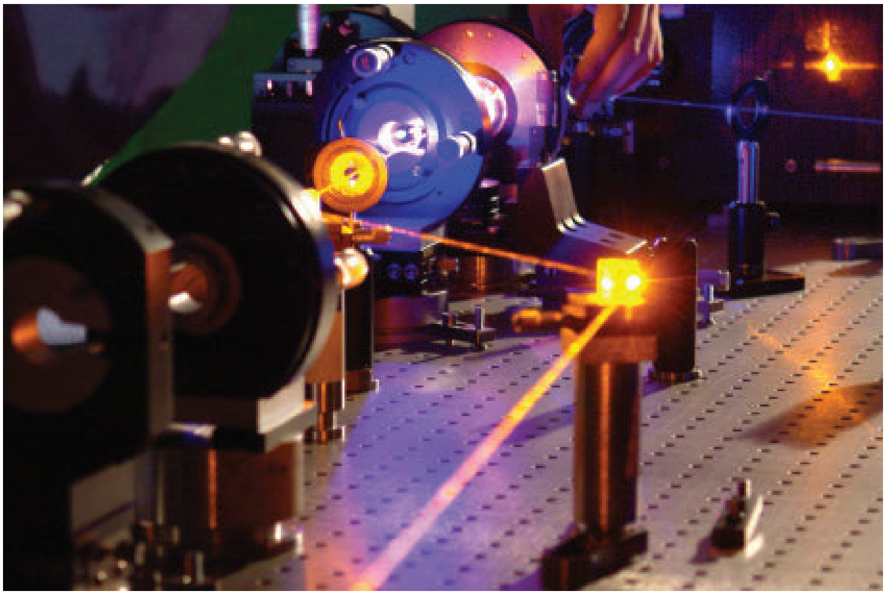
Commenting on challenges to the industry, Carrasco noted that large- and medium-size companies face difficulties that differ from those of small businesses because of the markets they tend to target. However, she added, the broad scope of photonics technology allows companies to have diversified portfolios, so, although they may suffer in one market, they may do well and even enhance sales in other segments.

When asked about projects that are nearing the commercialization phase, Carrasco noted that the institute is particularly active in patenting different types of optical sensors, nanophotonic devices and ultrathin-film technology. “Our patent portfolio includes innovations in microscopy, plasmonics, sensors for hostile environments, and transparent electrodes technology,” she said. She mentioned that their spin-off company Radiant Light commercializes optical parametric oscillators and frequency conversion devices.

## ICFO expands

The institute will broaden and complete its scope with a few new areas, and it will expand its existing facilities: the Nanophotonics Fabrication Lab, the Super-Resolution Light Microscopy and Nanoscopy Lab, and the Advanced Engineering Lab. It will begin construction next fall on a building that will house a new program called Nest, which will target young talent in the field.

“The photonics industry in Spain is organized by the Spanish photonics technology platform Fotónica21, which has more than 120 members. It is the Spanish mir-



Pictured is the generation of tunable laser light at ICFO – Institute of Photonic Sciences in Spain. Photo courtesy of ICFO; photographer, Luis Montesdeoca.

ror of the European technology platform Photonics21," Carrasco explained. She commented that the large poles of photonics activity in Spain include Barcelona, Madrid, Valencia, Zaragoza and Cantabria. Madrid and Valencia offer strong capabilities in silicon photonics, she added.

"The number of companies based in Spain that use light as a tool keeps growing, especially medium-size enterprises. We team up with all types," Carrasco said. She mentioned the spin-off company On-Laser. The recently launched startup specializes in commercializing new laser technology for niche applications. There are also many large corporations and international companies involved in the Spanish photonics industry, she added.

### New construction

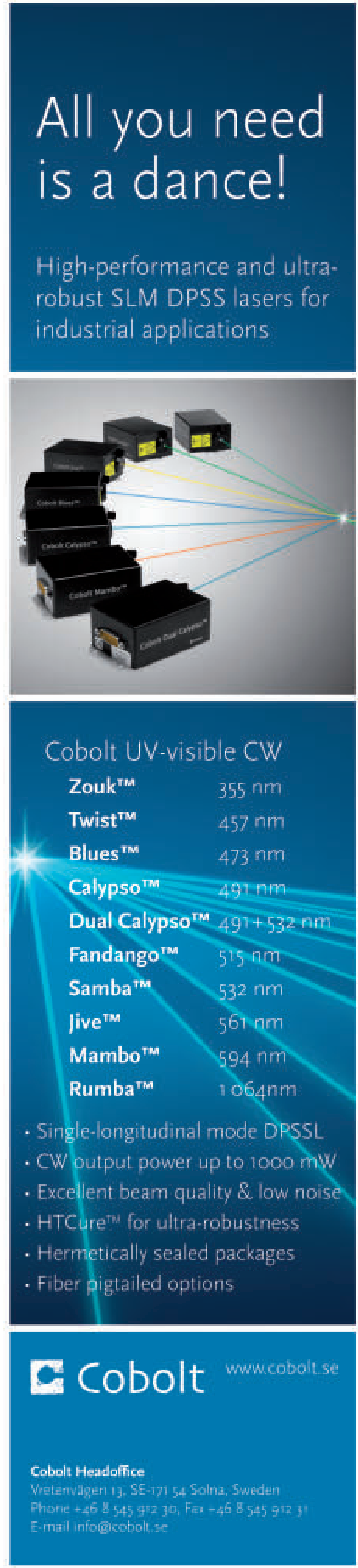
"The Spanish photonics industry had been experiencing a growth rate of 18 percent before the international economic crisis, with a turnover of €1.4 billion. Even in the economic downturn, many companies continued to invest in R&D, especially small- to medium-size enterprises," said Andrés Cifuentes, director of SECPhO, the Southern European Cluster in Photonics and Optics. "This is an excellent moment to look at Spain for photonics innovation and investment opportunities in the coming years, especially with its strong research capabilities and laboratories," he added.

Based in Terrassa, Spain, SECPhO was founded in April 2009 by nine companies and the research center CD6 (Research Center for Sensor, Instrument & Systems Development), which is an innovation center of the Technical University of Catalonia.

The founding members of SECPhO include laser diode manufacturer Monocrom, which holds the presidency of the cluster; Indra, a multinational company with an electro-optics business unit; Sensofar, with expertise in confocal/interferometric microscopy technology; and Easy Laser, a developer of industrial laser systems.

Currently there are more than 40 cluster members, many of which are heavily involved in research activities. The membership represents 35 percent of the current photonics industry in Spain, Cifuentes said. He added that there are many top-level research centers in the country with decades of experience.

One of the major projects in Spain is the construction of a petawatt laser facility in Salamanca, Cifuentes said. The CLPU (Center for Ultrashort Pulsed Lasers) will house the most powerful laser in Spain, he said. The CLPU is considered a scientific large-scale user facility and is funded by Spain and the European Union. It will develop ultrashort, ultraintense laser technology and promote its use and development in fields such as physics, biology, chemistry, medicine and energy. The facility will be open to international as well as Spanish users.




### Research and development

As with many other sectors, the photonics industry in Spain has to tackle a major challenge: the reduction in R&D funds for high-risk medium- to long-term research, Cifuentes said. This will have a detrimental effect on innovative product development and increase the time-to-market cycle.

He commented that the current model in Spain forces companies to take research loans, meaning less willingness to take risks and longer innovation times. The industry will take at least two years to adapt to the new conditions, but, at the same time, the situation will force companies and researchers to consider markets and end users more closely when defining research strategy.

"On the other hand, Spain has internationally recognized higher education programs in photonics, which attract talented students from around the world," Cifuentes said.

"As surely is the case in many other countries, the photonics industry in Spain has realized that R&D must be more market-oriented than ever. Given the current global economic conditions and the national funding cutbacks, companies will have to work together to fund innovative research and engage labs and research centers in an effort to align strategy such that projects will result in value-added photonics-based technology, in shorter time – reducing the gap between research and market," he said.

### Outlook is good

The photonics industry in Spain, although still in an early stage, has experienced rapid growth in the past five years. Optical technologies can increase the value of products or manufacturing processes; in addition, nonphotonics companies are actively introducing optical and photonic solutions in their products or processes.

An interesting indicator of optics and photonics industry health is the fact that CD6 income has been growing since 2000, keeping a balance between public funding (40%) and industry contracts (60%), Jaume Castellà, managing director of CD6 said.

"Our outlook for the photonics industry in the next few years is clear: It will continue growing, pushed by market demand and supported by the Catalan and Spanish research agencies. Also, the increasing offer of venture capital will improve the environment needed for the creation of spin-off companies that will market top-of-the-line research results."

Castellà noted several institutions in Spain that conduct research in photonics, among them, Laboratorio de Óptica, Universidad Murcia, and the Instituto de Optica, Consejo Superior de Investigaciones Cientificas in Madrid. These two institutions, along with CD6, have long-term research programs related to vision, including programs on physiological optics and adaptive optics applied to vision, he said.

### Adaptive optics

In 2008, Imagine Optic SA of Orsay, France, created a subsidiary in Barcelona to respond to growing demand from the Iberian market. Cosingo-Imagine Optic Spain SL enabled the company to identify wavefront metrology and adaptive optics customers engaged in innovative applications, including high-power lasers, astronomy and life sciences microscopy. The company distributes the Orsay-based Imagine Eyes' research instruments for wavefront aberrometry and adaptive optics vision simulation.

Recently, Cosingo teamed up with European partners to develop an ultrasensitive point-of-care device for early cancer diagnosis, treatment monitoring and follow-up. The project, Spedoc, of which ICFO is a partner, is based on surface plasmon resonance and microfluidic lab-on-a-chip technologies.

"In contrast to many other European countries, the Spanish photonics market is primarily led and represented through academic institutions, as its industry is not as dense as it is in some of its neighbors," said Rafael Porcar Guezenec, business manager of the subsidiary, who added that things are changing quickly and that several organizations are working hard to counteract this situation.

"At the representative level, organizations such as SECPhO are helping photonics companies to work together and giving them the visibility they need through national exhibitions organized by and for the industry. These organizations equally help foster international growth and give them a voice at the European level. It may sound odd, but there was no such support in Spain five or 10 years ago!" Porcar said.

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# Solar energy receives a boost from UK government

SOUTHAMPTON, UK – The feed-in tariffs for renewable energy recently introduced by the government heightened interest at the sixth Photovoltaic Science Application and Technology Conference (PVSAT-6), hosted by the University of Southampton's School of Electronics and Computer Science in late March.

Event organizer professor Darren M. Bagnall, a member of the school's Nano Research Group, said: "With householders alone, the feed-in tariffs provide an exciting opportunity for PV that we believe will have a big and lasting impact in the UK."

Under the scheme, a subsidy will be paid to anyone generating electricity from a renewable source, ranging from solar rooftop panel systems to wind turbines. Feed-in tariff regulations already exist in more than 40 countries.

According to Bagnall, the conference provides an ideal opportunity for the PV community to come together to share ideas and keep current with developments including materials characterization, manufacturing processes, system modeling, system design and system components, performance measurement and field experience, economics, market development and the environment.

"Photovoltaics has rapidly evolved into a multibillion dollar industry. It continues to grow, and as it grows, new technologies and challenges arise," he said. "The PVSAT conference looks at a wide range of issues surrounding PV and invites speakers from around the world in order to gain a comprehensive and up-to-date overview on a range of aspects of PV systems."

Among the invited speakers was Christian N. Jardine, senior researcher at the University of Oxford's Environmental Change Institute and the technical director of Joju Ltd., a solar PV installation company. Jardine provided careful analysis of the government's intended subsidy scheme and suggested that the new tariffs represent a marked improvement on prior policy that should, however, be treated with caution.

"Rates of return are modest, between 3 and 5 percent per annum, depending on interest rates and electricity gas prices," he said. "Returns will not be as high as might be hoped, and although householders will be attracted, it is less obvious that business, local government and communities will be attracted, since the return on investment is not sufficient to justify a bank loan."

Although it is hoped that the government has or will allocate further resources to make low-interest bank loans available to make up for this shortfall, the news is still being met with enthusiasm. "The subsidy could help to build an infrastructure while we await grid parity," Bagnall said.

## Innovations in PV technology

The economics of PV systems was not the only thing on the agenda at PVSAT, however, as guest speakers from around the globe discussed their latest research. For example, Christopher R. Wronski, professor emeritus of electrical engineering at the University Park campus of Pennsylvania State University in the US, highlighted the current massive scale of thin-film silicon manufacture. He also described ways in which new technologies and designs are improving the efficiency and stability of these devices, in particular noting that double- and triple-junction formations (two or three different solar cells on top of each other) can achieve laboratory cell efficiency values of up to 14 percent.

Some of the most promising avenues of research involve looking for ways in which nanotechnology can be used to make better solar cells, especially how nanostructured metal nanoparticles might be used to scatter – and thereby trap – light in thin-film solar cells. The hope is that these plasmonic particles will boost the efficiency of a solar cell or greatly reduce the cost.

Perhaps the most important question in terms of PV technology is: When might grid parity be reached?

According to Bagnall, there is a feeling that, over the next two or three years, module and system costs will be sufficiently low to ensure a big rise in PV uptake that is no longer driven by subsidy but by straightforward economics.

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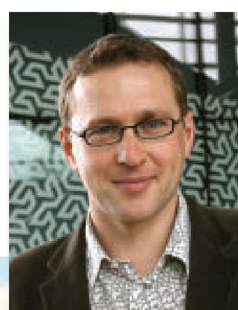


Event organizer Darren M. Bagnall, a member of the University of Southampton's Nano Research Group, discussed the hottest topics up for debate at the sixth Photovoltaic Science Application and Technology Conference. Inset photo courtesy of the University of Southampton.

# Measurement of centering errors, automated adjustment and mounting of lenses

BY JOSEF HEINISCH, TRIOPTICS GMBH

*Classical optical measurement techniques combined with modern PC technology provide accurate alignment, bonding and cementing of optical components and systems. These processes are fully automated and significantly reduce production time and cost.*

The processes involved in manufacturing optical lenses – grinding, polishing and coating – have become increasingly automated in the past few decades. Computer numerical controlled grinding and polishing machines, as well as computer-controlled interferometers for the examination of the surface profile, are in widespread use.

However, many lens manufacturers still use simple optical or tactile measurement instruments for determining centering errors. More often than not, the lenses are still adjusted manually. The adjustment and centering errors of the optical components have a decisive influence on the image quality of the lens. The use of electronic autocollimators and automated adjustment equipment makes the mounting process quicker and more precise – for example, when cementing achromatic lenses or bonding lenses into a mount.

## Centration error measurement

When measuring a centering error using the reflection mode (Figure 1), an electronic autocollimator, read via a PC, is at the core of the measurement. An illuminated target (usually a reticule) is projected at the center of curvature of the spherical or almost spherical lens surface under investigation. In this instance, the rays of light meet the surface at an almost perpendicular angle. Some of the light is reflected back along the exact path it came (a condition of autocollimation) and displays the target on a CCD camera. A lateral shift of the center of curvature creates a direct lateral shift of the reticule image.

If the surface under investigation is rotated around a reference axis, a corresponding circular movement of the reticule image is created on the CCD sensor. The radius of this circular path is directly proportional to the position of the center of curvature in relation to the reference axis. The live reticule image depicts the exact position of the center of curvature in the X-Y axis, whereby the center of the circular path represents a reference point in the overall space. Powerful light sources and light-sensitive CCD sensors ensure that even test items that are well antireflection-coated produce a sufficient autocollimation image.

In extreme cases, it is also possible to

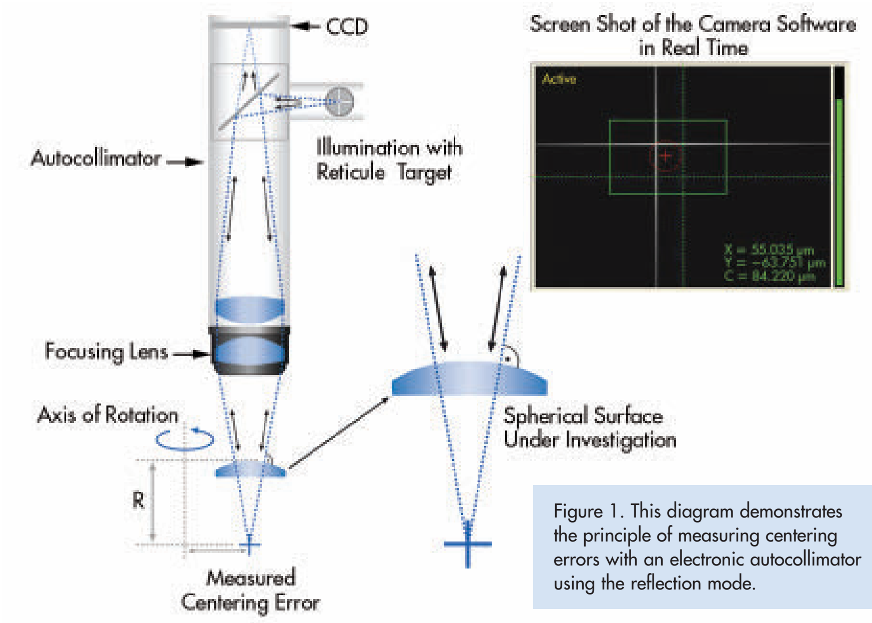
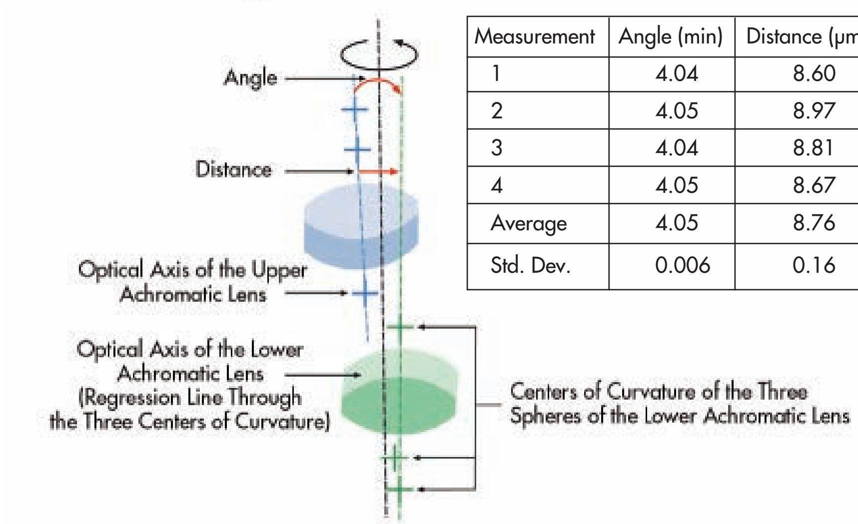



Figure 1. This diagram demonstrates the principle of measuring centering errors with an electronic autocollimator using the reflection mode.




| Measurement | Angle (min) | Distance (µm) |
|---|---|---|
| 1 | 4.04 | 8.60 |
| 2 | 4.05 | 8.97 |
| 3 | 4.04 | 8.81 |
| 4 | 4.05 | 8.67 |
| Average | 4.05 | 8.76 |
| Std. Dev. | 0.006 | 0.16 |

Figure 2: Measurement of the angle and the distance of the optical axes of the lenses to each other.

carry out the measurement using near-infrared (750- to 1000-nm) illumination. In this spectral range, the antireflection coatings optimized for the visible range have enough reflectivity. As an alternative to incoherent light sources, laser autocollimators are available, although these can produce images that are difficult to interpret due to speckling.

### Centration error measurement of objectives

The effectiveness of measuring centering errors with an electronic autocollimator in combination with computers is apparent when measuring multiple lenses.[1] This method identifies the centering error of each individual lens surface in a mounted optical assembly. Any selected axis of rotation serves as a reference axis. Suitably precise air bearings with radial and axial runout errors of <0.05 µm are available.

First, the centering error of the outermost optical surface is measured in relation to the axis of rotation. The next step is to focus in to the center of curvature of the second optical surface. For the calculation of the position of the center of curvature (Z), the optical properties of the first outermost surface must be taken into account. When evaluating the true centering error (X, Y) of the second surface using optical calculations, it is also necessary to take into consideration both the optical properties and the centering error of the first surface previously measured. This calculation simply requires the design data (radius, center thickness, refractive index) of the item under investigation. When the exact centering error of the second surface has been identified, the centering error of the third surface can be measured, and so on. This measurement process has proved itself to be extremely robust.

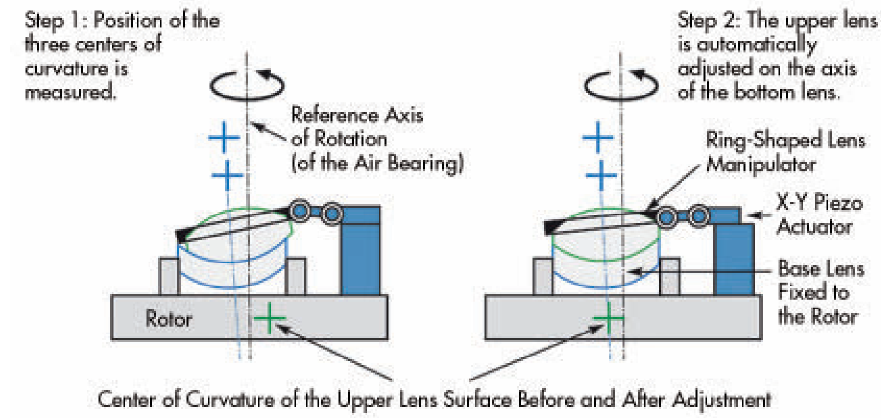



Figure 3. The multilens measurement method is used for the automated adjustment of achromatic lenses in the cementing process.

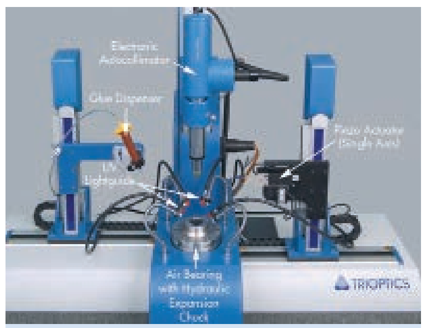


Figure 4. The frontal view is shown of an automated centering and bonding station for the assembly of lenses into a mount.

Using design data alone is more than suitable for the evaluation, as it is unusual for a significant difference to exist between that data and actual lens measurements. In practice, it is possible to gauge with a single autocollimator the positioning errors of 20 or more surfaces to an exactness of <1 µm. To clarify the effectiveness of this measurement process, Figure 2 shows the measurement results of an optical assembly. The sample assembly consists of two identical achromatic lenses with surface radii in the region of 40 to 120 mm. The multiple-lens measurement provides the exact position of all the centers of curvature in relation to the rotational axis. Since an achromatic system consists of three optical surfaces, the optical axis of a single achromatic lens can be displayed via a regression line through the three centers of curvature. This is indicated by the dotted blue and green lines in Figure 2.

If the optical axes are known, it is possible to define the angle and distance between both optical axes (here in the plane of the upper vertex). These calculations are automatically executed as part of the measurement process. The results are shown in Figure 2. The multiple-lens measurement of the objective has been carried out four times. After each measurement, the item under investigation was removed from the bearing and, without any particular provisions, replaced for the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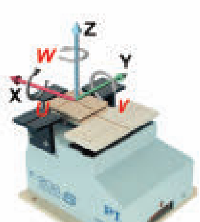

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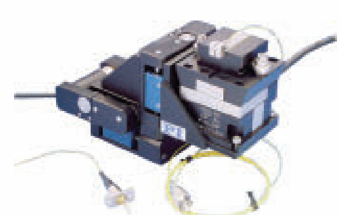

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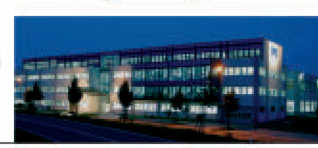

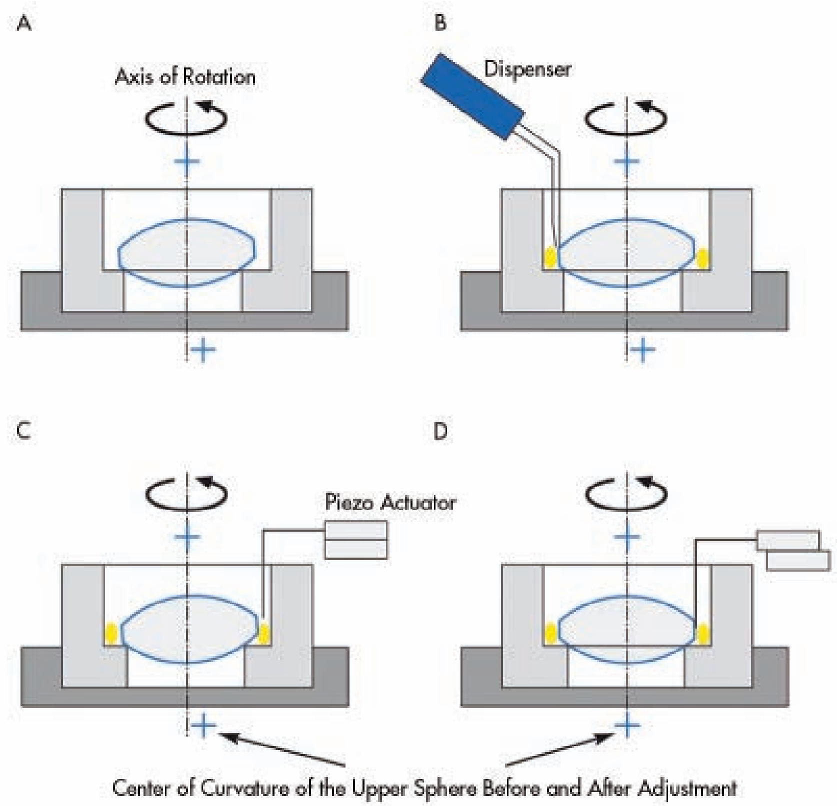


Figure 5. Panels A to D show the step-by-step process of automatically bonding a lens into a mount.

next (measurement at a 90° azimuth angle). The result is a standard deviation of 0.16 µm in the distance measurement of both optical axes.

If the exact positions (X, Y, Z) of all centers of curvature are known in a fixed system of coordinates, this information may be used to optimize the optical assembly. In the example given here, the upper achromatic lens can be realigned by the previously measured magnitude of 8.8 µm in the direction of the optical axis of the lower lens (green line).

### Automated cementing of achromatic lenses

There is a new process for adjusting two single lenses of an achromatic lens.[2] Based on the multiple lens method, it does away with the precise initial adjustment of both lenses. Instead, the exact position of each of the three centers of curvature is identified in its uncemented state. The axis of rotation of a highly accurate bearing serves as a reference axis for the measurement of the centering error, but not as a reference axis for the adjustment. Hence there is no need for precise, self-centering mechanical holders. Both lenses are fixed

to the rotor of the bearing, and their center remains unaltered throughout the measurement process. The cement between the lenses is still fluid at this point.

Once the centering error has been measured, the center of curvature of the upper sphere is adjusted according to the optical axis of the lower lens. A ring-shaped support, fitted with an X-Y piezo actuator, is placed on the upper lens. It moves the upper lens so that all three centers of curvature eventually lie on the one line, the optical axis (Figure 3). The cement is then hardened using UV light. The entire measurement and adjustment cycle lasts only 10 to 15 seconds. This method is five to 10 times more accurate than the manual process and is particularly effective in the production of small optical components with 1-mm diameters – endoscopes, for example.

### Automated bonding of lenses into a mount

When bonding lenses and optical elements into a mount, the optical axes of these elements must be brought into line with the axis of the mount itself. The axis of the mount can be given in terms of the symmetrical axis of a cylindrical mount. An instrument for the precise alignment and bonding is shown in Figure 4.

Figure 5 is a schematic representation of the basic process. The workpiece (mount with unglued lens) is positioned on the rotor of a rotational axis. The mount's support has previously been aligned to the axis of rotation to a degree of accuracy of 2 µm. A so-called hydraulic expansion chuck is used as the support, which can transfer the center accuracy almost perfectly to the lens mount.

Before the centering error is measured, a robot arm moves in with a dispenser of UV-curable glue. The glue is applied to the lens and the mount by rotating the test item 360°. The centering error of the upper lens surface is now determined using the autocollimator.

Since the mount and therefore also the ring-shaped face of the lower lens surface are centered perfectly with respect to the axis of rotation, it is sufficient to center the upper surface. To achieve this, a manipulator is introduced on another robot arm. The manipulator may be fitted with either a single-axis piezo actuator (Figure 4) or with three single-axis piezo actuators (Figure 6), which are fixed at 120° from one another on a ring. In the instance where only one actuator is used, the test item must be rotated before the final adjustment in such a way that the axis of rotation, the center of curvature and the piezo axis are all on the same line. If three actuators are used, the lens can be adjusted on the center of rotation without rotating the sample again.

The accuracy of the adjustment can be increased by taking an additional measurement of the position of the mount's axis. A linear measuring sensor (resolution 0.1 µm) is placed on the edge of the mount (Figure 7) and takes measurements over a 360° rotation. The results are presented using a sine curve that identifies the X-Y coordinates (centering error) of the mount. Using the piezo actuators, the lens can now be adjusted to the direct center of the mount (green cross in Figure 7).

Once the lens has been successfully adjusted, the glue can be hardened by switching on a UV light source. The advantage of such a process is that the lens can be adjusted with great exactness on the mount, without the mount itself having to be perfectly adjusted to the axis of rota-

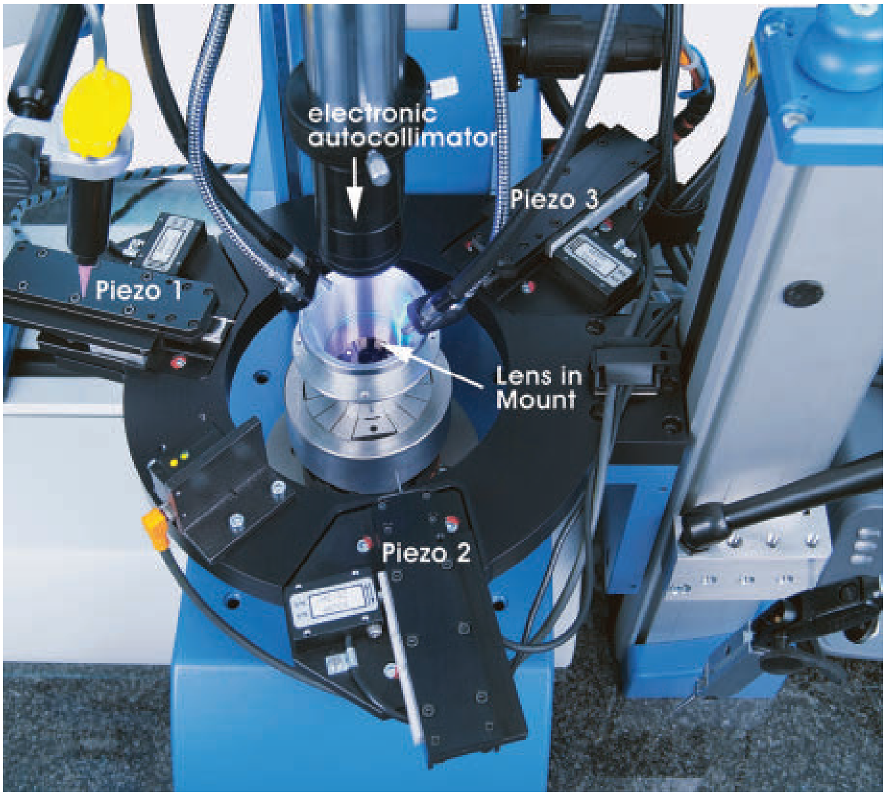


Figure 6. Pictured is an automated bonding station with three piezo actuators.

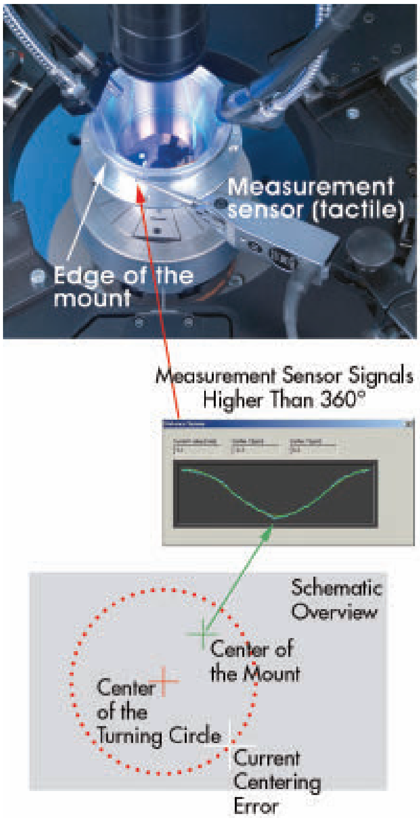


Figure 7. The center of the mount's circumference can be identified using an additional measurement sensor. The lens is positioned using three needles (set apart from one another at a 120° angle) and adjusted to the center of the mount.

tion. The multiple-lens measurement described here, the cementing of achromatic lenses and the gluing of lenses are perfect examples of the advantages of a computer-aided measurement of centering errors.

The previously laborious and therefore expensive form of adjustment has been simplified by intelligent measurement technology. The consistent use of this technology enables a greater degree of accuracy in the production of optical systems and therefore new design opportunities for more compact and higher-quality lenses.

## Meet the author

Josef Heinisch is a physicist at Trioptics GmbH in Wedel, Germany; e-mail: j.heinisch@trioptics.com.

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# TOWARD ROLL-TO-ROLL PRINTED POWER SOURCES AND CONTROL ELECTRONICS

BY DR. JUKKA HAST, DR. KIMMO SOLEHMAINEN AND MARJA VILKMAN, VTT TECHNICAL RESEARCH CENTRE OF FINLAND

To pave the way for commercialization of printed electronics and optics applications, two European Union-funded projects are developing roll-to-roll-based fabrication technologies.

In the first project, called FACESS (Flexible Autonomous Cost efficient Energy Source and Storage), roll-to-roll printed organic photovoltaics and energy storage devices are being developed. In the second one, POLARIC (Printed, Organic and Large-Area Realisation of Integrated Circuits), the aim is to bring the performance of printed electronics to a new level by combining roll-to-roll compatible high-resolution steps in the transistor fabrication process, and to demonstrate the developed high-performance organic electronics in various consumer applications.

Traditionally, the primary function of printing has been the delivery of data and information for visual inspection and further interpretation by humans or machines. Nowadays, printing and other large-area R2R (roll-to-roll)-compatible processes enable cost-efficient mass manufacturing of electronics and other functionalities on large-area and flexible substrates such as plastic, paper and fabrics. Figure 1 shows one of the pilot machines for printed electronics at VTT Technical Research Centre of Finland.

New printable-functional materials, print-production processes and reading mechanisms are expanding the role and function of printing toward novel application fields. This is the opportunity gap between traditional paper, packaging and printing industry products, and ICT/electronics industry products, and it can realize completely new types of applications and businesses; e.g., disposable sensors, simple "electronic" components and circuits, large-area functional paper-like intelligent products, smart packages, tag-and-code technology-based ICT and hybrid media services.

Figure 1. Shown is a pilot printing machine for printed electronics. Images courtesy of VTT Technical Research Centre of Finland, Printed Functional Solutions.

The market potential loaded to printed and organic electronics is extremely high. Several independent market analysts expect it to become a $250 billion to $300 billion market within 20 years. All electronic applications require power, a challenge that will be emphasized in printed electronics applications, where power sources also must be implemented on flexible form.

In the FACESS project, energy harvesting and storage are being tackled. The goal of the project partners – VTT Technical Research Centre and Suntrica Oy, both of Finland; Interuniversity Micro-Electronics Centre of Belgium; Commissariat à l'Energie Atomique of France; Politechnika Warszawska of Poland; Umicore SA of Belgium; and Coatema Coating Machinery GmbH and Coatema Maschinenbau GmbH, both of Germany – is to develop cost-efficient R2R production techniques for organic solar cell modules and rechargeable lithium batteries.

Also in development is an application-specific integrated circuit (ASIC) chip that would optimize and control the battery charge from the organic solar modules. To be flexible, the chip is thinned to 30 μm and interconnected on the flexible backplane. The plan is to use R2R-compatible production technologies to manufacture an energy storage foil of four printed organic




solar cell modules comprising a 100-cm$^2$ area, a printed battery and an interconnected ASIC to control the charge operation. Under AM1.5, a reference organic solar cell module can produce 250 mW of power to charge the battery. The battery size is approximately 30 cm$^2$ and its capacity, between 1 and 3 mAh/cm$^2$.

In Figure 2, four gravure-printed organic solar cell modules operate at 2.3 percent photon-conversion efficiency at air mass 1.5 illumination on a 15.5-cm$^2$ area per module. The modules are manufactured using commercially available conductive – and photoactive – polymers. The rechargeable lithium battery has anode and cathode electrodes screen-printed on aluminum and copper foils, and an assembled commercial separator foil. The battery produces ~40-mAh capacity. The 30-µm-thick ASIC is flip-chip-bonded using anisotropically conducting adhesive on the backplane substrate.

All other components of the energy source built for the FACESS project are printed, except for the electronic part. This is because the performance limitations of printed electronic circuits force the use of traditional, silicon-based microchips for the control electronics. To enable wholly printed devices, the printed circuits must be improved significantly.

In response to this challenge, the partners launched POLARIC earlier this year. The new project is expected to lead to smaller transistor dimensions, with the aim of improving their performance and demonstrating their use in applications

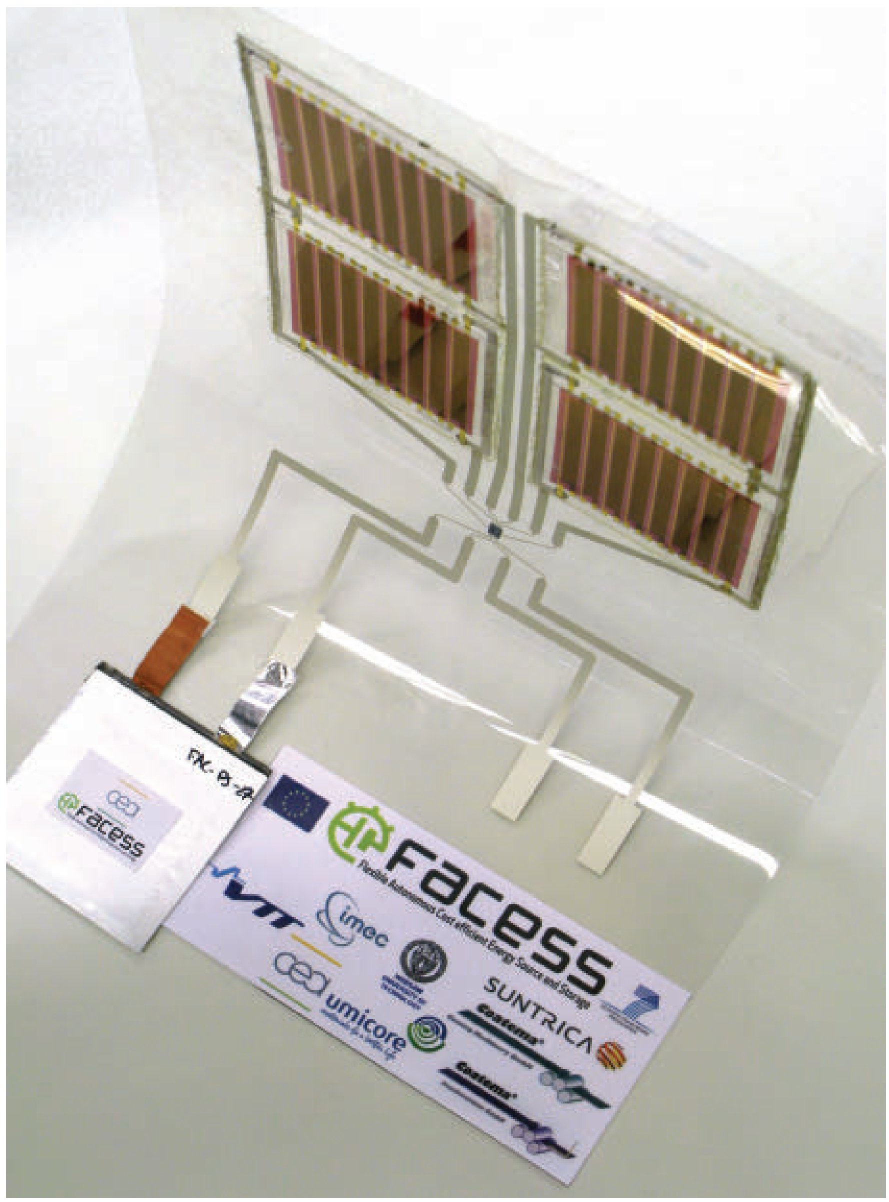


Figure 2. This energy storage foil is from the FACESS project.

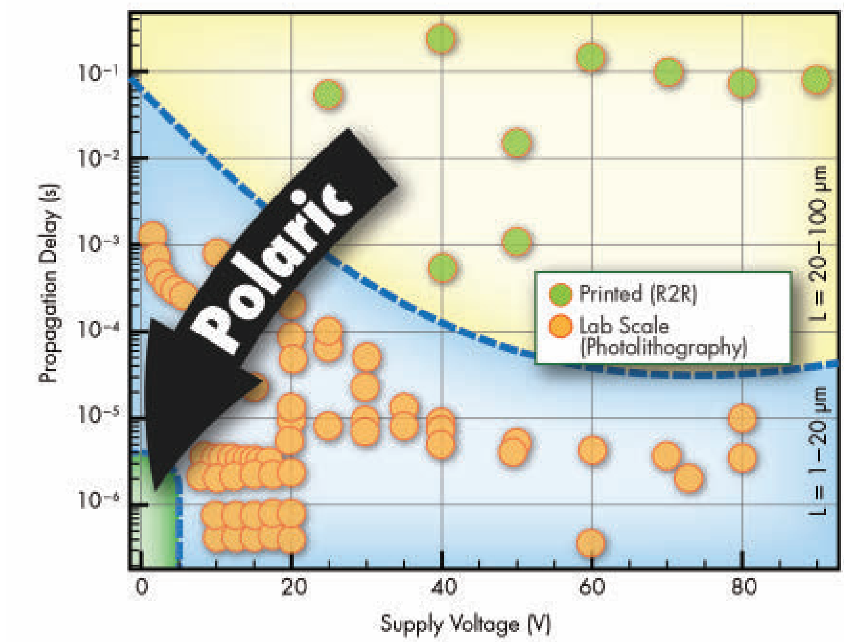


Figure 3. The POLARIC target is compared with the state of the art in organic electronics. R2R = roll to roll.

including printed radio frequency identification tags and active matrix displays.

The work is divided among the coordinator, VTT Technical Research Centre of Finland; AMO GmbH, 3D-Micromac AG, Fraunhofer-Gesellschaft IZM and micro resist technology GmbH, all of Germany; BASF, CSEM SA and Asulab, a division of The Swatch Group Research and Development Ltd., all of Switzerland; Cardiff University and Imperial College London, both of the UK; IMEC of Belgium; Joanneum Research Forschungsgesellschaft mbH of Austria; and Obducat Technologies AB of Sweden.

Figure 3 demonstrates state-of-the-art organic electronics (printed and lithographically prepared) and compares it to the performance required for operationally good enough organic circuits; i.e., the POLARIC target. In detail, the high performance of the organic circuits referred to means high speed (kilohertz to megahertz), low operating voltage (±<5 V), low power consumption and low parasitic capacitance. The POLARIC target of improved performance is indeed challenging. However, that level of performance is needed to enable substantial market penetration of organic electronics.

Besides improved performance, the manufacturing process of organic electronics must be suitable for large-scale production. Thus, another, equally important goal of the project is to develop further R2R printing methods; e.g., using R2R-compatible nanoimprinting technologies for short-channel configuration of the electrodes to produce components and circuits with extremely high yield. The project also will provide solutions for the fabrication of R2R tools, making serial replication viable. Finally, the circuit design, modeling and characterization of organic electronics will be developed to offer a toolbox similar to that of silicon-based microelectronics. Thus, it is justified to say that the project will revolutionize the way printed electronic circuits are made by combining large-area fabrication methods with high-performance organic electronic circuits on a scale not previously attempted.

After the FACESS and POLARIC projects, high-performing organic electronic building blocks and manufacturing platforms can be used in all areas of printed electronics, including sensors, memory, batteries, photovoltaics, lighting and any combination of these devices. By combining different functionalities and blocks on the same flexible foil, and integrating the whole process in a cost-efficient way, the huge market potential for printed electronics and optics will turn into reality.

### Meet the authors

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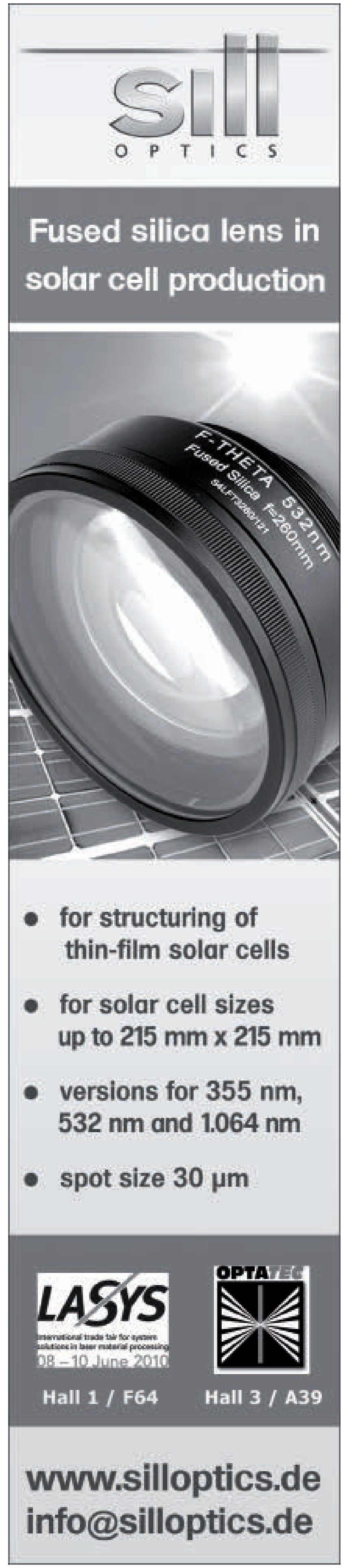


# PRODUCT PREVIEW

## Tapered Amplifiers▼

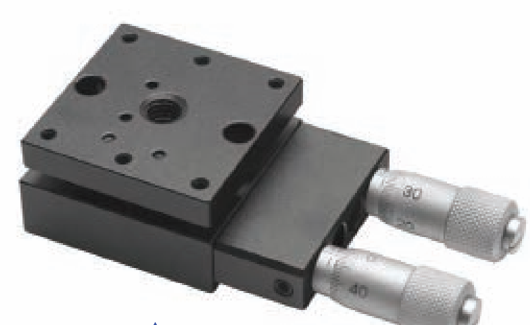
The New Focus brand of Newport Corp. has introduced a series of semiconductor tapered amplifiers for high-power tunable and fixed-wavelength applications. Designed to accept many fiber-coupled seed sources, the Vamp series helps protect the chip from unintentional misalignment. Its design includes output isolation, overcurrent protection and input seed monitoring in every amplifier for stable operation. It delivers more than 1 W of tunable signal frequency radiation when seeded with the brand's Vortex II and Velocity tunable lasers. Additionally, it can operate with homemade seed sources. With extremely high amplified spontaneous emission rejection to improve the signal-to-noise ratio, it is suitable for atomic cooling, spectroscopy and for Bose-Einstein condensates.

**New Focus**
**hans.dabeesing@newport.com**

## CCD Microscope Cameras▶


The Jenoptik Optical Systems digital imaging business unit has added two USB camera types to its ProgRes CCD microscope range. The SpeedXT core 3 and core 5 cameras feature proprietary SpeedXT$^{core}$ technology. The core 3 model delivers a live image speed of 17 fps at maximum 2080 × 1542-pixel resolution, while the core 5 model offers a live image speed of 13 fps at 2580 × 1944-pixel resolution. When maximum resolution is not required, they can achieve frame rates of 30 and 45 fps, respectively. Exposure times up to 180 s are possible to ensure optimum captured images, even in low-light conditions. Both models can be connected to any microscope, computer or notebook with C-mount connection, and the included CapturePro image capture software offers extensive functionalities and an intuitive user interface.

**Jenoptik**
**progres.os@jenoptik.com**



## Tip-Tilt Stages▲

Edmund Optics Inc. has released its TechSpec tip-tilt stages for tilt control of optics and mounting posts on two axes. The stages are constructed from black anodized aluminum and are available in three sizes: 30, 40 and 70 mm square, with each size offered in a choice of English or metric hole pattern configurations. A precision micrometer drive provides good movement repeatability. The high-resolution stages are mechanically compatible to other TechSpec stages and are designed to integrate with other TechSpec components, providing flexibility and allowing the user to create any number of axes in different configurations. Integrated with two micrometer drives, one for each axis, they offer good resolution with tip-tilt motion of up to 6°. A bottom adapter plate, sold separately, is required to mount the 30- and 40-mm stages to a standard breadboard.

**Edmund Optics**
**sales@edmundoptics.com**

## Diode Lasers▼

The iBeam smart, an ultracompact OEM diode laser manufactured by Toptica Photonics Inc., measures 100 × 40 × 40 mm and delivers 150-mW single-mode power at 660 nm. The feedback-induced noise eraser function protects against optical feedback, and the RS-232 serial interface and a standard software package control all laser parameters and generate status reports. The one-box module has a beam diameter of ~1.1 mm 1/$e^2$, beam quality of $M^2$ <1.2, wavefront error of <0.05 λ and drift of <0.5% over 48 h. Applications include flow cytometry, confocal microscopy, microlithography, retina scanning, fluorescein angiography and microplate readout.


**Toptica**
**info@toptica.com**

## Imaging Sensor▲

The V10M sensor from Specim, Spectral Imaging Ltd., operates in the VIS/NIR range of 380 to 1000 nm and provides spectral and spatial imaging with negligible subpixel distortions. It features a spatial resolution of 1300 pixels, and a 2000-pixel version will be released later this year. Based on the company's ImSpector M series of imaging spectrographs, its design is optimized for operation in harsh conditions. It produces 100 images/s, and higher when coupled with spectral binning. Its good optical light throughput results in a good signal-to-noise ratio. It is suitable for target detection with a wide swath width for efficiency in airborne uses as well as in industrial quality control applications.

**Specim**
**ana.aranda@specim.fi**

## ◀Plate Reader

Hamamatsu Photonics UK Ltd. has announced a new imaging-based plate reader, designed for compound screening and assay development applications in the pharmaceutical, cathode ray oscilloscope and biotechnology industries. The FDSSμCell is optimized for fluorescent kinetic assays using calcium and membrane potential dyes, including FLUO4 and FMP. It is available in either 96- or 384-well dispensing formats with easily interchangeable heads. An optional washing system reduces carryover and allows tips to be reused several times. It uses the company's camera range to provide high sensitivity and readout times of a few minutes. Assay and compound plates can be easily loaded, and the software helps to set parameters quickly in a single protocol.

**Hamamatsu**
**europe@hamamatsu.com**

## High-Speed Camera

Lambert Instruments has announced the HiCam 5000, a high-speed CMOS camera that is fiber optically coupled to a gatable 18-mm hybrid image intensifier. The gating is synchronized with the readout of the sensor and offers exposure times down to 3 ns. Operating at rates of up to 5000 fps at full resolution, the camera is completely computer controlled, including the gain and gating of the image intensifier, and has a Gigabit Ethernet interface and up to 16 GB of solid-state memory. Capable of detecting single photons, the camera is suitable for use in high-speed fluorescence microscopy, and in combustion and plasma imaging.

**Lambert Instruments**
**jeroen@lambert-instruments.com**

## Bioimaging Tools

The RFP-Trap and GFP-Booster bioimaging tools have been released by ChromoTek. RFP-Trap is used to identify and pull down interaction partners of proteins tagged with red fluorescent protein (RFP), while the GFP-Booster restores or increases the green fluorescent protein (GFP) signal in superresolution microscopy applications. The red tool is suitable for biochemical and cell biological analysis of RFP-tagged fusion proteins in pull down assays frequently used for in vitro methods to determine physical interaction between two or more proteins. To study protein localization and dynamics in living cells, the GFP tool is suitable. It consists of a chemical fluorescent dye that covalently attaches to a GFP Nano-trap to provide high fluorescence intensities and signal-to-noise ratios.

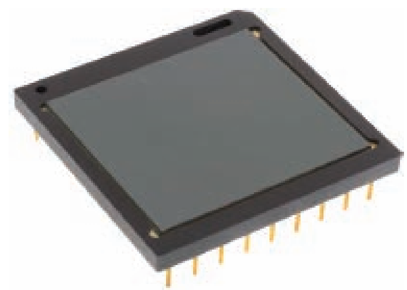
**ChromoTek**
**u.rothbauer@chromotek.com**

## Picosecond Oscillator

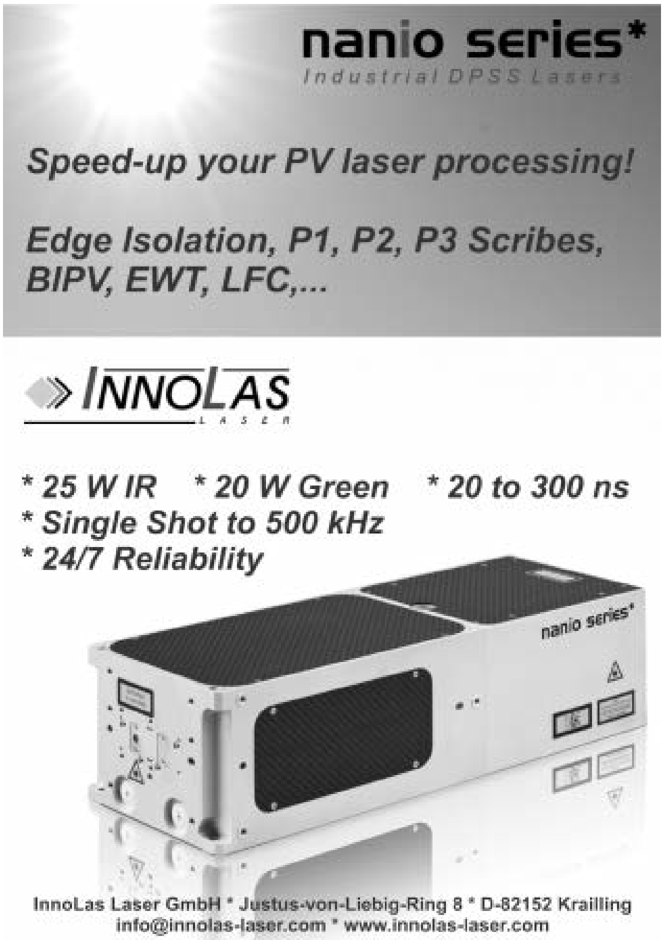
High Q Laser Inc. has launched the picoTrain high-power picosecond oscillators with wavelengths in the UV, green and IR. They deliver output powers of up to 50 W. Depending upon customer requirements, the devices can be individually configured, beginning with a basic oscillator, the picoTrain IC-10000, which delivers 7.5-ps-long pulse trains and 10-W output power at 1064 nm. Starting with the basic oscillator, the laser sources can be extended or field-upgraded with four external modules that can be attached to it. The power can be increased up to 50 W at 1064 nm by attaching the external power amplifier module to the laser exit of the basic oscillator. Combined with the pulse picker module, the 50-W picosecond laser delivers pulses with energy of up to 10 μJ, controllable by an external TTL signal that enables single pulses or pulse bursts up to a maximum repetition rate of 80 MHz. The green module offers visible picosecond laser radiation with 20 W at 532 nm.

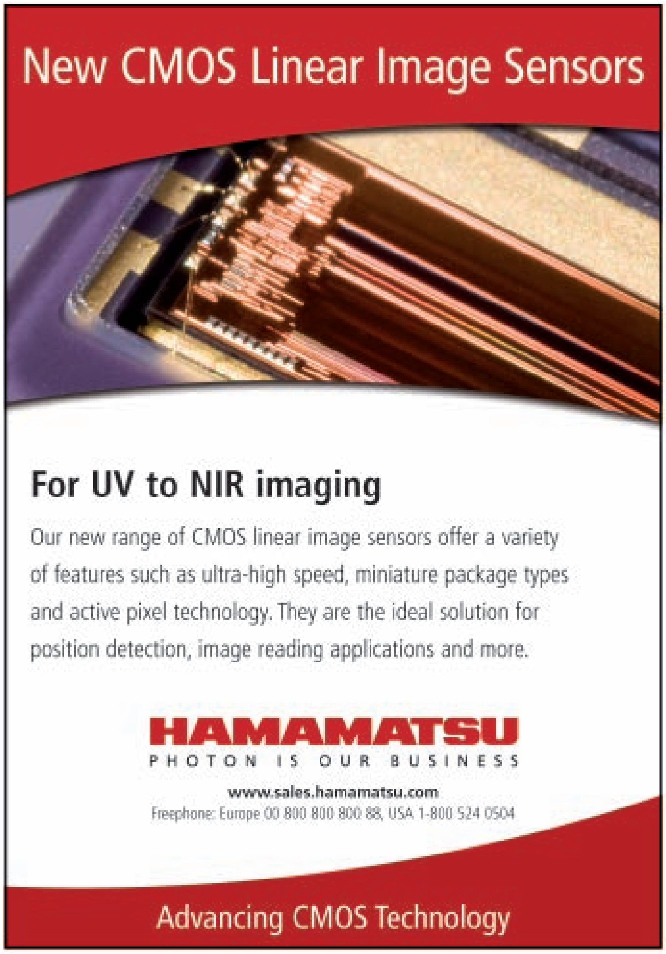
**High Q Laser**
**sales@highqlaser.at**

## Infrared Detector



Ulis has introduced a long-wave 640 × 480-pixel uncooled 17-μm-format infrared detector to upgrade the image quality of the infrared cameras used in surveillance, enhanced night driving and thermography applications, such as detecting heat loss in buildings. Measuring 24 × 24 mm and weighing 10 g, it consumes



<0.160 W of power and operates at a temperature range from –40 to 85 °C. Typical array operability is >99.9%, typical signal response is >7 mV/K, and standard deviation is ≤1.5%. Spectral response is from 8 to 14 μm, area fill factor is 70%, and thermal time constant is <10 ms. The focal plane array, featuring a CMOS multiplexer integrated circuit with ripple imaging operation, is made of resistive amorphous silicon.

**Ulis**
**c.chapuis@ulis-ir.com**

## Stent Cutting

Rofin Baasel Lasertech's stent cutting system with a femtosecond laser, the StarCut Tube Femto, offers cold laser cutting for medical device manufacturing. Femtosecond lasers process materials faster than energy can diffuse within the atomic lattice; therefore, no heat is transferred to the surrounding material, eliminating recast, distortion and burr. The device integrates a compact laser source with field-proven and long-term stability, properties that are essential for industrial manufacturing. Manufacturing of medical devices from tube stock typically relies on laser fusion cutting with pulse widths on the microsecond scale. The StarCut Tube Femto mechanics were adapted to the specific requirements for handling thin-walled, mechanically fragile semifinished products.

**Rofin**
**sales@rofin-baasel.co.uk**

## CMOS Camera

The VDS Vosskühler CMC-4000 camera can produce up to 200 images per second at a resolution of 2320 × 1726 pixels. The 4-megapixel high-speed CMOS camera's image rate can be increased considerably by decreasing the region of interest. It is equipped with a global shutter sensor that records all pixels simultaneously, enabling exact recording of fast-moving objects. The CMOS sensor with 10-bit analog-to-digital converters delivers noise-free images in connection with the camera's internal fixed-pattern noise correction. A digital output Camera Link interface is available.

**VDS**
**vds@vdsvossk.de**

## Camera Line Upgrade

SVS-Vistek GmbH has introduced upgraded models in its SVCam-HR camera line as well as two new models to the market, the svs8050 and svs4050 with dual GigE Vision interface, so the whole bandwidth of a four-tap CCD sensor can be used. The technology works in compliance with the convention of the link aggregation group. While the 8-megapixel 8050 version operates at up to 20 fps, the 4-megapixel 4050 model can achieve 39 fps. The two versions work with interline-CCD progressive-scan sensors from Kodak and are available in monochrome and color versions.

**SVS-Vistek**
**info@svs-vistek.com**

## Fiber Coupling

LIMO Lissotschenko Mikrooptik GmbH has released a concept with a single micro-optical element for beam shaping and fiber coupling of laser diode bars. The monolithic fiber optic,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which was tested with a 50-W laser mini-bar and 600-μm core, achieved a coupling efficiency of 90%. Additional advantages include reduced materials costs, compact design and just two optical surfaces, which are antireflection-coated. The device is suitable for mass production of high-power diode laser systems for cost-sensitive applications with limited brightness requirements.

**LIMO**
**k.reinecke@limo.de**

### CCD Microscopy Camera


The Infinity3-1U CCD microscopy camera from Lumenera Corp. is a USB 2.0 camera that offers large 6.45 × 6.45-μm pixels in a ⅔-in. format with maximum resolution of 1392 × 1040. Employing the Sony ICX285 1.4-megapixel CCD sensor, it is suitable for low-light applications such as fluorescence imaging as well as for bright-field mode. Its adaptability to various resolutions and frame rate requirements, combined with low noise and 8- or 12-bit-pixel data mode, makes it suitable for live- and fixed-cell imaging. Live video preview allows for real-time focus, while autoexposure and auto/manual white balance help capture the optimal image.

**Lumenera**
**info@lumenera.com**

### Autocollimator

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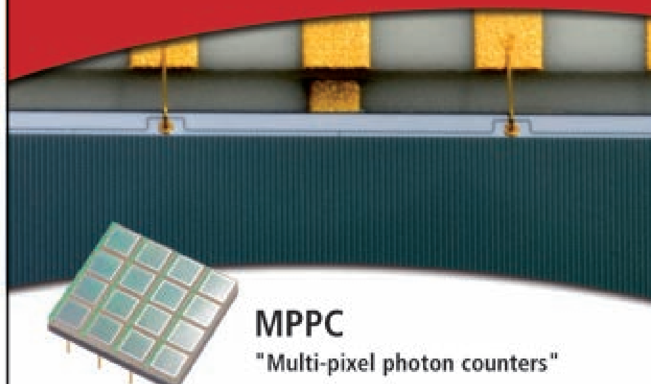

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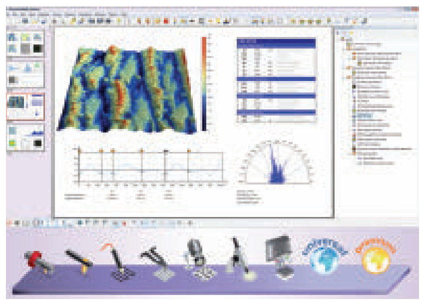
plications include adjustment and verification of the straightness of linear stages, run out measurement of rotary tables, measurement of large-area surface flatness, adjustment of optical components, stability studies, and alignment of machines and equipment. Each device is calibrated with PTB angle standards and supplied with test certificates and individual calibration curves. Traceability of the measuring results to international standards of the angle measuring variable is consistently ensured.

**Trioptics**
**info@trioptics.com**

## Surface Texture Analysis



Digital Surf SARL's MountainsMap 6 surface analysis software is based on its industry-standard Mountains Technology. It offers a powerful platform, enhanced interactivity, higher-quality imaging, advanced analysis features and more flexible report generation. The software is for tactile and optical scanning profilers, confocal laser scanning microscopes, white light interferometers, scanning probe and optical microscopes, and form and contour measurement systems. With native 64-bit code and optimal exploitation of multicore technology, it provides surface analysis power with accelerated calculations, and performs well with large measurement data sets and in advanced applications that require heavy processing.

**Digital Surf**
**contact@digitalsurf.fr**

## Benchtop Machine


Engis (UK) Ltd. has unveiled a benchtop four-way, double-sided lapping and polishing machine for research applications and short production runs in precision optical and small component manufacturing. The Engis 432 planetary machine is flexible, lapping most precision optics and advanced materials, including sapphire, GaN, SiC and other optical materials. It can be operated in unmanned mode, either timed or thickness-controlled, if required, while still maintaining its accuracy and repeatability. Despite its compact size, it can accommodate components measuring up to 55 mm in diameter, with 18-mm maximum thickness, making it able to produce a wide range of precision components. Available accessories include cast iron lap plates, stainless steel plates for pad polishing, composite metal diamond polishing plates, an abrasive lapping slurry pump and a diamond dispensing system.

**Engis**
**sales@engis.uk.com**

## Mass Spectrometer

A family of quadrupole mass spectrometers designed specifically for UHV/XHV performance is available from Hiden Analytical Ltd. Evolved from the company's 3F-series concept, the instruments incorporate triple-stage mass filter technology for optimum mass separation, ion transmission efficiency and contamination resistance. All systems feature the Windows-MASsoft Pro control program with multiparameter scanning. Ion detection is measured by fast pulse counting with continuous seven-decade scaling from 1 c/s to $1 \times 10^7$ c/s. Sampling rates exceed 500 measurements per second, with partial pressure detection down to $5 \times 10^{-15}$ mbar and trace level detection to 5 ppb. Applications include laser ablation, thermal desorption, molecular beam and general neutrals studies.

**Hiden Analytical**
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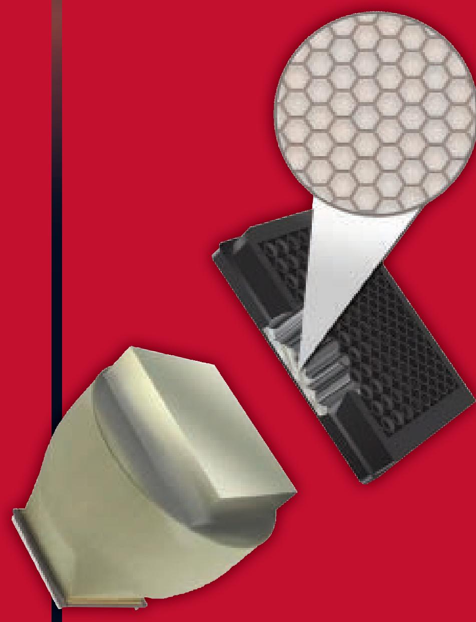

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