Report from CLEO/QELS and PhAST 2006:

The Latest in Lasers and Photonics

Patricia Daukantas

More than 5,200 engineers, researchers and students came together in Long Beach, Calif., in May for the 2006 Conference on Lasers and Electro-Optics/Quantum Electronics and Laser Science (CLEO/QELS). This year’s gathering highlighted important new work on optical materials, high-intensity lasers, ultrafast optoelectronics, quantum communication and biomedical applications. For the third year, the Photonic Applications, Systems and Technologies Conference (PhAST) provided technical and business advice on manufacturing, homeland security and nanophotonics.
The 25th-anniversary edition of CLEO—first held in Washington, D.C., in 1981—covered up-and-coming laser applications, whereas QELS focused on quantum optics, cold atoms, metamaterials and nanophotonics. PhAST explored ways to integrate the latest technology into national security and biomedical applications.

The use of fluorescence-based triggers to detect biochemical weapons was the subject of a PhAST presentation by David Silcott, representing S3I LLC of Reisterstown, Md. He said that this technology offers the most sensitive and rapid approach for detecting covert bio-aerosol attacks in their early stages.

S3I’s Instantaneous Bio-Analyzer and Collector (IBAC) ingests three liters of air per minute, excites airborne particles with a 405-nm laser and collects scattered and fluorescent light with multiwavelength detectors. The IBAC has a built-in chamber to isolate a suspicious air sample for further study. It can detect single particles up to 2 µm wide and aggregate particles larger than 2 µm.

PhAST plenary speaker Robert F. Leheny, deputy director of the Defense Advanced Research Projects Agency, said DARPA has been investing in photonics for more than 20 years. He estimated that roughly 10 percent of the agency’s nearly $3 billion budget is tied up in some aspect of photonics.

The agency’s areas of interest within the photonics field include sensors (from the terahertz to the ultraviolet band), analog-digital interfaces, digital processing and enabling science, Leheny said. One DARPA project called MANTIS—for Multispectral Adaptive Networked Tactical Imaging System—would give soldiers better night-time imaging capability. MANTIS consists of a head-mounted visible/infrared sensor system and a body-mounted image processing unit.

DARPA is also interested in mixing electronic and photonic integrated circuits on silicon to make optoelectronic chips, Leheny said. The agency is developing a free-space optical and radio-frequency communications system that can share a single aperture. In addition, DARPA has a tactical laser program involving diode-pumped, high-energy laser systems.

The latest in lasers

David Payne, director of the Optoelectronics Research Centre at the University of Southampton in England, joked that the disastrous fire in his lab last October had absolutely nothing to do with his work on high-power fiber lasers, the subject of his CLEO plenary lecture.

A fiber laser consists of a rare-earth-doped silica fiber with a diode laser pump at one end. Fiber lasers withstand heat because of large surface area, a guided mode that resists thermal distortion and the excellent heat resistance of silica. Payne said that fiber lasers are challenging conventional laser technology and gaining market share.

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Twenty-one years after the invention of the diode-pumped silica fiber laser, these devices are powerful enough to cut through 30-mm-thick steel, said British researcher David Payne.

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record is 2.5 kW, but the power output is limited by the available diode pumps, not by the fiber itself.

Payne said he believes that 10-kW fiber lasers should be possible in the not-so-distant future. Fiber lasers provide superb beam quality and pointing accuracy at kilowatt powers, plus excellent pulse stability, ease of thermal management and low cost.

According to Kazuo Tanaka of Osaka University in Japan, researchers at Osaka’s Institute of Laser Engineering have already done experiments using a unique hollow gold cone to direct the laser pulse into the compressed fuel core in a fusion experiment. The cone apparently reduces nonlinear laser-plasma interactions in the corona surrounding the core. “We still don’t know why this gold cone is so efficient,” Tanaka said. Tanaka’s lab is planning to build a 10-kJ petawatt laser system for fast-ignition fusion experiments, starting in 2008.

Researchers from Northrop Grumman Space Technology in Redondo Beach, Calif., announced that they have built a high-power, high-brightness pulsed system called the Strategic Illuminator Laser for the Missile Defense Agency. This pulsed Nd:YAG phase-conjugated master-oscillator-power-amplifier (MOPA) laser produced 4 kW of output with near-diffraction-limited beam output. Such MOPA lasers could be used for long-range tracking and imaging of military targets.

Two researchers at the Institute of Photonic Sciences in Barcelona, Spain, said that they have constructed a femtosecond optical parametric oscillator (OPO) that is continuously tunable across the visible (480 to 710 nm) and—thanks to internal second harmonic generation of the near-infrared signal pulses—the ultraviolet range of 240 to 355 nm.

Quantum technologies

In his QELS plenary lecture, Richard Slusher, director of quantum information at Bell Laboratories, described the critical role that quantum phenomena play in determining the channel capacities of today’s optical communications systems.

Computing and networking bandwidth increase tenfold every 5.5 years, and lightwave transmission capacity has also increased exponentially, Slusher said. The erbium-doped optical fiber amplifier is already near the quantum limit. He described potential future “quantum repeaters” that could be built from about 100 ions each and that might have future uses in teleportation of molecules, cryptography and quantum computing.

In the postdeadline session, a group led by Tara M. Fortier of Los Alamos National Laboratory reported that they performed spectroscopy on cold calcium atoms with a femtosecond frequency comb. Working with a forbidden one-photon transition, the team resolved features as narrow as 2.1 kHz.

Four researchers from the Swiss Federal Institute of Technology reported the first successful continuous-wave (cw) mode-locking of a 1.3-μm vertical-cavity surface-emitting laser (VCSEL). The team, which included Women in OSA Luncheon speaker Ursula Keller (see sidebar on p. 32), combined a GaInNAs VCSEL with a GaInNAs saturable absorber mirror in a laser cavity. Other researchers had reported cw lasing of a
GaInNAs VCSEL, but not mode-locking. The Swiss scientists used the same annealed semiconductor material for both the absorbing and gain medium.

**Optics and the final frontier**

During his CLEO plenary speech, Don M. Boroson, a group leader at MIT’s Lincoln Laboratory in Lexington, Mass., discussed a laser experiment that had been scheduled to fly to Mars. Unfortunately, budgetary shortfalls led to the cancellation in mid-2005 of the satellite on which the experiment would have traveled.

Dedicated high-rate, long-haul space data communications could revolutionize deep-space science, Boroson said. The Mars Laser Communications Demonstration (MLCD) project had the goal of providing a free-space optical link between Earth and its neighboring planet at 1 to 30 Mbps, depending on conditions.

The MLCD device was to have ridden aboard the Mars Telecommunications Orbiter, with a planned launch in October 2009. NASA’s Goddard Space Flight Center collaborated with the Jet Propulsion Laboratory and MIT Lincoln Lab on the preliminary MLCD design, which had a successful review a few months before the orbiter was canceled.

At the time it was designed in 2003, the transmitter on the satellite would have made the best tradeoff of transmitter technology, detector technology, link losses and atmospheric distortion, Boroson said. The amplifier would have been an ytterbium-doped fiber amplifier with an average output of 5 W. The photon-counting detectors were of the Geiger-mode avalanche photo diode type with low noise (10-60 kHz at room temperature), detector efficiency of 0.5 and a refresh-time limitation of about 1 µs. JPL developed special hybrid photomultiplier tubes (PMTs) with InGaAs anodes.

NASA is still planning to build the Space Interferometry Mission, also known as SIM PlanetQuest. According to Bijan Nemati of JPL, the satellite will search for Earth-sized planets around distant stars by measuring the “wobble” of approximately 100 of our Sun’s nearest stellar neighbors.

Such a task will require exceedingly precise measurements of stellar positions—down to about 1 micro-arcsecond, or 10⁻⁹ degree. That means that the path length difference of the two collectors in an SIM PlanetQuest interferometer needs to be known to an accuracy of only 45 pm (or 4.5 x 1₀⁻¹¹ m).

SIM PlanetQuest will consist of three interferometers, one to study the stars of interest and the other two to measure guide stars as a reference. The three instruments will be linked together with a carefully designed truss to form one big satellite.

**Topics in biomedicine**

In an invited CLEO/QELS talk, Vasan Venugopalan of the Beckman Laser Institute at the University of California, Irvine, discussed diffuse optical tomography and light transport in living tissue. The technique can extract properties of both epithelial tissues and the underlying stroma, or connective tissue.
Ursula Keller Addresses Women in OSA Luncheon

At the annual CLEO/QELS Women in OSA Luncheon, Ursula Keller, a physicist with the Institute of Quantum Electronics at the Swiss Federal Institute of Technology (ETH), talked about how she got where she is today, and shared her advice about balancing her distinguished scientific career with family life and other priorities.

Keller, who was born in Switzerland, obtained her Ph.D. from Stanford University in 1989 and spent the next four years as a technical staff member at Bell Laboratories in Holmdel, N.J. She moved back to Switzerland in 1993, when she earned a tenured professorship at ETH Zurich. She is now a full professor of experimental physics and head of the Ultrafast Laser Physics Laboratory.

Keller’s current research interests include ultrafast lasers, high harmonic generation and attosecond science, ultrafast spectroscopy and optical information processing. She has published more than 240 journal articles and 11 book chapters.

However, she got a surprise in 2000 when ISI (now Thomson Scientific) informed her that, based on the number of citations of her papers, she was the world’s third-ranked researcher in optoelectronics during the 1990s. If that were so, she asked herself, why hadn’t she won more than two career awards by the age of 41?

Deciding to manage her resume better, Keller started applying for honors and asking her colleagues to nominate her. As a result of her efforts, she became an OSA Fellow and won two additional research prizes.

Keller urged the novice researchers in her audience to “sell” their results and fight for recognition. Unfortunately, good work alone is not sufficient, especially when other people don’t know about it.

Only a small number of colleagues are in a position to judge your work, Keller said, so awards are a way of highlighting your successes to a broader audience. She challenged her listeners to promote or nominate 10 other women during the course of their careers.

Keller also recommended that all scientists set their priorities to leave time for networking and non-work-related activities in order to avoid burnout. Striking the right balance between work and motherhood was an important priority for her. She said that she and her husband chose to wait until she had a tenured position before having their two sons, and, looking back, she has no regrets.

——Patricia Daukantas

To separate the optical properties of the two tissue layers, Venugopal and his colleagues have been developing Monte Carlo methods to determine the photon interrogation probabilities in heterogeneous media, which in turn will guide optical probe design.

The Beckman team has been comparing its computer simulations of cervical tissue layers to experimental results, but more work to distinguish absorption from scattering in the tissue layers has not yet been done, Venugopal said.

In a Ph.D. session on in-vivo imaging techniques, James R. Mansfield of Cambridge Instrumentation Inc. in Woburn, Mass., said that the method results in better statistics and lower costs for longitudinal studies. (Using each animal as its own experimental control saves time, money and energy.)

Types of whole-animal optical imaging include “bright-field” visible and near-infrared (NIR) imaging, bioluminescence and fluorescence, Mansfield said. Bioluminescent and fluorescent imaging of small animals is a rapidly growing field in medical and pharmaceutical research.

In bioluminescent imaging, researchers introduce the luciferase enzyme into the cells of interest within a transgenic mouse or inject luciferin into animal tissue, Mansfield said. Then, they capture an image in a device that is basically a light-tight box with a high-quality CCD camera. There is a rainbow of injectable fluorescent proteins and probes available for fluorescent imaging.

Fluorescence and bioluminescence techniques both have tradeoffs. Mansfield said. Bioluminescence has much more sensitivity than fluorescence, but it is also more expensive due to the camera it requires.

Single-photon detectors

There’s no single-photon detector (SPD) that will excel at every application, said Danna Rosenberg of Los Alamos National Laboratory, who gave an invited survey of modern detector technologies. Applications for SPDs include astronomy, medical imaging, LIDAR, quantum optics and quantum key distribution.

The conventional “photon counting” detector gives the same output signal for varying photon numbers, Rosenberg said. True photon-number-resolving technology is different. Detector efficiency considers only the photons that are incident on the detector’s active area. The system efficiency considers all photons from the source.

Single-photon avalanche diodes are the most commonly used type of semiconductor SPD, Rosenberg said. These p-n junction devices are commercially available and do not require extensive cooling. They provide very good performance at visible wavelengths, with lower efficiency and higher dark counts in the infrared.

The visible-light photon counter, another type of semiconductor SPD, is a large-area detector that relies on the impact ionization of arsenic impurities in silicon. These counters require cooling down to 6 K, operate only in the visible range.
and have moderate dark counts. They also have high efficiency (88 percent at 694 nm) and provide photo-number resolution. Quantum-dot-gated field-effect transistors have a layer of quantum dots between the transistor's gate and channel. The absorption of a single photon generates carriers that can be trapped in a quantum dot, resulting in persistent photoconductivity.

In a superconducting nanowire SPD, a photon hits the detector and creates a “hot spot.” It requires cooling to below 10 K. These are small-area devices (a few microns on a side) but work over a broad wavelength range (ultraviolet to near-infrared). Results show 57 percent efficiency at 1,550 nm.

Rosenberg and her colleagues have been working to increase the detection efficiency of superconducting SPDs to the highest known efficiency: 88.6 percent. They require cooling to 100 mK and have their highest efficiency at 1,550 nm, but are tunable over a wide range with no intrinsic dark counts.

Kristine M. Rosfjord of MIT proposed a way to boost the detection efficiencies of superconducting nanowire SPDs. Her team fabricated these SPDs with an integrated optical cavity and anti-reflection coating. These additions boosted the detection efficiency to a maximum of 57 percent at a wavelength of 1,550 nm. Such a fast high-efficiency detector could be an enabling technology for a number of applications, including ultra-long-range communications and quantum cryptography.

**Highlighting lighting**

“It is feasible to reduce energy consumption for lighting by 50 percent and still keep the lights on,” said E. Fred Schubert of Rensselaer Polytechnic Institute in his informative tutorial on the state of LED lighting technology. He believes solid-state lighting offers a lot of opportunities for innovation in terms of energy, environment and new functionality. Nationwide, 22 percent of electricity is used for lighting. LED-based lighting can be 20 times more efficient than incandescent bulbs and five times more efficient than fluorescents.

Markets for organic LED (OLED) devices that were virtually nonexistent in 2004 will grow to $1 billion in a decade, Schubert predicted. Whereas conventional LEDs are point sources that are blindingly bright, OLEDs are suitable for large-area light sources. Because the luminance of OLEDs is roughly 10,000 times lower than that of their inorganic cousins, however, the manufacturing cost per unit area for OLEDs must be correspondingly lower for them to gain wide acceptance. Fortunately, OLEDs can benefit from low-cost reel-to-reel manufacturing techniques.

Nikolay Zheludev, a physics professor at the University of Southampton, described his group’s optical magnetic mirror—a nanopatterned aluminum film. In a conventional mirror, the E vector of an electromagnetic wave changes sign upon reflection, whereas in a magnetic mirror, the H vector changes sign. Although the same group had created microwave magnetic mirrors on thin copper films last year, this was the first demonstration of these properties in the optical region of the spectrum, Zheludev said.

Zheludev and his colleagues at Southampton, Rutherford Appleton Laboratory and Kharkov National University in the Ukraine built the optical magnetic mirror by using high-resolution electron beam lithography to fabricate aluminum “fish scales” on top of a silica-aluminum-silicon substrate (see figure). This pattern is 30,000 times smaller than the structures needed to create a magnetic mirror for microwaves.

Such a magnetic mirror could be used to perform molecular spectroscopy at interfaces or to build exotic resonators, Zheludev said.

Optical magnetic mirrors are likely a long way from commercialization. However, the words of plenary speaker Slusher, reflecting on his 41-year career in physics, might apply to them as well as to quantum computing.

“There’s just been an incredible amount of things that have happened in that 41-year time period, so I think it’s not a time to be skeptical about what might evolve....” he said. “...It’s simply the exploration of this field that I think will lead to exciting new things.”

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**References and Resources**

- Space Interferometry Mission (SIM PlanetQuest): planetquest.jpl.nasa.gov/SIM/sim_index.cfm
- Mars Reconnaissance Orbiter: marsprogram.jpl.nasa.gov/mro/
- LED technology group at Rensselaer Polytechnic Institute: www.lightemittingdiodes.org
- In 2007, CLEO/QELS and PHAST will be in Baltimore. For more information, visit www.cleoconference.org and www.phastconference.org.