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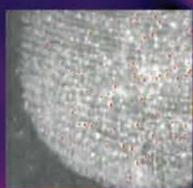

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newsbreaks

world news

columns

departments

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Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Subscribe

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features

Coming in March

Horizontal imaging through turbulence enables new applications of AO
Adaptive optics has a history of imaging stellar objects from the ground but has faced challenges when imaging horizontally through the atmosphere. Gleb Vdovin and colleagues at Flexible Optical (Rijswijk, the Netherlands) have developed a new approach using adaptable multiaperture imaging through turbulence on a horizontal atmospheric path.

Laser Focus World | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | Subscribe

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More Features, News & Products

trending now

Exclusive Feature: Sensor Fusion

AFM-IR characterizes photovoltaics at the nanoscale

The integration of atomic-force microscopy with nanoscale IR spectroscopy provides new insights into organic photovoltaic materials. *Michael Lo, Kevin Kjoller, and Roshan Shetty*
http://bit.ly/yCD23y

News: Science & Research

Anti-counterfeiting program uses DNA to uniquely code computer chips

The College of Nanoscale Science and Engineering of the University at Albany and Applied DNA Sciences (APDN) are partnering to enable nanotechnology to play a critical role in preventing the counterfeiting of computer chips. *Gail Overton*
http://bit.ly/wM0cLE

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cool content

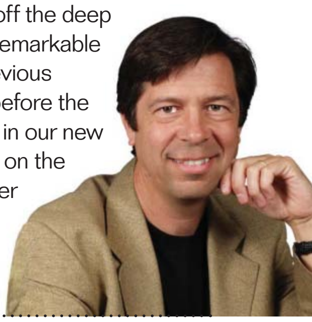
Blog: Science & Technology Education

OSA Foundation, Edmund Optics team to support student chapters

To encourage strong relationships between OSA Student Chapters and the corporate sector, the OSA Foundation (OSAF) created the "Adopt a Student Chapter Program." One participating company, Edmund Optics (EO), is providing financial support to four student chapters in China and India.
http://bit.ly/AfDG9i

Blog: Opto Insider

2011 is a record year for laser sales



Here's some good news as we weather the winter storms: 2011 was a record year for the laser industry, finishing over $7 billion for the first time ever. That's coming off the deep recession in 2009 and a remarkable recovery in 2010. The previous record was in 2007, just before the recession. This is just out in our new market report on the worldwide laser market.
http://bit.ly/zVOWuW

Blog: Larry's VC View

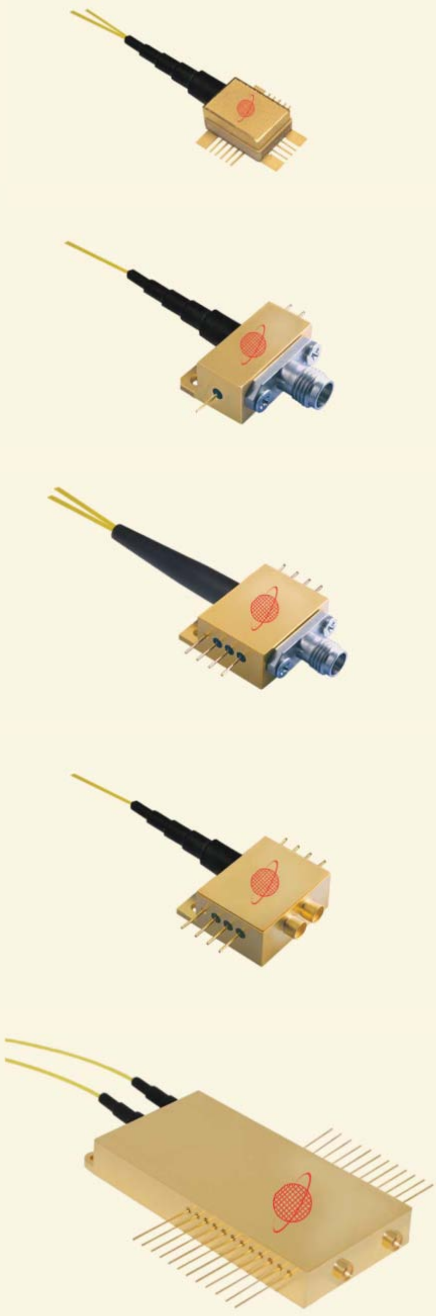
Cleantech

When I left Australia in the late '80s, "entrepreneur" was a dirty word; it had all manner of negative connotations. In Silicon Valley, I became a serial entrepreneur, which is even worse, and after six tech startups with two IPOs and four successful trade sales, in 2007 I was asked by an Aussie fund manager what my problem was and why I couldn't keep a job! http://bit.ly/ypOt7k

LaserFocusWorld Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Subscribe

New Era of Lab Buddy

Put any of these...



...in one of these...

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editor's desk

The limitations of time

Photonics West lived up to expectations for innovation, diversity, and enthusiasm. Held in San Francisco in late January (next year from February 2–7), the event attracted more than 20,000 attendees. Coverage of the technical sessions, events, and new products can be found in next month's issue and online now (www.laserfocusworld.com) in the form of articles, blogs, and videos.

Spectroscopy was a tool referenced in all five Photonics West symposia—BiOS, LASE, OPTO, MOEMMEMS, and Green Photonics—and it's a tool found as well in many articles this issue. For example, in her feature on photonics in forensics (see page 54), senior editor Gail Overton describes how Raman spectroscopy can definitively analyze diluted bodily fluids without destroying the samples or requiring hazardous chemicals.

For more examples, see the article by contributing editor Jeff Hecht on how improved high-harmonic-generation techniques have extended frequency-comb spectroscopy into the extreme UV (see page 44). Or read the feature by Baylor University's Jonathan Hu and MIRTHE director Clare Gmachl on how quantum-cascade lasers can be used in spectroscopy techniques for medical diagnostics and environmental monitoring (see page 39). Finally, the feature by Neil Anderson and Ramin Lalezari from IDEX Optics & Photonics describes how high-reflectivity, low-loss mirrors enable applications such as detecting and quantifying chemical species at part-per-billion levels with cavity ring-down spectroscopy (see page 48).

Describing these few spectroscopy-related articles does not do justice to the variety of optical technologies, products, and applications covered in this issue. It's a bit like attending a good trade show: Everything you can get to see is very interesting yet there's an impossibly short time in which to see it all.

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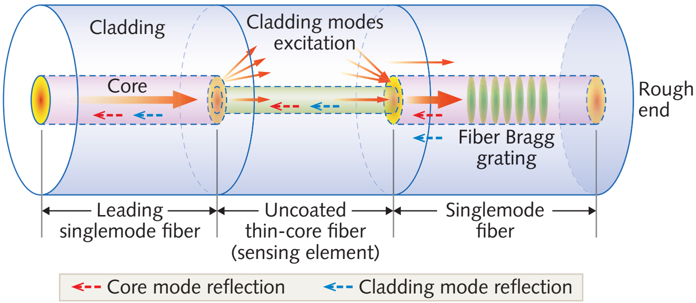
newsbreaks

Fiber-optic refractometer shows promise for measuring biological SRI



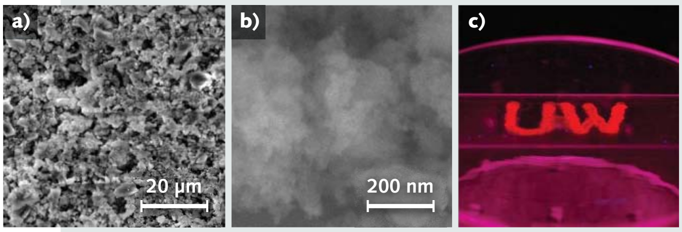
A reflective fiber-optic refractometer with a thin-core fiber (TCF) section achieves a sensitivity of 133/26 dB/refractive-index unit for temperature immune surrounding-refractive-index (SRI) measurement. The device has potential for measurement of biological samples, which have refractive indices ranging from about 1.33 to 1.41. Developed by researchers at Northwest University (Xi'an, China) and Jinan University (Guangzhou, China), the refractometer can also potentially measure temperature as well as SRI.

A 10 mm section of TCF is connected on one end to a standard single-mode fiber (SMF), and on the other end to a fiber stub containing a fiber-Bragg grating (FBG). Incoming core-mode light in the SMF excites both core and cladding modes in the TCF due to the mismatch in core diameters. A strong evanescent field on the outer surface of the TCF interacts with the surrounding medium under test. The resulting cladding modes enter both the core and cladding of the FBG. Upon reflection and propagation back along the SMF, an irregular waveband structure with wavelengths shifted due to the SRI modifies the power of the reflected core mode; monitoring the power variation of the core reflection at a given wavelength produces the SRI measurement. Simultaneous wavelength and power detection would enable temperature measurements, too. *Contact Yue Ma at* yuemanwu@gmail.com.

Bright red phosphor is based on silicon quantum dots

A group at the University of Washington (Seattle, WA) has demonstrated phosphors based on silicon (Si) quantum dots (QDs) that are efficient emitters (with an external quantum efficiency up to 15.9%), can be made to have a peak wavelength that falls anywhere from the near-IR to the green, and can be fabricated cheaply. The phosphors, which are stable at room temperature due to an oxide passivating shell, are nontoxic—unlike otherwise useful conventional QD phosphors based on II-VI semiconductors like cadmium selenide, cadmium zinc selenide, or cadmium zinc sulfide.

Electrochemical etching of a Si wafer produces Si microparticles with attached QDs; these particles are dispersed in ethanol and can be made to react with alkoxysilanes to form a suspension in nonpolar *Cont. on page 10*



Algorithm is faster than FFT for all sparse signals

Being able to compute the Fourier transform of an input signal is crucial in photonics—for example, in determining the spatial frequencies in an image. The standard method of computing a discrete Fourier transform (DFT) is by using the fast Fourier transform (FFT) algorithm. However, algorithms faster than the FFT would be desirable. Researchers at the Massachusetts Institute of technology (Cambridge, MA) have developed two algorithms that are faster than the FFT for all sparse signals. (A sparse signal is one in which some of its Fourier coefficients are near enough to zero that they can be ignored.) While other algorithms have previously been developed to improve on the FFT for sparse signals, none of them have improved on the FFT's runtime for the whole range of sparse signals.

For a signal with k nonzero Fourier coefficients, and a length n of the input signal that is a power of 2, the researchers show two new DFT algorithms. The first is an $O(k \log n)$-time algorithm for the exactly k-sparse case (where k is small). (O means "on the order of.") The second is an $O(k \log n \log(n/k))$-time algorithm for the general case. In contrast, the FFT computes the DFT in $O(n \log n)$ time. *Contact Haitham Hassanieh at* haithamh@mit.edu.

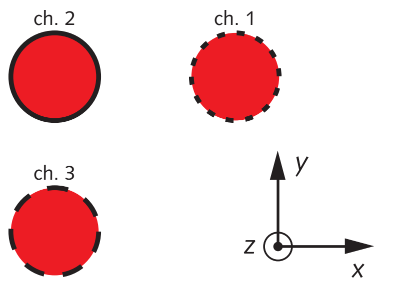
Laser Focus World | Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page | Subscribe

newsbreaks

Cont. from page 9 solvents for further processing. The red-emitting version of the phosphor has a broadband excitation band with a 70% excitation efficiency between 345 and 475 nm—a good match for blue- and violet-emitting gallium nitride-based LEDs (the figure shows excitation at 365 nm). The red phosphor in solvent can be formed into thin films by drop-casting or spin-coating. Scanning-electron micrographs of the films show micron- and submicron-sized clusters. Such red phosphors are needed to improve the color rendition of white LEDs. *Contact Chang-Ching Tu at* tucc@u.washington.edu.

Slow-light lidar scans independently in two dimensions

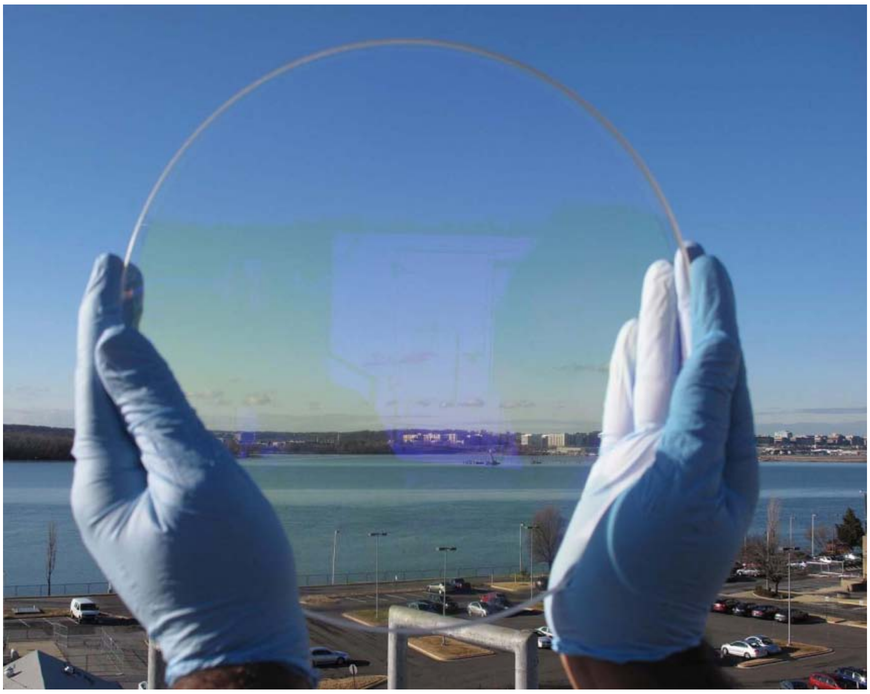
Researchers from the University of Rochester (Rochester, NY) and the University of Ottawa (Ottawa, ON, Canada) who had previously demonstrated the one-dimensional (1D) steering of a lidar beam using slow light have now used two independent slow-light mechanisms to steer a lidar beam in two



dimensions. Their previous system had used dispersive delay for 1D steering; to this, they have now added stimulated Brillouin scattering (SBS) for steering in the orthogonal dimension.

The original 1D system had three apertures (channels) in a row; the 2D system has three channels also, but arranged in an L shape. (These *Cont. on page 11*

Transparent ceramic suits high-energy laser systems



Unlike fused silica and oxyfluoride glasses that cannot survive in some harsh environments, a new transparent ceramic for high-energy laser (HEL) systems developed at the US Naval Research Laboratory (NRL; Washington, DC) can withstand impact from rain droplets at 600 mph and sand particles at speeds up to 460 mph with no change in transmission parameters.

The transparent magnesium aluminate spinel ($MgAl_2O_4$) ceramic, developed as a window and dome material for protecting sensors operating from the UV to the mid-IR region to 5 μm, was designed with optimized low absorption loss of 6 ppm/cm to minimize the beam distortions and loss of output power that are measured as optical-path distortions in HEL systems. The ceramic spinel was made by hot-pressing ball-milled spinel powders at 1400-1650 °C for 2–4 hours using a uniform coating of a small amount of lithium fluoride sintering aid that was eliminated by evaporation prior to full densification. The NRL spinel powder (synthesized by an aqueous process) had crystallites 100–200 nm in size with excellent phase purity based on x-ray diffraction and chemical analysis, with an impurity content several orders of magnitude lower than commercially available spinel powders. *Contact Jas Sanghera at* jas.sanghera@nrl.navy.mil.

Cont. from page 10 are first prototypes; later versions can have many more channels.) The SBS generator includes 3.3 km of dispersion-shifted fiber (DSF) with a 10.5 GHz Brillouin frequency shift. An SBS slow-light module consists of 2.2 km of DSF with a counterpropagating pump field. Controlling the power of the pump field tunes the delay. Tests showed precise phase-locking among all three channels; simulated steering in the *x* and *y* directions applied by translation stages were independently compensated by the two delay mechanisms. *Contact Zhimin Shi at* zshi@optics.rochester.edu.

world news

light in slow motion
See page 16

Technical advances from around the globe

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QUANTUM PHYSICS

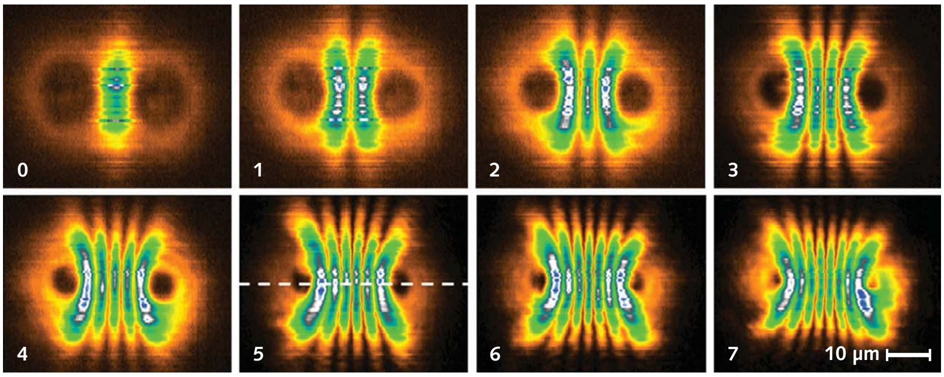
Semiconductor chip converts laser to visible quantum fluid

University of Cambridge (Cambridge, England) researchers can see quantum mechanics at work with the naked eye. They have developed a semiconductor chip that tightly traps laser light in the vicinity of electrons inside microscopic cavities, producing polaritons—quasi-particles created by mixing semiconductor excitons with microcavity photons—that enable direct visualization of quantum states of light.[1]

Superfluidity

The 1 × 10 cm chip consists of a 5λ/2 period aluminum gallium arsenide (AlGaAs) distributed Bragg reflector (DBR) microcavity with four sets of three quantum wells placed at the antinodes of the DBR cavity electric field. The cavity quality factor Q exceeds 8000, and illumination from the two pump lasers is chopped at 100 Hz to avoid heating and input directly to the chip through a 0.7 numerical-aperture lens. The chip is held at cryogenic temperatures below 50 K, and images are recorded on an uncooled silicon CCD in a magnified image plane.

When the semiconductor chip is illuminated with two or more 1-μm-diameter spots of pump-laser light at 750 nm, two-dimensional polariton condensates form a spontaneously oscillating quantum fluid that allows visualization of quantum mechanics in action. The effects are possible because the polaritons, which Bose-condense above a certain threshold, feel an outward force and form an expanding polariton condensate that interacts with the opposing condensate from the other pump spot.



Interfering polariton condensates induced from two pump-laser beams input to a semiconductor microcavity produce oscillating quantum states of laser light as the spacing between pump spots is varied. Each image shows a different quantum state directly.

Naked-eye visibility

As the two polariton (quasi-particle) condensates interact, the interference effects differ depending on the pump intensity and the spacing between the two (or more) pump sources on the chip. On the line between pump spots, the polaritons experience a potential that causes them to redistribute as if trapped in a simple harmonic oscillator, occupying different oscillator states as the spacing between pump spots is varied (see figure).

The sloshing of coherent polaritons back and forth at tunable terahertz frequencies is visualized using time-delayed interferometric combination of images of the superfluid quantum states.

"Controlling the motion and better understanding the behavior—and quantum-mechanical entanglement—of this quantum fluid could lead to a new generation of ultrasensitive gyroscopes to measure gravity, magnetic fields, and create quantum circuits," says postdoc member Gabriel Christmann at the University of Cambridge. "It is amazing to see quantum mechanics in front of your eyes on this macroscopic scale as big as a human hair." —*Gail Overton*

REFERENCE

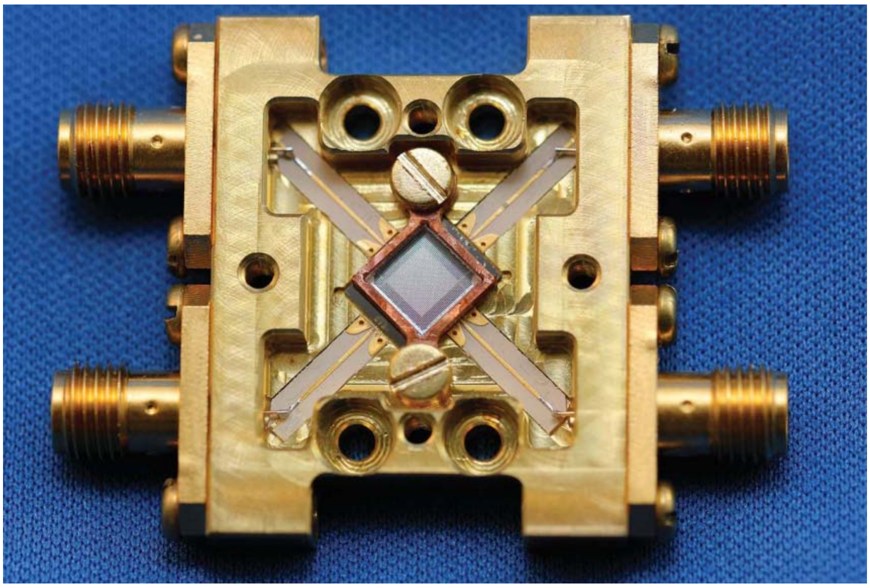
1. G. Tosi et al., *Nature Phys.* online (Jan. 10, 2012); doi:10.1038/nphys2182.

ASTRONOMY

Superconducting focal-plane array spans UV to near-IR

A superconducting array of cryogenic microwave kinetic inductance detectors (MKIDs) is the basis of a photon-counting focal-plane array developed by researchers at the University of California–Santa Barbara (UCSB) and the NASA Jet Propulsion Laboratory (JPL; Pasadena, CA) that operates from the UV to the near-IR.[1] Because the MKID arrays have virtually no false photon counts and can determine the time of incidence and approximate wavelength of the photons it receives, the researchers believe the array could replace most semiconductor detectors (such as CCDs) for use in astronomical imaging.

In an MKID, an incident photon changes the surface impedance of a superconductor in a resonator; the photon



A superconducting array of microwave kinetic inductance detectors (MKIDs) is mounted in a gold-plated copper box (shown); a square array of circular microlenses (at center) focuses incoming light onto the individual detectors. The entire structure is cooled in a dilution refrigerator to about 100 mK. (*Courtesy of UCSB*) changes the phase and amplitude of a microwave probe signal tuned near the resonant frequency. Each pixel in the MKID array is fabricated to tune to a different frequency; all signals from different pixels can be separately recovered with little crosstalk by using a frequency comb of probe signals.

32 × 32 superconducting pixels

The researchers created an optical lumped element (OLE) design in which the resonator consists of a 20 nm substoichiometric titanium nitride (TiN) film with a superconducting transition temperature of about 800 mK. Two feedlines that read out the array each serve 512 resonators, which have resonant frequencies in the 4–5 GHz band and are separated from each other by 2 MHz. A "double meander" inductor design precisely cancels out the electric fields from the electrical charges in the sections of the meander.

A rectangular array of circular microlenses with a 100 μm spacing (see figure) focuses the light onto the superconductor with a fill factor of 67% (square lens elements would boost this to at least 95%). Shape optimizations such as tapered resonators ensure uniform responsivity to photons across the resonator. A microwave high-electron-mobility transistor (HEMT) with a 4 K noise temperature amplifies the signal.

For a first experiment, the resonators were illuminated by light at a 254 nm wavelength from a mercury-vapor lamp. The pulse from a single photon has a fall time of about 50 μs, limiting the maximum count per pixel to about 2000 counts/s. The dominant noise source was the HEMT amplifier; reduction of the amplifier noise temperature to something below 4 K should improve the energy resolution.

In a typical 32 × 32 pixel device, about 85% of the resonators were usable, due to fabrication errors causing nonuniformities in the thickness of the TiN film and overlapping resonator frequencies. Future improvements in fabrication will reduce the numbers of overlapping resonator frequencies. Quantum efficiency as a function of wavelength was gauged by measuring the reflection and transmission of a 40 nm TiN film as a function of wavelength with a spectrometer to determine the fraction of photons absorbed in the superconducting film. The approximate measurement (which ignores losses such as due to the microlens array) showed that quantum efficiency approached 80% at 200 nm but dipped to about 30% at 1 μm. —*John Wallace*

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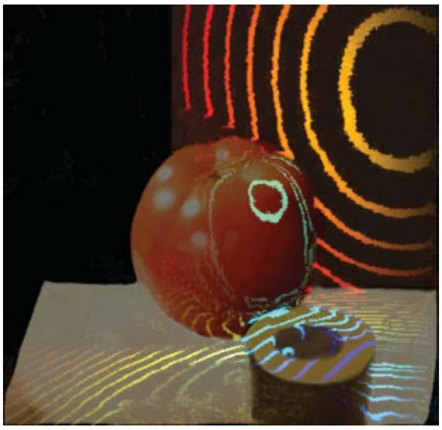
1. B.A. Mazin et al., *Opt. Exp.*, 20, 2, 1503 (Jan. 16, 2012).

HIGH-SPEED CAMERAS

Trillion fps visualizations image light in slow motion

Researchers at the Massachusetts Institute of Technology (MIT; Cambridge MA) Media Lab have developed a variety of streak camera that can be used to create trillion frame/s visualizations—slowing down and capturing even the motion of speed-of-light photons.[1]



The spherical front of a light pulse illuminates a tomato and a roll of tape. The colored bands represent the pulse as it travels over time during a movie, with each band separated by approximately 20 ps.

For most high-speed time-of-flight and gated intensified CCD or ICCD imaging techniques used for light detection and ranging (lidar) and other ultrafast molecular imaging applications, the data revealed are typically depth-of-field or depth imaging data. The MIT Media Lab technique instead uses the two-dimensional (2D) narrow aperture of a streak camera to capture one-dimensional (1D) spatial information corresponding to the direction of the slit, and in the second dimension corresponding to the degree of deflection, to capture time information.

Ultrafast enablers

Enabled by ultrafast sources, detectors, and optical systems, the modified streak camera captures images that are used to reconstruct a full 2D movie at a resolution of 672 × 1000 pixels at a speed of about 0.5×10^{12} frames/s (2 ps time resolution).

A 795 nm, 600 mW ultrafast Ti:sapphire laser delivers 50 fs pulses at a repetition rate of 75 MHz to the scene. A small fraction of the beam is split off with a glass slide to synchronize the photodetector with the Hamamatsu C5680 streak camera, which has a time resolution of 512 samples over a 1 ns duration and a 1D field of view with a spatial resolution of 672 pixels.

Because the streak camera provides only the temporal evolution of a line in the scene (a 1D movie), a mirror system scans the field of view of the camera across the scene to capture a series of images—up to 1000 images over a two-hour period—to create a 2D movie since the laser and camera are synchronized.

"We call this 'the world's slowest fastest camera' because it takes about an hour to collect all the data for a nanosecond-long video," says MIT Media Lab associate professor Ramesh Raskar. "However, the camera enables the exploration of ultrafast phenomena such as the propagation of light in anisotropic media and photonic crystals, and could be used in materials-analysis applications to detect embedded defects or to analyze materials in a scene without entering the scene, for example."

Trillion frame/s movies

Using the ultrafast trillion frame/s setup, one of the movies developed by the researchers shows a pulse of light as it transits a soda bottle filled with water (see http://youtu.be/EtsXgODHMWk), showing multibounce light transport and subsurface scattering.

In another video, a tomato and a roll of tape are imaged as a pulse of light energizes the scene (see figure and video at http://youtu.be/P-HqKjBgLPM). The pulse is reflected by a diffusely scattering surface on the right side of the scene to create a virtual light source, emerging as a spherical pulse front. As the pulse moves across the scene from left to right, some stray light first hits the tomato. After striking the diffuser, light floods the scene.

Indirectly illuminated parts of the scene (top of the tomato and inside the roll of tape) are not reached by the first direct wave of light, but only light up later as indirect light from the scattered wave reaches them. Shadows are visible after illumination, and the direct light that hits the back wall of the scene is reflected back toward the tomato and is trapped under the skin of the tomato due to subsurface scattering, where it glows for a while as the light fades. —*Gail Overton*

REFERENCE

1. L. Hardesty, "Trillion-frame-per-second video," MIT News Office, http://web.mit.edu/newsoffice/2011/trillion-fps-camera-1213.html (Dec. 13, 2011).

LASER LIGHT SHOWS

Blue lasers launch BMW's 'green' cars

To officially launch its i-series of high-efficiency, environmentally friendly automobiles at the Frankfurt International Motor Show IAA, BMW used the services of Lobo (Aalen, Germany), a laser light-show company, to create effects that included a "birthing tunnel" of blue laser light. In keeping with the "green" theme of the launch, Lobo used energy-efficient optically pumped semiconductor laser (OPSL) technology in the show.

A pre-launch for press and industry insiders was held two months before show opening. The launch was conceived by the BlueScope agency (Berlin) and managed by Rockservice (Salzgitter, Germany). The overarching concept was to unveil each of the cars through a birthing tunnel formed of light. The pre-launch presentation included other effects also, such as moving laser patterns and sheets of light that hid all areas of BMW's large exhibition area that were not intended for the public viewing at that time. The lasers were also used to create a roof of light over the entire BMW exhibition, covering all of Hall 11.0 at the Exhibition Center in Frankfurt.

The laser birthing canal and other effects were created using nine of Lobo's Sparks laser light engines, based on OPSL laser heads made by Coherent (Santa Clara, CA), resulting in a total output power of more than 150 W. "In addition to fulfilling the creative concept created by Bluescope, this unique laser display had to fulfill three other important prerequisites," says Alex Hennig, Lobo's creative director. "We had to exactly match BMW's corporate blue color, we had to do this with a small carbon footprint congruent with the

world news

whole concept of these i-series cars, and we had to provide a visually bright yet eye-safe display."

Two blue wavelengths for precise color control

Exactly matching BMW's corporate blue was a particularly interesting challenge, says Hennig. "Color is actually a human perception and one that varies depending on the location, background

Blue laser light forms a "birthing tunnel" that highlights a BMW high-efficiency i-series car. In keeping with the theme of energy efficiency, optically pumped semiconductor lasers (OPSLs) were used to create the light tunnel and other effects. (*Courtesy of BMW*) lighting, and other factors," he notes. "So we had to be able to tweak this on site to match the way other blue light components of the BMW display appeared in the actual show setting." To do this, Hennig used modified RGB Sparks engines that incorporated two blue lasers, rather than a single laser. These were Coherent Taipan lasers emitting at 460 and 488 nm. This enabled more complete and subtle control over the final blue output than would be possible just using a standard red-green-blue setup.

The lasers' small carbon footprint results from their diode-pumped solid-state nature; in addition, there is no internal requirement for tightly matching the diode output wavelength used to pump the OPSL's semiconductor gain chip, thus eliminating the power required to closely control the diode operating temperature.

Sparks laser projectors also deliver the industry's brightest laser effects for a given power level for two reasons. First, OPSL heads already deliver superior beam quality, enabling low divergence projection of beams and images. The Sparks laser projectors use Lobo's post-collimated scanning (PCS) system, which lowers beam divergence by a factor of three, according to Lobo. This helped to enable a bright display having the minimum possible carbon footprint for its size. *—John Wallace*

OPTICAL DATA STORAGE

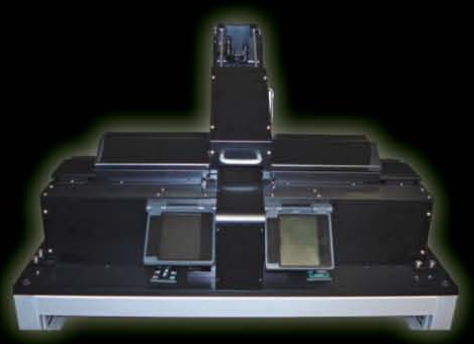
Holographic data storage uses volumetric crystal media

Access Optical Networks (AON; Monmouth Junction, NJ) has developed several technologies for holographic data storage (HDS) with write-only, read-only, and rewrite capability in a volumetric crystal media. The new nonvolatile-memory HDS products are designed to have a storage density of 1.2 terabytes (Tbytes), with read/rewrite performance of 1 Gbit/s. The company is currently seeking partners to commercialize the HDS products, which will initially target cloud computing, high-performance computing, enterprise, and solid-state device applications.

Volumetric storage

In the AON HDS method, an optical signal from a coherent laser source is split into separate data and reference beams that travel two separate paths before they are directed into a volumetric storage medium. A proprietary device placed in the reference beam serves to control its phase, enabling on/off switching, hologram writing, and erasure. A second proprietary device enables rapid addressing to a selected multiplexed angle when writing and also later, when searching and accessing an individual hologram. All holograms are stored near 90° for greatest diffraction efficiency. Finally, the data beam is reflected from the individual micromirror surfaces of a microelectromechanical-systems (MEMS)-type spatial light modulator (SLM) that transports the information to be stored into the photorefractive crystalline material.


LIGHT YEARS AHEAD



Principal advantages of the AON method include volume rather than surface holographic storage, with greater than an order-of-magnitude layer depth in the storage medium compared to holographic disks; angle multiplexing of a large number of holograms within a 1-cm-cube crystalline medium to store more than 1 Tbyte of data; selective erasure of portions of individually stored holograms by external computer control—essential for data storage applications; and scalability to >10 Tbyte density and read/rewrite performance exceeding 10 Gbit/s while concurrently reducing the form factor and power requirement compared to conventional optical storage methods.

AON is currently storing digitized parallel data in rectangular 1000 × 1000 (1 million) arrays within the crystal volume and using the latest CMOS camera readout methods. This parallel recording and readout of a million bits at a time enables the rapid data-transfer rates in holographic storage. And the ability to multiplex or superimpose images throughout the volume enables the enormous storage-density capabilities of holographic storage.

MEMS-enabled storage

To date, most HDS manufacturers such as General Electric (GE; Fairfield, CT) and InPhase Technologies (Longmont, CO) have focused on spindle disk media. In addition to being slow write and read devices, these are also write-once-read-many (WORM)

Holographic data storage using volumetric crystals has some significant advantages compared to other methods

Attribute	AON HDS	Tapestry	Blue laser optical*	Data tape	Hard disk	Video tape
Capacity roadmap	1.2–9.6 Tbyte	300 Gbyte–1.6 Tbyte	15–100 Gbyte	100 Gbyte–1.6 Tbyte	18 Gbyte–1.5 Tbyte	1–251 Gbyte
Transfer rate roadmap	155–1240 Mbyte/s	20–120 Mbyte/s	4–12 Mbyte/s	20–120 Mbyte/s	40–150 Mbyte/s	3–25 Mbyte/s
Media archive life	Permanent	50 years	20 years	7–10 years	5 years	7 years
Low media price	\$0.11–0.83/Gbyte**	\$0.06–0.20/Gbyte	\$1.00/Gbyte	\$0.25–1.00/Gbyte	\$3.00/Gbyte	\$1.00–3.00/Gbyte
Media handling issues	Operates up to 300 K temperature; radiation hardened	Office environment	Office environment	Temperature and relative humidity control needed	Must spin-up drive periodically	Temperature and relative humidity control needed
Physical WORM	No	Yes	Yes	No	No	No
Random access	Yes	Yes	Yes	No	Yes	No
Head contact on write/read	No	No	No	Yes	Yes	Yes
Hardware security features	Optical encryption	Optical encryption	None	None	Yes	None

Notes: AON HDS = Access Optical Networks holographic data storage
Tapestry = Holographic media from InPhase Technologies
* Blu-ray, HD DVD, UDO; source IDC
** Lithium niobate crystals' volume pricing = \$1000/unit
WORM = Write once read many

devices with limited market applications. The advantage of the spindle disk approach was to benefit from the existing mechanical architecture and infrastructure. Another advantage included the ability to use low-power lasers because of the relatively thin disk media. However, HDS in volumetric crystal media can scale performance by more than an order of magnitude beyond the most competitive spindle-disk-media-based electronic nonvolatile storage solution available today (see table).

Success of the AON HDS system is possible thanks to the availability of enabling MEMS devices, including high-reflectivity SLMs that can paginate a small-form-factor, continuous-wave laser beam with high fidelity, speed, and accuracy, producing multilevel grayscale-encoded holographic images within volumetric crystal media.

The AON HDS system incorporates a 90° geometry angle multiplexing optical signal-processing technology that increases data rate and recording density. The method is designed to record and uniquely address a large number of data pages composed of clusters and sectors. The selective erase enables the rewriting of previously used data-storage locations in the storage media. And the 90° geometry angle multiplexing enables faster data access, eliminating the latency and seek time associated with spindle disk media. In addition, the low-mass MEMS devices provide higher reliability with less susceptibility to shock and vibration.

"We are currently seeking strategic partners to collaborate in completing the development of our holographic data-storage technologies," says Glenn Gladney, president and CEO of AON. "Our products offer a 300 K radiation-hardened storage medium that can be clean-erased in minutes." —*Gail Overton*

BusinessForum

Co-investments and conceptual businesses

MILTON CHANG

Q *We are a €20 million venture fund in Eastern Europe. Would you be willing to introduce us to American VCs who are interested in co-investing with us, both here and in the US?*

A Sure. I will keep my ear to the ground for you. I am sure there are funds that are willing to accept additional capital and also to bring others on board to co-invest. After all, the laser/photonics industry can use additional seed capital! Outside of some really big firms, most of the funds in the US would only invest locally, choosing those within easy reach. I believe few if any US funds are willing to invest in faraway places that are outside of their control.

Q *The concept of starting with a prototype business you described makes sense. How would this apply to a photonics startup?*

A Starting a photonics business using this prototype approach makes perfect sense because ours is not being viewed as a hot industry that has investors flocking to it. A venture capitalist can be more easily convinced to make a modest investment to get their foot in the door for a potentially big opportunity. Starting with a simple business also allows a technical founder who has no prior business experience to learn and prove that he or she has the aptitude to run a full-fledged business.

Now let me remind our readers what is involved in "prototyping" a business.

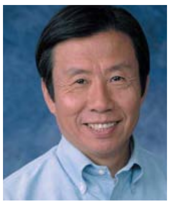
Many conventional startups are geared up from day one to build out the company as if the business will develop strictly in accordance with the business plan. That involves hiring a full senior executive team, building out the facility, and implementing the necessary operational infrastructure to run a substantial business. The catch is that most business plans tend to be overly optimistic. Business may not develop as quickly while senior executives would continue to spend in the meantime, sometimes creating work to keep busy.

It is easy for an entrepreneur to take this approach in their eagerness to build out the business quickly, and to forget the first principle of entrepreneurship: Create the maximum possible value with a given amount of capital; or simply put, spend wisely to achieve capital efficiency.

A more sensible approach is how we engineers are taught to manage a product development project: First, complete a prototype and work through all the manufacturing processes before committing to volume production. I coined the term "prototype business" in my book to draw an analogy that would remind entrepreneurs to do likewise before committing to a big investment in building out the company. So spend *as little as possible* to validate assumptions and the business model before making the logical next move. What you actually do to prototype the business is different for each business, and is based on your judgment call. Getting a few orders shipped to respectable customers is always the best move; getting potential customers to express genuine interest is a distant second.

Your options are wide open when you have the beginnings of a real business. You can raise money at an attractive valuation to grow fast, modify your business model, or even choose to abandon the project. You may also become an attractive acquisition target.

What about having first mover advantage? I was struck by the recent announcement that Johnson & Johnson is getting out the coronary stent business it pioneered. How can that be, given that J&J is a health care and pharmaceutical behemoth? It proves that being the first mover does not always provide an advantage, considering pioneers get arrows in their backs. It is true that first developing the business prototype actually slows you down, but doing it properly can avoid haste-makes-waste mistakes. But you certainly do want to put in place an intellectual property (IP) strategy to avoid being shut out of the market by blocking patents.



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Wavelength stabilization improves laser diode efficiency and brightness

KENDRA GALLUP, WENTAO HU, ROBERT LAMMERT, and **JEFFREY UNGAR**

On-chip wavelength stabilization technology for high-power laser diodes operating between 700 and 2000 nm brings an accurate and narrow spectral width that is locked over a wide temperature range, enabling new laser diode applications.

In his keynote address to the 1991 Diode Laser Technology Program conference in Washington, DC, the nuclear physicist Edward Teller famously asserted, "No one should use a laser unless it's a diode laser." Those of us who hail from the laser diode manufacturing industry will wholeheartedly endorse that statement, but even less biased observers will admit that there is considerable truth to what he said: Compared to other near-infrared (NIR) lasers, diodes are by a wide margin unsurpassed as efficient, low cost, compact, and rugged sources of radiation. Technological advances over the last two decades have more than substantiated Teller's statement.

Because of these attractive features, diodes have carved out dominant positions in many laser applications. The market for laser diodes exceeds all other lasers combined, and it is a fair statement to say that the largest laser applications such as fiber-optic telecommunications and optical data storage—each of which is a multibillion-dollar per year market—would not exist at all without the laser diode.

In the interest of fairness, however, it must be admitted that laser diodes cannot do everything, and in two respects their performance lags behind other laser sources. The first deficiency is beam quality at high power. Above 1 or 2 W, commercial laser diodes do not provide diffraction-limited beams. And second, high-power diodes cannot match the brightness generated by their fiber, solid-state, and carbon-dioxide (CO_2) laser brethren. But diode brightness is improving rapidly, and a time in the not very distant future can be foreseen where direct diodes will be used even for demanding applications such as keyhole welding. For the time being, however, the lower brightness of diodes shuts them out of most materials processing applications, and they are confined to uses such as plastic welding and heat treatment.

Spectral properties of laser diodes

For applications such as pumping of solid-state or fiber lasers, diode beam quality is adequate. A more serious issue is the output spectra, which for diodes are broader and less stable than other lasers.

The difference in spectra of diodes compared to other lasers has its origin in fundamental physics, which is best illustrated by comparing diodes to a typical solid-state laser. The active crystal of an Nd:YAG laser is lightly doped, with 99% of the crystal taken up by the passive YAG host, and only a small fraction by the active Nd ion, Nd^{+3}. The Nd ions are on average spaced many atomic diameters from one another, and there is negligible overlap between their electron clouds. Broadening mechanisms such as host-crystal field Stark splitting do broaden the spectrum of each ion, but by and large the overall gain spectrum—and the laser output as well—reflects the narrow gain profile of the individual ion.

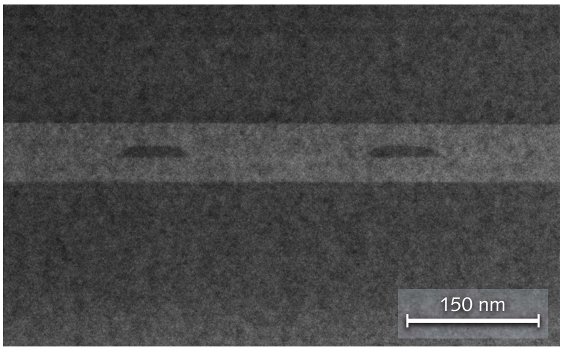

FIGURE 1. A transmission electron micrograph shows the Brightlock monolithic diffraction-grating spectral control layer within a high-power laser diode.

Laser diodes are fundamentally different. Gain is not generated by widely spaced atoms that are guests in a host crystal, but by the crystal as a whole. The semiconductor atoms the crystal comprises are nearest neighbors whose electronic states are so strongly overlapped that they lose their individual identity completely. Because of the Pauli principle, the individual energy levels broaden into energy bands.

Diodes, therefore, have very broad gain spectra, with spectral widths that are defined by Boltzmann-statistical thermal energy scales (typically 20 nm or so in the NIR) that are many orders-of-magnitude wider than solid-state lasers, and the gain spectrum changes with temperature due to crystal lattice-electronic state interactions.

As a result, laser diodes simultaneously oscillate in a large number of modes spread out over a wide range of frequencies. Multimode diode spectra are typically 1–3 nm wide and vary with temperature at a rate of 0.35 nm/°C for diodes emitting from 800 to 1000 nm. These numbers increase to 15–20 nm widths and >0.5 nm/°C temperature variations at 1400 nm and beyond. Moreover, peak wavelengths are poorly defined, and center wavelength manufacturing tolerances range from ±3 nm at shorter wavelengths to as much as ±10 nm at longer wavelengths.

For example, for Nd:YAG pumped lasers at 808 nm or fiber lasers pumped at 915 nm, the absorption lines are wide enough to make the broad emission spectrum of diodes a relatively minor issue. However, as demands on performance grow, attention is increasingly focusing on newer pump bands such as 880 nm in Nd for higher efficiency and beam quality, 976 nm for low-phase-noise ytterbium (Yb) fiber amplifiers, and 1532 nm for eye-safe erbium (Er) lasers. These lasers require accurately defined, well controlled, narrow linewidth pump sources that exceed the capabilities of standard diodes and arrays.

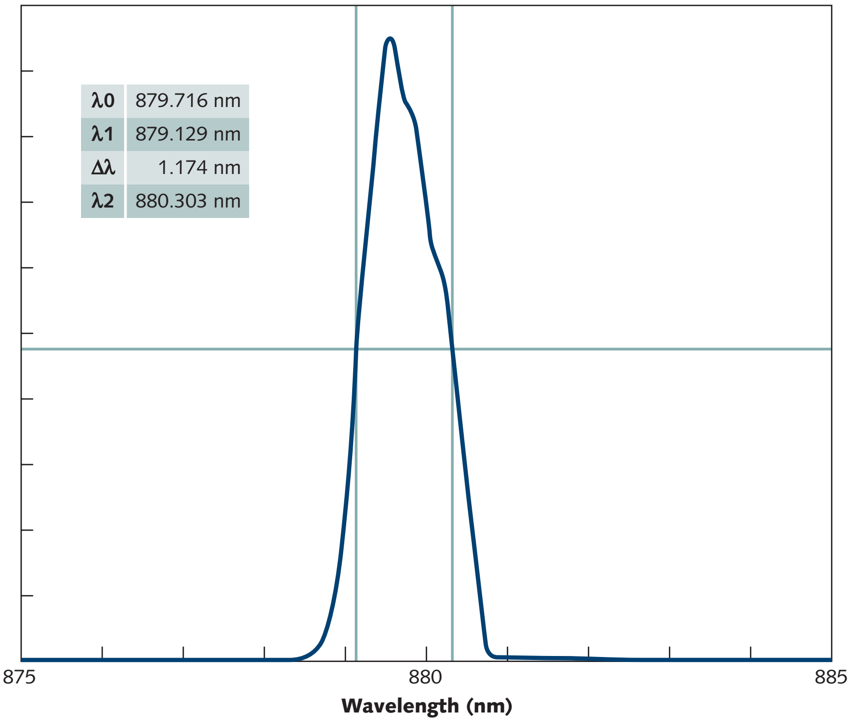

FIGURE 2. The output spectrum of a Brightlock 365 W fiber-coupled laser diode module at 880 nm is narrow, accurately defined, and well controlled by the internal grating, making it ideal for pumping neodymium materials.

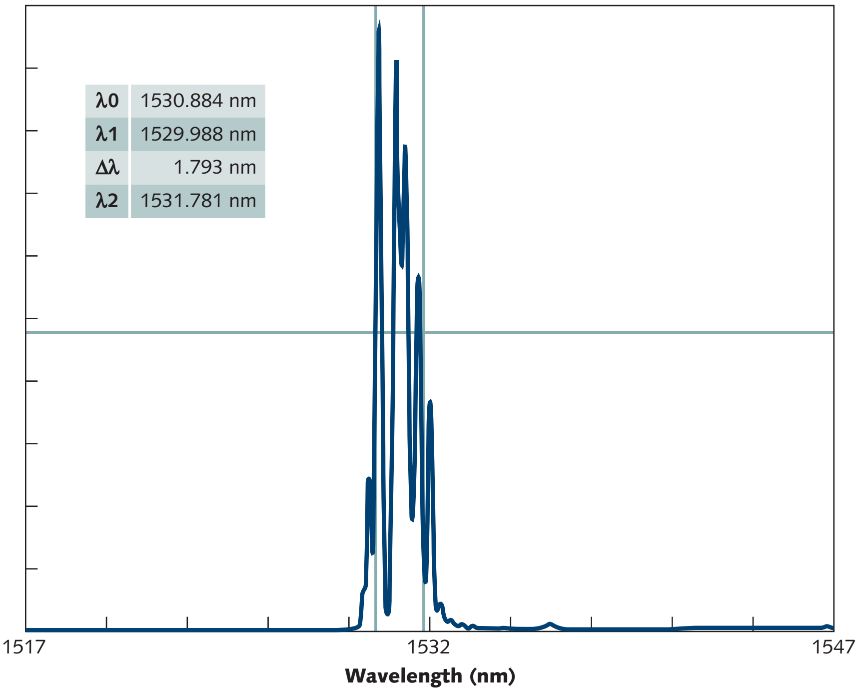

FIGURE 3. The output spectrum is shown for a 26 W, 105-μm-core (0.15 NA) fiber-coupled pump module for erbium pumping.

Controlling spectra with internal gratings

Narrowband optical feedback from an external diffraction grating can narrow and stabilize the spectrum of laser diodes. This technique has long been used to narrow the linewidth of single-emitter diodes, and with the advent of volume Bragg gratings (VBGs), stabilized arrays and fiber-coupled modules have become commercially available.

For VBG-stabilized diodes, expense is a consideration because of grating cost and the labor to individually actively align each bar to its grating. Locking efficiency and spectrum are sensitive to the optical alignment between diode and grating, and micron-level "smile" across each bar contributes to variations in locking efficiency and center wavelength. Accurate alignment between bar, collimating lens, and grating must be stably maintained over the lifetime of the pump system to prevent wavelength drifts. Most important, VBG stabilized systems cannot be broadly temperature tuned; tuning rates are only 10 pm/°C, which makes temperature trimming the pump source onto the absorption peak difficult.

An alternative is to use internal diffraction gratings that are monolithically fabricated at wafer level into the structure of the laser diode. This is similar to low-power distributed feedback (DFB) lasers that are used at 1550 nm for long-haul fiber-optic communications. Internal gratings offer many advantages,

including simplicity, low cost of manufacture, long-term stability, and uniformity. Temperature tuning rates range from 80 to 150 pm/°C (depending on wavelength), providing enough tuning range to match absorption peaks, but still small enough so that precise temperature control is not required.

Brightlock laser diode sources

Until recently, internal-grating-based diodes were unavailable at high powers. Adapting monolithic grating techniques to high-power lasers required the QPC Lasers division of Laser Operations LLC to overcome challenges ranging from material epitaxy to multimode competition effects. But over the last few years, we have commercialized chip-based, internal-grating-stabilized laser diodes at a wide range of wavelengths, powers, and brightness levels under the trade name Brightlock.

For a Brightlock 976 nm laser, for example, a monolithic diffraction grating layer is located within a few hundred nanometers of the quantum-well diode active layer and acts to periodically modulate the effective refractive index and generate selective feedback for the laser (see Fig. 1).

This second-order diffraction grating is fabricated in two steps: A corrugated pattern is first holographically formed on the surface of a multi-quantum-well epitaxial wafer by two-beam interference of an ultraviolet laser, after which a second

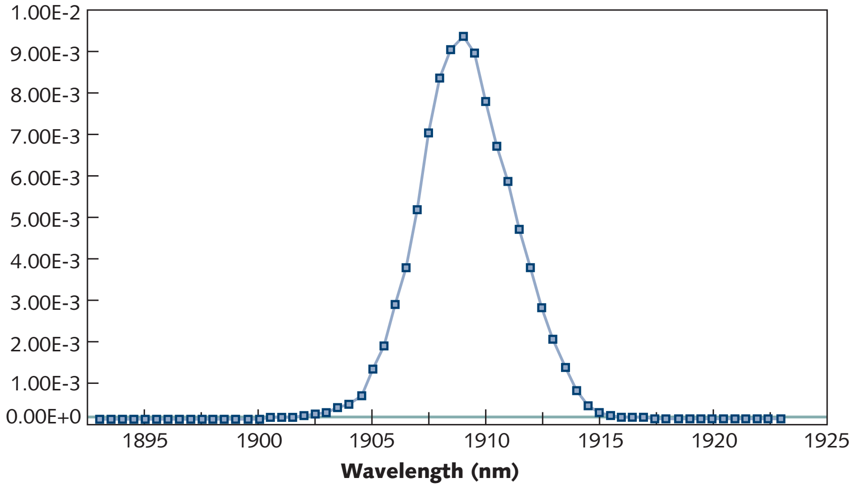

FIGURE 4. An output spectrum is shown for a Brightlock 1908 nm, 36 W laser diode module; the wavelength is important for pumping holmium to create 2100 nm sources used in medical sensor applications, for example.

epitaxial step is performed to embed the grating inside the semiconductor.

Brightlock pump modules were first developed at wavelengths from 792–980 nm in both free-space and fiber-coupled packages. Fiber-coupled packages can provide 30 W of stabilized 808 nm power with 0.3 nm linewidth into a 400 µm fiber. Other wavelengths followed. Pumping of Nd-based laser materials at 880 nm offers reduced thermal loading and beam distortion (see Fig. 2).

Brightlock technology has been extended to longer wavelengths as well as higher powers and brightness. One case is providing narrowband pump power at 1532 nm for pumping Er-doped glass for eye-safe lasers. This system is challenging for two reasons: Typical 1532 nm unstabilized diodes have linewidths exceeding 15 nm, but the pump linewidth must be less than 3 nm for efficient absorption; second, long-wavelength diodes have spatial brightness that is inferior to 808 and 976 nm lasers, but because Er is a quasi-three-level system, pump spatial brightness must be very high for full inversion.

Within the last year, new developments in adapting Brightlock technology to high-spatial-brightness diode architectures have enabled diode sources with both narrow linewidth and spatial brightness. The 2-nm-wide output spectrum of a recent fiber-coupled laser yields 26 W at numerical aperture (NA) 0.15 from a 105-µm-core fiber (see Fig. 3). This corresponds to brightness exceeding 4 MW/cm^2 sr—a figure that is higher than commercially available modules in the 808 nm band with no stabilization.

Brightlock power at 1532 nm has also been scaled to very high total outputs, with pump systems providing as much as 10 kW at an overall linewidth of 2 nm. At longer wavelengths, narrowband pumping at 1908 nm is important for trivalent holmium (Ho) pumping to create 2100 nm beams used in various sensing and medical applications. The 2100 nm wavelength also serves as a jumping-off point for parametric conversion into the mid-IR.

The required 1908 nm pump beams were generated by a two-step process of diode-pumping thulium fiber such as Tm:YLF or by direct pumping of co-doped Tm:Ho crystals. With recent advances in Brightlock technology, direct diode pumping at 1908 nm is now practical (see Fig. 4).

Internal-grating-stabilized pump diodes are still relatively unfamiliar, but they are expected to impact solid-state laser designs within the next few years.

Kendra Gallup is director of sales, North America; **Wentao Hu** is vice president of engineering; **Robert Lammert** is vice president of R&D; and **Jeffrey Ungar** is CTO at the QPC Lasers division of Laser Operations LLC, Sylmar, CA; e-mail: kgallup@laseroperations.net; www.qpclasers.com.

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Three-chip color CCD captures more accurate surface profiles

JOHN WALLACE

Basing a white-light scanning interferometer on a color CCD camera with three separate chips reduces root-mean-square (RMS) measurement error.

For obtaining precise surface profiles quickly over a large area, optical scanning interferometry cannot be surpassed. As long as the surface under test is reflective enough and does not stray too far in shape from the wavefront of the interferometric beam, information over the whole field can be captured at once. However, if the surface under test contains discontinuous structures such as steps, a phase ambiguity remains if only a single wavelength is used. Such surfaces are becoming ever more important: The development of integrated photonics and microelectromechanical systems (MEMS) devices can both benefit from precise measurements of heights and microprofiles of various fabricated objects.

White-light or multiwavelength interferometric surface profilometers solve this phase ambiguity by capturing multiple data points at each measurement location, allowing the relative phase across a step to be determined.

Various forms of white-light scanning interferometer (WLSI) are based on the use of a color sensor (usually a CCD camera). However, a single-chip color CCD camera has limitations: For one, each of its pixels measures only an intensity on one channel, with the rest of the values produced through an electronic spatial color interpolation.

Engineers at the National University of Singapore and the Nanjing University of Science and Technology (Nanjing, China) have simulated, fabricated, and tested a WLSI that uses a three-chip color CCD, which correctly records the actual color information.[1] (In a three-chip color CCD, a trichroic beamsplitter prism divides the incoming white-light beam into blue, green, and red channels, which are each measured by an individual CCD array.)

The layout of the instrument is typical of a Michelson-type WLSI (see Fig. 1). The light source is a tungsten lamp; its output is focused into an optical fiber (not shown in the figure) and guided to the focal position of the collimating lens. An attenuator modifies the spectral energy distribution, boosting the signal-to-noise ratio of the blue channel by evening out the intensity of the three colors. The surface under test is placed on a piezoelectric PZT (lead zirconate titanate crystal-driven) stage, which is computer-controlled. The setup has a scanning resolution of 1 nm and a repeatability of better than 0.02%. The three-chip camera is a commercial device produced by JAI (Valby, Denmark) with 1035 × 780 pixels per color and operates in a linear and unsaturated regime in the instrument.

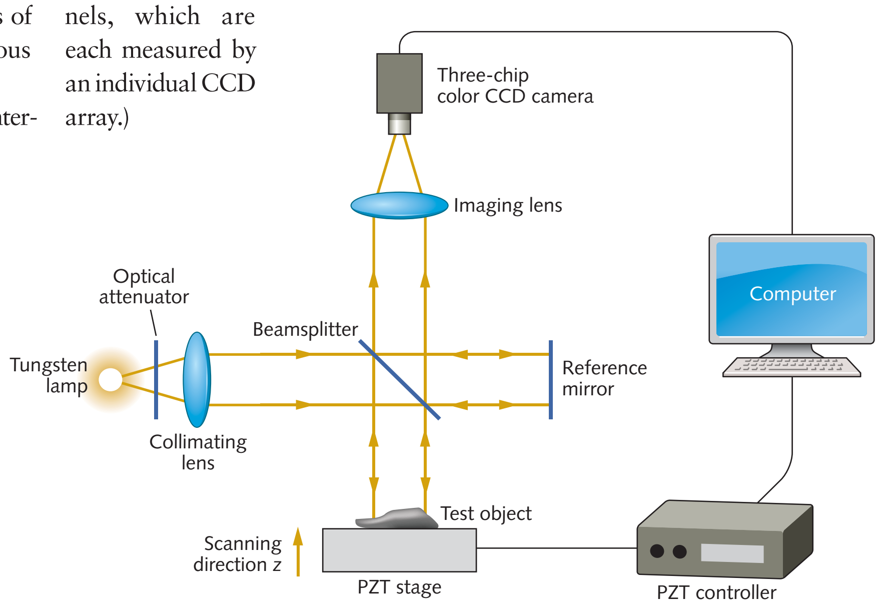

FIGURE 1. A Michelson white-light scanning interferometer takes advantage of a three-chip color CCD camera to obtain accurate surface profiles.

Simulations

The researchers simulated the setup, with some approximations. A two-dimensional 128 × 128 pixel area containing two flat-top rectangular objects 0.013 and 0.028 μm in height was used, along with a simulated light source with a Gaussian spectrum; center wavelengths for the channels were 600, 520, and 450 nm. A scanning interval of 0.05 μm and a scanning range of 10 μm were chosen. The researchers added random intensity noise that they could vary from 0% to 25% of the total intensity.

Two types of interferogram-analysis algorithms were examined: a phase-crossing method with a fast Fourier transform (FFT) using information from only two channels (the green and the blue), as do some pre-existing white-light interferometers; and the researchers' chosen windowed Fourier transform (WFT), which uses information from all three channels. The modeled RMS profile error for the WFT was far lower than that for the FFT as a function of random intensity noise: For example, at a 25% noise level, the WFT and the FFT show 0.27 nm and 1.86 nm RMS error, respectively. An additional analysis showed that any color-coupling effect related to the three-chip camera was small enough (0.08 nm) that it could be ignored.

Experiment

Because the researchers were more concerned with characterizing the accuracy of measurement along the scanning axis than with accumulating voluminous amounts of lateral data, they reduced the number of pixels from 1035 × 780 to 207 × 156 by resampling the images using only 20% of the pixels. As a result, computing time for a single set of profile data using MATLAB software from The MathWorks (Natick, MA) was reduced to about five minutes on a 3.16 GHz computer with a Core 2 Duo processor.

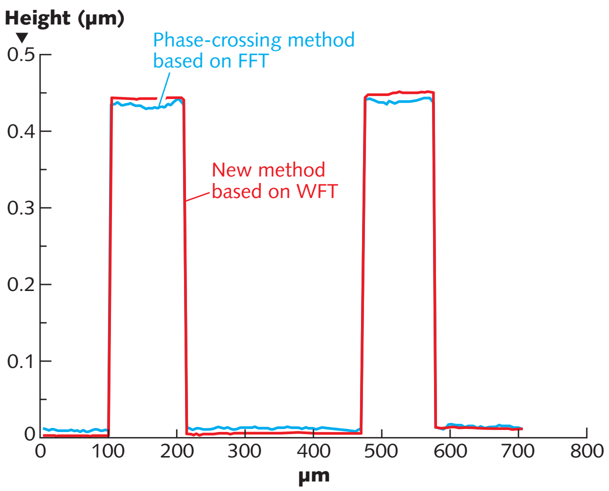

FIGURE 2. A three-chip, three-channel color technique based on a windowed Fourier transform (WFT) achieves more accurate surface profiles of MEMS features than does a two-channel technique based on a fast Fourier transform (FFT). The latter is representative of some existing approaches to white-light profilometry.

The researchers started by testing a flat mirror with an RMS height of 0.51 nm and a convex wafer with peak-to-valley (PV) and RMS values of 70 and 15.1 nm, respectively. Deviations were 11% and 16.5% for PV and RMS errors respectively for FFT, and 4.3% and 2.6% for PV and RMS errors respectively for WFT. These errors were mainly due to vibration of the light source.

The true test came with the measurement of a MEMS wafer. Here, several cross-shaped features of various lateral sizes ranging from about a hundred to a few hundred microns, all with a nominal height specified at 450 nm by the MEMS wafer manufacturer, were measured. Height data across an area approximately 700 × 950 μm in size were taken, from which profiles could be extracted (see Fig. 2).

The average height of the features analyzed by FFT was 441.8 nm with a deviation of 8.2 nm, or a 1.8% relative error, while that obtained by WFT was 446.5 nm with a deviation of 3.5 nm, or a 0.8% relative error. The WFT method also obtained profiles of narrow objects that more truly captured their actual flat tops. ◂

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QCL-based sensors target health and environmental applications

JONATHAN HU and CLAIRE GMACHL

With an emission wavelength that reaches from the mid-IR to the far-IR and high power efficiency, quantum-cascade lasers are the heart of powerful chemical sensors for environmental monitoring, homeland security, and medical diagnostics.

Trace-gas analysis and chemical sensing using quantum cascade lasers (QCLs) has attracted more attention in recent years since most molecules have a unique absorption spectrum in the mid-infrared (mid-IR) region. With many commercial options available, QCLs are ideal candidates for mid-IR spectroscopy because their emission wavelength reaches from the mid-IR to the far-IR with high power efficiency.[1]

The conventional semiconductor laser is based on electrons transitioning between the conduction band and valence band, with photon emission taking place as a result of the recombination of carriers across the bandgap. These QCLs are based on the intersubband transitions between quantized subbands in one band—usually the conduction band—in multiple-quantum-well heterostructures, which is fundamentally different from conventional semiconductor lasers.

Since QCLs use intersubband optical transitions, they were once thought to be inefficient and their emission spectra were considered to be inherently limited in tunability and breadth. However, recent research shows that different quantum designs of the heterostructure can be implemented to significantly improve the performance of QCLs.[2] A widely voltage-tunable intersubband emission can be achieved via Stark effect in coupled quantum wells, and transitions from the multiple subbands yield a broadband spectrum.[3,4]

The National Science Foundation's Engineering Research Center on Mid-InfraRed Technologies for Health and the Environment (MIRTHE; www.mirthecenter.org; Princeton, NJ) develops QCL-based mid-IR chemical sensors for environmental monitoring, homeland security, and medical diagnostics. In this article, we will present selected examples of recent developments for quartz-enhanced photoacoustic spectroscopy, Faraday rotation spectroscopy, a QCL open-path system, and a wireless sensor network over Princeton.

Quartz-enhanced photoacoustic spectroscopy

Acoustic waves in gas samples can be produced by the absorption of acoustically modulated laser radiation at acoustic frequencies by the target trace-gas species. Such photoacoustic spectroscopy is an indirect technique in which the effect on the absorbing medium is detected instead of direct light attenuation. Only absorbed light contributes to the photoacoustic spectroscopy signal, and drawbacks of regular spectroscopy with background absorption and scattered light do not play a role.

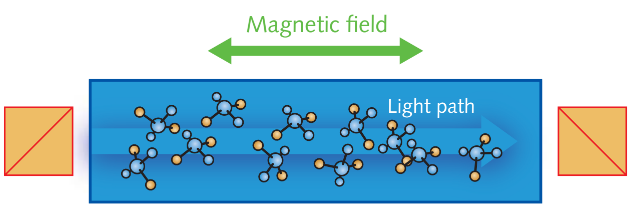

FIGURE 1. A schematic shows the Faraday rotation spectroscopy (FRS) detection scheme. The input linearly polarized light is a superposition of two circularly polarized waves that have different refractive indices under magnetic circular birefringence (MCB). The FRS signal is measured by placing the sample between two polarizers so that the Faraday rotation can be detected as intensity modulation of the light emerging from the second polarizer. The magnetic field is in the same direction with the light path.

A novel and recently much improved approach to using quartz-enhanced photoacoustic spectroscopy (QEPAS) is to accumulate the acoustic energy in a sharply resonant acoustic transducer in the form of a quartz tuning fork. This QEPAS technique has been applied to the detection of various chemical species, such as ammonia (NH_3), water (H_2O), carbon dioxide and carbon monoxide (CO_2 and CO), nitrous oxide (N_2O), and formaldehyde (CH_2O).[5]

In one QEPAS example, a rapidly tunable external-cavity QCL from Daylight Solutions (San Diego, CA) was used as an excitation source to detect and quantify molecules with wide and quasi-unstructured absorption bands. The QCL is continuously tunable in the 1196–1281 cm^{-1} spectral range, which matches the absorption spectra of the studied molecules.[6]

The QEPAS technique has many unique properties such as an extremely high quality factor of more than 10,000; rapid spectral measurement; immunity to environmental acoustic noise; high sensitivity; and wide dynamic range. When the microresonator tubes are cut to the correct length to match the resonant frequency of the quartz tuning fork, the sensitivity of QEPAS can be increased 1.5–2 times. Measurement precision of 13 parts per billion by volume (ppbv) for pentafluoroethane and 15 ppbv for nitrogen oxide concentrations can be achieved.[7, 8]

Faraday rotation spectroscopy

Faraday rotation spectroscopy (FRS) exploits the magnetic circular birefringence (MCB) observed in the vicinity of Zeeman split absorption lines and provides enhanced detection of paramagnetic molecules such as nitric oxide (NO), nitrogen dioxide (NO_2), hydroxide ions (OH^-), or oxygen (O_2).[9] The paramagnetic molecules exhibit MCB when an external magnetic field is applied in the same direction as the light propagation. The magnetic field along the direction of optical beam propagation induces the circular birefringence. The refractive index is different for left-handed and right-handed circularly polarized waves, which leads to rotation of the polarization axis of linearly polarized light (see Fig. 1).

Using a broadly tunable external-cavity QCL allows the selection of the optimum line for the FRS detection of nitrogen oxide and provides flexibility in selecting the required laser wavelength to perform sensitive detection of paramagnetic species. Precisions of 4.3 ppbv and 0.38 ppbv to detect atmospheric nitric oxide using only 44 cm effective optical path length are obtained by using a thermoelectrically cooled mercury cadmium telluride photodetector and liquid-nitrogen-cooled indium antimonide photodetector, respectively.[10]

FIGURE 2. The MIRTHE QCL open-path system was deployed at Elmina, Ghana, on a day when many of the women were smoking fish. The picture shows the kiosk housing the sensor, the retroreflector, and the humidity sensor. The round-trip path length of the laser radiation is about 58 m. The signal from the detector is digitized and saved to a file using LabVIEW and alignment is aided with the help of a HeNe laser. (*Image courtesy of MIRTHE*)

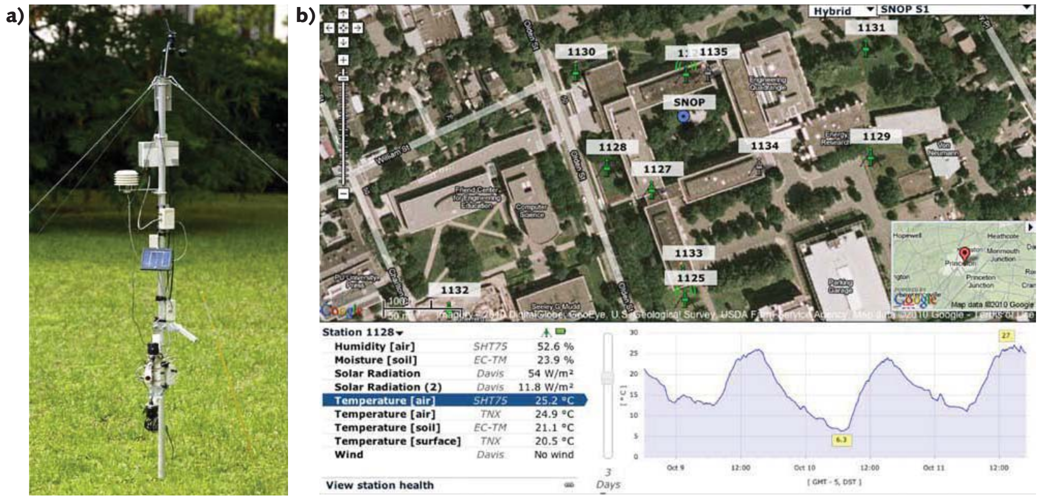

FIGURE 3. A wireless sensor network over Princeton (SNOP) station (a; *image courtesy of F. Wojciechowski*) has been deployed with 12 stations in the Princeton University Engineering Quadrangle (b; *image courtesy of MIRTHE*). The temperature was measured (b; bottom portion) at station 1128 using an IR temperature sensor from Oct. 9–11, 2011, with a maximum temperature of 27°C and a minimum temperature of 6.3°C.

QCL open-path system

The MIRTHE QCL open-path system (QCLOPS) was designed to use laser absorption spectroscopy for detecting a range of trace gases in field deployment with a broadly tunable QCL from Daylight Solutions as the light source. Open-path sensors are important, for example, in air quality measurements.

The QCLOPS system can potentially monitor ozone, ammonia, and carbon dioxide, and was recently tested in sensing complex chemicals in wood smoke in the rural fishing village of Elmina, Ghana in the summer of 2010 (see Fig. 2).[11] Two gases from the wood smoke, 2-methyl phenol and benzyl alcohol, were targeted and successfully identified by QCLOPS. These gases were chosen because they are harmful and have fingerprints in the emission region of the available QCL (965–1260 cm^{-1}).

Wireless sensor network over Princeton

To make a testbed for the development of new sensor technologies, a wireless sensor network over Princeton (SNOP) has been installed. The SNOP includes 12 wireless stations deployed over the Princeton University campus at ground and roof levels (see Fig. 3). The sensor instruments include an IR thermometer for measuring surface temperature, a solar radiation sensor, a three-dimensional sonic anemometer, an open-path IR gas analyzer, a temperature and relative humidity probe, an IR surface temperature sensor, and a four-component radiometer.[12]

The data collected from SNOP can be visualized and downloaded in quasi-real time at http://snop.princeton.edu. The SNOP wireless network will help MIRTHE and its academic and industrial collaborators develop next-generation mid-IR sensing technology that will hopefully lead to commercial sensing product lines important to numerous industries worldwide.

ACKNOWLEDGMENTS

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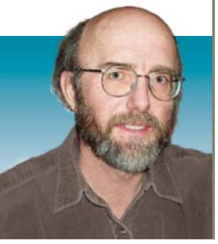

High harmonic generation pushes spectroscopy to the cutting edge

JEFF HECHT contributing editor

Improved high harmonic generation techniques are squeezing pulse duration down toward zeptosecond time scales, and have extended frequency-comb spectroscopy into the extreme ultraviolet.

High harmonic generation uses a quirk of nonlinear physics to generate frequencies much higher than the second, third, or fourth harmonics produced by conventional nonlinear optics. Directing an ultrashort laser pulse into a suitable gas produces a burst of coherent light at odd harmonics of the pump-light frequency spanning many octaves. The energy in each harmonic drops at low frequencies, then levels out in a plateau of successive harmonics that have similar energy before eventually dropping to zero at even higher levels, as illustrated in Fig. 1.

First demonstrated in the late 1980s, high harmonic generation has become a hot field because it can produce coherent light in the extreme ultraviolet (EUV) and soft x-ray region without the need for a costly and cumbersome accelerator. Now it's pushing the frontier in ultrafast physics, where researchers are seeking to move from attoseconds to zeptoseconds. And in a new experiment, researchers have used high harmonic techniques to produce EUV femtosecond frequency combs powerful enough to perform previously impossible spectroscopic measurements.

High harmonic physics

Extremely short and intense laser pulses produce high-order harmonics when they interact with a noble gas. The strong electric field near the peak of the pulse pulls an electron from the atom's outer shell, but the direction of the electric field changes before it ionizes the atom. The electron then drops back to a lower-energy state in the atom, releasing its extra energy in a series of odd harmonics of the pump laser frequency. When the pump intensity is above 10^{13} W/cm^2, intensity of the emitted light stays nearly constant across a number of harmonics before dropping sharply at higher harmonics. The process is not very efficient, and high harmonic intensities are much lower than the input power.

Details such as what harmonics are generated, the harmonic power, and the cutoff wavelength depend on the gas used, and on characteristics of the pump light including wavelength, pulse duration, and pulse repetition rate. Longer pump wavelengths can produce higher harmonics despite their lower photon energy. Martin Fermann, director of laser research at IMRA America (Ann Arbor, MI), explains that the electric fields change more slowly at longer pump wavelengths, giving the fields more time to accelerate electrons, so they have more energy to emit when they recombine with the atom. For example, the cutoff wavelength for argon excited by an

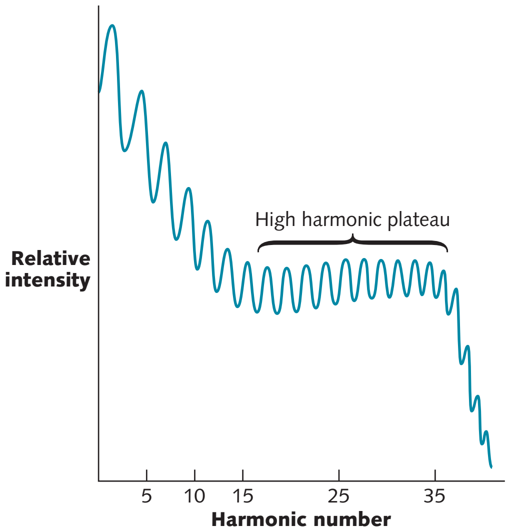

FIGURE 1. High harmonic generation in a noble gas generates peaks at odd harmonics. Power drops at higher harmonic numbers up to a point, then levels out in a plateau before dropping at much higher harmonics. Actual measurements of harmonic power may include more features, such as a low-intensity zone between the lowest harmonics and the plateau.

800 nm Ti:sapphire laser is about 25 nm (50 eV), but pumping at 1.4 µm yielded wavelengths as short as 12 nm (50 eV).[1] Tradeoffs are complex; intensity of the high harmonics decreases as their cutoff wavelength decreases.

Although high harmonic power is low, it is adequate for many research applications in the EUV and soft x-ray region, where conventional lasers are not available, and synchrotron sources are bulky, costly, and complex. Early high harmonic systems were built around modelocked Ti:sapphire lasers with repetition rates of a few hertz to several thousand hertz, followed by regenerative amplifiers to boost their output power. Developers are now fine-tuning their systems for other specific applications.

Attosecond physics

One attraction of the broad bandwidth attainable with high harmonic generation is the ability to generate pulses in the attosecond (10^{-18} s) regime. This requires laser drivers delivering few-cycle pulses at low repetition rates.

Researchers first pressed deeper into the attosecond regime by developing laser drivers, which themselves emitted shorter and shorter pulses, and shifting to lighter noble gases, which can generate higher harmonics. In 2008, Eleftherios Goulielmakis of the Max Planck Institute for Quantum Optics (Garching, Germany) and colleagues directly excited neon gas to produce record 80-as pulses containing more than 10^{11} EUV photons in a band from about 12 to 21 nm (60 to 100 eV). That required generating 300 µj pulses of 720 nm light lasting 3.3 fs (about 1.5-cycles), and focusing it onto the neon. They attributed their success to the extreme speed of the process, which avoided dephasing of the generated harmonics, and expressed hope that such short pulses could "push the resolution limit of attosecond spectroscopy to the atomic unit of time (~24 as) and allow for the real-time observation of electron correlations."[2]

Generating pulses with an even broader bandwidth required a longer-wavelength driver and exciting the lightest of the noble gases, helium. Tenio Popmintchev and colleagues at JILA and the University of Colorado (Boulder, CO) used a novel optical parametric chirped-pulse amplifier pumped by a 20 Hz picosecond Nd:YAG laser to generate 8.5 mj idler pulses lasting six cycles at 3.9 µm. Those

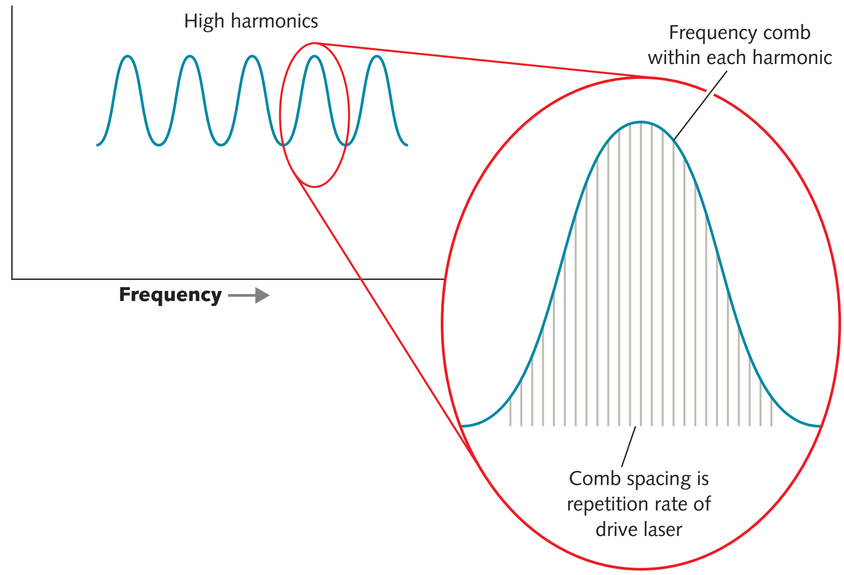

FIGURE 2. Each high harmonic peak contains frequency comb lines, with their frequency separated by the repetition rate of the femtosecond laser driving the high harmonic generator. Typically 10,000 to 1 million comb lines fall within one harmonic peak.

Laser Focus World Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Subscribe

are the highest pulse energies reported for a mid-infrared femtosecond pulse, they reported at CLEO 2011.[3] Guiding those pulses through a hollow waveguide holding phase-matching gas at multi-atmosphere pressures yielded a high-harmonic supercontinuum. With 35 atm of helium in the waveguide, they generated phase-matched emission extending to 0.78 nm (1.6 keV), equivalent to the 5031st harmonic. The pressure is far higher than others have used, and yielded the broadest coherent supercontinuum yet reported, spanning 1.3 keV (from 4 to 0.78 nm). That bandwidth is broad enough to support a Fourier transform pulse lasting only 2.5 as. They did not measure the pulse duration, but said their approach is "scalable to zeptosecond time scales" (1 zs is 10^{-21} s).

EUV frequency combs

Driving high harmonic generation with femtosecond lasers modelocked at high repetition rates produces rather different results—frequency combs in the EUV. When the driver pulses are repeated steadily at high rates the high harmonic waves they generate interfere with each other to produce frequency combs. The result is not a single frequency comb spanning the entire EUV, but a series of shorter combs—each one a series of closely spaced teeth in a different harmonic band, as shown in Fig. 2.

A simple modelocked femtosecond laser does not emit powerful enough pulses for ordinary high harmonic generation. A recent experiment has shown that amplification and pulse compression of pulses from a Yb:KGW laser modelocked at 20.8 MHz can produce high harmonics when focused into a xenon jet, but so far powers are limited to nanowatts.[4]

However, the power can be stepped up by coupling the laser pulses into a femtosecond enhancement cavity and moving the harmonic generation into the cavity, as shown in Fig. 3.[5] Stabilizing the cavity and adjusting it so its cavity round-trip time matches that of the laser produces a resonance that in early experiments at JILA enhanced intracavity pulse energy by nearly a factor of 1000.[5] Placing a high harmonic generation cell inside the cavity took advantage of those higher-energy drive pulses, yielding a train of high harmonic pulses at the same repetition rate as the driver.

The resulting EUV frequency comb offers a powerful spectroscopic probe. However, the output power in each harmonic is divided among 10^4 to 10^6 teeth,

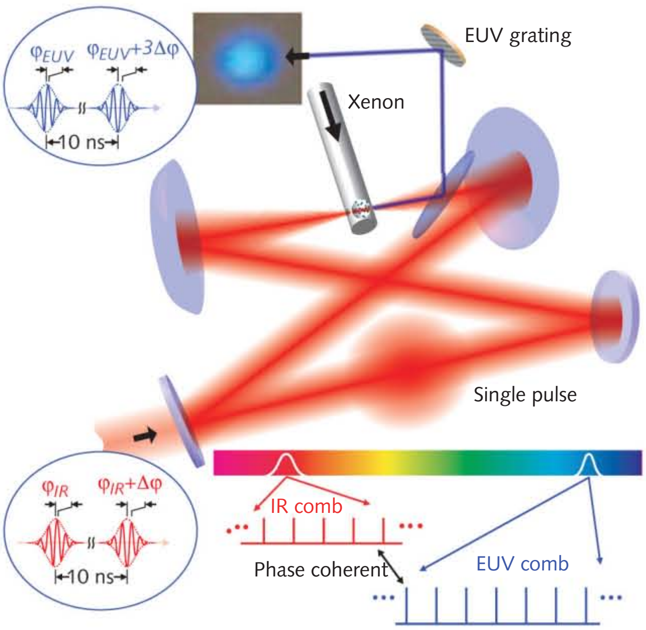

FIGURE 3. Pulse train from an external modelocked femtosecond laser is coupled into an enhancement cavity for high harmonic generation. Matching the cavity to the pulse train resonantly enhances the power of the circulating single pulse, which is focused onto xenon gas to generate high harmonics that are phase coherent with the drive laser. *(Courtesy of R.J. Jones)*

so each tooth has little power. At visible wavelengths, frequency combs can calibrate more powerful lasers for spectroscopic measurements. However, in the EUV no suitable lasers exist, so frequency comb lines must be used directly for spectroscopy, and high harmonic generation is inefficient.

Now two groups have demonstrated different approaches to higher-power EUV combs, and one has used theirs for the first EUV comb spectroscopy.

R. Jason Jones's group at the University of Arizona developed a novel high-power Ti:sapphire laser and optimized design of their femtosecond enhancement cavity. Their laser, injection-locked to an amplifier, generated 80 fs pulses at 50 MHz, yielding average power of 6 W and delivering pulses of more than 100 nJ to the enhancement cavity. Pumping xenon, they produced 77 μW at the 72 nm 11th harmonic, and microwatt powers as high as the 53 nm 15th harmonic.[6]

A team from JILA and IMRA America turned instead to Yb-doped fiber lasers to produce higher powers in a femtosecond frequency comb. In 2010, Axel Ruehl and colleagues at IMRA reported generating average frequency-comb power of 80 W from a Yb-fiber laser emitting 120 fs pulses at 154 MHz.[7] A key to their success was building a chirped-pulse amplifier with large stretching ratios—achieved in more than 380 m of passive fiber—and perfect balancing of pulse dispersion.

Using that system as a drive, a JILA-IMRA team produced average power of about 7 kW in a femtosecond-enhanced cavity containing a xenon cell for high harmonic generation. Challenges included avoiding intracavity optical damage, coupling the EUV output out of the cavity, and filtering the output to select the desired EUV harmonic. Because both output coupling and filtering are only 10–20% efficient in the EUV, they combined the two functions in a single diffraction grating with 420 nm period. That allowed them to generate average EUV powers greater than 200 μW per harmonic at 50 to 120 nm.[8]

They also were able to take the next step and use the EUV output for spectroscopy. This required isolating a single harmonic, which reduced delivered power to 20 μW. To show that this harmonic contained a comb structure, they resolved high-energy transitions of argon at 82 nm and of neon at 63 nm. In a paper posted at Arxiv.org, they conclude that the upper bound for the width of individual comb teeth was under 10 MHz, and that the line center could be determined to within 500 kHz, a record fractional frequency precision of less than 2×10^{-10} in the EUV.[9]

That's quite an impressive feat in the EUV, and it required extreme care in adjusting every detail to make the demonstration work just right. EUV frequency combs are the bleeding edge of spectroscopy today. But don't forget that optical frequency combs were at the bleeding edge just a dozen years ago. ◀

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High-performance mirrors excel for intracavity applications

NEIL ANDERSON and RAMIN LALEZARI

With carefully controlled absorption and scattering losses, high-reflectivity, low-loss dielectric mirrors enable demanding applications such as gravitational-wave detection and cavity ring-down spectroscopy.

High-performance mirrored optics are an enabling technology in a variety of high-sensitivity measurement techniques such as cavity-based absorption spectroscopy, optical atomic-clock spectroscopy, ring-laser gyroscopes (RLGs), and gravitational-wave detection. In each technique, high-reflectivity, low-loss mirrors that can operate under a variety of environmental conditions without any sacrifice in spectral performance are critical. Here, we describe how mirrors manufactured by ion beam sputtering (IBS) and using dielectric materials are designed to achieve extremely high reflectivity (*R*) greater than 99.99% and low loss over a broad spectral range. Particular emphasis is given to how the losses associated with light absorption, scattering, and transmission are minimized and quantified by direct measurement. An example of the importance of these mirrors in cavity ring-down spectroscopy (CRDS) will also be discussed.

Most mirrors are made using thin metal films deposited on glass and are suitable for many applications where some level of loss is acceptable. The main advantage of metals such as silver, gold, and aluminum is that they can provide *R* >95% over a spectral range spanning several microns. However, enhancement of the reflectivity of metal mirrors requires additional processing steps involving dielectric overcoat layers.

Despite the fact that metallic mirrors are relatively low in cost and can have a relatively high mirror reflectivity over a very broad wavelength range, they are not well suited to applications where high sensitivity and high-precision measurements demand light loss in the part-per-million range and thus require mirrors having extremely high reflectivity. An additional disadvantage of metal coatings is that they are both chemically (silver) and mechanically (aluminum, silver, gold) unstable, and in most cases it is necessary to apply a protective layer, such as silicon oxide over aluminum, to limit mirror degradation. Therefore, to overcome the inherent inadequacies associated with metal coatings, an

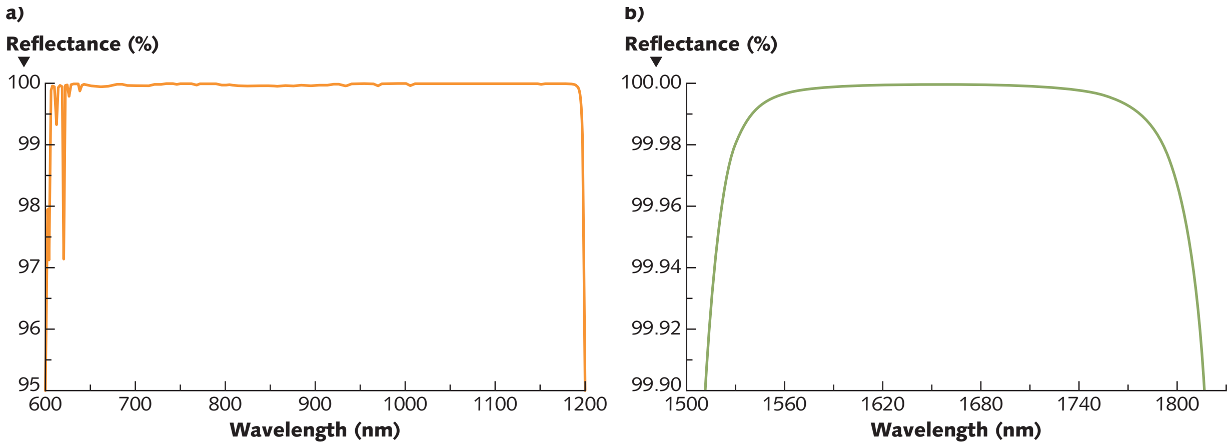

FIGURE 1. A mirror designed for use inside a laser cavity has *R* >99.95% over a bandwidth of 500 nm (a). A mirror for cavity ring-down spectroscopy (CRDS) has *R* = 99.9994% at 1650 nm (b).

alternative is required. One approach is to use ion-beam sputtering (IBS) to manufacture high-reflectivity, low-loss mirrors suitable for high-sensitivity laser-based instrumentation.

A dielectric mirror is formed by depositing a stack of alternating high- and low-refractive index layers on an underlying (glass, crystal, or metal) substrate. Through a judicious choice of the multilayer design, coating materials, and deposition process, it is possible to manufacture dielectric mirrors having extremely high reflectivity over a reasonably wide range of wavelengths in the ultraviolet (UV) to near-infrared (NIR) spectral region.

The key requirements when designing hard-coated, low-loss dielectric mirrors are: high (R >99.95%) reflectivity over the mirror bandwidth; operation over a range of angle-of-incidence (AOI) values for both *s*- and *p*-polarized light; and a high laser-induced-damage threshold (LIDT; for example, a LIDT >20 J/cm^2 for 10 ns, 1064 nm pulses). Reflectance data for two examples of high-reflectivity dielectric mirrors designed to operate in the visible and NIR are shown in Fig. 1. In what follows we describe the performance characteristics of hard-coated dielectric mirrors, focusing on how losses associated with transmission (T), scattering (S), and absorption (A) are controlled and minimized in order to achieve extremely high reflectivity values. An example of their use in CRDS will be described.

Scattering, absorption, and transmission properties

When light interacts with a mirrored surface, several distinct optical phenomena occur. The majority of the incident light is reflected. However, a fraction of the light is lost through scattering, absorption, or transmission at the mirror. Energy conservation dictates that:

$$R = 1 - (S + A + T)$$

The reflectivity of any mirror is primarily governed by its design, and can be made arbitrarily high depending on the number of layers of high- and low-index material used to form the multilayer stack. Due to the aforementioned loss mechanisms, it is not possible to achieve R = 100%. Nonetheless, in some special cases dielectric mirrors having R = 99.9998% at a single wavelength (850 nm) and R = 99.99965% over a narrow wavelength range (830-880 nm) have been fabricated.[1] What ultimately limits higher reflectivity values are losses associated with scattering and absorption. Therefore, it is crucial to understand how the losses associated with both scattering and absorption mechanisms can be minimized and controlled.

Light loss due to scattering is dominated by surface defects and substrate roughness, and does not originate from the actual multilayer coating. Surface defects manifest themselves in the form of scratches, digs, and small particulates. For the case where the highest-quality glass substrates and deposition processes are used, particulate defects are not a significant source of scattering loss.

The single most dominant source of scattering loss is the surface roughness of the underlying substrate. In this case, light

scattering losses can be understood in terms of diffraction effects resulting from random phase variations that are induced upon the reflected lightwaves by submicron surface features present across the surface of the substrate. A strongly scattering surface is defined as one in which the randomly distributed features have a root-mean-square (RMS) roughness (*d*) on the order of the wavelength of the incident light (*d* ~ *l*). In this case, the incident light is strongly scattered. A weakly scattering surface is defined as a surface in which *d* << *l*. In this case, the incident light is weakly scattered and the resultant losses are reduced.

Scattering losses due to surface roughness can be readily understood based on a theoretical calculation of the total integrated scatter (TIS) from a surface having RMS roughness *d*. The total integrated scatter is exponentially dependent on the square of the ratio of the RMS roughness to the wavelength (*l*):

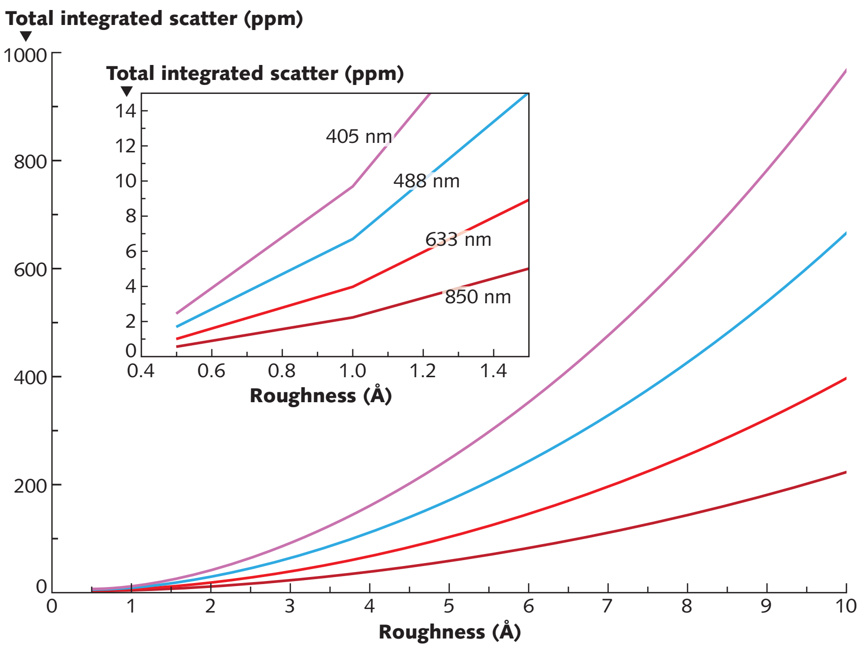

FIGURE 2. Theoretical plots show total integrated scatter (TIS) as a function of RMS surface roughness *d* for four common laser wavelengths. The inset shows the same data for surface-roughness values below 1.5 Å.

$$TIS = 1 - \exp[-(4pd/l)^2]$$

Plots of the TIS measured in parts-per-million (ppm) versus RMS surface roughness *d* for four common laser wavelengths are seen in Fig. 2. As seen in this simple theoretical model, it is evident that the host substrate upon which the mirror coating is deposited must have subnanometer RMS surface roughness to minimize scattering losses and enable the manufacture of mirrors having *R* >99.995%.

To reduce scattering losses due to nanoscale surface roughness, super-polishing techniques are typically used. Super-polishing involves a series of sequential steps that use successively finer grinding and polishing materials to reduce the overall surface RMS of the substrate below 1 Å. For those applications that demand mirrors having *R* >99.995%, substrates are required with RMS surface roughness values on the order of 1 Å or less.

In addition to losses associated with scattering effects, absorption losses must also be minimized and controlled. Light absorption is an intrinsic effect governed by the electronic structure of a specific material. As a result, it is important to select the right dielectric material pairs that provide optimal high-low index contrast (n_H/n_L) without leading to excessive light absorption over the range of wavelengths over which the mirror must operate efficiently.

The refractory oxides silicon dioxide (SiO_2) as the low-index material, and titanium dioxide (TiO_2), hafnium dioxide (HfO_2), and tantalum pentoxide (Ta_2O_5) as high-index materials are common choices for hard-coated dielectric mirrors and can be used to provide high index contrast and low absorption loss in the UV to mid-IR range of wavelengths. Fluorides and amorphous semiconductors like silicon (Si) and germanium (Ge), as well as III-V and II-VI compounds, provide for an extended range of operation into the deep-UV or far-IR regions.

Absorption losses can also be affected by imperfect stoichiometry, the presence of chemical impurities, and nonlinear optical processes at high laser intensities, with the last being difficult to control as it is ultimately user-dependent. Variations in stoichiometry can be controlled by selecting the most suitable deposition process, while contributions that result from chemical impurities can be quelled by enforcing the highest quality-control measures to ensure that only the highest-purity starting materials are used.

As described, the ability to control and minimize the primary sources of absorption loss is relatively well understood. What makes achieving low loss so challenging in practice is the difficulty of accurately measuring these losses at the part-per-million level.

One way to achieve this is to use photothermal common-path interferometry (PCI). A photothermal common-path interferometer consists of two laser sources, a probe beam (typically 633 nm), and a pump beam that are spatially overlapped at the mirror surface, with the wavelength of the pump beam chosen based on the spectral range over which the mirror is designed to operate. In PCI, absorption of the pump beam causes local heating in the mirror. This heating leads to a small, yet measurable phase distortion in the probe beam that is measured as an intensity change in the detector arm of the interferometer. Point-by-point or continuous scanning measurements can be used to generate spatial maps of absorption "hot spots" across a mirror surface.

Transmission losses also require careful consideration. Like mirror reflectivity, the transmission properties of the mirror coating are controlled and optimized through the design of the multilayer stack and can in essence be made arbitrarily small. However, in most applications some transmission loss is necessary to allow light to be detected as part of the measurement process. A classic example of where a small amount of loss is necessary is in the output mirror of a laser cavity. In many practical applications, mirrors are designed such that $T = S + A$.

High-reflectivity, low-loss hard-coated dielectric mirrors are a key enabling technology in a wide variety of high-sensitivity optical measurement instruments. Key factors underlining recent advances in mirror performance are the use of superpolishing techniques to minimize and control scattering losses, coupled with the implementation of state-of-the-art IBS deposition processes to reliably and repeatedly manufacture mirrors having R >99.999%, and scattering and absorption losses at the part-per-million level.

As a direct result of these advances, several high-precision, high-sensitivity optical measurements techniques have benefited. One important example is the development of CRDS instruments that are capable of detecting chemical species and quantifying their concentration at the part-per-billion level and below.

Editor's Note: *To find out more about the manufacture of these high-reflectivity, low-loss mirrors as well as their use in an example application, please see the extended version of this article with our February issue online at www.laserfocusworld.com.*

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When photonics meets forensics, crime really doesn't pay

GAIL OVERTON

Once limited to destructive chemical and laboratory intensive procedures, the processing of crime scene evidence is now possible using nondestructive photonics technology—even when trace evidence is minute or microscopic in size.

The phrase "crime doesn't pay" is truer than ever before: Scientific techniques—many of them photonic or optical in nature—have reached a level of sophistication that allows the forensic scientist to definitively link a suspect to a crime scene. There is no "getting away with murder" when the tiniest trace of bodily fluids, hair and clothing particulates, or even soil or vegetation clues are left behind during a traumatic event.

We all know that chemical DNA analysis has been instrumental in solving numerous current and decades-old cold cases. But were you aware of the ability of microspectrophotometry to identify microscopic textile samples, or that laser ablation of a single hair sample (http://opfocus.org/index php?topic=story&v=8&s=6) can reveal the isotopic ratios of such chemicals as oxygen, nitrogen, sulfur, and carbon present in the keratin to reveal where an individual was living and what they were eating as a function of time?

Television shows such as *CSI: Crime Scene Investigation*, *Bones*, and *Forensic Files* have popularized the science of forensics. Once limited to archaic and destructive chemical and laboratory intensive procedures, the processing of crime scene evidence is now possible using light- and laser-based optical and photonic methods—even when only very minute or microscopic trace evidence is left behind. For example, Raman spectroscopy, which is approximately ten times more sensitive than mid-infrared (IR) spectroscopy, can definitively analyze diluted bodily fluids to a high degree of accuracy without destroying the sample or requiring hazardous chemicals.[1]

The scene of the crime

In any forensic investigation, the first step is to analyze the crime scene, looking for traces of fluids or solids that could provide clues. While an ordinary "black light" or ultraviolet (UV) light (coupled with filters and goggles to improve visualization) can find naturally fluorescing semen, vaginal fluids, urine, sweat, and saliva, blood stains are a different matter: Blood absorbs

FIGURE 1. An image shows a polyester fabric with lettering made from blood, with "I" at full concentration and "X," "V," "L," and "C" made from blood at 10-, 25-, 50-, and 100-fold dilutions. The image was made using in-phase detection of an AC (alternating-current)-modulated reflectance. The object in the lower right is a reflectance reference for phase detection. *(Reprinted with permission from Analyt. Chem., 82, 8427–8431; Copyright 2010 American Chemical Society)*

all UV wavelengths and can be viewed as a dark stain against a brighter background. Unfortunately, criminals often attempt to hide any trace of bodily fluids through cleaning, rendering UV analysis useless. But high-tech photonics offers a solution: IR spectroscopy.

Even for a bloodstain that has been diluted 100 times through cleaning, IR spectroscopy can be an effective detection tool. Professors Stephen L. Morgan and Michael L. Myrick at the University of South Carolina (Columbia, SC) concluded a National Institute of Justice (NIJ) grant (https://www.ncjrs.gov/pdffiles1/nij/grants/235286.pdf) in June 2011 by developing a technique for "Rapid Visualization of Biological Fluids at Crime Scenes using Optical Spectroscopy." They point out that for very small volumes of blood, chemical analysis using luminol or other enhancement chemicals such as amido black, fluorescein, or leuco-crystal violet often creates false positives. The reason for this is because fluorescence of these materials is catalyzed not only by the iron in blood hemoglobin but also by any naturally occurring iron at the crime scene as well as other common household materials.

Alternatively, Fourier transform IR (FTIR) spectroscopy can nondestructively and in a noncontact fashion detect the strong absorption of hemoglobin at 1650 and 1540 cm^{-1} against the nonabsorbing background of common surfaces and textiles.

Morgan and Myrick's instrument uses an IR source (a glow-bar or space heater) combined with a conventional thermal IR camera. The source is chopped and each pixel in the image is digitally processed by a lock-in amplifier to reveal the visual contrast between stain/no-stain regions. The detector response is optimized by a combinatorial, simulation-driven design process to select chemical filters that maximize the discrimination between blood and unstained surfaces. In addition to ready detection of blood using this thermal IR imaging technique, the team is also working to be able to distinguish blood from other interfering compounds by viewing samples through one or more chemical filters composed of polymer films on IR-transparent substrates (see Fig. 1).

Beyond IR imaging and spectroscopy, Raman spectroscopy can provide improved sensitivity in bloodstain and semen detection, but it is also critical for the identification of tiny amounts of unknown substances at the crime scene.

"Raman spectroscopy has several advantages over IR spectroscopy, but the most important is that it can be used in aqueous solvents due to the low Raman scattering of water," says John R. Lombardi, chemistry professor at the City College of New York (CCNY; New York, NY). As we learned in certain handheld spectrometer applications and as Lombardi reiterates, "Water is a strong IR absorber and interferes with the IR signal, making Raman best for biochemical studies."

But Lombardi says that there are two distinct disadvantages of Raman spectroscopy: weakness of the Raman signal and interference from fluorescence. Fortunately, both of these weaknesses are overcome by surface-enhanced Raman spectroscopy (SERS), in which a molecule is adsorbed on a metal nanoparticle surface (usually silver or gold). "Using SERS, the Raman signal is enhanced by many orders of magnitude while simultaneously quenching fluorescence," says Lombardi. "Enhancement factors of up to 10^{14} have been reported, making possible the detection of a single molecule.[2] This makes it ideal for detection and identification of trace quantities of materials, and is the basis for the increasing use of SERS in forensic applications."

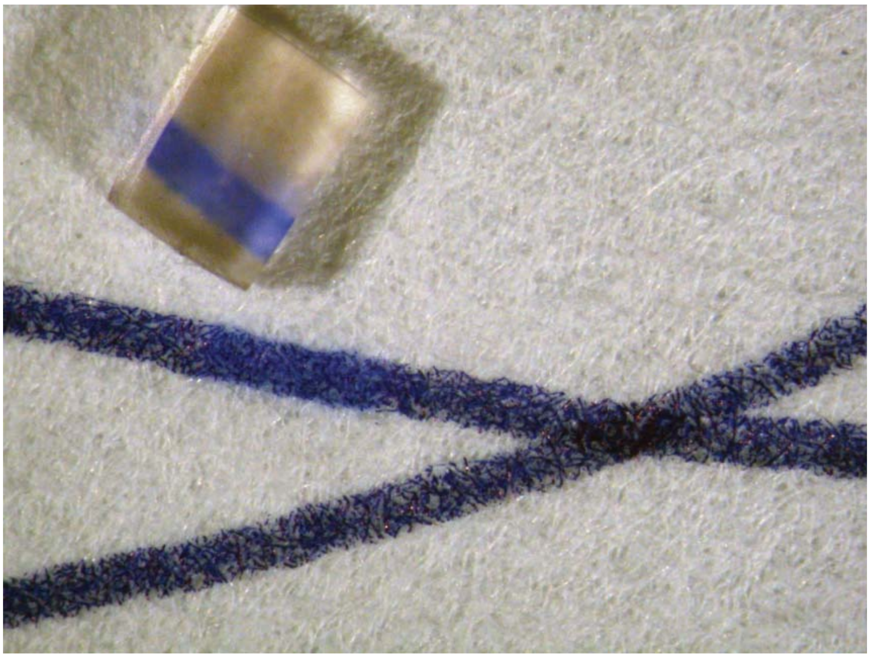


FIGURE 2. In order to facilitate Raman spectroscopic identification of a dye embedded in a textile, special chemicals are used to lift a small percentage of dye onto a hydrogel cube without harmfully affecting the sample. The dye is then dissolved in a solution of metal nanoparticles for Raman detection. (*Courtesy of City College of New York*)

In conjunction with the Metropolitan Museum of Art, the NYPD crime laboratory, and the forensic science program at John Jay College of Criminal Justice (all in New York, NY), Lombardi says that CCNY has been developing techniques to apply SERS to examine trace quantities of substances of interest in forensic science, such as controlled substances (drugs), dyes used in tattoo inks, and inks and dyes used in artwork and textiles.[3-6] For example, the team has developed a technique similar to solid phase microextraction (SPME), in which a methacrylate hydrogel and a 1:1 dimethylformamide (DMF) and water solution with 1% weight by volume disodium ethylenediaminetetraacetic acid (EDTA) is used to extract trace amounts of a target colorant from a substrate (see Fig. 2). Once the trace amount of dye is extracted by the hydrogel, it is dissolved in a photonic solution of metal nanoparticles for SERS detection.

In cases of controlled substance analysis as part of an autopsy—or alternatively, the analysis of what can turn out to be counterfeit drugs at a crime scene—Raman spectroscopy and its variations are also playing a major role. Senior scientist Pavel Matousek and his colleagues at the Central Laser Facility at STFC's Rutherford Appleton Laboratory (Oxfordshire, England) developed the spatially offset Raman spectroscopy (SORS) technique that analyzes the Raman signal returned from regions up to 10 mm beyond the initial entry point of a beam into an even opaque sample such as a pill bottle or biological tissue. The instrument uses conventional CW laser excitation and dispersive Raman-CCD detection. The method relies on the fact that Raman signals emerging from deeper areas of turbid samples are more broadly spread on the surface of the sample than those originating from shallower depths—a direct consequence of photon diffusion within the sample.[7]

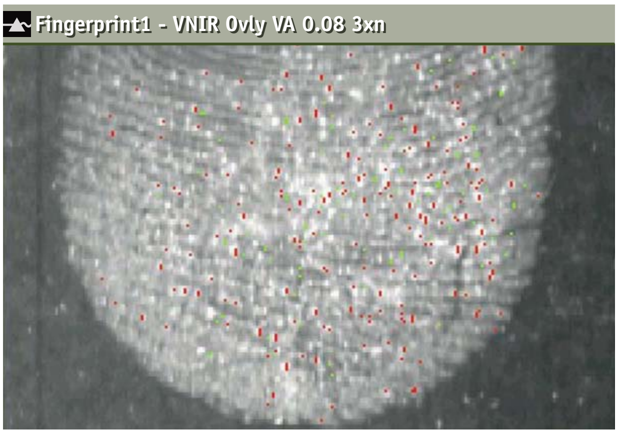
Since its development in 2005, SORS has been commercialized through STFC spinout Cobalt Light Systems (Oxfordshire, England). Recent developments include a SORS device for the noninvasive screening of liquid explosives concealed in plastic and glass bottles for aviation security, which has exceptionally low false alarm rates compared with alternative technologies and is currently being tested at major European airports (www.cobaltlight.com/products/insight100). Another commercial instrument under development is a SORS scanner for the noninvasive identification of incoming raw materials in pharmaceutical manufacturing that can establish the identity of chemicals within seconds—without opening the packaging. The SORS technique is also being developed worldwide in a number of academic research laboratories for noninvasive screening of bone diseases and for breast cancer diagnosis.[8]

DNA fragments, partial fingerprints

Just as the crime scene often reveals only diluted bloodstains and minute traces of other substances, DNA material and fingerprints are rarely complete. However, DNA fragments and partial fingerprints are sometimes enough to identify an individual, especially considering how photonics technology continues to evolve and gain in detection sensitivity.

In 2008, after earlier false identifications based on dental records and preliminary DNA analysis, the identity of a young boy recovered from the Titanic disaster of 1912 and buried in Halifax, Nova Scotia, was finally revealed: His name was Sidney Leslie Goodwin. "The boy's positive identification was made possible through several iterations of a capillary electrophoresis method of detecting fluorescently labeled DNA markers called single nucleotide polymorphisms [SNPs]," says forensic genealogist Colleen Fitzpatrick from Identifinders International (Huntington Beach, CA), who worked with the Armed Forces DNA Identification Laboratory (Rockville, MD) as part of the team that scientifically identified the remains.[9]

Detailed DNA analysis uses a variety of photonic methods; principally, the techniques involve fluorescence. Commercially available instrumentation such as the PCR Amplification Kit and SNaPshot from Applied Biosystems



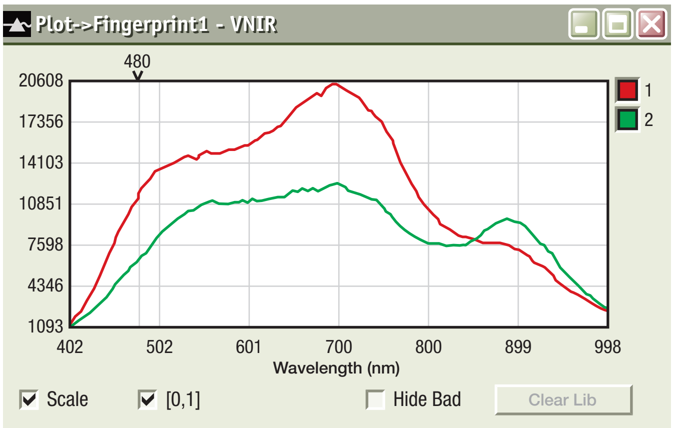


FIGURE 3. Traces of compounds left in the ridges of a fingerprint (left) can be hyperspectrally analyzed in a forensic investigation (right) and matched to compounds or chemicals in a database. (*Courtesy of Headwall Photonics*)

(Foster City, CA) use one or more laser sources to excite particular fluorescent dyes or fluorophores that have been attached to DNA strands. Methods that amplify and then measure the fluorescent signals, as well as other photonic sensor techniques, can provide definitive DNA matching using even very small amounts or fragments of DNA material.

"Hyperspectral sensors can identify material and compounds left in the ridges of a fingerprint based on the inherent chemical composition of the sample," says David Bannon, CEO of Headwall Photonics (Fitchburg, MA).

Using a Headwall Hyperspec very near-infrared (VNIR) imaging sensor with a spectral range of 380–1000 nm and a Hyperspec shortwave infrared (SWIR) sensor covering the 900–2500 nm spectral region, hyperspectral data cubes for a fingerprint are obtained using a "pushbroom" technique that requires movement to capture the linescan images. Each sensor is mounted on a Headwall Starter Kit that includes a mounting gantry for the sensors, a very stable illumination source, and a translation stage for moving the sample under the sensor. The fingerprint is scanned in a few seconds and a 3D data cube displays *x* and *y* spatial positions as well as the spectral content at each point in the scene, which can be compared to a spectral library of known chemicals, explosives, or other materials of interest (see Fig. 3).

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Multilevel modulation formats push capacities beyond 100 Gbit/s

ABHAY M. JOSHI, SHUBHASHISH DATTA, and **ANDREW CRAWFORD**

The implementation of multilevel modulation formats, in conjunction with coherent detection, will significantly increase the information capacity of future fiber-optic links through increased spectral efficiency.

Since the late 1980s, fiber-optic networks have steadily become the bedrock for the ever-expanding global telecommunications system. Early fiber-optic links, such as the eighth transatlantic telecommunications cable (TAT-8) installed in 1988, were relatively simple systems by today's standards and used on-off signaling to transmit a few hundred megabits per second (Mbit/s) over a single optical fiber.

The year 1992 saw the deployment of wavelength-division multiplexing (WDM) that allowed multiple optical channels, each allocated a unique optical carrier frequency, to co-propagate over the same optical fiber. Coupled with innovations in optical amplification, WDM triggered an exponential growth in information capacity of a single optical fiber and heralded the "Information Age."

Modern WDM networks, incorporating as many as 80 optical channels with 50 GHz grid spacing, have reached the spectral limit of optical fiber amplifiers used in these systems. As a result, further expansion of information capacity through incremental "horizontal stacking" of optical channels is not feasible. However, the global demand for information, primarily fueled by video traffic, is expected to continue its growth (see Fig. 1).[1] Coherent detection of high-level modulation formats, supplemented by WDM, has lately emerged as the solution to further upgrade the fiber-optic backbone networks.

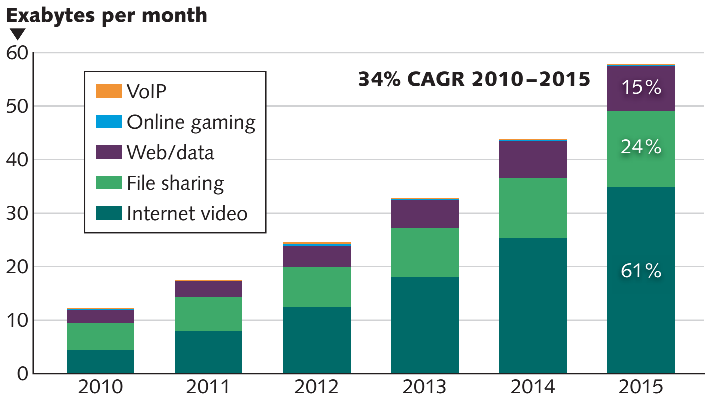
High-level modulation formats

Information channels fundamentally transport binary data streams between various signal-processing systems incorporating binary electronic logic circuits. Efficient transmission of information over a physical medium invariably involves aggregating multiple binary streams in independent orthogonal dimensions.

Wavelength-division multiplexing exploited one such dimension, namely optical carrier frequency, to allow aggregation of multiple optical channels. Each individual optical channel has so far used binary signaling schemes, such as on-off keying (OOK) or differential phase-shift keying (DPSK), having a spectral efficiency of 1 bit/symbol. Consequently, the information throughput of a single optical channel has been progressively enhanced to 40 Gbit/s by increasing the corresponding symbol rate and the analog bandwidths of optoelectronic and electronic subsystems.

Given the current WDM grid spacing of 50 GHz, it is difficult to further increase the symbol rate to, say, 100 Gbaud, while avoiding crosstalk between optical channels. Therefore, it has become necessary to utilize other orthogonal dimensions, namely optical phase and optical polarization, through high-level

FIGURE 1. Global Internet traffic demand as projected by Cisco in 2011.



modulation to enhance the information throughput without increasing the symbol rate (see Fig. 2).

Exploiting optical phase allows multiplexing two binary data streams, in-phase (I) and in quadrature (Q) to the same optical carrier, as demonstrated by the signal constellation for quadrature phase-shift keying (QPSK). Two such QPSK signals can be independently modulated on orthogonal optical polarization states, resulting in a spectral efficiency of 4 bits/symbol. In fact, the telecommunications industry has agreed to utilize dual-polarization QPSK (DP-QPSK) for upgrading optical channels to 100 Gbit/s with a symbol rate of 25 Gbaud.[2]

Further increase in spectral efficiency will require combining multiple binary data streams on a single orthogonal dimension; that is, a combination of optical carrier frequency, phase, and polarization, as is the case with dual-polarization 16-quadrature amplitude modulation (DP-16QAM). More complicated modulation schemes with very high spectral efficiency, such as DP-64QAM, are also being investigated.[3] Unfortunately, enhancing the dimensionality of the symbols increases the complexity of the transceiver design.

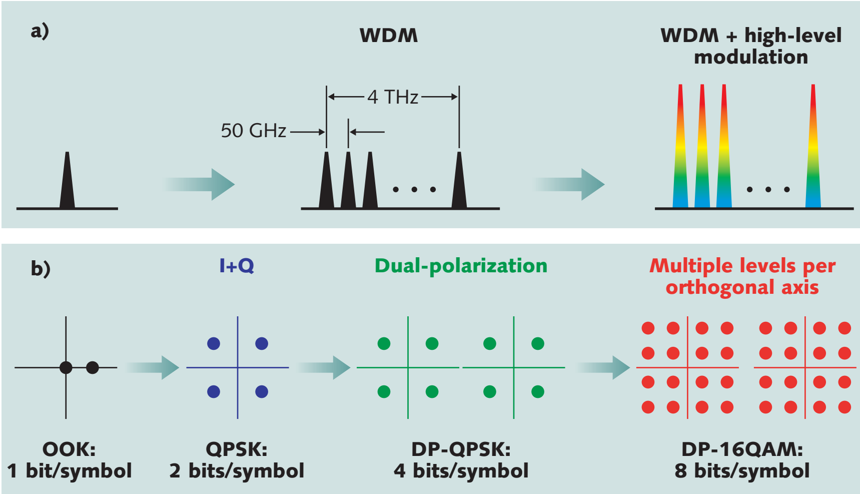


FIGURE 2. a) A graphical depiction shows "horizontal stacking" of information channels through wavelength-division multiplexing (WDM) and "vertical stacking" through high-level modulation formats in a single optical fiber. b) The optical signal constellation in a single optical channel is shown for modulation formats with increasing spectral efficiency.

DP I-Q optical transmitter

Imposing a binary modulation format, OOK or DPSK, on an optical carrier requires only one Mach-Zehnder modulator (MZM) in the optical transmitter. Exploiting both optical phase and polarization necessitates four MZMs—one for each orthogonal dimension. Each MZM impinges the input electrical signal on one polarization state and in-phase to the transmitter laser signal (optical carrier). Two optical phase shifters and a polarization rotator are needed to transfer the relevant binary data streams into the other three dimensions (see Fig. 3). For modulation formats with higher spectral efficiency than DP-QPSK, digital-to-analog converters (DACs) are also needed to aggregate multiple electrical binary signals prior to optical modulation.

Coherent DP I-Q optical receiver

Variations in optical intensity can be directly detected by a photoreceiver of sufficient bandwidth, as is the case with OOK optical receivers. In contrast, optical phase and polarization can only be defined with respect to a reference optical signal. Therefore, deciphering high-order modulation formats requires mixing the received signal with an optical local oscillator (LO) in a coherent receiver.

In addition, coherent detection results in a linear transfer function between the received optical field and the electrical output. This allows correcting for linear fiber propagation impairments such as chromatic dispersion and polarization-mode dispersion in the electronic domain using ultrafast analog-to-digital converters (ADCs) integrated with digital signal-processing (DSP) chips (see Fig. 4). Unlike the DP I-Q transmitter, no additional receiver components are needed for detecting higher-level modulation formats, such as DP-16QAM.

Challenges

Generation and reception of optical signals with high-level modulation formats substantially increases the component count in the transceiver design, raising concerns about size constraints. Also, multiplexing and demultiplexing four optical orthogonal dimensions requires careful consideration of amplitude and phase symmetry between the parallel signal paths.

But these issues can be reasonably addressed through photonic integration, as envisioned by the Optical Internetworking Forum (OIF; Fremont, CA)—a consortium of member companies that promotes the development and deployment of interoperable communications network solutions through Implementation Agreements (IAs).[4, 5] Photonic integration also shows the promise of reducing manufacturing costs incurred during optical packaging of the transceivers' subsystems.

Inclusion of ADC and DSP in the coherent receiver adds another technical challenge; namely, dynamic range. Optical receivers for binary OOK and DPSK formats require an essentially

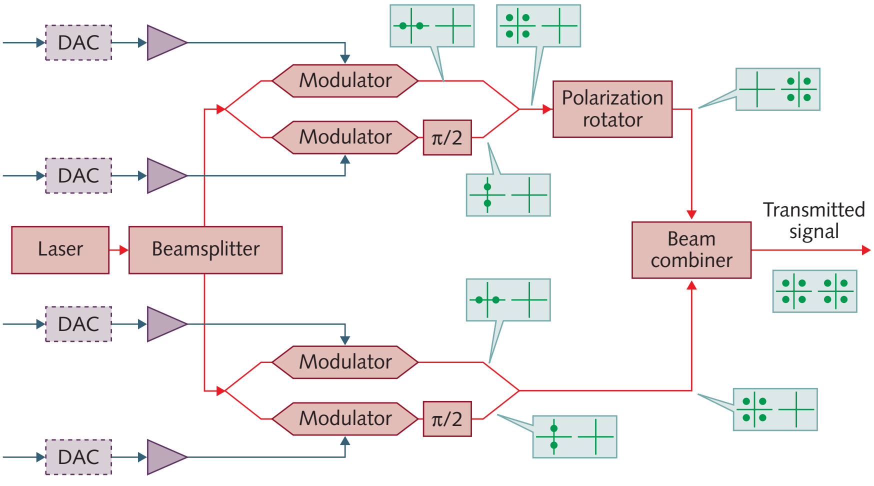


FIGURE 3. A schematic shows a dual-polarization (DP) in phase/quadrature (I-Q) optical transmitter demonstrating the evolution of the DP quadrature phase-shift keying (DP-QPSK) signal constellation. The electronic digital-to-analog converters (DACs) are needed for higher-level modulation formats, such as DP-16QAM. *Note:* This transmitter is required for each optical channel in a WDM system.

high-speed comparator, implemented in clock and data recovery (CDR) chips, to convert the photoreceivers' electrical analog output into the electronic digital domain.

One would imagine that four such CDR circuits would suffice in a DP-QPSK coherent receiver, where each optically deconstructed orthogonal axis should ideally contain binary (1 bit) information. But due to lack of a polarization stabilizer and an optically phaselocked local oscillator in the receiver design, the four electrical analog outputs of the balanced photoreceiver array are significantly cross-coupled, and are separated only in the digital domain.

Consequently, it is necessary to quantize the electrical analog signals with effective number of bits (ENOBS), assuming that forward error correction (FEC) can convert a bit-error-ratio (BER) of 1×10^{-3} to an essentially error-free performance. This overhead of approximately 3 bits is expected to hold for higher-order modulation formats, such as DP-16QAM and DP-64QAM.[6] Combined with concerns over power dissipation and synchronization, achieving such dynamic range or ENOBS in the ADC and DSP is not trivial.

Recent advances provide a solution for 25 Gbaud (100 Gbit/s) DP-QPSK transmission: 40 nm complementary metal-oxide semiconductor (CMOS) application-specific integrated circuits (ASICs) incorporating both ADC and DSP functionality.[7] Higher-order modulation formats will require further improvements in ADCs as well as similar performance for the DACs required for the transmitter.

Increasing the information capacity of optical WDM links, while maintaining the current 50 GHz grid spacing, requires increasing the spectral efficiency of the modulation format. Optical coherent detection of high-order modulation formats exploits the hitherto unused parameters of optical phase and polarization to upgrade the information capacity of optical channels to 100 Gbit/s and beyond. Enabled by significant advances in photonic integration and ultrafast electronic processing, these upgraded links are expected to fuel the continuing growth of global telecommunications. ◀

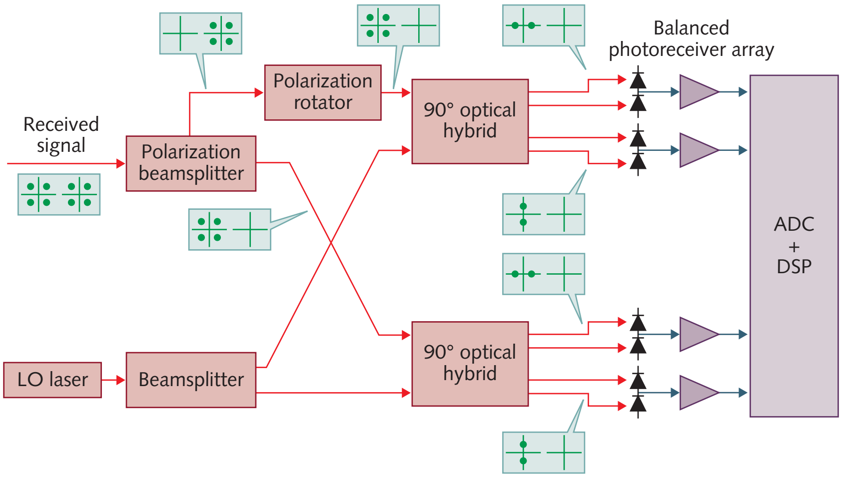


FIGURE 4. A schematic of a coherent dual-polarization I-Q optical receiver shows the deconstruction of the DP-QPSK signal constellation. Mismatch in optical phase and polarization between the LO laser and the received signal have been ignored in the signal constellations. *Note:* This receiver is required for each optical channel in a WDM system.

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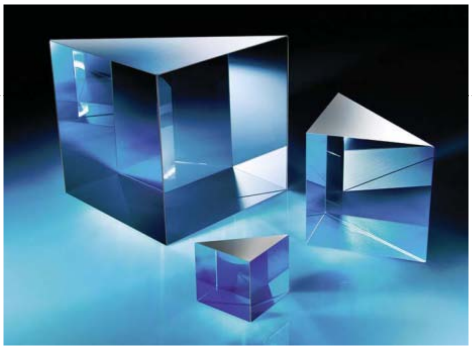

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Toptica Photonics
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JPK Instruments
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table offers travel of 50 mm with positional accuracy of 1μm, straightness/flatness runout of ±1 μm, and repeatability of ± 0.2 μm. A linear encoder has 0.1 μm resolution.

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The NS3 NanoSpectralyzer for multi-mode spectrometry of nanomaterials captures fluorescence spectra from 400

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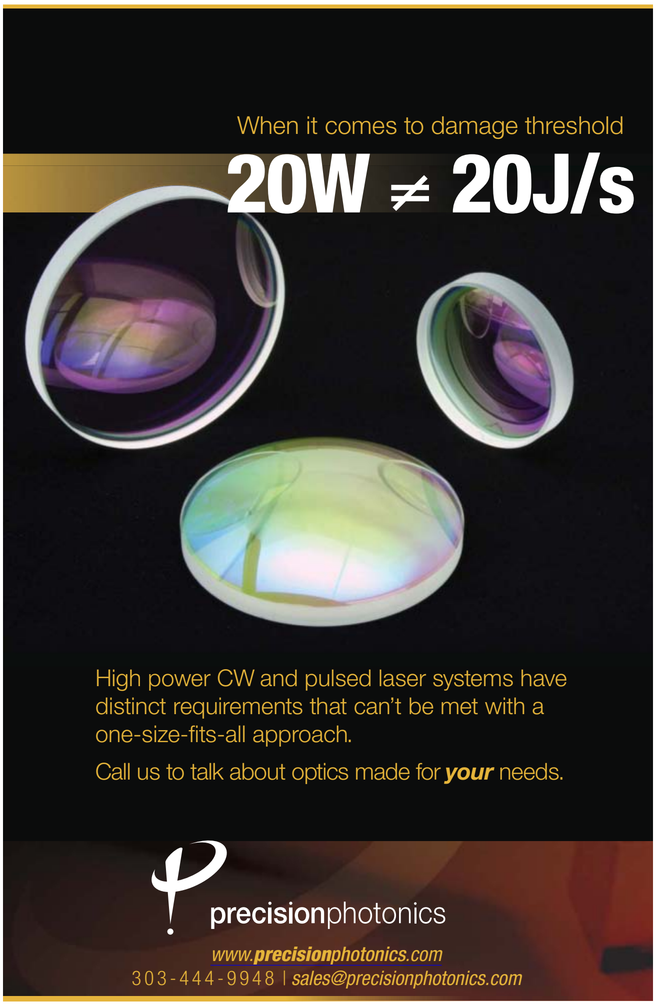

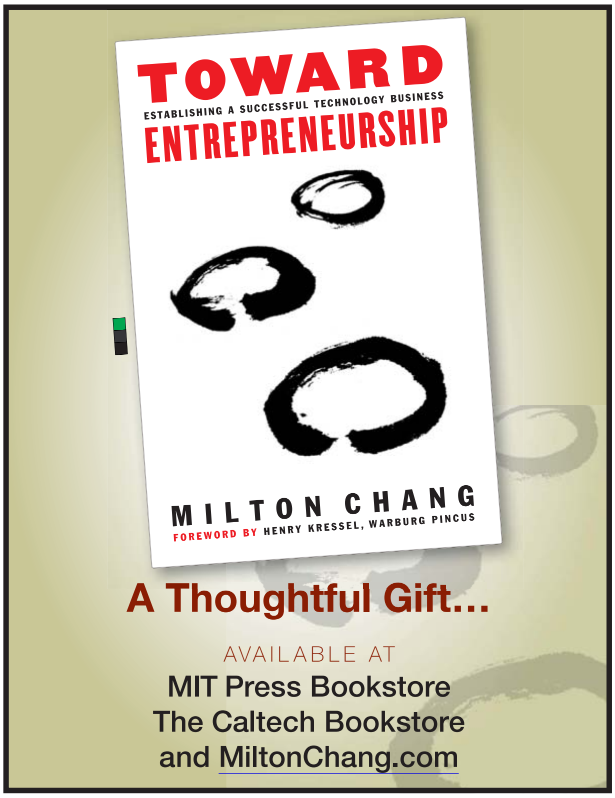

New products

optimized for the sensor's 3.5 μm pixel size. They include a coating for 400–1000 nm. The aperture setting can be locked to deal with strong vibrations.

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Faro Technologies
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Manufacturers' Product Showcase

PHOTONIS' 2010 Prism Award-winning Optical Communications Receiver

PHOTONIS' 2010 Prism Award-winning Optical Communications Receiver promotes an active area of 12mm, making the new receiver ideal for through air, water, or space applications. Typical optical communication receivers have an active optical collection area of approximately 1mm. PHOTONIS optical receivers outperform conventional photomultiplier designs by a range of 3-5×, and are ideal for unmanned or long-term communication sites due to sustained signal current over an indefinite period. The PHOTONIS receiver also has an integrated power supply offering low power consumption within a very small footprint. Data rates reach 2GHz, with rise times of 220 pS.

PHOTONIS

660 Main Street, Sturbridge Business Park,
Sturbridge MA 01566 • 508 347 4000
www.photonis.com • sales@usa.photonis.com

Highest resolution SWIR line-scan camera

Xenics' GigE Vision compatible Lynx-1.7-2048 camera is perfectly suited for spectroscopy, remote sensing, machine vision and medical OCT applications:

- Smallest InGaAs detector with 12.5 µm pixel pitch
- Highest resolution up to 1 × 2048 pixels
- High line rate of 10 kHz up to 40 kHz (1024-pixel version)
- Low noise and high dynamic range

Xenics
Infrared Solutions

Xenics headquarters
Ambachtenlaan 44, BE-3001 Leuven, Belgium
Tel +32 16 38 99 00, sales@xenics.com, www.xenics.com

Laser Beam Analysis Software

BeamGage
See your beam as never before

Spiricon, the global leader in precision laser measurement equipment and a Newport Corporation brand, released **BeamGage® version 5.7**, the company's next generation laser beam analysis software. BeamGage is now 32/64 bit Windows compatible and multilingual, with user interface in English, Japanese, and Chinese languages.

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Spiricon
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Our wavelength meters need to be better than your experiment! Accuracy and speed, we give both!

With the introduction of the WS6-200 IR3, TOPTICA's wavelength meters now cover an extremely wide wavelength range, from 192nm to 11µm. The ultimate precision (within ± 2MHz) and highest speed (up to 500Hz) make our wavelength meters quick and easy to use. The unique instrumental design allows for no moving parts ensuring greater stability with no down time. With effective high speed measurement (up to 500Hz) and feedback control of up to 8 lasers, our wavelength meters can measure single pulse, pulse, quasi-cw and cw lasers.

Greater stability, better accuracy, faster measurement speeds, terrific reliability and coverage from hard UV to Mid-IR — TOPTICA's wavelength meters give you everything you need and more!

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

Next-Generation Fiber Lasers: FemtoFiber smart Family

TOPTICA introduces the FemtoFiber smart family, a new series of ultrafast fiber lasers. These robust all-fiber lasers offer a compact footprint uniting optics and electronics in one box — making them the perfect choice for flexible OEM integration.

Based on polarization-maintaining fibers and Saturable Absorber Modelocking (SAM) technology, they offer reliable performance and hands-off operation.

The FemtoFiber pro family models provide excellent laser sources for a variety of applications. For example, the FemtoFErb 1560 (with pulses below 100fs) easily lends itself to THz generation with InGaAs antennae. The FemtoFErb 780 is perfectly suited for non-linear microscopy or micro-lithography, and the PicoFYb/ FemtoFYb 1030 are ideal for seeding high-power amplifiers.

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

CHARMing diode laser technology

TOPTICA Photonics has expanded its successful BlueMode diode laser family product portfolio with **high power and high coherence from a single diode** — across the visible spectrum. The new **GreenMode** (515nm) and **RedMode** (638 and 685nm) models feature TOPTICA's proprietary CHARM technology, a "world's first" technique for active coherence control, guaranteeing **continuous single-frequency operation** — and thus excellent laser wavelength and output power stability. Mode-hops and resulting "step changes" of the laser's power or frequency are now a hassle from the past!

All BlueMode / GreenMode / RedMode lasers feature a TEM_{00} beam profile and a coherence length of more than 25m, making them perfect tools for interferometry, quantum cryptography and industrial inspection/metrology.

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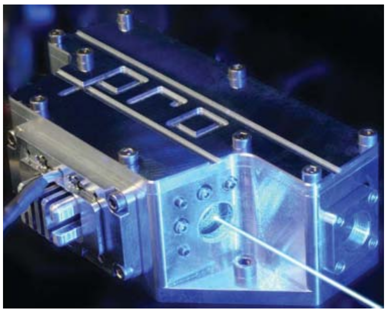
TOPTICA pro series diode lasers

Industrial technology for scientific applications! Motivated by the immense success of the DL pro laser and based on its key design ideas, TOPTICA re-engineered other scientific lasers and now introduces the "pro series".



"Pro technology" is now integrated in our amplified (TA pro) and frequency converted (SHG/FHG pro) diode laser systems, as well as in scientific femtosecond fiber lasers (FemtoFiber pro). "Pro" lasers feature specially made ultra-stable flexure-based mirror mounts where appropriate, a compact housing machined from a solid metal block, and other design details which stand for the "pro philosophy".

The benefits for the user are best technical specifications (like output power, linewidth, pulse width), highest stability and optimized hands-off operation, all at the same time.

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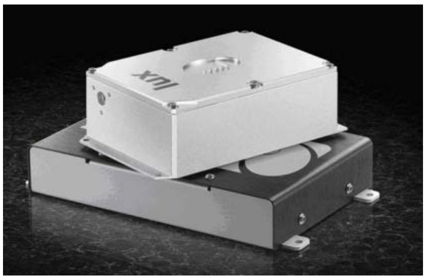
Business Resource Center

of kink-free, continuous-wave power at 780–800 nm, with higher power capability at wavelengths to 1100 nm. The compact, rugged devices are packaged in an industry-standard, hermetically sealed 9 mm diameter TO-9 can.
Laser Light Solutions
Somerset, NJ
sales@laserlightsolutions.com

Red laser

Designed for applications such as DNA sequencing, fluorescence, and Raman spectroscopy, the Lux laser delivers up



to 1 W of 660 nm power in a compact head design. The laser has beam quality M^2 of <1.2, RMS noise levels of 0.6%, and power stability of 1%.
Laser Quantum
San Jose, CA
sales@laserquantum.com

Sensor

The Comet L3D 5M 5-megapixel sensor has a maximum measuring field size of 500 mm. Its pulsed operation is adapted to the LED for higher light intensity. The portable 3D sensor has a

low working distance and is designed for applications such as quality control in industrial settings.
Steinbichler Optotechnik
Neubeuern, Germany
www.steinbichler.de

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LaserFocusWorld Previous Page | Contents | Zoom in | Zoom out | Front Cover | Search Issue | Next Page Subscribe

IN MY VIEW

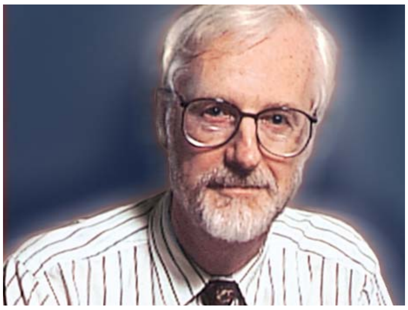
BY JEFFREY BAIRSTOW

A virtual trip to a real show

This year, due largely to tougher economic reasons, I did not cover the giant Consumer Electronics Show, held last month in Las Vegas, NV. Happily, however, I discovered an alternative way of finding interesting technology applications and new products without actually attending the show. I could find new companies without tramping through the cavernous exhibit halls or searching for a rare shuttle bus or a taxi.

The nature of this blockbuster show has also changed significantly over the years. Time was when many exhibitors were conventional TV set makers introducing ever larger tube sets and, later, plasma and LCD sets. Electronic games grew by leaps and bounds and 3-D displays began to appear.

These were the so-called "leading-edge" products developed specifically for introduction at CES. Frankly, I have always found these products rather boring. The more advanced applications could be found on the "fringes" of the show, either buried deep in one of the lesser exhibit halls or in a scruffy hotel suite of the type usually associated with ladies of easy virtue.



I discovered an alternative way of finding interesting technology applications and new products without actually attending the recent Consumer Electronics Show in Las Vegas.

I began to see that even the most shoestring of developers could use creative marketing via the Internet and could easily develop their own videos. And along came YouTube, a simple way of publishing amateur videos. YouTube has developed into a more professional way of distributing videos to both amateurs and business professionals and to the business press.

Another development has been the electronic press room with video press releases supplementing the conventional text and B&W photo that was the standard press kit. Now the CES managers have offered a simple way to produce what the marketers call "CES Exhibitor Press Pitch Videos" so that embryo companies can be more easily reached by reporters for the technical press.

To see these videos, go to the CES web site (www.ces.org) and click on the PRESS tab and then on the dropdown list until you get "CES Press Pitch Videos Program."

Here is a very short list of a few of the exhibitors who took advantage of the CES Press Pitch Video program and my own impressions. (Just in case CES has taken the original YouTube videos down, I have given alternate URLs or e-mail addresses.)

Wilocity. A demonstration of high-speed WiGig wireless technology. A little more enthusiasm needed here! Wilocity is a fabless chip company developing 60 GHz wireless systems for mobile computing applications. (www.wilocity.com)

ooVoo. A confusing demonstration of a new high-density social networking system. Video is produced by an incredibly frenetic and loud marketing director. Loud does not mean "better." In any case, who needs yet another social networking application? (www.oovoo.com)

Omnimount. While Omnimount is not a new company, it does offer one of the most smoothly functioning TV/monitor/display mounts that switches between desktop and standing positions. The well-made and compact mount is easily adjustable and folds out of the way. (www.omnimount.com)

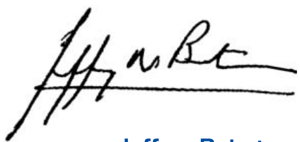
In10did. A bizarre mobile phone keyboard about the size of a pack of cheap cigarettes. Another good reason for banning use of mobile devices when on the road. (www.in10did.com)

MSW Wireless. Yet another and more powerful WiFi for use in areas with poor or nonexistent mobile wireless reception. PR director looks like a baseball fanatic. Maybe a business suit might help? (www.mswwireless.com)

HDbaseT Alliance. A group of small cell phone network manufacturers dedicated to the idea of only one line to your TV. Probably the simplest demo at CES—just a TV monitor with only a single coax pipe at the back. Quite an effective video. (www.hdbaset.com)

Net Nanny. A new and revised version of a gateway program that protects users from themselves and malicious programs. A simple video heralding the addition of Net Nanny to mobile and other computing platforms. Low-key but effective presentation. (www.netnanny.com)

Happy New YouTube viewing.



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