Opto & Laser Europe

The European magazine for photonics professionals

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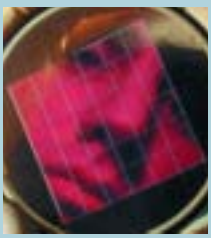
February 2004 Issue 114

BUYER'S GUIDE

The requirements of thin-film optical coatings explained



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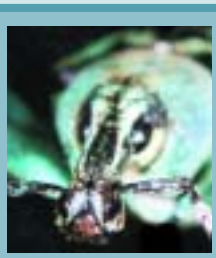

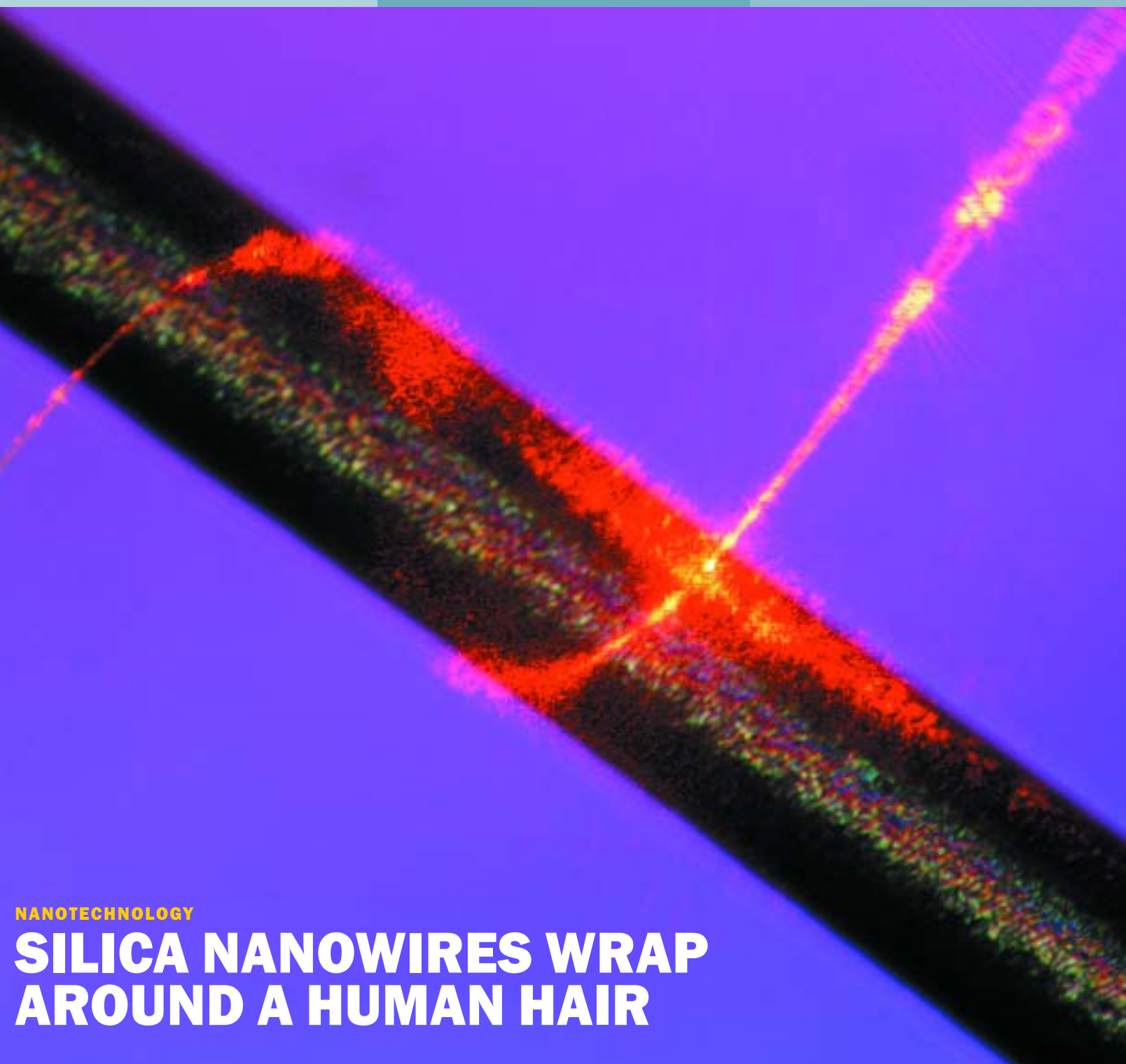

NANOTECHNOLOGY

SILICA NANOWIRES WRAP AROUND A HUMAN HAIR

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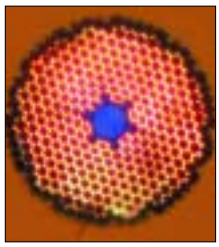
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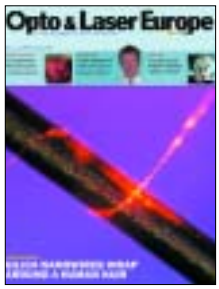

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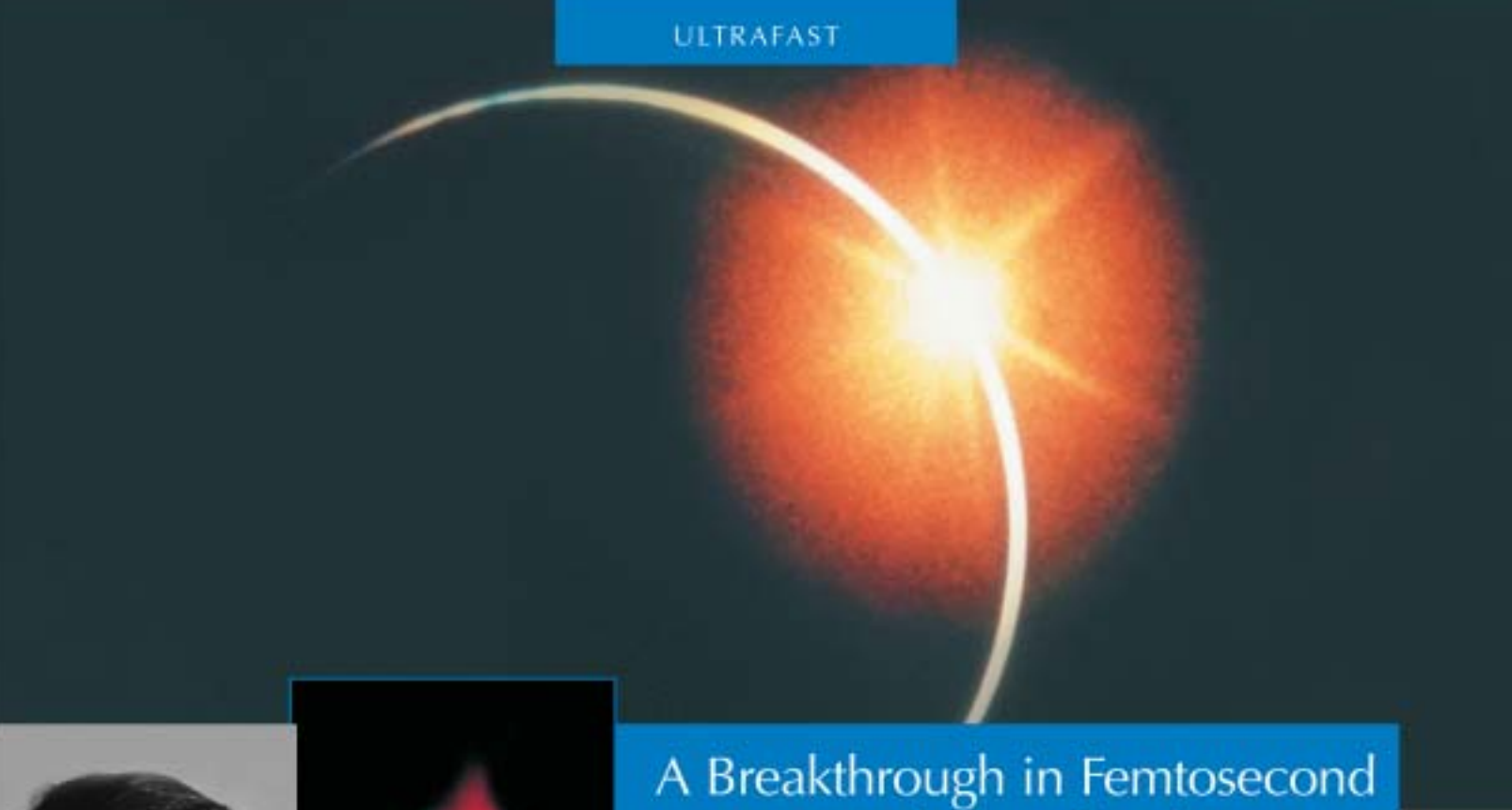

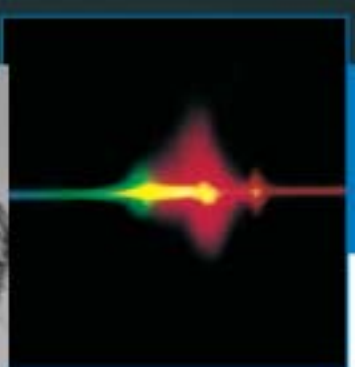

A Breakthrough in Femtosecond Lasers to Eclipse All Others.

Features

- Femtosecond Pulses
- High Repetition Rates
- Highest Average Power
- Simple Architecture
- Compact Platform
- OPA for Wide Tunability

The world of ultrafast amplifiers will take a giant step forward in January 2004, as Spectra-Physics unveils a revolutionary line of amplified femtosecond products. Over the past decade, scientific and industrial ultrafast applications have relied almost exclusively on Ti:sapphire. But now a completely new approach will offer an alternative route to high energy, high repetition rate femtosecond pulses, in a compact platform that will establish new standards in simplicity, reliability and ease of use.

Of course, it's no surprise that this breakthrough comes from Spectra-Physics. As the world's first laser company and the pioneer in Ti:sapphire lasers, we've held market leadership in ultrafast technology through a program of continuous development and landmark product innovations. For more information on Eclipse™, the bright new light in ultrafast lasers, call 1-800-775-5273, or go to www.spectra-physics.com/eclipse.

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Spectra-Physics
Lasers & Photonics

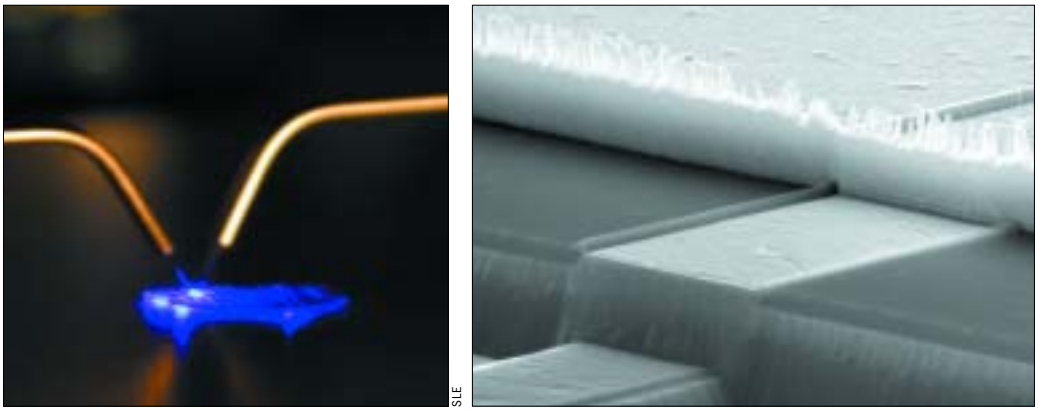
FABRICATION

Sharp makes blue lasers by MBE

Scientists at Sharp Laboratories of Europe (SLE) have produced the world's first blue-violet laser diodes fabricated by molecular beam epitaxy (MBE). Jonathan Heffernan, manager of advanced optoelectronic devices at SLE, and colleagues at the UK-based subsidiary of the Japanese electronics giant reported their work in the 8 January issue of the journal *Electronics Letters* (40(1) 33–34).

Grown on a sapphire substrate, the ridge waveguide InGaN multiple quantum-well lasers operate in pulsed mode at room temperature. They have an output wavelength of around 400 nm which is compatible with Blu-ray, a standard that is being developed for next-generation high-capacity DVD disks.

The first blue LEDs and lasers, developed by Shuji Nakamura and colleagues at Nichia Chemical Industries in Japan in the mid-1990s, were all fabricated using MOCVD (metal organic chemical vapour deposition) and this technique has dominated since then. However, for some time Sharp and other semiconductor specialists have been trying to make blue lasers from MBE.



SLE

MBE magic: light emission from a blue laser-diode wafer grown by MBE (left) and a scanning electron microscope image of the structure showing the dry-etched laser facet (right). Sharp is now working hard to improve the laser's performance.

"Reproducing the success of MOCVD for blue lasers has been a goal for many groups since Nichia's breakthrough in 1995 and there are a large number working on the MBE growth of nitrides," said Heffernan.

"Many have given up hope of achieving highly efficient optical devices by MBE. Our achievements are based on good understanding and control of the growth mechanism, particularly for the quantum-well active region and in the doped cladding layers."

The attraction of MBE as a fabrication technology is that it requires less source material and no post-growth annealing. "There is a significant reduction in the use of source materials, particularly ammonia for nitrides," explained Heffernan. "We currently require less than 1% of the ammonia required for MOCVD. This has cost implications if used in production and also in the environmental impact of the production method."

In addition, MBE-grown devices require no post-growth thermal annealing to activate the p-type dopant, a process that is required for devices fabricated using MOCVD.

However, the prototype MBE lasers are not yet ready to leave the lab, as their performance still needs to be optimized. They currently have an operating voltage of 33 V and a threshold current density of about 30 kA/cm^2 – figures that are about 10 times higher than those of competing commercial devices. The output power of the devices has not yet been measured but it is estimated to be a few milliwatts.

"To demonstrate the viability of the method for high-volume production, we require low threshold CW [continuous wave] operation of lasers. This is the focus of our research in the near future," commented Heffernan.

OLE Digital is here

If you can't wait to receive your copy of *OLE* through the post each month, we have some good news. The magazine is now available in PDF file format and can be downloaded free of charge from our sister website *Optics.org*. To view *OLE Digital* your computer will need to be equipped with Adobe's Acrobat Reader software.

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If you would like to start receiving *OLE* electronically instead of by post, you can sign up for *OLE Digital* at optics.org/subscribe/old. Your print subscription will cease and you will receive an e-mail every time the latest issue is ready to download.

Happy reading,
Oliver Graydon, editor

MARKETS

Global laser market will exceed $3 bn by 2008

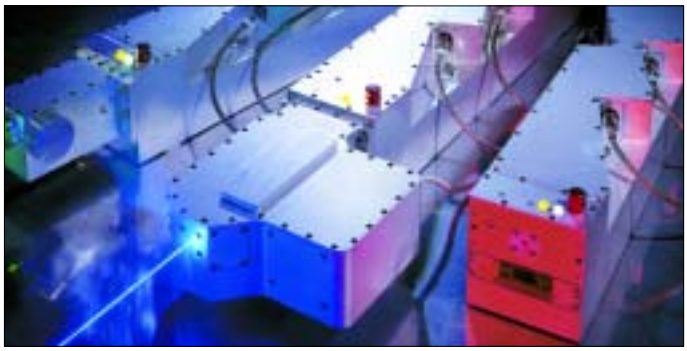
By Jacqueline Hewett

The worldwide laser market will reach $3 bn (€2.4 bn) by 2008, according to a report by the US market analyst Business Communications Company (BCC).

The report, titled RGB-292 Solid State, Gas and Dye Lasers: Outlook for the Future, estimates that the value of the worldwide laser market in 2003 was just over $2 bn. With an average annual growth rate (AAGR) of 9.1%, this figure is expected to cross the $3 bn mark by 2008. This growth is being fuelled by industrial applications such as cutting, welding and trimming, as well as uses in the medical and printing industries.

BCC divides its report into two sections: solid-state lasers, and gas and dye lasers. The firm predicts that the value of the solid-state laser market will rise from $914.1 m in 2003 to $1.47 bn in 2008 – an AAGR of 10%. Lamp-pumped lasers form the largest part of this sector and are predicted to grow at an AAGR of 8%, reaching $980.9 m by 2008.

By contrast, the market for diode-pumped solid-state lasers is expected to grow with an AAGR of 14.8% to reach $490.5 m in 2008. According to the report's author, "Diode-pumped solid state lasers possess all the advantages of solid state lasers but with more specific characteristics." These include high efficiency, excellent thermal management and the possibility of obtaining high output-power from a compact system.



The worldwide laser market is forecasted to grow by over 9% per year between now and 2000. This growth is fuelled by industrial, medical and printing applications.

BCC says that Nd:YAG crystals, in either a flash-lamp-pumped or diode-pumped configuration, hold a 50–65% share of the solid-state market. Crystals such as Nd:YLF or Nd:YVO_4 are said to hold a 10% share while the rest of the market comprises other rare-earth or transition-metal-based systems.

Despite its greater value, BCC forecasts that the combined gas and dye laser market will have an AAGR of 8.4% between 2003 and 2008. Starting at a value of $1.11 bn in 2003, the company estimates that the market's value will rise to $1.66 bn in 2008. The report claims that excimer lasers will show a high AAGR through 2008, thanks to their popularity in R&D applications such as spectroscopy.

OUTPUT POWER

Rohm ramps up red laser power

By Michael Hatcher

Japanese diode-laser manufacturer Rohm has developed a high-output laser with a maximum 16× capacity for DVD writing.

Samples of the 240 mW devices, which emit at around 650 nm, are currently being shipped. Volume production of 500 000 units per month will begin this April, with volumes set to increase thereafter.

The market for DVD recorders, DVD-R/RW and RAM is rapidly expanding. Rohm expects 50 million units for PC use, plus a further 10 million units for audiovisual applications, to be shipped this year.

"Year 2005 is expected to show even greater growth," said the company. "While DVD media will become indispensable for recording large volumes of data such as video, [these] larger volumes will entail longer recording times."

Recording speed is directly related to the writing laser's optical output and Rohm says that the 240 mW from its device is sufficient for a maximum speed of 16× DVD recording. The company adds that it has developed a new element to manage the rise in current associated with higher output.

The high-output DVD laser is also being developed in a 650/780 nm monolithic two-wavelength design to meet demand from the DVD/CD multi-drive market.

Mitsubishi recently announced that it would also be ramping up DVD laser diode production by 40% from March 2004.

Michael Hatcher is editor of Compound Semiconductor.

IN BRIEF

UK

MicroVue, a UK-based microdisplay production firm, has gone into voluntary liquidation. CRL Opto, a UK firm that uses MicroVue as its supplier, says that it will continue to sell reflective ferroelectric liquid-crystal-on-silicon XGA and SXGA microdisplays. CRL's managing director Greg Truman commented: "We have a high level of confidence that a new source will be available soon."

US

Agere Systems has acquired TeraBlaze, a maker of gigabit ethernet (GbE) switching systems, in an all-stock deal valued at $21 m (€16.6 m). All 16 TeraBlaze employees will join Agere's workforce. Agere hopes to use the acquisition as a route into the fast-growing GbE market.

France

The French Commissariat à l'Energie Atomique (CEA) has awarded SAGEM a follow-on contract worth €200 m. The contract will see SAGEM design and implement the laser beam lines of the Megajoule Laser, a facility being built to perform inertial confinement fusion. SAGEM says that the contract excludes the amplifiers used in the laser beam lines.

Japan

Toshiba has developed a prototype high-definition DVD player. The Japanese consumer electronics giant says the player contains a single-lens optical head that uses a red diode laser to read current DVDs and a blue diode laser to read next-generation discs.

US

Xanoptix has completed its purchase of Bell Labs spinout AraLight. Xanoptix makes 3D stacked hybrid integrated circuits and high-speed optical connection products, while AraLight manufactures high-density opto-electronic components.

DATA STORAGE

Joint firm targets optical storage

Japanese consumer electronics giants Toshiba and Samsung Electronics are to team up to form a specialist optical disk-drive company.

The new firm, to be called Toshiba Samsung Storage Technology Corporation, will integrate the two firms' activities in the field and will manufacture devices such as CD-ROM and DVD-ROM drives.

The two companies are investing ¥14.9 bn (€111.6 m) into the venture. Toshiba will own 51% of the new business, while Samsung will own the remainder. The venture is expected to bring in ¥250 bn in the 2004 financial year.

Toshiba Samsung Storage Technology Corporation is to commence operation on 1 April and will employ 700 people. It will be headquartered in Japan with a subsidiary in Korea.

MARKETS

Mobile phone market boosts Cree's earnings

Cree, US, has seen a second-quarter revenue of $72.68 m (€57.51 m) – an increase of 28% from the $56.72 m gained in the same quarter last year. The firm's net income for the quarter, which ended on 28 December 2003, increased by 45% year-on-year to $13 m.

LED sales accounted for $56.5 m of the quarter's revenue. Of this, mid-brightness and high-brightness LEDs brought in 46% each, with 8% from standard LEDs.

"Our record revenue and higher profitability were driven by strong LED sales as we benefited from increased demand for LEDs in mobile phone applications," said Cree's president Chuck Swoboda.

● The mobile phone market is also a major target for Kyocera of Japan. The company's subsidiary, Kyocera Display Institute, has announced plans to develop and sell 2–8 inch organic light-emitting diodes for cellphones and digital cameras.

LEDs have many uses in mobile phones, from indicating battery-life status to backlighting liquid-crystal displays.

IMAGING

Kodak cuts jobs in new digital strategy

Kodak has announced that it is cutting its global workforce by 20% – which equates to between 12 000 and 15 000 employees – over the next three years. The cutbacks result from Kodak's decision in September 2003 to focus more heavily on digital imaging, rather than conventional photography.

The company's plans, which also involve reducing the total size of its facilities by one-third, are expected to generate full-year continued savings of between $800 m and $1 bn by 2007.

"These plans are the consequence of market realities," said Kodak's president Antonio Perez. "They are absolutely required for Kodak to succeed in traditional markets, as well as the digital markets to which our businesses are rapidly shifting."

FUNDING ROUND-UP

UK

Southampton-based Mesophotonics has collected $10 m (€8 m) in a second funding round. The money will help the firm to take its photonic-crystal optical devices from the prototype to development phase. The company's first products are expected on the market within two years and it claims to have already lined up customers.

SWITZERLAND

ACOL Technologies of Switzerland has attracted €9 m in first-round funding from Amadeus Capital, Apax Partners and Mint Capital. The Geneva-based firm, which spun out from Corvette Light of Russia, develops high-brightness LEDs for use in applications such as road and rail signals, outdoor signage and general illumination.

US

MicroDisplay has secured $18 m (€14.2 m) in its third round of financing. The US firm develops high-definition imaging components based on liquid-crystal-on-silicon technology. MicroDisplay says it will use the cash to ramp up manufacturing, expand its customer-engineering support and double its research workforce.

UK

TeraView, a Cambridge-based maker of terahertz imaging equipment, has secured £6 m (€8.7 m) in second-round venture capital funding. The round was led by Amadeus Capital Partners and included first-round investors TTP Ventures, Cambridge Gateway and Quester. "TeraView is without doubt the world's leading company in this important new field," said TTP's chairman David Connell.

US

Calient Networks of the US has raised $20 m (€15.8 m) in its fourth funding round. The company will use the cash to further develop its intelligent photonic switching technology. This cash injection raises the total capital invested in Calient to more than a quarter of a billion dollars. The company hopes to raise a further $10 m through a second closing scheduled for March 2004.

US

OmniGuide Communications, a US developer of hollow-core cylindrical photonic bandgap fibres, has announced $15 m (€11.9 m) in series C funding. The company has now raised a total of $29.5 m.

BIOMEDICAL OPTICS

Smart optics: time to think big?

By Joe McEntee

When Tony Horn talks about next-generation healthcare technologies, his audience tends to pay close attention. Hardly surprising: as director for the health technology devices research programme at the UK's Department of Health, he is instrumental in shaping how the government allocates its multi-million-euro annual R&D budget for primary and secondary healthcare and emergency services.

Earlier this month, Horn outlined what he called a "personal rather than departmental" vision of optical and imaging technologies that, if commercialized successfully, could transform not only the National Health Service in Britain, but public healthcare worldwide. His presentation – the keynote address at the Smart Biomedical Optics Forum at the University of Cambridge, UK – was notable on two counts.

Firstly, it gave an innovation roadmap for biomedical equipment manufacturers looking for competitive product differentiation and credible growth potential.

Secondly, his hit-list of optical/imaging innovations could be a starting point for R&D funding agencies and investment professionals, as and when they revisit their priorities in biomedical optics and instrumentation. The list included applications like enhanced diagnostics for Alzheimer's disease, surgical microendoscopy and preventative medicine.

Take Horn's case study on clinical depression. The statistics are revealing: in the US alone, 19 million people were diagnosed with clinical depression last year. Of those, 6 million were over 65 years old, but only 40% of this group asked for any help with depression. Meanwhile in the UK, the sharpest increase in suicides was seen in men aged over 75 years.

For doctors, the problems are compounded by the difficulty in determining if clinical depression is a primary cause or a secondary effect from another disease such as Alzheimer's onset or complications with stroke recovery.

Left: the Smart Biomedical Optics Forum gives delegates a peek into the future. Right: Tony Horn of the UK's Department of Health delivers the keynote address.

The task for biomedical equipment makers and the research community is clear: to come up with imaging diagnostics that remove this uncertainty. The aim is faster diagnosis and more appropriate treatment, which should equate to a better quality of life for millions of sufferers.

The latest funding grants in the US, for example, are directed towards the use of single-photon emission-computed tomography, positron emission tomography and magnetic resonance imaging as diagnostic tools. Horn speculated: "Will we end up with an imaging-like helmet that patients put on in a doctor's surgery to distinguish the primary and secondary causes of depression? Possibly one in four patients visiting a doctor could benefit from such a low-cost, easy-to-interpret technology."

Another challenge on Horn's list is the development of non-invasive imaging techniques that offer screening options for early-stage Alzheimer's, "where either medication or a vaccine may halt the progression of the disease".

He also sees the need for a robust imaging tool capable of rapidly distinguishing types of stroke "to provide quicker onset of appropriate treatment and limit subsequent disability for the patient".

In addition, accurate diagnosis of osteoporosis is needed. This would probably combine imaging and pathology, and be sensitive enough to detect positive responses to treatment.

Cross-fertilization

The Cambridge conference was hosted by the Smart Optics Faraday Partnership, a Government-backed initiative set up to foster technology transfer between the optics community and all manner of end-user industries. On this score, it was encouraging to see that the optics professionals are making plenty of progress.

Peter Bryanston-Cross and colleagues in the Optical Engineering Laboratory (OEL) at the University of Warwick demonstrate this. "The OEL has created a strong interaction between industrial research and the creation of medical ophthalmic instrumentation," said Bryanston-Cross.

More specifically, he explained how his team's optical know-how in fields like aerospace engineering and combustion analysis is being applied to diagnostic and surgical problems in ophthalmics. The cross-fertilization works on several levels. Take holographic interferometry, for example, a technique pioneered by Warwick scientists and applied extensively by them over the past decade in studies of turbine blades in jet engines.

Now that same approach has been combined with advances in synthetic intelligence (sophisticated signal-processing software for solving complex image connectivity problems) to yield a system for phase-mapping the eye's lens. The technique generates maps of stresses across the lens surface, which is useful to clinicians carrying out corrective surgery.

In addition, the team is developing a non-invasive, non-contact "tonometer", which uses acoustic resonance to measure the intra-ocular pressure of the eye for the early detection of glaucoma. The device is still an early-stage prototype but Bryanston-Cross said his long-term goal is "to develop a low-cost probe which could be used by mobile medics, small practices and surgeons in the third world".

Other areas of ophthalmic research at Warwick include new laser-cutting tools for eye surgery, fluorescence sensors to test for diabetes and a low-cost optical headset (Loupe system) designed for use by third-world eye surgeons.

"The combination of increasing computing power and the use of active optical elements is creating many new types of diagnostic ophthalmic instrumentation," concluded Bryanston-Cross. He added: "The objective is to provide new types of surgical instrumentation and [to assist] in the early diagnosis of eye disease."

● To learn more about smart optics, see Insitute of Physics Publishing's latest Technology Tracking report, *Industrial and Medical Applications of Adaptive Optics*. If you would like to receive a copy of the report's table of contents and executive summary, please e-mail the editor Susan Curtis at susan.curtis@iop.org.

More: www.technology-tracking.com

IDENTIFICATION TECHNOLOGY

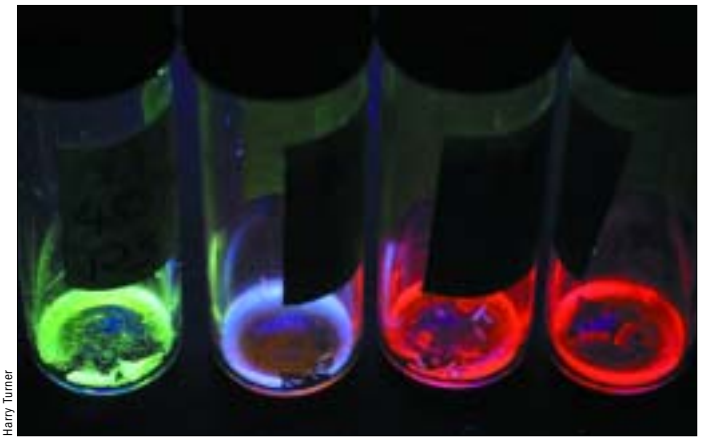
Quantum dots create secret codes

By Siân Harris

Fluorescent inks containing quantum dots could be the key to creating identification codes that are invisible to the naked eye and very hard to counterfeit. The "Info-ink" codes developed at the Institute for National Measurement Standards in Ottawa, Canada, could be ideal for use on passports or identity cards *(Optics Express* 12 143).

Fluorescent quantum dots, light-emitting semiconductor nanocrystals, are already widely used in biology to tag different molecules. "In principle, the quantum dots we use are the same. However, some special issues, such as long-term stability and adhesion to the objects, must be taken into consideration," said Shoude Chang, a member of the research team.

Info-inks are composed of a polymer, a solvent and a mixture of quantum dots, and can be painted or printed onto the surface of a document or object. By adjusting the number and emission wavelength of the quantum dots in the ink it is possible to create a digital fluorescence code unique to that object. Calculations suggest that the use of six different wavelengths and ten intensity values could create 1 million distinct codes.



Harry Turner

Quantum-dot coding: dots with different emission colours can be combined to create a unique identification label. The invention could put an end to barcodes.

To date, Chang and colleagues have made Info-inks containing CdSe nanocrystals (quantum dots), polystyrene and toluene. Experiments with five different emission wavelengths (535, 560, 585, 610 and 640 nm) have allowed the creation of inks containing a three-digit code.

The codes are read out by illuminating the ink with light from an ultraviolet (370 nm) LED to excite fluorescence from the dots. This fluorescence is captured by an optical-fibre bundle and fed to a spectrometer connected to a PC. Analysing the fluorescence spectrum reveals the code and thus the authenticity or identity of the item.

This overcomes many of the limitations that are associated with conventional identification technology. For example, although barcodes are widely used, they occupy a significant amount of space on the object and can only be read from a certain orientation.

In contrast, the quantum-dot code can be tiny and is easy to read out. "Compared with barcode readers, the information retrieval of this technology is simpler," said Chang. "It just collects the fluorescence emitted from the labelled object, and analyses the spectrum. No considerations need to be given to changes in the object's rotation, scale and position."

Chang and colleagues have now made a prototype read-out system which they say can retrieve a quantum-dot code that is encoded on the surface of a passport page, an identity card or the nail of a human finger.

The researchers are looking for industrial partners to help take this technology into practical devices. However, before it can be commercialized, the noise in the detection process and the durability of the quantum dots need to be investigated further.

LASERS

New laser system detects tiny cracks

A laser-based system for detecting tiny cracks in mechanical parts could soon be spotting invisible flaws in pressure vessels in a nuclear reactor or components of a car engine.

Framatome, a French maker of nuclear plants, has patented the technique and is working with CEDIP Infrared Systems, an infrared camera specialist, to turn the concept into reality.

"The technique can detect very small cracks that have a depth of less than 1 mm and are not visible to the eye," explained Pierre Potet, CEDIP's chief executive officer. "Our goal for 2004 is to make several versions to suit different applications, such as checking components in automobile engines or high-performance materials."

The so-called photothermal or "flying-spot" technique works by irradiating a target surface with a laser beam in order to raise the temperature of a small region by a few degrees. An infrared camera then maps the heat flow over the irradiated region. Any flaws or cracks in the surface interrupt the heat flow and show up clearly on the infrared image. The process is repeated over the entire surface to inspect the part completely.

Typical operating parameters are a temperature rise of up to 5 °C and a laser beam that is up to 20 cm wide. The duration and power of the laser irradiation are both dictated by the properties of the target material concerned.

Framatome

Shedding some light: from left to right, visible, dye-based fluorescence and photothermal images of a crack in a metal component. The crack is almost invisible in the first two images but shows up clearly in the third as an imperfection measuring 12 mm long.

According to CEDIP, the technique is compatible with any kind of laser and material providing that it is possible to perform the laser-heating. However, so far tests have centred on the use of Nd:YAG and CO_2 lasers and metal parts.

CEDIP believes that its photothermal technique could become a promising alternative to dye-penetration inspection, which uses a fluorescent dye that gets trapped in cracks to reveal tiny flaws in surfaces.

"We started this work about 10 years ago with the goal of replacing dye penetration, which is messy and uses nasty liquids that are pollutants," explained Potet.

The biggest drawback of the new technique is undoubtedly its expense. CEDIP says that photothermal systems are expected to cost around €200 000.

CONSUMER ELECTRONICS

Laser-projected keyboard gives PDAs a helping hand

A laser-projected keyboard for use with PDAs (personal digital assistants) was launched at the Consumer Electronics Show (CES 2004) held in Las Vegas, US, last month. The developer of the invention, iBIZ Technology of Arizona, is now selling the device from its website for $99 (€78).

The unit, which weights about 50 g and is the size of a cigarette lighter, projects a full-size QWERTY keyboard made of red laser light onto the desk where the PDA is placed. A built-in sensor then monitors the position of the user's fingers to determine what they are typing. Currently, this information is passed back to the PDA via a USB cable; however, a Bluetooth or infrared link will provide a wireless solution in future units.

iBIZ

Light touch: iBIZ's Virtual Laser Keyboard makes it easier to enter data into a PDA.

"The Virtual Laser Keyboard leverages the power of laser and infrared technology and projects a full-size keyboard onto any flat surface," explained Ken Schilling, the company's CEO. "As you type on that projection it realizes what you're typing by the co-ordinates of that location."

The new device also contains a rechargeable lithium ion battery so that the keyboard doesn't drain any power from the PDA. The battery lasts about 3–4 hours before it needs recharging.

The Virtual Laser Keyboard is compatible with Palm PCs, Pocket PCs, laptops and desktop PCs.

OLEDs

Head-up displays rise in resolution

Delegates at January's Consumer Electronics Show (CES 2004) in Las Vegas, US, received their first glimpse of an 800×600 pixels (SVGA) head-mounted display that uses the latest organic light-emitting display (OLED) technology.

The display, named X-eye, is the result of a collaboration between the US OLED specialist eMagin and Leadtek Research of Taiwan. Both monocular and binocular versions were on display at CES 2004.

Leadtek says that the headset provides a screen size equivalent to a 15 inch notebook computer or a 60 inch television. The device will initially be targeted at PC, PC DVD and PC game users.

The display plugs into an RGB port and can be used as a second "virtual" monitor for notebook PCs for editing multiple documents or to provide data privacy while travelling.

This set-up allows a user to view one document on the notebook screen while simultaneously viewing a second document on the headset screen.

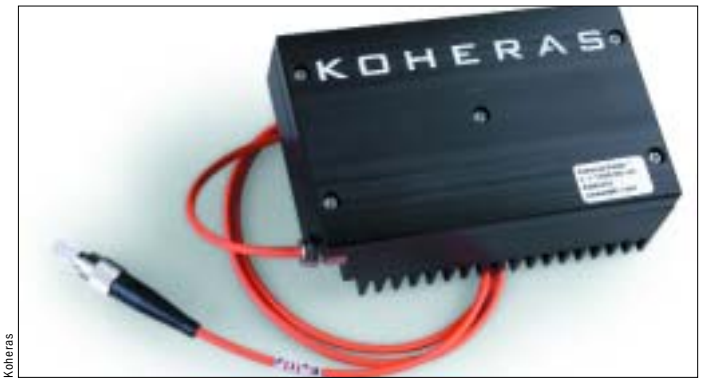
SOURCES

Danish fibre lasers help create compact LIDAR

A new range of miniature fibre lasers released at Photonics West 2004 last month by the Danish firm Koheras are enabling small, high-performance LIDAR systems for measuring wind conditions around aircraft.

To date, most compact LIDAR systems rely on semiconductor lasers, but their noise characteristics limit performance. "Compared to these, our fibre DFB [distributed feedback] laser typically has several decades' better frequency-noise performance, and comparable or even better intensity-noise performance," said Christian Poulsen, Koheras's chief technology officer.

The 125×175×75 mm module, named Pulsik, emits a train of nanosecond pulses at a single frequency in the near-infrared (which is selectable between 1535 and 1570 nm). Pulsik's typical specifications include a linewidth of about 1 kHz, a pulse width of 1–10 ns, a repetition rate of 10 kHz and peak power of 100 W.



Koheras

Koheras's new fibre lasers are helping to create high-performance compact LIDAR.

As a result, the Pulsik laser offers similar optical performance to a Nd:YAG laser, but with a footprint and electrical power consumption that rival a semiconductor source.

The key to the fibre laser's low noise is its DFB design, where a fibre grating is used to ensure very stable laser emission that has a very narrow linewidth.

According to Poulsen, the lasers are currently being used at several airports to measure windshear and turbulence. "These have been operating over some time with great success. There is also the potential to equip planes with such LIDAR to give 30 seconds of information on the future wind conditions," he told *OLE*.

The Copenhagen-based company also released a high-power continuous-wave DFB fibre laser at Photonics West. The Boostik module emits up to 5 W of optical power in the near-infrared.

PHOTONIC CRYSTALS

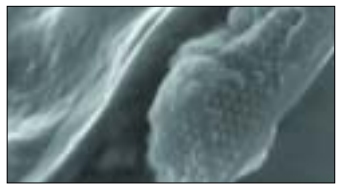
Weevil fabricates photonic crystal

Researchers at the University of Oxford, UK, have discovered what they say is the first example of an opal-type photonic-crystal structure in an animal.

The intricate 3D structure occurs in a small beetle which is just a few centimetres long. If the creature's self-assembly process can be emulated, the team says it could lead to a simpler and cheaper way to produce artificial opals (*Nature* 426 786).

"The interesting thing is that this has been found in a living organism," explained researcher Andrew Parker. "This means that the beetle must have cells that are making the structure, which gives us something to copy. There is a whole manufacturing process going on which starts with a series of chemicals and ends with a perfect opal structure."

All images: Andrew Parker



Top row: an anterior view of the weevil. Its body appears a metallic green colour from all angles thanks to a photonic-crystal structure. Bottom row: the scales are in patches over the weevil's body (left). Their inner structure contains tens of layers of 250 nm diameter transparent spheres in hexagonal-close packing order (right).

The opal-making animal is the weevil *Pachyrhynchus argus*, a small beetle that is found in forests in north-eastern Australia. Its body appears a metallic green colour from all angles thanks to a photonic-crystal structure that resembles opal.

The vivid colour comes courtesy of thin, flat scales which occur in patches over the beetle's body. The scales consist of an outer shell and an inner structure that contains layers of transparent spheres that are 250 nm in diameter.

"The spheres are arranged in hexagonal-close packing order," explained Parker. "The scales contain the opal structure. There are tens of layers packed on top of each other in a single scale."

The scales produce the green colour by thin-film reflection. "Because we have stacks of spheres instead of flat layers, we have a 3D structure where you can effectively form layers in many directions," he said."The reflections from each of these layers are superimposed and you get a colour-averaging effect which appears green."

DISPLAYS

Organic electrode brightens OLEDs

Brighter, more efficient OLED displays could be on the horizon thanks to a transparent organic electrode developed at Eastman Kodak's Display Technology Laboratory in the US (*Applied Physics Letters* 84 167).

Stacking OLEDs on top of each other in a so-called tandem design is one way to achieve brighter, more stable displays. Unfortunately, the metal-based electrodes which usually connect multiple OLEDs are not very transparent.

Now, researchers at Kodak have come up with an attractive alternative to the traditional metal electrode. They discovered that a combination of n- and p-type doped organic layers gives a contact that has good electrical properties, is highly transparent and is easy to fabricate.

The use of a transparent contact in a tandem structure looks set to have a significant impact on display performance.

As no light is lost between the separate OLEDs, the brightness of the display will scale linearly with the number of OLEDs that it contains. For example, a tandem device with three OLEDs is roughly three times as bright as a single OLED device.

The researchers have observed a luminous yield of approximately 130 cd/A for a green tandem device that consists of three distinct OLEDs.

According to the scientists, this means that a peak brightness in excess of 100 000 cd/m^2 is possible for this device with a modest current density.

"In passive-matrix OLED displays, the ability to produce high peak brightness is critical as it directly impacts the display brightness, size and resolution," commented Liang Sheng Liao, a Kodak researcher. "By capitalizing on tandem OLED structure, it is possible to produce passive-matrix OLED displays that are both efficient and sunlight-readable for important applications such as cellular phones."

According to Liao, tandem OLED research is currently still in its infancy. "An issue is the increase in the number of layers in the tandem structure. A more simplified structure may be necessary to reduce the cost of fabrication," Liao explained.

However, he added: "While we are not able to predict the time frame for commercialization at this point, we are confident that it will broaden the range of applications based on OLED technology."

FIBRE LAYERS

US scientists claim a Raman laser first

Scientists in the US say they have observed singlemode operation from a Raman fibre laser (RFL) based on a multimode fibre for the first time (*Optics Letters* 29 153).

In the past, RFLs have used singlemode fibre as the lasing medium. But according to Sung Baek and Won Roh at the US Air Force Institute of Technology, this limits the coupling efficiency between the pump beam and the fibre, which in turn decreases the overall conversion efficiency of the RFL.

The researchers' RFL uses a commercially available 40 m long, 50 μm diameter silica fibre as the lasing medium. They place a fibre Bragg grating which is highly reflective at 1116 nm at each end of the fibre and pump the system with a multimode Nd:YAG laser operating at 1064 nm.

SEMICONDUCTOR SOURCES

Disk laser provides orange solution

By Jacqueline Hewett

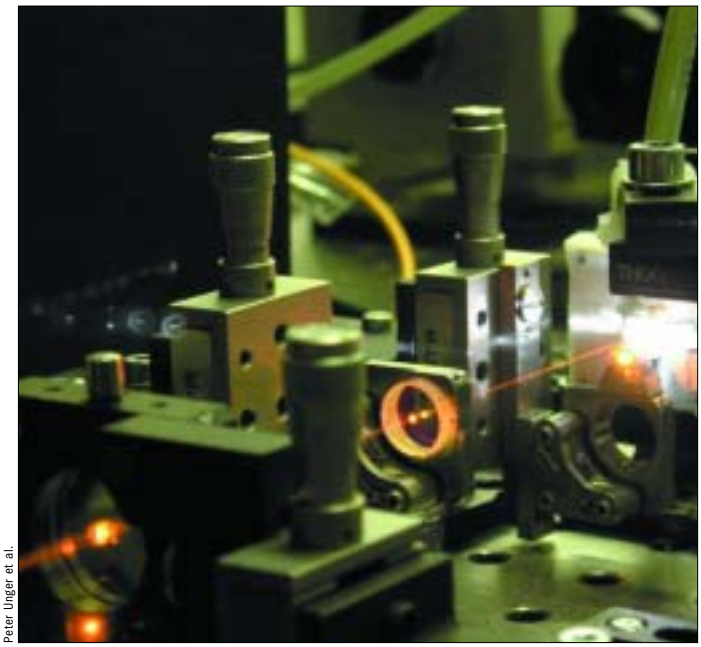
Researchers at the University of Ulm in Germany have developed a semiconductor disk laser that emits 30 mW at 610 nm.

The laser is based on a simple frequency-doubling scheme, and the team says it could replace expensive, power-hungry sources of orange light like diode-pumped solid-state and dye lasers (*Journal of Applied Physics* 94 7379).

"The main advantages of our device are its excellent beam quality, high output power and the possibility to scale the power by enlarging the optically pumped surface of the disk laser," said research leader Peter Unger.

The Ulm laser is based on the intracavity frequency doubling of a layered semiconductor structure that emits at 1220 nm. Today there are no semiconductor materials available that can produce orange wavelengths directly, so frequency doubling is the only option.

Unger explained: "Frequency doubling of semiconductor lasers in a conventional set-up usually requires an optical isolator, and may require a sophisticated optical design together with regulation electronics." However, intracavity frequency doubling does not have these disadvantages.



Peter Unger et al.

Orange emitter: the external mirror can be seen in the centre of the image and the doubling crystal on the right. The doubling crystal is hiding the semiconductor disk.

The semiconductor chip within Unger's laser consists of a gain region made up of GaAsSb quantum-well layers and a Bragg mirror of layers of AlGaAs and AlAs. Once grown, the chip is mounted on a heat sink in the laser cavity.

The laser cavity is formed by the Bragg mirror and an external concave mirror. A lithium-triborate crystal inside the cavity performs the second harmonic generation.

Pumped by an 80 nm broad-area laser diode, the fundamental wavelength of the disk laser is 1220 nm which is doubled to 610 nm. According to Unger, the laser emits 30 mW of 610 nm light at –15°C and 12 mW of 610 nm light at room temperature.

"We want to optimize the epitaxial structure to improve the output power and access other wavelengths," added Unger. "A longer-term goal is to develop compact, cheap and speckle-free RGB laser sources (at 630, 530 and 460 nm respectively) based on a semiconductor disk laser with intracavity frequency doubling."

LASERS

VCSEL breaks the world speed record

Scientists in the US say that they appear to have made the fastest vertical-cavity surface-emitting laser (VCSEL) in the world.

The device consists of an InGaAs laser structure which is passively modelocked by a semiconductor saturable absorber. The VCSEL generates a train of 980 nm wavelength pulses with a duration of only 15 ps and a repetition rate of 15 GHz.

The light-emitting and modelocking parts of the device are connected by a 1 mm thick microlens and a beamsplitter which acts as an output coupler.

The developers are from Brown University, the Massachusetts Institute of Technology and Novalux, a Californian maker of VCSELs. They reported the result last month (*Electronics Letters* 40 1).

The researchers believe that it could be possible to make even faster devices by increasing the bandwidth of the laser structure. This could be achieved by reducing the reflectivity of its n-type distributed Bragg reflector while increasing the gain in its multiple quantum wells.

"With an optimized saturable absorber, compacting the cavity into a fully monolithic structure should ultimately enable pulse repetition rates up towards 100 GHz with sub-picosecond pulse duration," said Art Nurmikko and co-workers in the paper.

"The concepts we use are rather general so porting this approach to other wavelengths, such as 1300 and 1550 nm regimes, seems feasible," they continued.

OPTOELECTRONICS

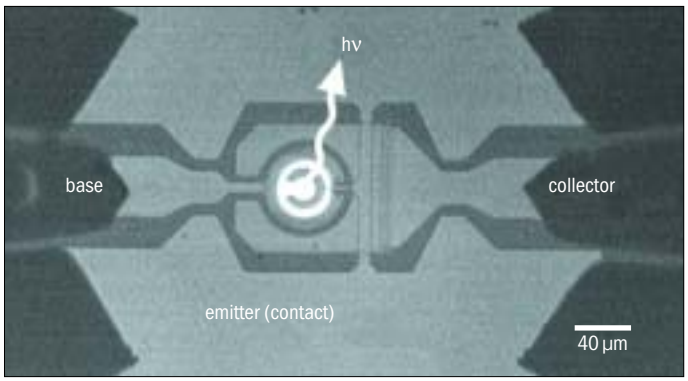
Light-emitting transistor unveiled

By Michael Hatcher

Scientists at the University of Illinois at Urbana-Champaign, US, say that they have made a light-emitting transistor that will bridge the worlds of optics and electronics. Grown using metal-organic chemical vapour deposition, Nick Holonyak Jr and Milton Feng's device consists of InGaP, InGaAs and GaAs layers and is based on a GaAs substrate (*Applied Physics Letters* 84 151).

"We have demonstrated light emission from the base layer of a heterojunction bipolar transistor, and showed that the light intensity can be controlled by varying the base current," said Holonyak. His work has previously been essential in producing the first practical LED and the first semiconductor laser to operate in the visible spectrum.

He continued: "A light-emitting transistor opens up a rich domain of integrated circuitry and high-speed signal processing that involves both electrical signals and optical signals."



Bridging the gap: the researchers say their light-emitting transistor is the key to high-speed signal processing involving both electrical signals and optical signals.

A transistor usually has just two ports: one for input and one for output. "Our new device has three ports: an input, an electrical output and an optical output," revealed Feng. "This means that we can interconnect optical and electrical signals for display or communication purposes."

Feng has also developed the world's fastest bipolar transistor, an InP-based device that operates at 509 GHz.

"In a bipolar device, there are two kinds of injected carriers: negatively charged electrons and positively charged holes," Holonyak said. "Some of these carriers will recombine rapidly, supported by a base current that is essential for the normal transistor function."

The recombination process in InGaP and GaAs creates infrared photons, which in the past has been regarded as a waste current generating unwanted heat, said Holonyak. "We've shown that for a certain type of transistor, the base current creates light that can be modulated at transistor speed."

So far, the researchers have demonstrated the modulation of light emission in phase with a base current in transistors operating at 1 MHz. However, much higher speeds are anticipated. "At such speeds, optical interconnects could replace electrical wiring between electronic components on a circuit board," Feng said.

Michael Hatcher is editor of Compound Semiconductor *magazine.*

PATENTS

PATENT INFRINGEMENT

Diomed challenges competitor over treatment of varicose veins

Diomed, a maker of medical laser systems, has started legal action against fellow US firm AngioDynamics in the US Federal District Court for the District of Massachusetts. Diomed is seeking injunctive relief and damages for infringement of its US patent number 6398777.

The patent covers endovascular treatment of varicose veins, including Diomed's EVLT product. "Diomed has invested more than $20 m [€15.7 m] in the commercialization of EVLT over the last three years and we will aggressively protect this investment," commented Diomed's president James Wylie.

SETTLEMENT

Medical laser makers settle and enter commercial partnership

Medical laser makers Lumenis of Israel and Trimedyne of the US have settled their long-running patent-infringement litigation. Under the terms of the settlement, the companies have entered into a long-term commercial arrangement covering the manufacture and sale of side- and angle-firing optical fibres.

Lumenis says the use of side-firing laser devices in spinal treatments is one of the fastest-growing segments in healthcare. Trimedyne's side-firing laser needles, which have a diameter of one-twelfth of an inch, are used to treat herniated or ruptured lumbar discs in the spine.

APPLICATIONS

Unwanted vibrations rattle the cages of QinetiQ researchers

Researchers at UK-based QinetiQ have come up with a device that they say can protect fibre-optic sensors and sources from unwanted vibrations. The design relies on a cage-like structure that is attached to the optical fibre. Any vibrations are coupled into the cage rather than passing into the sensor itself. According to the company, this structure is particularly useful when working with fibre-laser hydrophones.

Zinc selenide LED emits white light with high level of luminance

Japanese firm Sumitomo Electric Industries is trying to patent a white LED based on zinc selenide (ZnSe). According to the application, the device is based on an n-type ZnSe substrate which contains self-active luminescence centres. An active layer is fabricated on top of the substrate and an aluminium layer reflects light towards the device's output face. Sumitomo says that the device's luminance is high and the chromaticity of the white light can be adjusted easily.

Heat, light and electric fields alter the bandgap of photonic crystal

Photeon Technologies of Austria is trying to patent a way to alter the bandgap of a photonic crystal. The photonic crystal needs to be made of two materials, one with a variable refractive index. Changing the refractive index by applying an electric field, heating it or irradiating it with a specific wavelength of light changes the optical properties of the photonic crystal.

To search for recently published applications, visit http://pctgazette.wipo.int and http://ep.espacenet.com.

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Fibre-sensor specialist breaks the price barrier

A UK start-up has a cunning plan to make fibre-optic sensors a commodity item that sell in their thousands. **Oliver Graydon** visited Insensys in Southampton to find out more.

Last month was undoubtedly a milestone for the UK start-up Insensys. Just 18 months after it was founded the developer of fibre-optic strain and temperature sensors has begun to manufacture commercial products.

"The first units are rolling off the production line and we have orders for 70 systems in the first quarter of 2004," Martin Jones, its CEO, told *OLE* just before we went to press.

The first batch of sensors will be used to monitor the strain in wind-turbine blades, measure temperature profiles in oil wells and monitor the stress in composite structures in the marine and aerospace industries.

The news is the first step towards Insensys's dream of becoming a volume supplier of low-cost fibre Bragg grating (FBG) sensor systems. "We envisage being able to get into serious volumes and aim to make hundreds of units this year and thousands in 2005," explained Jones. "At the moment, we've got clients that we're quoting for anything from 50 to 300 systems."

The Southampton-based firm, with a workforce of 18, will soon move into larger premises in the area and plans to open an overseas office before long.

According to Jones, the key to the company's success in winning orders is that it has managed to hammer down the price of its products. Conversations with potential customers convinced him that to be successful, Insensys would have to sell a complete fibre-optic sensing system for around €5000 – which many in the optoelectronics industry would say was impossible.

"It's the price-point that's the key; in this market you've got to be really aggressive," Jones said. "We're not quite there [€5000] yet but we're not far away, and that's what's made these orders possible."

All images: Insensys

Insensys's Jones: "It's the price-point that's the key; in this market you've got to be really aggressive."

FBG sensors made by Insensys monitored stress in the mast of Ellen McArthur's yacht Kingfisher2.

Cutting costs

So just how has Insensys managed to make such a cost-effective system? The first reason is a new kind of FBG sensor system, one much cheaper and simpler than conventional designs which rely on wavelength-division multiplexing (WDM).

In a traditional WDM sensing system, each grating is written at a specific but distinct wavelength and interrogated using a tunable laser or tunable filter. The wavelength shift in the reflection from each grating reveals the strain that it is under. While this technique is well-proven it has disadvantages, namely the cost of a wavelength-swept optical source and the complexity of writing all the gratings at a different wavelength.

As the number of sensors increases, so does the technique's cost and complexity. This is not ideal where tens or hundreds of measurement points are required.

Insensys decided that it was impossible to make this kind of system at a price that was attractive to its customer base, so it started searching for an alternative. The solution came from Indigo Photonics, a spin-off from Aston University in the UK which specializes in FBGs. Its scientists had a brainwave and came up with a revolutionary sensor design that relies on time-division multiplexing (TDM) rather than WDM.

Put simply, in the Indigo design all the FBGs are written (and interrogated) at the same wavelength but are read out at different time slots. As a result there's no need for a tunable laser and a single mask can be used to write all the gratings, which have a reflectivity of around 4%.

"Essentially, we approached Indigo and said what we wanted was a system where we could interrogate up to 100 sensors in a fibre with each measuring up to ±6000 microstrain – and the architecture couldn't be WDM," explained Jones. "We also said that it had to be a solid-state solution with no moving parts, and consume less than 3 W at 12 V – so that it could be powered by solar panels or batteries. They delivered and came back to us with the TDM design."

In fact, Insensys liked the Indigo design so much that it purchased the company in July 2003. Indigo's photonics know-how seemed to be a perfect fit with Insensys's experience of working with composite structures.

The second key to reaching a low price-point was Insensys's decision to outsource its manufacturing – a strategy that many start-ups would be wise to follow. All too often, fledgling ventures try to do everything in-house and end up floundering where they have no expertise or experience. Insensys was determined not to make this mistake.

"All the manufacturing is outsourced as we have to be cost-effective and able to scale quickly. Insensys provides the innovation and the applications expertise," said Jones. "We're having the [printed circuit] boards manufactured by Foundation Technology and the optics assembled by Sifam."

By making systems that break through the price barrier associated with optics, Insensys plans to get ahead of its competitors and change the perception that FBGs are an expensive, impractical technology.

"My honest feeling is that the sensing area frustrates a lot of people. They can come ▷

Lucrative market: optical-fibre strain sensors deployed in oil riser pipes could be big business.

An Insensys rosette patch for measuring strain. It contains two FBGs at right angles to each other.

up with a great optical idea, but the distance between the idea and using it commercially is one that many companies are not capable of bridging," commented Jones. "On one side you've got specialists in optoelectronics saying 'This is a great technology – try it', and on the other you've got people saying 'You could never deploy this – it breaks and costs far too much'. I see our job as bridging that gap."

An array of applications

As for markets, Insensys is not short of applications for its TDM-based sensor systems. One area which is proving fruitful is the wind-turbine business, as engineers wish to monitor the stress being placed on the composite turbine blades which are several tens of metres in length.

"If you can measure the stress on the blade very accurately then you can feed that back into the blade computer, adjust the blade angles and improve efficiency," Jones told *OLE*. "That's a huge commercial driver for installing these systems."

Insensys's sensors are well-suited to this kind of application for several reasons. Firstly, they have been engineered to be deployed inside the composite material of the blades during manufacture. Secondly, since they are made of glass they are immune to electrical effects caused by lightning strikes or the generation of electricity at the hub of the turbine. Thirdly, the interrogator is compact, less than half the size of a laptop computer, and can be powered by a battery.

"Fibre-optic technology lends itself extremely well to wind turbines, as you've got a composite environment with high electric fields and serious risk of a lightning strike," said Jones. "A turbine typically needs 10–20 sensors, each with a wide strain range, and the customers require compact instrumentation with a 20 year life and minimal power consumption."

Two other markets which are a close fit with Insensys are the marine and aerospace industries. The firm fitted out Kingfisher2, the yacht of record-breaking sailor Ellen McArthur, with FBG sensors for monitoring stresses in the mast. A total of 12 FBG sensors were used. Arrays of four sensors were epoxyed to the inside of the mast at three heights in order to gain information about the mast's operating conditions.

Although the yacht broke in February 2003 during its attempt to beat the non-stop round-the-world sailing record, the data from the sensor were invaluable. Insensys is now collaborating with the Kingfisher team on their new carbon-fibre trimaran which launched last month.

Insensys is now working hard on another large marine project, to oversee the construction of sensor-equipped masts in the world's largest private yacht. When the yacht is complete in about 18 months' time it will feature three giant 60 m carbon-fibre masts that contain fibre sensors to measure the driving force of the rigs.

And that's not the only world first that Insensys is involved in. It's also part of a project to produce the first fully sensed composite aircraft, although details are being kept under wraps at the moment. Keep reading *OLE* to find out more later in the year.

The most recent study involves putting FBG sensors into the hull of a lifeboat to measure slamming loads. The aim is to obtain some real data on the conditions that the boat has to cope with to aid designers. Although it's early days, Jones says that trials just before Christmas generated some excellent data. The sensors were so sensitive that they could even measure the pressure of the surrounding water as the lifeboat was lowered into the sea.

He is now looking forward to what 2004 brings and is optimistic about the development of the market.

"Ultimately, I think that fibre sensors will become a commodity, and that people will view a piece of fibre with an FBG as equivalent to a conventional strain gauge," explained Jones.

"The sensor companies that strive for volume will strike price-points that make it very difficult for others to compete. Insensys is well on track to be one of these players." □

Innovative optics targets next-generation telecoms

Despite the telecoms downturn there is still plenty of innovation emerging from the R&D labs. **Steve Ferguson** of Marconi Communications examines 10 optical technologies.

There has been plenty of bad news in the telecoms industry over the last two years, but if you take a long-term view then telecoms has been a resounding success. Revenues of telecoms operators have risen enormously over the last 150 years, the amount of traffic per bearer has increased steadily and analysts forecast that the market for "next-generation optical products" is healthy.

Equipment vendors and network operators that want to take advantage of the long-term potential of the industry must now watch the innovation going on in research labs in order to see which optical technologies will be key for future growth.

In the near future, industry emphasis will continue to be on consolidation and cost reduction and many products will be based on existing components and product types. However, looking beyond 2005, there are a variety of emerging technologies that could well prove invaluable to this industry.

Marconi

The best of both worlds: many future technologies combine the strengths of electronics and photonics.

Enhance and advance

Much of the research currently under way builds on techniques and ideas that already exist and combines them to create dramatically better systems. Wavelength switching and broadband passive optical networks are key examples.

Wavelength switching can be used to reroute traffic, independently of payload protocol. Remotely reconfigurable optical add–drop multiplexers (R-OADMs) provide the first stage of wavelength switching, and Marconi has already deployed more than 300 R-OADMs in public networks, each capable of supporting up to 32×10 Gbit/s.

Before full photonic cross-connects, which promise massive savings in cost, space and power consumption, can be deployed, traffic needs to grow. Current 32-, 40- and 80-channel systems still have light traffic loads.

With greater loads, many operators and vendors view R-OADMs as a significant feature of future networks. Wavelength switching will offer the greatest value when combined in nodes with electronic switching, under a single level of automated management control.

Broadband passive optical networks (B-PONs) are an attractive way to deliver fibre-to-the-home (FTTH). Although the major investments in B-PONs in the mid-1990s were too early to impact the market, investors have recently begun to show increased interest again.

Japan leads the way in FTTH deployment and authorities predict more than 7 million users there by 2006. This is in part because of Japan's high density of housing, but also owing to a national policy for broadband. Some European countries, such as Italy and Germany, are also deploying FTTH in areas such as greenfield housing.

One application that could also drive FTTH deployments is the provision of video services, which several operators have earmarked as their best bet for good future margins. While asymmetric digital subscriber line systems combined with MPEG4 coding could deliver video services, there are many constraints. Delivery across fibre removes these.

Electronic integration

The use of electronics to improve the performance of photonic systems is another major research area, and the technology is now moving beyond 10 Gbit/s. One example application is enabling multimode fibre (which offers low installation costs but is often thought to be limited in terms of speed or distance) to achieve 10 Gbit/s in B-PON or access network applications that require a range of around 1 km. Techniques that could help this include forward error correction and fibre compensation.

Forward error correction (FEC) improves photonic-performance margins by digitally correcting errors after they occur but before the data are used. The fast response of electronics, compared with today's typical photonic devices, is an advantage when compensating for polarization-mode dispersion. FEC uses powerful processing electronics for 10 Gbit/s systems and is being developed further for use at 40 Gbit/s. In addition, true digital photonics techniques could give 160 Gbit/s.

Fibre compensation is a precursor to the true integration of electronic and photonic technologies on the same chip. This technique compensates for fibre impairments at the photonic level to prevent digital errors before they occur. The technique is similar to that of the phone-line modem in a PC, but 200 000 times faster. ▷

Many fibre routes need conditioning for use beyond 2.5 Gbit/s owing to the effects of dispersion. The effects of current photonic-compensation techniques are marginal for 40 Gbit/s and introduce a 20–30% loss. Electronic compensation is not as effective as true photonic compensation, but its costs are much lower.

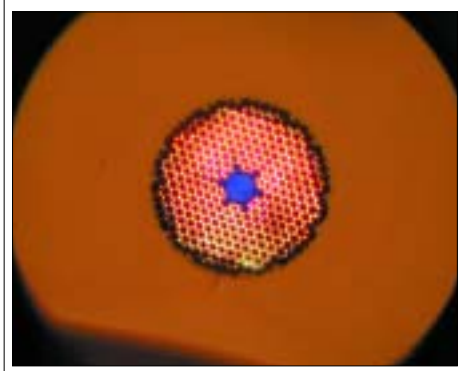
Digital boost

Although still at the research stage, digital photonics techniques such as multiwavelength regenerators, multiple integrated photonic digital devices and optical packet switching could greatly improve system capacity, cost and functionality.

Multiwavelength regenerators promise to remove the planning burden of analogue characterization for long-distance routes. Two approaches are being studied at present. The first employs multiple regenerators in a chip, which is difficult to do and is really just putting more electronics in a package. A more innovative approach is the regeneration of multiple (about 10) wave-division multiplexing (WDM) channels within one optical-processing device, typically a variant of a semiconductor optical amplifier. Such devices could be deployed in around three to five years.

Multiple integrated photonic digital devices (devices integrated onto one substrate and suitable for mass production) could be used to create devices for FEC, demultiplexing and more intriguing applications such as encryption. Photonics researchers want to be ready for the day when substrates other than silicon will be used.

As is the case with many photonics applications that burst onto the market, distributed switching and control have been the focus of much research in universities. However, improvements in all-optical switching and optical memories are still needed, and **optical packet switching** will probably first appear as optically assisted packet switching in single-router nodes.



BlazePhotonics

Ahead of the rest: photonic-crystal fibre is the most commercialized photonic-bandgap technology.

Holey structures

Photonic-crystal devices and fibres rely on photonic bandgaps and promise impressive control over the properties of optical devices.

Just as electronic bandgaps are the basis of transistors and integrated circuits, **photonic bandgaps** could form the basis of many types of active and passive optical devices. A photonic crystal is a lattice in a dielectric material created, for example, by an array of holes in an optical waveguide. These holey structures can be tailored to create photonic bandgaps – a range of frequencies in which electromagnetic waves cannot propagate.

On a substrate such as silicon, a pattern of microscopic holes or similar discontinuities shapes the light field, enabling overall device sizes just a fraction of those today. For example, 3 dB fibre couplers now on the market are tens of millimetres long. In a photonic-crystal device, the equivalent functionality could fit into just 20 μm.

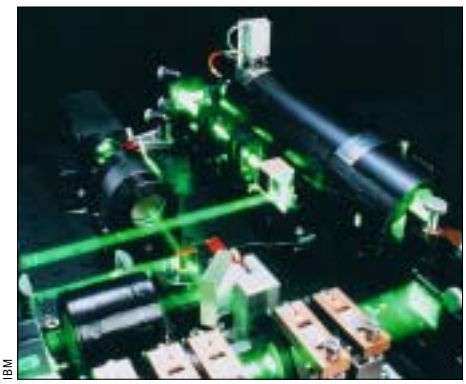
Most work at present is on 2D devices – structures patterned in two directions and

constant in the third. Fabricated via photolithography, plasma etching and metallization, such structures can produce nearly lossless filters, waveguides and mirrors, lasers with a low current threshold and holey optical fibres (see below).

Three-dimensional devices are just starting to emerge. These are much harder to create, but will be needed to make active photonic-bandgap-based devices. Scientists in Japan plan to build commercial 3D optical crystals in space, relying on the zero gravity to prevent distortions in the lattice.

Photonic crystals offer the possibility of single-substrate integration of photonics and electronics. When combined with digital photonics, this could enable the multiple parallel processing of ultrahigh-speed signals.

Photonic-crystal fibre is the most commercialized photonic-crystal technology, and comprises a long thread of silica glass with a periodic array of holes (containing vacuum, air or liquid) running along its length. It can give extreme properties, such as selective forbidden regions of wavelengths or high nonlinearity. Other fibre designs can offer greatly reduced signal degradation for transport applications, nonlinearity 100 times lower than current fibres and almost perfect control of chromatic dispersion.



IBM

From research to business: optical technologies will continue to play a valuable role in telecoms.

In the longer term, the attenuation could potentially be much lower than on legacy fibre. The industry is not there yet, however – current loss from photonic-crystal fibre is 13 dB/km compared with legacy-fibre loss of 0.2 dB/km – and there are big questions regarding what to do about splices.

Data storage

The final category of emerging technologies is a wild card – optical signal storage. Researchers in this field have come up with many ideas but, so far, few useful techniques. For example, there is still no optical random-access memory. Such a device could revolutionize router design because optical memory is potentially much faster, although it would not necessarily be smaller or denser than electronics.

There is considerable ongoing research in this area. Light has already been slowed by 2000 times in a solid-state device and the latest results show that it can be slowed at room temperature. This could prove a crucial breakthrough. After all, laser development only began seriously once the first room-temperature lasers appeared.

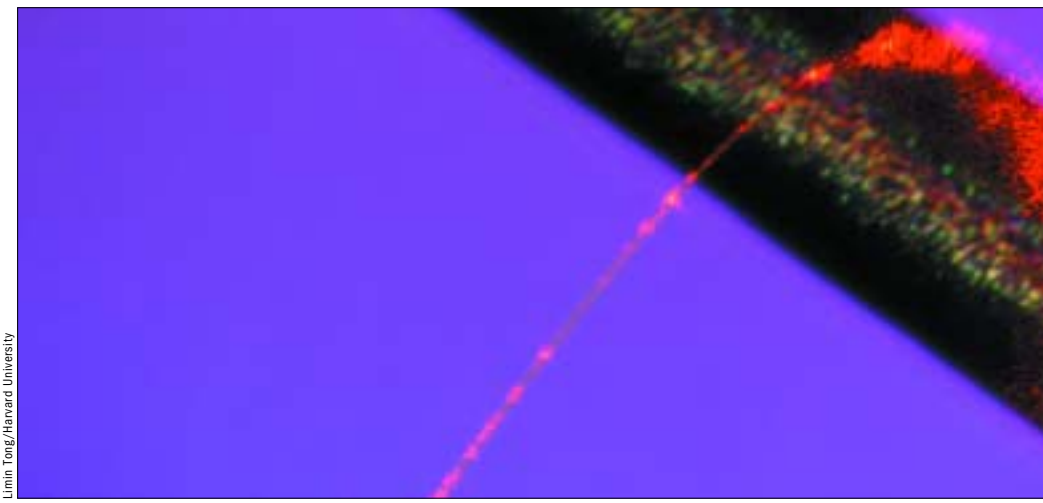
Commercial potential

All of the above technologies could prove highly useful in tomorrow's optical networks. Photonics is inherently as powerful as electronics, and the potential of the emerging combination of the two is awesome. There are plenty of areas for innovation, as is evident at the key industry conferences and meetings. Positioning these ideas for commercial success is a real challenge but, crucially, the long-term market in telecoms is still healthy. □

Steve Ferguson (stephen.ferguson@marconi.com) is photonics strategy director at UK telecoms equipment maker Marconi Communications.

Low-loss nanowires creat

Optical sensors, integrated circuits and photonic devices are just some of the applications set to benefit from nanowires made out of glass. **Jacqueline Hewett** speaks to the researchers pioneering the development of these ultra-fine fibres.



Limin Tong/Harvard University

Stephanie Mitchell/Harvard News Office

Limin Tong/Harvard University

Top: a light-conducting silica nanowire wrapped around a human hair – Eric Mazur's team has made nanowires as thin a Mazur in his laboratory at Harvard University; to create the nanowires, a silica wire is wrapped around a sapphire taper super-smooth glass nanowire (right); SEM image of a nanowire curled in a loop in front of a strand of human hair; a tiny

When you think of thin or fine strands of material, human hair and spider silk may be two examples that spring to mind. But these structures are several orders of magnitude larger than the latest optical waveguide.

An international team of scientists has created silica nanowires – ultrafine strands of glass that guide light and have a diameter of about one-thousandth of a human hair.

Despite their small size, low-loss silica nanowires look set to have a big future. For example, they could become connections for miniature photonic circuits, optical probes capable of detecting biological particles or even the basis of photonic devices such as tiny wavelength splitters.

Fabricating silica fibres that are smaller than 1 µm in diameter is much easier said than done. But last December a team from the US, China and Japan succeeded. Eric Mazur and colleagues from Harvard University, Zhejiang University and Tohoku University claim to have developed a fabrication method that is both repeatable and reliable.

"About two years ago Limin Tong, a researcher from China, joined my group and he was interested in making very-small-scale fibres," explained Mazur. "While in my group he developed this two-step technique to pull these incredibly thin fibres."

Tiny wires, major achievement

The process creates glass wires, which have diameters as small as 50 nm and boast an optical loss of less than 0.1 dB/mm for visible and infrared light. According to the research team, this level of transmission is good enough for use in optoelectronic devices.

"Many attempts have already been made to create thin fibres, but none have had the length and smoothness that we have accomplished," Mazur explained. "All the other processes have resulted in fibres with much rougher sidewalls, which makes them useless at guiding light because it gets scattered. The walls of our nanowires are almost atomically smooth."

These days, scientists can reliably make glass wires with diameters on the order of a few microns by heating a conventional 125 µm diameter optical fibre in a flame then pulling it. When it comes to thinner structures, Mazur says that the temperature distribution of the flame causes problems.

"The flame tends to be very turbulent and the temperature around its edge varies continuously," he said. "If you pull the fibre too fast, or it is too hot, then the wire breaks or the diameter is not uniform."

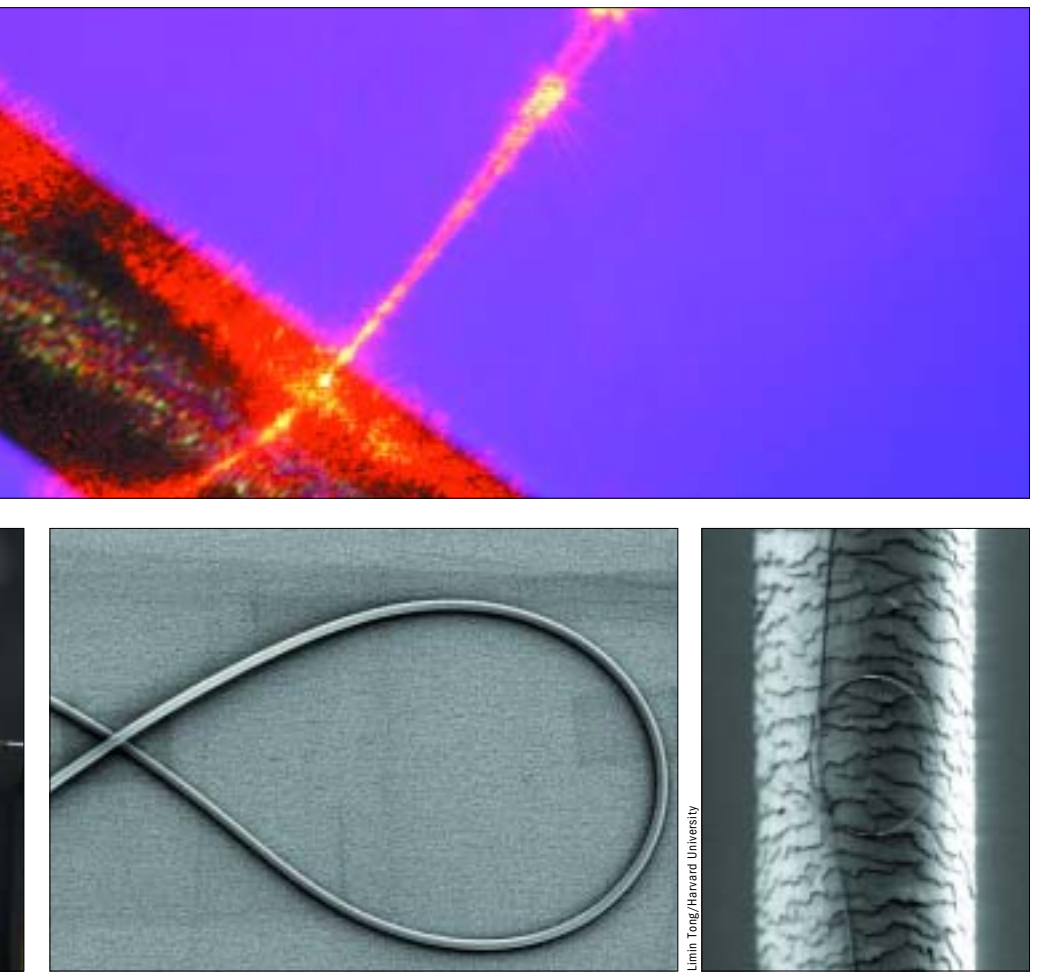
The solution to the problem, and the secret behind Mazur's uniform nanowires, is a surprisingly simple technique. A flame-heated fibre is drawn into a 1 µm wide wire and wrapped in a spool around a sapphire taper before it is drawn a second time.

"The sapphire taper is then placed in the flame keeping the spool just outside it," explained Mazur. "The taper serves as a buffer to even out the temperature. This is why we are able to draw such reliably uniform wires." Mazur and colleagues have been able to pull uniform nanowires around 2 cm in length.

Another advantage of these ultrafine wires is that they are incredibly strong and flexible, and can be twisted and tied into tight knots. For example, Mazur's team have bent a 280 nm wide wire into a radius of 2.7 µm without breaking, and fracture tests show that the wires have a typical tensile strength of 5.5 GPa. What's more, calculations suggest that a 450 nm diameter wire could route red light around a 90° bend (5 µm radius) with a bending loss of just 0.3 dB.

But perhaps the most amazing result is that, despite having a diameter that is much

e a wealth of applications



Limin Tong/Harvard University

as 50 nm and with an optical attenuation as low as 0.1 db/mm at 633 nm. Bottom, left to right: nanowire pioneer Eric (seen on the left) held over a flame, and as the wire reaches 1700 °C it is drawn along the taper to create an ultrathin, knot tied in a nanowire creates a simple photonic device – a tiny ring-cavity with a high Q factor.

"Just by making a knot you have an extremely simple photonic device."

Eric Mazur, Harvard University

smaller than the wavelength of visible light, the nanowires act as a waveguide. "We have shown that most of the light is actually guided around the wire rather than inside it," explained Mazur. "The wire serves more as a rail than a funnel."

According to Mazur, a 300 nm diameter nanowire guides about the same amount of red (633 nm) light outside the wire as inside. This makes the nanowires very sensitive to their surroundings and opens up a vast range of applications.

Top of his list is using the nanowires as optical sensors. "One of the things we are doing right now is to coat the outside of these wires with biological receptor molecules," he explained. The idea is that when a specific pathogen binds to the receptor, it interacts with the propagating light and changes the transmission spectrum of the nanowire. "We can't detect single molecules – that would be really hard. But we can detect tens or hundreds of molecules, making this a very sensitive sensor."

The researchers are now collaborating with chemists and biologists at Harvard to construct and test such sensors.

The nanowires are also destined for use in photonic devices, ranging from simple low-loss connections to more complex devices, such as wavesplitters. As much of the light is guided around the wire, it is easy to couple light between two touching wires, through a process called evanescent field coupling. The ease with which light can be injected or removed from nanowires makes them particularly attractive for use in miniature photonic circuits.

Mazur claims that a contact region about 10 μm long is enough to transfer the light from one nanowire to another.

"It is very easy to slide the light from one wire to another and this is good for photonic circuits," said Mazur. "You can for example change the transmission of one fibre by having it on top of a grating. This is another thing that we are actively engaged in."

Turning to photonic devices, Mazur's team has already studied a simple nanowire knot, which also acts as a ring cavity, or in other words a miniature interferometer. Light travels around the ring of the knot then undergoes constructive or destructive interference, depending on the length of the knot and the wavelength of the light.

"Just by making a knot you have an extremely simple photonic device," said Mazur. "We have measured the Q factor of this and it is quite encouraging. If you were using normal optical fibre, you would not have a high Q factor and the ring would not be a good resonator. The reason our device works so well is that a lot of light travels outside the ring."

Mazur hopes that the applications being tested in his lab will cross over into industry within the next few years. Having patented the technique, he is also keen to persuade others to join him in developing new applications and devices.

Promise and potential

It seems obvious that the best is yet to come in this area of research, which is very much in its infancy. "Who would have thought that you could bend light around a radius of just a few times its wavelength?" said Mazur. "We've seen light with a wavelength of about a micron travel around a bend of around several microns. It's extraordinary."

And for Mazur, there is the added satisfaction that these amazing results have come out of research that is mounted on a simple breadboard. "On the one hand the guiding of light and things like nanotechnology and photonics are high-tech terms, but on the other the tools that we used to achieve all of this were exceedingly low-tech," he said. "It's simple, reliable and reproducible." □

Thin films give optical components a boost

Thin-film coatings can be essential to obtaining the desired performance from an optical component. **Stuart Allan** describes the types available and provides purchasing advice.

Optical thin-film coatings have now penetrated almost every aspect of everyday life. A little investigation shows that they are present in everything from the lenses in spectacles and cameras to the specialized optics inside lasers.

Of the optical components in use today, the vast majority are made of glass which has been coated. Coatings are usually made from either a single dielectric thin film or a stack of such films.

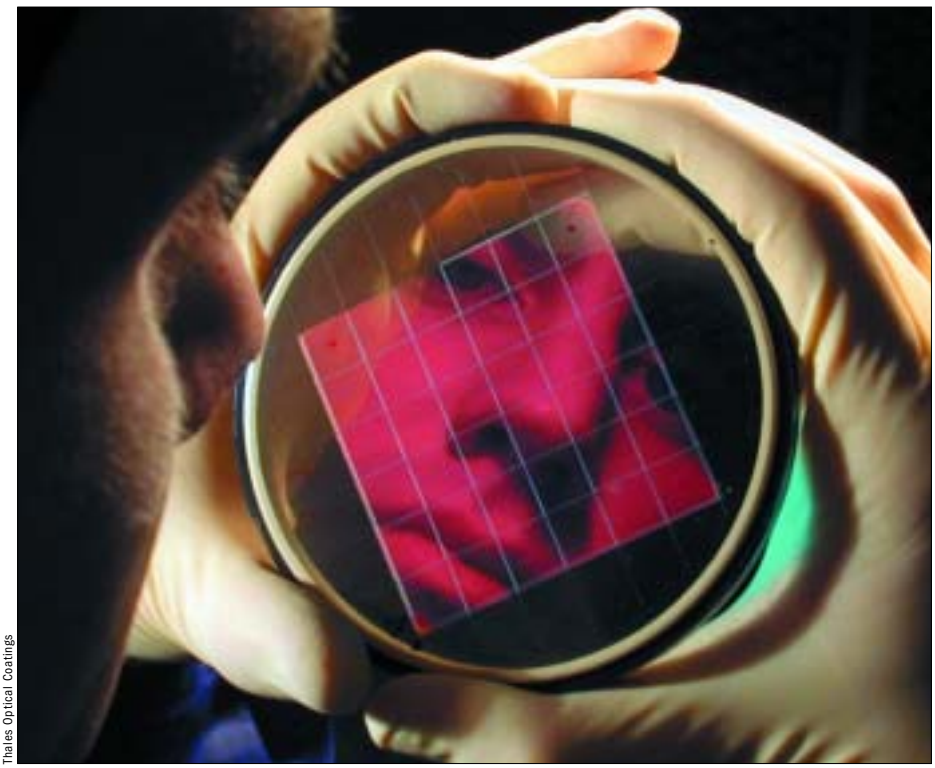
These films are often made from metal oxides and fluorides, and are typically just a few tens or hundreds of nanometres thick. The purpose of the coating is to modify the transmission and reflection of the optical part, such as minimizing reflections or blocking certain wavelengths.

The need for coatings, especially anti-reflection versions, is easy to understand. Whenever light passes from one medium to another, such as from air to glass, some of the light is transmitted and some reflected. The amount that is reflected is determined by the difference in the refractive index between the materials, and by the angle of incidence of the incoming light.

For a light beam in air striking uncoated glass at normal incidence, the strength of the reflection is typically just a few per cent of incident optical power. For example, in the case of the common glass BK7, which has a refractive index of 1.52, the reflection is 4.25% at each air–glass boundary.

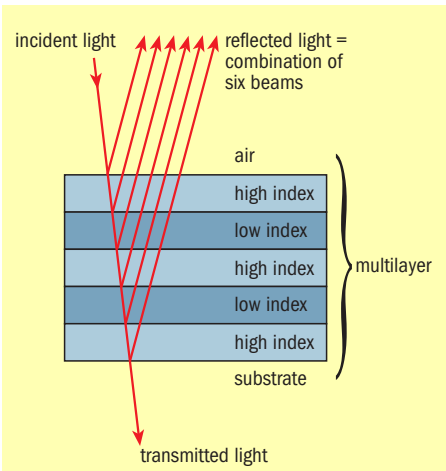
Although this may not seem much, for optical designs using more than a few components, losses in transmitted light can rapidly multiply, especially if high index glasses are used – as in the case of infrared systems. In imaging equipment, these weak reflections can also cause a significant loss in image contrast as ghost images, since the reflections may get superimposed on the primary image.

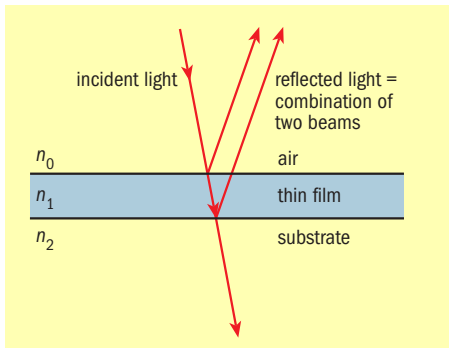
Fortunately, in many cases these troublesome reflections can be eliminated by the use of a thin-film anti-reflection coating. In a similar fashion it is possible to create highly reflective coatings that give almost perfect mirrors with a reflectivity of almost 100%.



Thales Optical Coatings

Mirror magic: thin-film coatings play a vital role in optimizing the performance of optical components.





The principle of a thin-film coating: interference between reflections from a single film (above) or multiple layers (left) determines the precise optical characteristics of a particular coating.

However, the use of thin-film coatings is not limited to these tasks – they can also be employed to create different kinds of wavelength filters and beamsplitters (see box "Filter types explained" p27).

The science behind optical coatings

So how do thin-film coatings work? Put simply, the optical properties of a coating are governed by optical interference between the reflections from the upper and lower sur- ▷

faces of the film. With a stack of thin films, reflections from each of the layers need to be considered to understand the coating's optical characteristics (see figures p25).

A simple anti-reflection coating can be made by choosing a film of a certain thickness and refractive index so that the reflections from its upper and lower surfaces are out of phase and will interfere destructively. In reality, this coating is often made from a single film with an optical thickness equal to a quarter of the incident light's wavelength. These "quarter-wave" films are a common building-block in many designs of coating.

For example, a highly reflective coating can be made from an alternating stack of high- and low-index quarter-wave films. All the reflections from the layers are designed to be in-phase so that they interfere constructively. The reflectance of the coating increases with the number of layers. Alternatively, optical elements can be coated with a metal such as aluminium or gold to create a high-performance mirror.

Coating materials

In principle, the surface of any optical element can be coated with thin-film layers of various materials to provide the desired transmission and/or reflection characteristics. Potential materials include titanium dioxide, tantalum oxide, zirconium oxide, aluminium oxide, silicon dioxide, magnesium fluoride, zinc sulphide, germanium, silicon and silicon oxide. With the exception of metallic coatings, the optical performance of the coating depends on the nature of the substrate material.

Note that thin-film coatings are designed to work under a precise set of operating conditions. The performance of a coated optical component is likely to vary with the wavelength of incident light, its angle of incidence and the polarization, as well as the ambient humidity and operating temperature.

Clever designs of multilayered films are useful for creating a coating that meets several sets of specific conditions (wavelength and angle of incidence) or a particular range of conditions.

Specifying an optical coating

Optical coatings generally fall into three main spectral regions: the ultraviolet (UV), the visible and near-infrared (VIS–NIR) and the infrared (IR). The coating materials used differ depending on the wavelength region of operation, though some specialized coatings are multi-spectral. Different coating houses may specialize in some or all of the wavelength regions.

When you are specifying an optical coating, the thin-film design engineer would benefit from the following information:

- the purpose of the intended optic;
- the type of coating proposed, for example whether it is long- or short-wave pass (see "Filter types explained");
- the wavelength range involved;
- the transmission, reflection, absorption and scatter requirements (with tolerances) of the filter;
- the angles of incidence, e.g. 45±5°;
- the polarization state or states of the incident light;
- the type of substrate material;
- the dimensions of the part;
- the clear aperture;
- the cosmetic quality required, i.e. the scratch/dig requirements;
- which side(s) of the optic can be coated;
- the optic's environmental requirements;
- any military (MIL) specifications or similar restraints; and finally,
- the quantity required.

In conclusion, there are many aspects to optical thin-film coatings that need to be taken into account before you place an

Filter types explained

Here is a summary of the most common types of optical thin-film filter.

ANTI-REFLECTION COATINGS

Single-layer anti-reflection (SLAR): this is a single-layer coating and is usually specified for one wavelength, one angle of incidence and one set of reflection/transmission requirements.

Broadband anti-reflection (BBAR): this is a multilayer anti-reflection coating that is designed to operate over a wavelength range, e.g. 400–700 nm, at designated angles of incidence and with specified reflection/transmission characteristics.

Extended-band anti-reflection: as above, except the wavelength range is extended to, for example, 400–1100 nm, and the reflection/transmission requirements are not usually as stringent as the broadband coating.

Dual- or triple-band anti-reflection: as suggested these are specified over two or three distinct wavelength ranges.

V-Coat anti-reflection: this type of coating is used at a specified wavelength with a very low reflection (R) requirement – usually $R < 0.1\%$, though in some telecoms applications $R < 0.0001\%$ is now demanded.

WAVELENGTH FILTERS

Short-wave pass (SWP): this type of coating is specifically designed to transmit shorter wavelengths and to reflect longer wavelengths. A sample specification could be a transmission of $T > 85\%$ absolute at 400–520 nm, $T = 50\%$ at 530±5 nm, $T < 0.1\%$ at 550–690 nm; angle of incidence 0±5°; random polarization. The transmission values can be higher if an anti-reflection coating is applied to the reverse face.

Long-wave pass (LWP): this coating type is designed to transmit longer wavelengths and reflect shorter wavelengths. A sample specification could be $T > 85\%$ at 540–700 nm, $T = 50\%$ at 530±5 nm, $T < 0.1\%$ at 410–510 nm; angle of incidence 0±5°; random polarization. Again, transmission values can be higher if an anti-reflection coating is applied to the reverse face.

Band pass (BP): these allow the transmission of light within a carefully defined wavelength range, while light outside this range is blocked. Available with narrow or wide wavelength windows of transmission, these filters are usually defined through their centre wavelength ($\lambda 0$), full-width half-maximum (FWHM), peak transmittance (T0) and rejection bands. For all the parameters, tolerances are required.

Notch: a notch filter is used to reflect a specified wavelength, or a narrow wavelength region with high transmission outside that region. A typical performance might be $T = 45 \pm 2\%$ at 550±3 nm, $T > 95\%$ at 420–520 nm and $T > 95\%$ at 580–770 nm for a specific notch-depth coating. Sometimes notches are specified with a wavelength window, e.g. $\Delta\lambda < 20$ nm at 10% points and $T < 0.0001\%$ at 560 nm. An alternative specification would be optical density $OD > 5$, $T > 95\%$ at 420–540 nm and $T > 95\%$ at 580–770 nm.

REFLECTIVE FILTERS

Three types are available: commonly high reflectors, metallic reflectors and enhanced metallic reflectors. These are all specified with various levels of reflection, angles of incidence, polarization and wavelength range. For a high reflectance over a restricted wavelength range a multilayer would be best. In contrast, for a wide wavelength range and a lower reflection requirement, the enhanced metallic reflector is suitable, and for a very wide wavelength region, potentially from the visible into the far-infrared, a metallic reflector is probably best.

BEAMSPLITTER COATINGS

Beamsplitters split an incoming light beam into two distinct output beams, and often make use of specialized coatings. When purchasing, the transmission and reflection characteristics, a wavelength range, angles of incidence and polarization must be specified, e.g. $T = 70 \pm 3\%$; $R = 30 \pm 3\%$ at 420–700 nm; angle of incidence 45±5°; random polarization.

order. Coatings can be made to meet the most stringent requirements from a technical point of view, but remember that the price depends significantly on the tightness of the specification. So always ask yourself, "Do I really need ±1 nm tolerance, or will ±5 or ±10 nm suffice?" The difference in price is remarkable.

Remember too that the optical thin-film design engineer is always willing to discuss your requirements. □

Stuart T Allan is the technical manager of Thales Optical Coatings, Plymouth, UK, and has worked in the thin-film industry for 15 years. For more information see www.thales-opticalcoatings.co.uk.

PRODUCTS

If you would like your company's products to be featured in this section, please send press releases and images to Jacqueline Hewett (jacqueline.hewett@iop.org).

Colour sensor

Laser Components (UK) Ltd

Laser Components says that its LT-FS series of colour sensors removes the ambiguity of the human eye when trying to discern the differences in the colour, hue and shade of objects. At the heart of the LT-FS module are a white-light source and a sensor housed within a rugged IP65-grade housing. RGB composite values of the target object are provided through an RS232 port.

Colour recognition has applications in areas such as the printing, medical, aeronautical and manufacturing industries. The LT-FS allows objects to be analysed quickly on high-speed conveyors, such as when checking the ripeness of fruit or the colour of paint, for example.

www.lasercomponents.co.uk

Fast-steering mirror

Newport

Newport, US, claims that its new FSM-300 fast-steering mirror offers the same automated beam-positioning capabilities as its "groundbreaking" 2 inch-diameter sibling in a more economical 1 inch-diameter configuration.

The FSM-300 provides the ability for high-bandwidth, two-axis stabilizing, pointing and scanning of laser beams over a ±52 µrad (±3°) range with a resolution of better than 1 µrad.

The FSM-300 utilizes a single mirror mounted on a two-axis flexure, which is said to deliver several advantages over two-mirror galvanometer driven systems. These include lower wavefront distortion, no displacement jitter and no polarization rotation.

The FSM-300 is supplied with a pyrex mirror which has either an enhanced aluminium coating with high reflectivity in the visible spectrum, or a protected gold coating for operation in the infrared.

www.newport.com

DBR laser diodes

Frankfurt Laser

The latest line of distributed Bragg reflector (DBR) fibre laser-diode modules from Frankfurt Laser Company offer an emission linewidth of just 250–200 kHz. The lasers comprise a Fabry–Perot laser chip which is coupled to a singlemode fibre containing a Bragg grating.

Laser diodes are available in the near-infrared (780–1690 nm) with output powers from the fibre ranging from 1 to 25 mW. They are supplied in DIL-14 and butterfly housing including TEC, thermistor and monitor diode. The output fibre can be terminated with any industry-standard optical connector.

Potential applications include spectroscopy, metrology, direct frequency doubling, Raman laser seeding, LIDAR and telecommunications.

www.frlaser.com

Eye-safe lasers

Photonics Industries International

Photonics Industries of the US claims to have launched the first eye-safe wavelength optical parametric oscillator (OPO) that can operate at 10 kHz in repetition-rate and in Q-switched mode.

The DS Series of Nd:YLF-based OPOs incorporates the company's own frequency-conversion technology, which enables it to produce a high-efficiency, high-pulse-rate laser source at the eye-safe wavelength of 1.516 µm.

The system produces 3 mJ per pulse at a repetition rate of 1 kHz and in excess of 3 W at 2.5 kHz. Photonics Industries says that this source suits applications such as rangefinders, environmental sensing, military target and security illumination, LIDAR and many more.

www.photonix.com

Faraday isolator

Del Mar Ventures

Del Mar Ventures of the US has released a Faraday isolator for use with femtosecond Ti:Sapphire lasers.

The model 5AFI36-800B is a broadband optical isolator that allows the transmission of incoming linearly polarized light, but blocks any other light that is travelling back towards the device in the opposite direction.

The isolator can be used to protect a laser from any potentially harmful back-reflections. It consists of a Faraday rotator and two polarizers. Del Mar says that the Faraday rotator contains a magneto-optical rod cut from glass (MOS-10), polished to flatness l/10 and with parallelism better than 10 arcseconds.

It has an anti-reflective coating to give a reflection of less than 0.2% (each side) in the range 765–835 nm. The polarizers are air-spaced Glan prisms made of calcite and also have an anti-reflective coating.

www.femtosecondsystems.com

PRODUCTS

Thin-disk laser
Spectra-Physics

The DisQ-Mark Q-switched, thin-disk laser from Spectra-Physics generates up to 8 W of near-infrared output with good beam quality ($M^2$4), and pulse-repetition rates of up to 50 kHz. The firm claims that the diode-pumped Nd:YAG laser delivers a unique combination of cost and performance benefits for marking and precision machining.

The laser can create surface marks on many organic materials, including most plastics, as well as on a wide variety of metals, such as aluminium and anodized aluminium. Spectra-Physics says that it also delivers higher intensity, resulting in deeper or faster marking compared with lamp-pumped lasers of inferior beam quality. Additionally, the DisQ-Mark laser is suitable for uninterrupted, 24 hour operation in other precision-machining applications, such as engraving and scribing.

www.spectra-physics.com

Software upgrade
Breault

Breault Research, a developer of optical-analysis software which is based in Arizona, US, has launched version 8.0 of its ASAP (Advanced Systems Analysis Program) optical-modelling package.

According to Breault, ASAP 8.0 has a host of new features to help optical designers. The major innovations include CIE numerical and graphical colour analysis, improved charting capabilities, spreadsheet-based tolerancing and XML-based CAD File Exchange.

www.breault.com

Achromatic doublets
Optarius

A new series of cemented and anti-reflection coated achromatic doublets is now available from Optarius of the UK. These lenses are designed to have minimum spherical and chromatic aberration over a wide range of wavelengths. They are useful for broadband imaging and also have high image quality when used with monochromatic light sources.

The lenses are optimized for a central wavelength of 550 nm and are said to have a superior performance across the visible spectrum. They are broadband anti-reflection coated to minimize reflections in the 450–650 nm wavelength range.

Optarius also offers doublets designed for the near-infrared spectrum and the 1550 nm telecoms wavelength.

www.optarius.co.uk

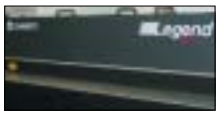
Beam profiler
Spiricon

A laser-beam profiler that is compatible with both digital (8- to 16-bit) and analogue camera interfaces is now available from Spiricon of the US. The LBA-700PC interfaces with industry-standard RS-422 digital cameras so a user is not restricted to one specialized camera.

The profiler comes with the manufacturer's exclusive Ultracal camera baseline-setting, fully featured software. Spiricon says that it has reduced its prices to make the beam analyser cost-competitive with those from other suppliers.

www.spiricon.com

Ultrafast amplifiers
Coherent



Coherent has released its Legend series of diode-pumped, ultrafast Ti:Sapphire regenerative amplifiers. The company says it has designed the amplifiers to suit applications such as ultrafast photochemistry and spectroscopy as well as pumping optical parametric amplifiers. The product range consists of the Legend-USP (which delivers 30–50 fs pulses), Legend-F (<130 fs), Legend-P (<2 ps) and the Legend-Dual (both picosecond and femtosecond configurations). Each amplifier features 1 and 5 kHz repetition rates and is wavelength-tunable from 750 to 900 nm. Coherent says that the amplifiers operate with any of its ultrafast lasers.

www.coherentinc.com

Green laser module
Lumics

Lumics, the German maker of laser chips, has introduced a fibre-pigtailed green laser to the market. The LU0546M005 module emits up to 5 mW optical power at 546 nm from a singlemode fibre.

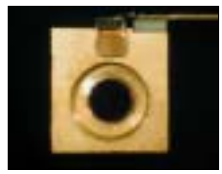
The device offers a high optical stability of less than 2% with a beam quality (M^2) of 1.1. The spectral linewidth of the emitted light is less than 1 nm. Target applications include analytical, medical and imaging.

The laser is available in a standardized cooled 14-pin butterfly package which is coupled to a 0.5 m length of protected optical fibre equipped with a collimator and filter. The laser footprint is only 30 × 15 mm with a height of 8 mm. The laser has a maximum operating current and voltage of 350 mA and 1.7 V respectively.

www.lumics.com

Laser diode

Axcel Photonics



The Lambda Lok laser diode offers superior performance for applications such as pump sources for solid-state lasers and Raman spectroscopy, according to its developer Axcel Photonics of the US.

The diode is available at 785, 808 and 976 nm. Axcel says the diode has a temperature coefficient of approximately 0.01 nm/°C and emits a beam with a spectral width of 0.3 nm. The device also uses fast-axis collimation resulting in a beam which is said to be less than 1°×8° full-width half-max (FWHM).

www.axcelphotonics.com

Optics

Jenoptik Laser Optik Systeme

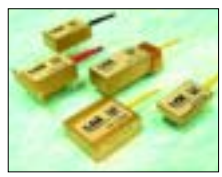
Jenoptik Laser Optik Systeme is now offering an expanded range of optical components. This includes a new series of coated UV and VUV laser optics including spherical, aspherical and cylindrical lenses, windows, mirrors and prisms.

The German firm is also offering precision aspheres for rotation-symmetrical, toric and non-symmetrical surfaces. Lenses and customized modules for optical metrology and material laser processing at visible, UV and VUV wavelengths are also available, as well as binary diffractive optics for 266, 248 and 193 nm.

www.jenoptik-los.com

Optoelectronic device packaging

Laser Diode Incorporated



Laser Diode Incorporated (LDI) says it can offer custom packaging of optoelectronic devices to commercial, industrial and military standards. Packages available from the company include DIL, mini-DIL, butterfly, coaxial and TO styles requiring hermetic environmental sealing.

LDI says it can package customer-supplied devices in bare chip form or on a submount. Additional custom test services and product-qualification plans are also available.

www.laserdiode.com

Photonic-crystal fibre

Blaze Photonics

Hollow-core photonic-crystal fibre (PCF) that can guide visible light is now available from Blaze Photonics. The UK firm is currently offering two types of fibre in evaluation quantities – one which guides red light and a second which guides green light.

According to Blaze, attenuation is of the order of 0.7 dB/m for the green-guiding fibre and 0.5 dB/m for the red-guiding one at their respective operating wavelengths of 520 and 630 nm. The fibres are protected by a single layer of acrylate coating, have outer diameters of 100 and 75 µm and can be stripped and cleaved like ordinary solid fibres.

www.blazephotonics.com

CCD camera

NET

NET of Germany is selling the latest third-of-an-inch progressive-scan CCD camera from Tokyo Electronic Industry (TELI) of Japan. The CS8550DiF is an 8-bit digital monochrome camera that captures 60 frames per second at a resolution of 640×480 pixels.

The camera uses an IEEE 1394 interface and transfers an uncompressed video stream at a rate of 400 Mbit/s. Its high-speed shutter can be timed and controlled by an external asynchronous trigger.

NET says that the camera has dimensions of 49×35×98 mm and a weight of 210 g, and is ideal for machine-vision applications where easy integration and high frame rates are required.

www.net-gmbh.com

Optoelectronics design software

Integrated Systems Engineering

Integrated Systems Engineering (ISE) has released a new version of its TCAD software, which is used to simulate optoelectronic devices. The firm says that the range of active devices that can be modelled includes edge-emitting lasers, vertical-cavity surface-emitting lasers (VCSELs) and LEDs.

ISE says that the latest version of its software includes a full vectorial finite-element-based calculation for determining the optical-field pattern in VCSELs. The company claims that the software can accurately measure a VCSEL's near and far fields, the cavity response and its diffraction loss.
www.ise.com

Off-axis paraboloids
Optical Surfaces

Off-axis paraboloids with diameters of up to 600 mm, surface accuracy of up to λ/20 and off-axis angles of up to 25° are available from Optical Surfaces. The UK company says that its components are suitable for use in broadband or multiple-wavelength applications such as telescopes, beam expanders and forward-looking infrared test systems.

A range of coatings is available for standard and custom components, from metallic and multilayer dielectrics to ultra-hard coatings for high-power lasers. Optical Surfaces says that off-axis paraboloids offer achromatic performance, and provide an unobstructed aperture and access to the focal region.
www.optisurf.com

Optical tables
Kinetic Systems

Kinetic Systems has announced that all of its vibration-isolation work surfaces are now available with twice as many mounting holes. Products with the MaxxAlign design have holes that are tapped at half-inch intervals in rows that are one inch apart. The holes have an M6 thread.

The US company says that the new design allows vibration-sensitive kit to be mounted with greater precision. The products include vibration-damping tabletops, benchtop platforms and breadboards.
www.kineticsystems.com

Surface profiler
Armstrong Optical

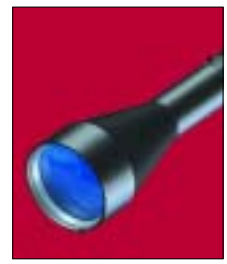
Armstrong Optical of Northampton, UK, has introduced the MicroMesure II system for 3D non-contact surface profiling. The system is an upgraded version of the firm's popular MicroMesure apparatus.

As for new features, Armstrong says that an optional mechanical turret system is now available to simplify the changeover between sensors. The turret allows up to four sensors and two cameras to be utilized during a profiling run without user interaction.

Other enhancements include the addition of optical encoders on the x- and y-scanning axes which leads to better positional accuracy and faster scanning.

The system comes with SurfaceMap system-control software that has been upgraded to include a rapid prescan and automatic surface-search functions, ensuring that surfaces are profiled under optimum conditions.
www.armstrongoptical.co.uk

Telecentric lenses
Edmund Optics



Edmund Optics of the US has introduced a line of telecentric lenses which it says are ideal for replacing standard fixed-focal-length lenses. Telecentric lenses correct perspective errors that result from variations in magnification through the depth-of-field.

Primary magnifications of 0.6×, 0.4×, 0.25× and 0.16× are available with fixed working distances varying from 100 to 170 mm. According to the firm, each lens has a telecentricity of less than 0.1°, less than 0.3% distortion and features a broadband anti-reflection coating covering 425–675 nm.
www.edmundoptics.com

Integrating spheres
SphereOptics

A series of integrating spheres with electrochemically plated gold surfaces is available from SphereOptics, based in the US. The company claims that its ZenithGold-plated surfaces exhibit diffuse reflectance values of approximately 94–96% over the 850 nm to 20 μm wavelength range.

The spheres, which are designed for infrared measurements, are available in diameters ranging from 1 to 20 inches. They feature multiple ports, and a selection of port plugs, port reducers, light traps and detector adapters are also available.
www.sphereoptics.com

Laser-diode driver
Analog Modules

Analog Modules has launched the 7701A laser-diode driver. According to the US-based company, the 7701A is designed to drive the pulsed or continuous-wave (CW) diodes used in

diode-pumped solid-state laser applications. Weighing in at 4.53 kg and measuring 11.66×5.18×5.94 inches, the 7701A can be configured for output currents up to 300 A peak (10 µs risetime) or 50 A CW for diode loads of up to 280 V.

In addition, the company says the DB-25 interface connector permits external control of features such as the CW or pulsed-mode operation, pulsewidth, current amplitude, current and load-voltage monitor.

The diode driver can be configured for either 115 or 220 V AC input powers and requires a DC power supply.

www.analogmodules.com

Single-photon detector

id Quantique

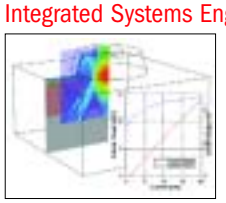
id Quantique, the Swiss start-up that is a specialist in quantum cryptography, has developed a single-photon detector module that suits applications in spectroscopy. According to the company, the id 200-MMF has a multimode fibre input in order to simplify the light coupling into the avalanche photodiode and improve the module's sensitivity.

Working in gated mode, the detector counts single photons in the spectral range between 1100 and 1600 nm with a quantum-detection efficiency greater than 10% at 1310 and 1550 nm. The dark-count probability and jitter are smaller than 5e−5/ns and 800 ps respectively. The detector comes as a stand-alone unit, with a counter and display, as well as a trigger generator with trigger output.

www.idquantique.com

Optoelectronic design software

Integrated Systems Engineering



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The latest release of the software includes a full-vectorial, finite-element-based calculation of the optical-field pattern in VCSELs. This allows users to calculate the near and far fields, the cavity resonance and the diffraction loss.

ISE says that TCAD also performs design tasks such as bandgap engineering and thermal management. As a result, ISE claims the software flags up issues such as carrier transport, local self-heating, quantum-well gain and optical-field distribution.

www.ise.com

DPSS laser

Bavarian Photonics

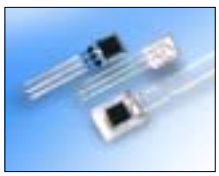
Bavarian Photonics of Germany has added a long-pulse Nd:YVO laser to its Aion Industrial-V family of diode-pumped solid-state systems. Called the Aion Industrial 1064-16-V-LP, the laser offers a pulse width of around 50 ns at 20 kHz, 70 ns at 40 kHz and 90 ns at 70 kHz. At a repetition rate of 10 kHz, the pulse energy is said to be 1.0 mJ.

The laser is available in both 16 W and 8 W versions. The firm adds that the laser has an M^2 of less than 1.3 and a pulse-to-pulse stability of less than 2% rms at 50 kHz. Typical applications for this product are said to be surface micromachining, deep engraving and solar-cell structuring.

www.bavarian-photonics.com

Plastic encapsulated photodiodes

UDT Sensors



UDT Sensors of the US, a subsidiary of OSI Systems, has released a line of low-cost, plastic-encapsulated silicon photodiodes. The detector incorporates a short-pass filter which blocks wavelengths longer than 700 nm.

UDT claims that in the past costly, externally mounted glass filters have been used to perform this type of filtering. According to the company, the new detector's design meets the cost-sensitive needs of the commercial market while reducing the overall physical size.

A variety of standard and custom devices are currently available for evaluation.

www.udt.com

Red laser diodes

Photonic Products

Two of Opnext's high-power red laser diodes are now available from Photonic Products of the UK. The HL6525MG and the HL6526FM are both said to offer a maximum output power of 80 mW continuous wave (CW) and 140 mW pulsed wave at a wavelength of 658 nm.

In addition, both devices are said to have a threshold current of 40 mA; a typical operating current of 110 mA; an operating voltage of 2.6 V and an astigmatism of 1 mm. According to the UK-based distributor, the diodes can operate between −10 °C and +70 °C when running CW or −10 °C to +75 °C when pulsed.

www.photonic-products.com

Diode laser bars

Alfalight

A range of high-power diode laser bars is now available from Alfalight. The US manufacturer of semiconductor sources says that its ALB1 family has a low series resistance, high thermal conductivity and high-facet damage threshold. These features make it suitable for all direct diode and diode-pumped solid-state laser applications.

The ALB1 laser bars are available at 808, 915, 940 and 976 nm and with fill factors of 20, 30, 50 and 90%. The bars measure 10 mm and have a standard cavity length of 1.0 mm, although 1.5 and 2.0 mm cavity lengths are available. Alfalight says its 808 nm bars have a slope efficiency of 1.1 W/A and a typical beam divergence of 10°×35° with TM polarization.

www.alfalight.com

Camera-Link interface

Basler Vision Components

Basler Vision Components has developed a

module that allows cameras and computers using a Camera-Link-based interface to be separated by 100 m. The firm claims that its giga-BIC converts the image data from a camera into Gigabit Ethernet format and sends it to a computer over standard copper cables up to 100 m in length.

According to Basler, the connection distance can be extended if Gigabit Ethernet switches are added. Using Basler's camera-configuration tool, the giga-BIC gives users access to all the features of the camera such as gain, offset and exposure time.

The device also features GPIB ports which support local triggering and control.

www.basler-vc.com

Display metrology software

Radiant Imaging

Radiant Imaging has released version 8.0 of its ProMetric display metrology software. The US company says that this latest version allows display developers to measure prototypes with greater precision and depth.

The software includes a new three-colour calibration routine which Radiant says improves the accuracy of luminance and illuminance measurements on RGB displays, such as CRTs, LCDs and LED displays.

The company claims that ProMetric 8.0 allows the user to define complex, freeform regions of interest with simple mouse movements. Radiant says this is useful when analysing instrument panels, which may contain several individually illuminated components.

www.radiantimaging.com

Raman microscope software

WITec

WITec of Germany has introduced a new software package for its CRM200 confocal Raman microscope. The company claims that the ScanControl Spectroscopy Plus module has been specifically designed for high-resolution imaging.

According to WITec, the software uses various filter utilities and imaging tools to enable the high-end processing of 3D Raman images. All Raman spectra are stored and a full Raman spectrum can be matched to any desired pixel.

The company says that when the package is used in combination with the CRM200 a resolution of 200 nm is possible and typical integration times are a few milliseconds per pixel. This means that a complete image would be recorded in only a few minutes.

www.witec.de

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FEBRUARY 2004

EOS NEWSLETTER

THE OFFICIAL PUBLICATION OF THE EUROPEAN OPTICAL SOCIETY

EOS event will aid enterprises that use lasers

A new event in Wales will help SMEs to get to grips with lasers.

Trumpf

The laser welding of tailored blanks.

Small and medium-sized enterprises are the target audience of a workshop that will take place in St Asaph in North Wales on 12–13 February 2004. The EOS Workshop on Laser System Technology and Applications for SMEs is intended to assist small companies in their use of lasers.

Topics under discussion will include precision manufacturing with lasers and the use of diode lasers for processing metals and plastics. New high-power systems for 2D and 3D metal processing will be considered, as will new system technology for cutting and welding.

The event will be chaired by Friedrich Bachmann of Germany's Rofin Sinar, Paul Hilton of The Welding Institute (TWI) in the UK, Kenneth Watkins of the UK's University of Liverpool and Tom Glynn of the National University of Ireland in Galway.

The workshop is being jointly organized by the EOS, the Welsh Optoelectronics Forum (WOF) and the Association of Industrial Laser Users (AILU). It is sponsored by the Welsh Development Agency (WDA).

The programme and registration details can be found at www.europeanopticalsociety.org.

Trio of workshops planned for Optatec 2004

Diffractive optics, terahertz technologies and plastic optics share the spotlight.

Three practice-oriented workshops will accompany Optatec 2004 which takes place on 22–25 June in Frankfurt, Germany. These have been organized by the EOS, the German Society for Applied Optics (DGaO) and OptecNet Deutschland.

The 22 June workshop will focus on terahertz technologies and be chaired by Martin Koch of the Technical University of Braunschweig, Germany. The next day's topic will be plastic optics and the chair will be Klaus Schindler of OptoNet eV, the Thuringian network of competence. Diffractive optics for white-light applications will be the topic of the final workshop on 24 June. This will be chaired by Theo Tschudi of the Technical University of Darmstadt, Germany.

"The visitors and exhibitors not only expect a successful exhibition, but also want comprehensive information and a forum for intensive discussions with their peers," commented Klaus Nowitzki, executive director of the EOS and the CEO of OptecNet Deutschland.

Entrance to Optatec is included in the workshop price. E-mail eos@optecnet.de or see www.europeanopticalsociety.org for more details.

Each issue we profile new members of EOS. This month several firms are featured.

New member profile: LINOS Photonics

LINOS Photonics GmbH of Germany is a subsidiary of LINOS AG, a supplier of sophisticated optical systems. The company's core operations include bespoke optical design and development. It also produces and sells optical, optomechanical and electro-optical systems and components.

For more information please see www.linos.com.

New member profile: Anteryon

Optical-engineering specialist Anteryon of the Netherlands offers everything from consultancy to co-development, prototyping and testing. Anteryon has the capability to deliver anything from a small series of prototypes to high-volume manufacturing. The company's expertise is focused in optical devices, mastering substrates, precision glass and fused fibre.

For more information please see www.anteryon.com.

New member profile: ZygoLOT

ZygoLOT GmbH of Germany is the European headquarters of US-based Zygo. Zygo designs, manufactures and distributes high-end optical systems and components for metrology and end-user applications. Its metrology systems are based on optical interferometry, measuring displacement, surface figure and optical wavefront.

For more information please see www.zygolot.de.

New corporate member

Philips Research, the Netherlands (www.research.philips.com)

For profiles of all of our corporate members, visit the EOS website (www.europeanopticalsociety.org).

Corporate member coordinates two consortia

Two projects will unite researchers all over Europe.

Wolfgang Sandner, coordinator of LASERLAB-EUROPE, speaks at November's inauguration ceremony.

A European consortium of 17 national laser institutions has been granted €14 m over four years to establish an integrated infrastructure initiative. LASERLAB-EUROPE is designed to strengthen the networking between large national laboratories within the European Union's Sixth Framework Programme.

LASERLAB-EUROPE is coordinated by Wolfgang Sandner, director of the Max Born Institute in Berlin, Germany. The initiative was launched at an inauguration ceremony on 10 November 2003, which was held at the Academy of Sciences in Prague, the Czech Republic. The Czech deputy prime minister Petr Mares and the minister of education Petra Buzkova were both present.

Lasers are becoming increasingly important in all areas of science and technology, so LASERLAB-EUROPE aims to unite most of Europe's largest national laboratories in interdisciplinary laser research. The consortium also includes smaller institutions with specialist expertise and equipment.

The consortium intends to use a novel Web-based "virtual infrastructure" to integrate the research carried out by its members. To help achieve this LASERLAB-EUROPE has a research laboratory that specializes in Internet services and communications.

LASERLAB-EUROPE also hopes to strengthen Europe's leading role in laser research through joint research activities. These will focus on the ultimate control of intense, short-pulse laser light, and overcoming the technological barriers on the route towards high power and high intensity.

The consortium promises to provide researchers across Europe with nearly 4000 days of access to laser facilities.

The Max Born Institute, which is a corporate member of the EOS, is also coordinating a European project on multifunctional materials based on double tungstate crystals. These crystals have promising applications in optoelectronics, the construction of efficient lasers and optical cooling.

The project has a total investment of €3.3 m and includes three partners from industry and six research institutes from six European countries. Their aim is to study systematically the properties and potential applications of double tungstate crystals. The consortium is coordinated by Valentin Petrov of the Max Born Institute.

Wolfgang Sandner (sandner@mbi-berlin.de) and **Valentin Petrov (petrov@ mbi-berlin.de)** are both at the Max Born Institute, Berlin, Germany.

EU spots the potential of optical technologies

Evening meeting emphasizes the value of funding.

On 9 December 2003, 50 organizations from 15 European countries, among them the EOS, invited 200 guests to Brussels for "An evening of optical technologies" to discuss their importance in Europe. The event was coordinated by the German Association of Engineers (VDI).

At the event, European Union parliament member Eryl McNally emphasized Europe's leading role in the field of optical technologies and that the funding of carefully selected research is indispensable. McNally said that the next research framework programme needs to place more importance on enabling technologies, and Europeans have to become aware that the photon is worthy of high investments in R&D. His remarks were echoed by the commissioner responsible for enterprise and the information society, Errki Liikanen.

Speakers from Jenoptik, Volkswagen and Thales described the great potential of optical technologies for the European economy. They believe that the sales opportunities are enormous and in these difficult economic times the optical sector is a rare growth industry.

During the last 10 years, for example, the laser industry has had annual growth rates of 15.5%. At the meeting Hubertus Christ, president of the VDI, predicted that the annual turnover of the worldwide optical technologies market will exceed €500 bn within 10 years.

At the Fascination Light exhibition in Brussels, Hasan Kar of the VDI Technology Centre in Düsseldorf explains the principle of a polarization filter to children.

A highlight of the event was the opening of an exhibition which is sponsored by the German Federal Ministry of Education and Research. With hands-on exhibits, posters and multimedia workstations, Fascination Light showcases the broad range of applications for optical technologies.

Poland embraces photonics

Research leads to collaborations and commercial enterprises.

A magneto-optical trap in the cold-atom facility of Poland's National Laboratory of AMO Physics.

Many universities across Poland now have research groups devoted to optics technologies. Historically, two of the strongest disciplines have been theoretical quantum optics and atomic and molecular nonlinear optics, and research has thrived despite scarce funding. The theoretical groups in Krakow, Gdansk and Warsaw (at both the university and the Polish Academy of Sciences) are home to renowned experts in quantum optics and co-operate with many groups around the world.

In contrast, little high-level experimental research took place. However, this situation has recently changed, and strong experimental centres in optical atomic and molecular (AMO) physics can now be found at the universities of Warsaw, Krakow, Torun, Poznan, Gdansk and Opole, as well as at the Polish Academy of Sciences.

In 2001, the National Laboratory of AMO Physics in Torun was created to perform experimental research on a level beyond the reach of individual groups. At present, the laboratory concentrates on cold-matter physics and on quantum-state engineering. Its apparatus for experiments on Bose–Einstein condensation and entangled states of trapped atoms, ions and photons is nearly complete.

Two other well-equipped laboratories conduct studies of ultrafast processes in physics and chemistry. These are the Laser Centre in Warsaw (a collaboration between Warsaw University and the Polish Academy of Sciences) and the Centre of Ultrafast Laser Spectroscopy at Poznan University.

Another field that is progressing well is applied optics. The late Maksymilian Pluta, who was a Polish pioneer in this field, laid a firm foundation in optical microscopy. Today several Polish institutes carry out research into Fourier optics, optical information processing, diffractive optics and interferometry.

Warsaw's University of Technology is particularly active in applications-based research and has opened centres for photonics engineering, microsystems, environmental protection and nanomaterials. Its Institute of Micromechanics and Photonics specializes in automated optical measurements and constructing sensors.

Biomedical applications

Research into biomedical applications of optics is also advancing rapidly. Wroclaw Technical University focuses on bio-optics, physiological optics and optometry, while scientists at Torun University have developed a new method of optical tomography for diagnosing eye disease.

Photodynamic therapy (PDT) is also a very popular research topic, and is studied at the Technical and Medical Universities at Lodz and the Silesian Medical Academy. The Military University of Technology in Warsaw has synthesized photo-sensibilizators for PDT that are better than anything currently available on the market.

However, medicine-related activity is not limited to academic research. At the Laser Diagnostics and Therapy Centre at the Technical University of Lodz, doctors and physicists have performed laser and optical treatment on thousands of patients.

Another important area of research is optical fibre. Fibre is produced and tested at Lublin University and the University of Technology in Lublin while other groups specialize in the theoretical modelling of its optical properties.

For example, groups at Warsaw University, the Military University of Technology, Wroclaw University of Technology and the Technical University of Szczecin work on modelling and developing new nonlinear optical materials for applications such as holography, sensing and biomaterials.

Commercial benefits of research

The importance of optics in Poland's research institutes is also influencing the commercial world. New Polish companies such as CTL Laser Instruments, a producer of medical systems, and VIGO Systems, which offers infrared detectors, are attempting to meet the needs of optoelectronics markets in Poland and abroad.

European collaboration is also becoming increasingly important. Many universities now give students the opportunity to participate in European Union exchange programmes, and the Institute of Plasma Physics and Laser Microfusion in Warsaw is an associate member of the LASERNET European Network.

In addition, several international learned societies including the International Commission for Optics (ICO), the International Society for Optical Engineering (SPIE) and the EOS have strong representation in Poland.

Katarzyna Chalasińska-Macukow is a professor and deputy rector of Warsaw University, the Polish representative of the advisory committee of the EOS and a vice-president of the Polish Physical Society. **Wojciech Gawlik** is a professor and head of the photonics department of the Jagiellonian University in Krakow and a member of the EOS board of directors. **Henryk Kasprzak** is a professor of the Wroclaw University of Technology, head of the physiological optics group and president of the optics section of the Polish Physical Society.

Calendar

DATE	EVENT	LOCATION
February 12–13	EOS Workshop on Laser System Technology and Applications for Small and Medium-sized Enterprises	St Asaph, Wales
April 19 – May 1	Nanophotonics Summer School	Corsica, France
April 21–24	EOS Topical Meeting on Optics in Computing	Engelberg, Switzerland
April 26–30	Photonics Europe	Strasbourg, France
June 9–11	2nd European Workshop on Optical Fibre Sensors	Santander, Spain
June 16–18	Optoelectronic Distance/Displacement Measurements and Applications	Oulu, Finland
June 21–25	6th International Conference on Vibration Measurements by Laser Techniques	Ancona, Italy
June 21–25	SPIE International Symposium on Astronomical Telescope	Glasgow, Scotland
June 22–24	EOS Workshop Programme at Optatec 2004	Frankfurt, Germany

For more information on any of these events, please visit **www.europeanopticalsociety.org**

Are you a member of EOS?

Look at the benefits

Individual members are eligible for:

- a regular EOS Newsletter e-mail
- reduced conference fees
- reduced prices for EOS journals
- free subscription to *Opto & Laser Europe*
- 20% discount on Institute of Physics Publishing books
- Members living outside Germany are entitled to a 50% discount on subscription to the German-language journal *Photonik*, published by AT-Fachverlag

Additional benefits for corporate members:

- a company profile in the EOS directory
- a presence on the EOS website
- free advertisements for jobs in the EOS market
- reduced conference fees for all employees

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CALENDAR

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DATE	EVENT	LOCATION	ORGANIZER	CONTACT
February 9–11	Laser Applications to Chemical and Environmental Analysis	Annapolis, US	OSA, US	www.osa.org/meetings/topicals/lacea
February 9–11	Design and Engineering of Optical Systems	Stansted, UK	Optima Research, UK	www.optima-research.com/training/designandeng.htm
February 14–19	Medical Imaging 2004	San Diego, US	SPIE, US	spie.org/conferences/calls/04/mi
February 18–20	China (Shanghai) International Optics Fair	Shanghai, China	China Optometric & Optical Association, China	www.orientexhibition.com.hk/english/index/index.html
February 22–27	Optical Fiber Communication Conference and Exposition	Los Angeles, US	OSA, US	www.ofcconference.org
February 22–27	Microlithography 2004	Santa Clara, US	SPIE, US	spie.org/conferences/calls/04/ml
February 25–28	First European Conference on Applications of Femtosecond Lasers in Materials Science	Bad Kleinkirchheim, Austria	Wolfgang Kautek and Tamás Szörény	http://titan.physx.u-szeged.hu/~opthome/FemtoMat
March 3–6	Source 2004 – Lasers in Dentistry	Palm Springs, US	Academy of Laser Dentistry, US	www.source2004.org/home.htm
March 30 – April 2	5th International Conference on Space Optics	Toulouse, France	Centre National d'Etudes Spatiales	http://dag.distinguez-vous.com/cnes/icso2004/index.php?lang=gb
April 4–7	EUROPT(R)ODE – Optical Chemical Sensors and Biosensors	Madrid, Spain	Universidad Complutense de Madrid, Spain	congresos.forodigital.com/europtrode
April 12–16	Defense and Security Symposium (formerly Aerosense)	Orlando, US	SPIE, US	spie.org/conferences/calls/04/or

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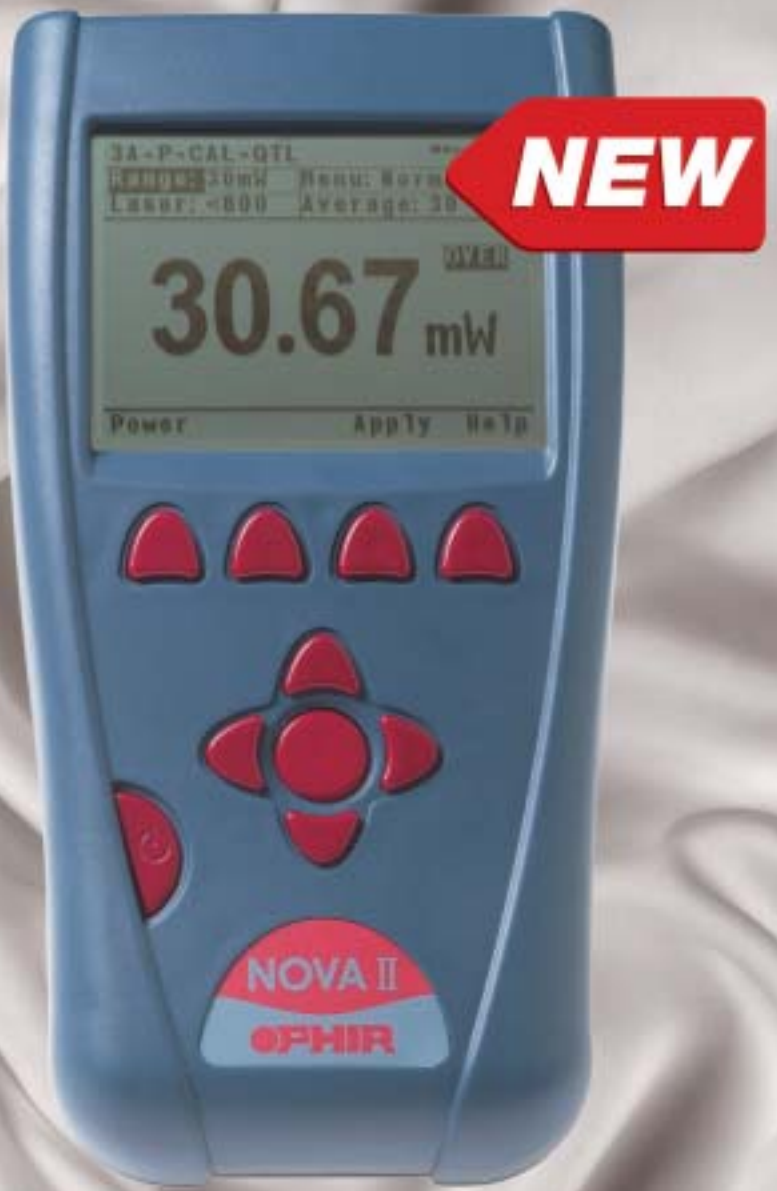

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