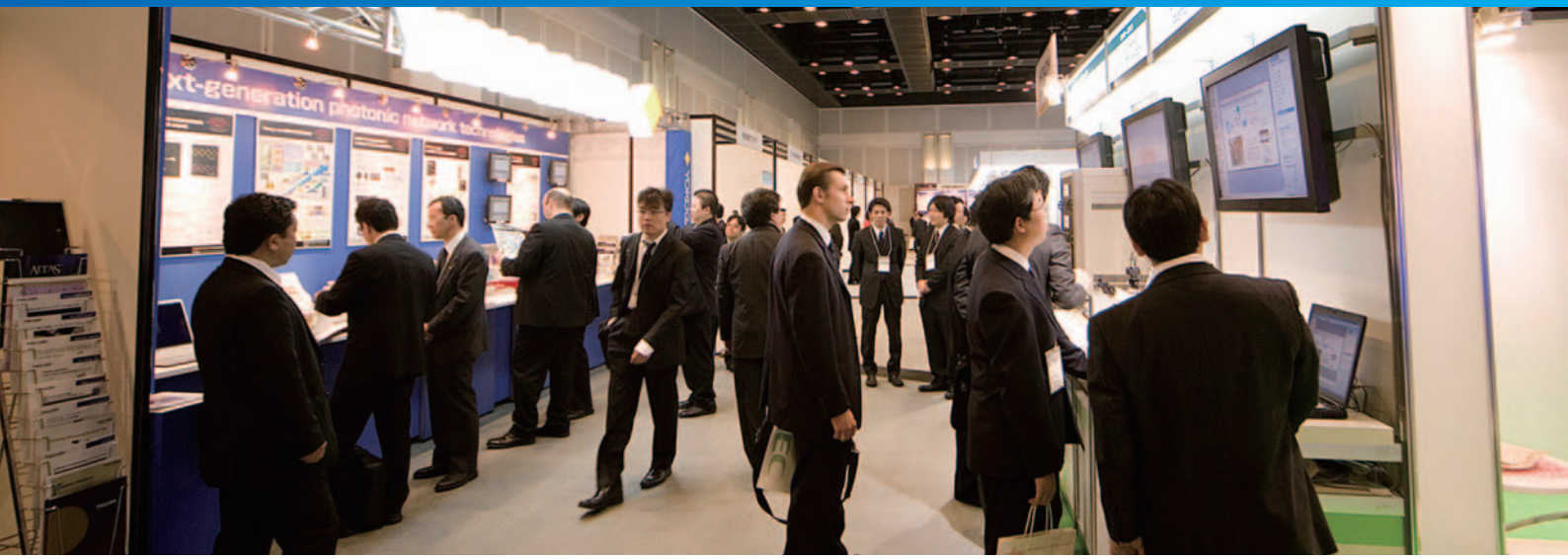
nature photonics

Technology Conference Report

23–25 October 2007
Tokyo, Japan

The future of optical communications



Nature Photonics conference

Speakers

John L. Hall	University of Colorado
Tatsuo Izawa	NTT Electronics
Will Stewart	University of Southampton, UK
Kaoru Yano	President, NEC
Liu Wen	Wuhan Research Institue
Mario Paniccia	Intel
Michiharu Nakamura	Hitachi
Tomonori Aoyama	Keio University
Fabrizio Forghieri	Cisco Systems
Masataka Nakazawa	Tohoku University
Colja Schubert	Heinrich-Hertz-Institut
Ken-ichi Kitayama	Osaka University
Stan Lumish	JDSU
Terumi Chikama	Fujitsu
Mitsuru Matsui	Mitsubishi Electric
Hiroshi Onaka	Fujitsu
Susumu Noda	Kyoto University
Masao Nakagawa	Keio University
Manabu Kagami	Toyota Central R&D Labs.
Yasuhiko Arakawa	Tokyo University
Masayuki Izutsu	NICT
Hiromichi Shinohara	NTT
Tomohiro Kudoh	AIST

The need to find more energy-efficient methods for transporting optical data around networks was arguably the most pressing issue that was raised at the recent *Nature Photonics* Technology Conference on optical communication. The unique three-day event held in Tokyo in October brought together over 20 experts from academic institutions and industry to present their perspectives on the future evolution of optical-network technology. A commonly held view was that as the demand for bandwidth continues to rise, solutions such as all-optical switching are urgently required to offer a practical alternative to energy-hungry electronic routers. Although 'cost-per-bit' calculations have historically been a measure of a network's efficiency and value, an assessment of 'energy per bit' is now becoming increasingly important, according to many of the speakers. Fortunately technologies, such as optical packet switching, low-threshold quantum-dot lasers, silicon photonics and multilevel modulation schemes, look set to drive networks to new levels of efficiency in coming years. These and other highlights from the conference and its accompanying exhibition are discussed in this report. I would like to thank our co-organizers Impress R&D and Tomonori Aoyama from Keio University and the other members of the advisory board for their guidance and assistance in preparing the conference's technical programme.

Oliver Graydon
Editor
Nature Photonics

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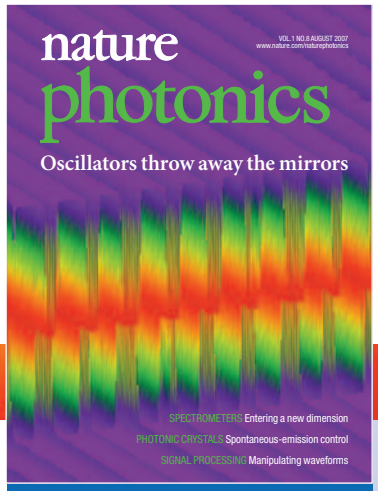

Launched in 2007

Nature Photonics covers the entire spectrum of photonics research for scientists in academia and industry. Published monthly, the journal offers insights into everything from fundamental light properties to the latest designs of optoelectronic devices. *Nature Photonics* is open to a broad range of topics whose central theme falls within the bounds of photonics.

In addition to publishing original research, *Nature Photonics* serves as a central source for top-quality information for the photonics and optoelectronic communities through the publication of Commentaries, Research Highlights, News & Views, Reviews and Correspondence.

Nature Photonics is committed to publishing top-tier original research in photonics through a fair and rapid review process. The journal features two research paper formats: Letters and Articles, and authors are encouraged to submit.

Authors can submit the following types of articles:

Article: a substantial novel research study that often involves several techniques or approaches and will typically occupy 6-8 printed journal pages. The main text (excluding abstract, Methods, references and figure legends) is 2,000–3,000 words. Articles have 4–6 display items (figures and/or tables). An introduction (of up to 500 words) is followed by sections headed Results, Discussion, and Methods. References are limited to 50.

Letter: an important novel research result that will typically occupy up to 4 printed journal pages. Letters begin with an introductory paragraph (not abstract) of 150 words followed by the main text (up to 1500 words) and a Methods section. References are limited to 30 and letters should not contain more than 3–5 display items (figures and/or tables).

Submissions: manuscripts should be submitted through our online submission system at **http://mts-nphot.nature.com**. Using this system, authors can upload manuscript files (text, figures and supplementary information, including video) directly to our office and check on the status of their manuscripts during the review process.

Research areas covered include:

- Lasers, LEDs and other light sources
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- Optoelectronic devices and components
- Novel materials and engineered structures
- Physics of light propagation, interaction & behaviour
- Quantum optics and cryptography
- Ultrafast photonics
- Biophotonics
- Optical data storage
- Spectroscopy
- Fibre optics and optical communications
- Solar energy and photovoltaics
- Displays
- Terahertz technology

Today's research driving tomorrow's applications

Conference Report

As the demand for bandwidth continues to grow, future networks for transporting data will need to be far more energy-efficient and flexible.

Over the past 30 years, optical communication has transformed the way information is passed around the world. The emergence of high-performance laser diodes, low-loss optical fibre, erbium-doped fibre amplifiers and wavelength-division multiplexing (WDM) have made it possible to transmit many gigabits of digital data over a single optical fibre every second.

The globe is now wrapped in a web of glass that spans oceans and continents to connect cities all over the world. This gigantic network plays a critical role in today's global society and economy, enabling efficient transmission of all kinds of digital data whether it is Internet pages and e-mails, mp3 music and images, or simply telephone conversations and faxes.

The big question is what does the next 10 or 20 years have in store? How will optical communication further evolve to meet society's needs and what challenges need to be overcome?

These are the two primary questions that *Nature Photonics* aimed to address at its first Technology Conference ('Optical communications: Looking to the next generation'), which took place in Tokyo at the end of October.

The three-day event brought together 23 invited speakers, each either a leading researcher in a particular optical technology or an important figure from industry, to present their opinions on the future. Although it is impossible to describe each and every talk in detail in this report, here are selected highlights of interesting points that were raised during the event.

FIBRE-TO-THE-HOME

Although for some time, optical communication has been the technology of choice for long-haul communication, over the past few years it has recently started to penetrate the access network and reach consumers' homes. The motivation for the deployment of this 'fibre-to-the-home' (FTTH) technology is simple to understand. Fibre-to-the-home enables much faster broadband access over longer distances when compared with rival existing electrical technologies, such as cable television connections or asymmetric digital subscriber line (ADSL), which that runs over telephone wires.

When it comes to deploying and developing FTTH technology, Japan and its national service provider NTT are at the forefront and leading the way. At present, NTT's B-FLETS FTTH service supports download speeds of up to 1 Gbit s^{-1} (hyper-family service). The uptake of FTTH services has been very rapid over the past five years, according to Hiromichi Shinohara, executive director of NTT's Information Sharing Laboratory Group.

"As for new broadband users, market share for ADSL and FTTH is reversing, and use of FTTH exceeded ADSL in Japan in Q1 [first quarter] 2005," commented Shinohara. "Fibre-to-the-home users are growing by 800,000 per quarter whereas ADSL has stagnated and is now losing around 200,000 users per quarter." NTT is optimistic about the future and plans to have 30 million FTTH subscribers by 2010 — about three times the current figure of 10 million users.

Shinohara points out that during the early days of FTTH, the priority was reducing the cost of the technology, whereas today the emphasis is on making it easier to deploy and more user friendly. "As for the future, as we enter the full-scale FTTH era, the focus is on developing easy to maintain technologies and DIY [do-it-yourself] installation and repair opportunities."

With this in mind, NTT has recently developed field-assembly connectors that avoid the need for fibre splicing, which has historically been an inconvenient installation necessity. It has also developed a bendable optical cord based on holey optical fibre that has a much smaller bending loss and can be tied in knots and coiled like a telephone handset cord without incurring any optical loss. Shinohara also says that in the future, next-generation FTTH architectures based on WDM technology will enable higher data speeds of 10 Gbit s^{-1}.

SILICON PHOTONICS

An area of R&D that has attracted intense interest in recent years, not only among universities but also companies such as IBM, Intel, NTT, NEC and others, is silicon photonics. The motivation is to create a suite of photonic devices that can be monolithically integrated with silicon electronics, thus enabling cost-effective mass production using standard CMOS manufacturing technology.

"There is this enormous CMOS manufacturing infrastructure and the question is how do we take advantage of this

for photonics?" Mario Paniccia, head of Intel's photonics R&D lab in California, told delegates during his talk on the topic. "The drive is to get 90% of the performance for a tenth of the cost."

Paniccia says progress has been rapid over recent years with the demonstration of high-performance silicon Raman lasers and high-speed modulators and photodetectors. "In 2003, the fastest silicon modulator was 20 MHz and earlier this year [2007] we announced a 40-Gbit s^{-1} model. That's three orders of magnitude improvement in just four years," stated Paniccia. "The next step is integration and moving towards monolithic optical and electronic solutions."

As for the future, Paniccia believes that we are heading towards the creation of miniature chips with enormous optical bandwidth. He envisages integrated silicon circuits that can transmit 1 Tbit s^{-1} by combining 25 lasers and 40-Gbit s^{-1}modulators into a device measuring 10 mm^2. However, before this is possible researchers will need to demonstrate monolithic integration of silicon electronics and optoelectronics on a chip.

Ken-Ichi Kitayama from Osaka University and Susumu Noda from Kyoto University are also both optimistic about the potential of silicon photonic-crystal technology for manipulating optical data bits. In the future, they believe that optical silicon chips based on this technology could be useful for performing functions such as optical buffering, which will be required for the creation of all-optical routers.

POWER CONSUMPTION AND ALL-OPTICAL ROUTERS

Interestingly, one point that nearly all the speakers raised was the urgent need to address the electrical power consumption of routers and find more energy-efficient, compact and cooler methods for directing the flow of optical data-bits.

"Power consumption of telecom carriers has become a serious problem," explained Kitayama during a talk on optical routing and photonic nodes. "Today, the annual electrical power consumption of a carrier is more than 7.4 TWh, and this is growing at 5% a year."

Kitayama explained that electronic routers are the main bottleneck as they generate a great deal of heat and need a lot of space. "The total power consumption of Google's data centres is now greater than 100 MW, of which around 50% is for air conditioning," he commented.

"BY 2015, ROUTERS WILL CONSUME 9% OF JAPAN'S ELECTRICITY. IT'S AN UNBELIEVABLE SITUATION"

Michiharu Nakamura, HITACHI

Similar thoughts were shared by many other speakers. "By 2015, routers will consume 9% of Japan's electricity. It's an unbelievable situation," explained Michiharu Nakamura from Hitachi. "[In terms of energy efficiency of transmission] we need to go from needing 100 pJ per bit to just 10 pJ per bit." Nakamura believes that disruptive technologies based on nanoelectronics will provide solutions for the future.

Looking further into the future, Tomonori Aoyama from Keio University also has cause for concern. "In 2020 we are going to move from switching terabits to petabits," he told delegates. "The problem is that a 100-Pbit s^{-1} router based on today's technology would consume 10 MW and require a nuclear power station to supply it with electricity."

Most agree that the answer to the problem lies with a move to all-optical switching and routing technologies that should be far more compact, consume less power and potentially be easier to upgrade to higher data rates owing to their transparent nature. "Today, power consumption per bit is a figure of merit that is becoming increasing important," explained Terumi Chikama from Fujitsu. "The move to an-optical network architecture will allow power consumption to go down."

Unsurprisingly, many of the firms and universities involved in the event are now working hard on solutions. In particular, NTT, NEC, Kyushu University and Osaka University have just started a five-year project funded by the National Institute of Information and Communications Technology (NICT) to develop the technology for all-optical RAM-based packet switching. The idea is to fabricate optical buffer memory from photonic-crystal resonators and use it to temporarily store optical data bits without needing to convert them into the electrical domain.

Meanwhile, Yokogawa has already developed an optical packet-switching technology based on cascaded pairs of crossed planar waveguides on a semiconductor. By actively controlling the refractive index at the waveguide junction using charge injection and an electrode it is possible to switch the light between the waveguides on the nanosecond timescale.

QUANTUM PHOTONICS

Several speakers commented that photonic technologies based on quantum science and the control of single photons will become increasingly important in the future. In particular quantum cryptography and quantum-dot lasers are two good examples that are at an advanced stage of development and poised to make an impact in the world of communications.

Quantum cryptography — a data-encryption scheme that uses single photons to transfer a secret key between two parties that wish to communicate securely — has certainly come a long way since the first experiments in the 1990s. Today many companies, such as idQuantique, MagiQ Technologies, Toshiba, Mitsubishi, NEC, NTT, Fujitsu and others, have working prototypes and have demonstrated the transfer of single-photon keys over distances of tens and hundreds of kilometres. The challenge for the technology is now improving the speed of the key generation beyond the kilobit-per-second domain to make it more practical for commercial deployment.

Indeed, Mitsuru Matsui from Mitsubishi Electric's Information Technology R&D Centre told delegates that a project funded by NICT in Japan involving NEC, Mitsubishi Electric and NTT has recently started with the goal of realizing a quantum-key communication system capable of a key transmission rate of 1 Mbit s^{-1} over 50 km by 2010.

According to Matsui, the market for quantum cryptography could potentially be as large as $30 million by 2008 with customers such as government departments, armed forces and financial institutions showing an interest in the technology.

"Quantum cryptography is a flagship of quantum technology but it is not a rival for modern cryptography schemes at the moment," commented Matsui. "A new practical quantum protocol other than key distribution is likely to be essential in the future."

The other quantum technology that drew attention at the conference was the development of high-performance quantum-dot lasers by a partnership between the University of Tokyo and Fujitsu. First proposed by Yasuhiko Arakawa and Hiroyuki Sakaki from the University of Tokyo in 1982, the concept is to confine electronics in carefully engineered tiny semiconductor structures to make high-performance lasers. Potential applications include high-bit-rate (more than 1 Mbit s^{-1}) single-photon sources required for quantum cryptography or highly efficient lasers with ultralow threshold currents and high temperatures of operation. According to Arakawa, quantum-dot technology is now being commercialized by a Fujitsu spin-out called QD Laser and the first application will probably be low-cost lasers operating at a wavelength of 1.3 μm for FTTH applications.

Arakawa also told delegates that the applications for quantum dots extend beyond just lasers and that the technology serves as an important 'building block' for enabling nanophotonics, quantum communication, and quantum information processing.

OPTICAL WIRELESS

Although optical communication is often conducted through glass or plastic fibres it should not be forgotten that free-space links are also an option for sending information. The Visible Light Communication Consortium (VLCC) is pioneering the approach of using the visible LEDs in lighting and displays as a means of communication. By modulating the LEDS it is possible for them to transmit digital information while still performing their primary role as a source of illumination. The idea is that room lighting, traffic signals and other common items containing LEDS could also convey navigation, voice or identification data. "The LED is becoming a ubiquitous device," commented Masao Nakagawa from Keio University who gave a talk on the topic. "The idea is that lighting will become a multifunctional infrastructure. Visible light communication does not ruin the room design and could be very useful for transmitting voice instructions to handicapped [visually impaired] people."

On the theme of wireless communication, Will Stewart from the University of Southampton stressed the importance of effective convergence between optical networks and radio wireless systems. He commented that both have become extremely popular but that the interface between the two could be better and the development of an optimized fibre–wireless interface may be inevitable. "Even fibre-to-the-home, where Japan leads Europe and the US, may become wireless for the last metre," he commented. "Perhaps we have been too distracted by [the question of] who owns and operates the wireless spectrum and so have not been paying enough attention to the problems of making a cheap, high-performance fibre–radiofrequency interface."

TRANSMISSION CAPACITY

Although today's WDM optical networks are already capable of handling vast amounts of information, many of the speakers believe that the demand for bandwidth will only increase.

"TOTAL GLOBAL IP TRAFFIC IS EXPECTED TO GROW BY A FACTOR OF FIVE BETWEEN 2006 AND 2011"

Stan Lumish, JDSU

According to Stan Lumish, the chief technology officer of JDSU, the advent of new bandwidth-hungry content such as iTunes, U-tube, MySpace and video services on the Internet is pushing network traffic to higher and higher levels. "AT&T's global backbone IP [Internet protocol] network carries 10.17 Pbytes of data traffic on an average day," commented Lumish. "And total global IP traffic is expected to grow by a factor of five between 2006 and 2011."

Lumish says that there is a shift towards agile-mesh optical networks that use dense WDM and reconfigurable optical add–drop multiplexers to minimize the need for electronic conversion of data.

At the same time, as well as routing wavelengths more efficiently, higher channel rates will probably be needed, according to Colja Schubert from the Heinrich Hertz Institute in Berlin. With 10-Gbit s^{-1} technology now mature and 40-Gbit s^{-1} channel technology starting to be deployed, Schubert says that the next jump will be to a channel rate of 100 Gbit s^{-1}, and that many of the devices required have already been demonstrated in the lab. Electronic time-division multiplexing and new multilevel modulation schemes will probably provide short-term solutions, however in the medium and long term optical time-division multiplexing may be the only answer.

"Today we have 25 Tbit s^{-1} on a single fibre in the lab by using 160 wavelengths," explained Schubert. "However, achieving 50 Tbit s^{-1} per fibre within the next 10 to 15 years will be hard to realize with incremental technology steps — a disruptive technology is needed."

NETWORKING IN THE CAR

Faster and more efficient communication systems are not just needed within buildings. The automotive industry is also now equipping cars with plastic-optical-fibre (POF) networks for transporting multimedia and control data around the interior.

"We have to do something about the weight and the number of wires [more than 2,000] in a vehicle, it is becoming unsustainable," explained Manabu Kagami from Toyota's Central R&D laboratories. "The network data rate in vehicles is expected to reach gigabits per second by 2010. This is being driven by multimedia applications, drive-by-wire and the use of field recognition and sensor technology."

According to Kagami, for data rates of more than 10 Mbit s^{-1} an optical solution is required. "At the moment we are at data rates of around 10–25 Mbit s^{-1}. In five years time it will be around 1 Gbit s^{-1} over a distance of 10–15 m."

At the moment the use of visible LEDs and 1-mm-diameter step-index POF is the most cost-effective answer for car optical networks, however in the future Kagami says that higher transmission speeds may require the use of vertical-cavity surface-emitting lasers (VCSELs) and graded-index POF.

Toyota is now conducting research on bi-directional transmission systems that use red and green LEDs. It is also investigating the use of self-grown waveguides, which are written by laser light to ease alignment problems.
In the future, optical star couplers for integrating different networks within the car and visible light amplifiers to overcome attenuation may also be required.

From petrochemicals to photons

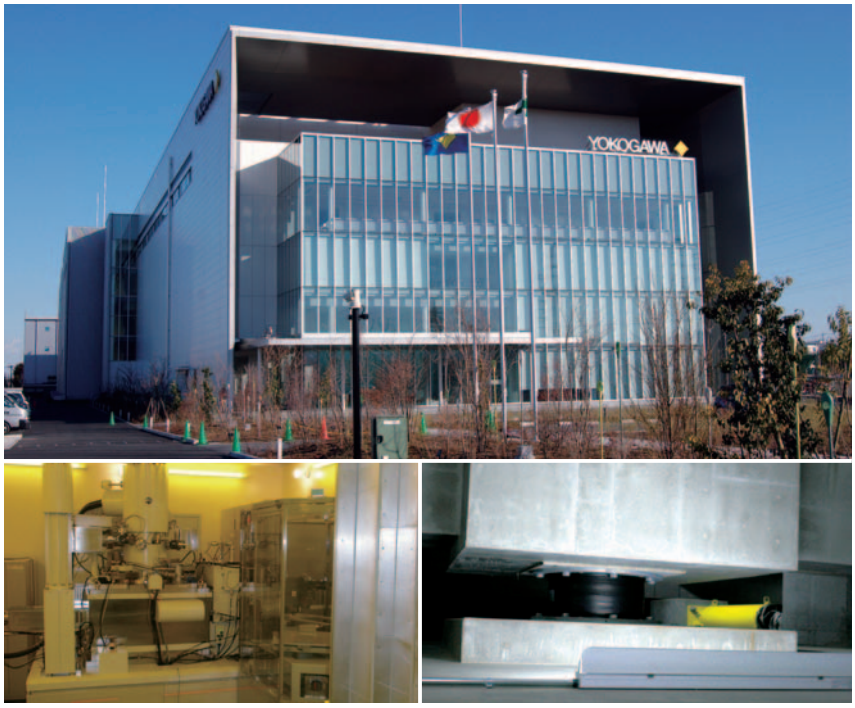
Yokogawa is famous for its efficient and reliable control of factories, now the Japanese firm is applying the same mindset to optical networks and the management of photons.

Founded in 1915, Yokogawa is one of the world's leading providers of industrial automation and control systems and test and measurement products. Today, it is a US$ 4 billion company with 18 manufacturing facilities around the globe and business operations in 33 countries. Products bearing its hallmark can be found in a diverse range of facilities ranging from oil refineries and power stations through to chemical plants and hospitals. For example, its CENTUM distributed control system for ensuring the efficient and reliable operation of an industrial plant has been installed in 19,000 projects in more than 75 countries since it was launched in 1975.

In the year 2000, the firm announced its VISION-21 and ACTION-21 corporate strategy which highlighted photonics is an area of strategic importance. "At Yokogawa it is our DNA to support society's infrastructure through the provision of products and services, and we take pride in this role," explained Akira Miura, vice-president of the firm's photonics business. "In 2000, our board members recognized that in the 21st century the photonic network is an important part of society's infrastructure and that Yokogawa is ideally placed to help build and maintain such networks."

Certainly, Yokogawa's expertise in ensuring efficient, reliable and automated operation and monitoring of factories will serve it well - after all these are all important qualities that can also be applied to the design of optical networks. With this in mind, Yokogawa is a strong advocate of all-optical switching technology that is not only much more compact than the electronics it replaces but also generates less heat and consumes less power.

"In the 21st century the use of all-optical switches and optical packet switching will allow the ultimate form of energy-efficient communication," Miura told Nature Photonics during a visit to the firm's new photonics headquarters. "You should never forget that electrons have mass, while photons have zero mass. What is the aim of communication? Of course, it is to transfer information not mass, which wastes energy."



The Sagamihara Technology Center (Top) and its electron beam stepper (Left) and seismic isolated foundations (Right)

SAGAMIHARA TECHNOLOGY CENTER

To help realize its move into the photonics field, Yokogawa has recently completed construction of its Sagamihara Technology Center which serves as the firm's Photonics Business Headquarters. Located 50km from central Tokyo, the centre represents a US$210 million investment and features state-of-the art "maskless" semiconductor fabrication facilities that exploit high-resolution electron beam lithography technology instead of mask-based projection. The centre, which was designed by Miura and opened at the end of 2006, also features unique seismic-isolated foundations to ensure uninterrupted operation during earthquakes. The entire building is isolated from the ground via a complex array of rubber vibration dampers and oil-filled pistons that suppress both vertical and horizontal vibration from the ground.

'This centre is now fully operational and houses all functions of our photonics business – R&D, manufacturing, sales

"You should never forget that electrons have mass, while photons have zero mass."

Akira Miura,

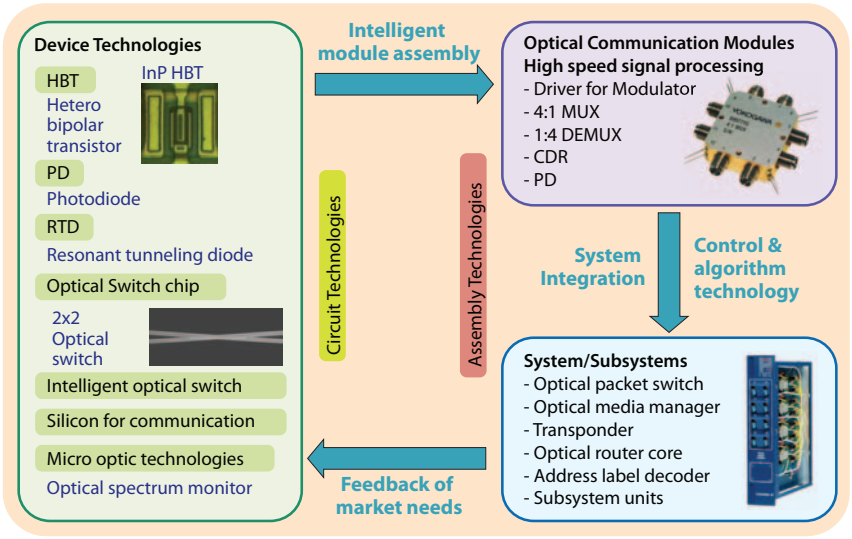
Akira Miura, vice president of Yokogawa's photonics division.

and administration," explained Miura. "It will guarantee a stable supply of photonics products to our customers worldwide and is proof of our strong commitment to being a major player in the telecommunications market for decades to come."

Despite entering optical communications only recently, Yokogawa has not wasted any time in bringing a range of advanced products to the marketplace. Building on its research into compound semiconductors which it started in 1983 the firm is rapidly building a reputation for itself in the development of semiconductor devices and modules for high-speed networks and optical packet switching.

An emphasis is clearly being placed on the needs of the network of the future with a comprehensive suite of semiconductor 40Gbit/s products including everything from PIN photodiodes and modulator drivers through to WDM channel monitors and transponders. In fact, a Yokogawa-Fujitsu partnership claims to have resulted in the world's first DQPSK 40Gbit/s optical transceiver that enables communication over a distance of 800km – eight times the range of conventional 40Gbit/s systems.

According to Miura, a big advantage that the company has is its very fast product development and optimization cycles. "As our Sagamihara facility is "maskless" and has all the design, manufacturing, packaging and testing capabilities under one roof we can achieve a very fast feedback cycle and iterate designs within just one month, whereas usually it would take at least one year," explains Miura.



Yokogawa's R&D Core Engine and Technology Drive Task Force

Aside from high-speed discrete components, another area where Yokogawa has been very successful is the development of optical packet switches. Such modules, which allow efficient redirection and flow-management of optical databits without the need to convert data back into the electrical domain, are likely to become an essential part of next generation all-optical networks.

Making optical switches that are fast enough for packet switching is a tough challenge and Yokogawa's ingenious solution to the problem is the use of 2x2 switches made from a pair of crossed planar semiconductor waveguides with an electrode at the crossing point. Injecting an electrical current via the electrode changes the local carrier density in the semiconductor and induces a refractive index change that determines with the optical packet passes straight through or is reflected and redirected to the other waveguide. The beauty of the approach is that it is scaleable to a large number of ports by cascading such switches and mass-producible with one semiconductor wafer potentially containing thousands of such switches.

"This technology allows an optical packet switching speed of less than 2ns which is a million times faster than that of other optical devices based on principles such as moveable MEMS or the thermo-optic effect," commented Miura. "Generally it is predicted that optical packet networks will not be realized until 2015, but we believe that it can be deployed earlier by focusing on the market for high-end local area networks."

If Yokogawa is successful with its photonics plans then it will have shown the world that it can efficiently control and manage the ultimate commodity – optical data.

Yokogawa Electric Corporation
http://www.yokogawa.com

YOKOGAWA

HISTORY OF YOKOGAWA

1915 Tamisuke Yokogawa, Ichiro Yokogawa and Shin Aoki establish an electric meter research institute in Shibuya, Tokyo
1917 Produces and sells the first electric meters in Japan
1920 Incorporated as Yokogawa Electric Works Ltd
1933 Started research and manufacture of aircraft instruments and flow, temperature and pressure controllers
1948 Public offering of company's stock
1950 Developed Japan's first electronic recorder
1957 Establishes North American sales office
1966 Commenced manufacture of vortex flowmeter
1974 Establishes Yokogawa Electric Singapore
Establishes Yokogawa Electric (Europe)
1975 Releases CENTUM, the world's first distributed process control system
1986 Changes company name to Yokogawa Electric Corporation
1988 Enters the high-speed frequency measuring business
2000 Announces VISION-21 and ACTION-21 corporate strategy
2001 Enters optical communication business and announces 40Gbit/s transceiver
2002 Acquires 100% of Ando Electric's stock
2004 Developed 40Gbit/s optical packet switch

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Exhibition Report

Mitsubishi Electric: Pushing high bit rates to the limit

www.mitsubishielectric.co.jp

The 40 Gbit s^{-1} Extender System showcased by Mitsubishi Electric is designed to compensate for signal distortion and attenuation encountered by 40 Gbit s^{-1} data-streams in the 1,540 nm to 1,555 nm window, thus enabling increased transmission distances. According to Mitsubishi, its MF-40GMCL is the first commercial product of its kind that can sustain an 80-km optical transmission link operating at a channel rate of 40 Gbit s^{-1}. The system is fully compatible with OC-768/STM-256 signals and boasts a compact, lightweight design ($442 \times 450 \times 88$ mm^3, 17 kg) containing the world's smallest 40 Gbit s^{-1} very-short-reach transponder together with built-in amplification and error-correction functions. When combined with Mitsubishi's tunable dispersion compensator, also displayed in the exhibition, the extender system is able to automatically compensate for chromatic dispersion in 40 Gbit s^{-1} systems. Designed for city-to-city connections, two versions with different transmission distances are available — the MF-40GMC for 40-km links and the MF-40GMCL for 80-km links. Unit prices are ¥15,000,000 (about $135,000) and ¥20,000,000 (about $180,000), respectively. Launched in August 2007, Mitsubishi estimates that the annual production for MF-40GMC and MF-40GMCL is 100 and 50, respectively.

Mitsubishi Rayon/Homefibre: Wiring the home with fibre

www.mrc.co.jp

In the near future, Ethernet and Gigabit Ethernet technologies are expected to become popular for transmitting ultrafast Internet data, Internet television and other bandwidth-hungry multimedia services around the home. With this in mind, Mitsubishi Rayon has introduced an in-house optical wiring solution based on plastic optical fibre, which is lightweight, flexible and has low attenuation. Mitsubishi is working with Homefibre, the transceiver maker Firecomms and Shimizu Kagaku Kougyo to provide a complete solution for installing home optical networks. The installation involves Homefibre laying Mitsubishi's ESKA plastic optical fibre in existing electricity ducts around the home. The house is then equipped with hybrid wall sockets, which offer both a digital broadband data connection and electrical power. Mitsubishi says that its plastic optical fibre also suits use in automotive networks, lighting, sensors, factory automation and data transmission.

JDSU: High-bit-rate test equipment

www.jdsu.com

With the commercial deployment of 40-Gbit s^{-1} transmission systems being a talking point of the conference, the need for compatible test and measurement equipment is clear. In the exhibition, JDSU proudly announced its ONT-506/512 Optical Network Tester (ONT), which the company claims is the industry's first portable single-box jitter tester for 40-Gbit s^{-1} and 43-Gbit s^{-1} networks. The ONT supports test and verification of network elements of up to 43 Gbit s^{-1} and enables physical layer evaluation, including jitter and wander at bit rates of 40 Gbit s^{-1} and 43 Gbit s^{-1} with unframed and framed

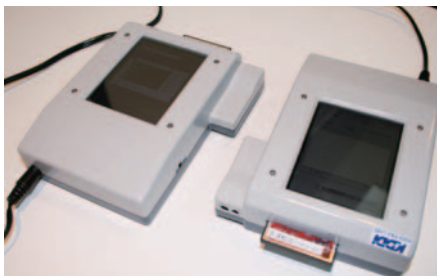
NEC: Submarine cable system

www.nec.co.jp

Displaying a gigantic submarine repeater for submarine intercontinental communication, NEC stole the limelight of the exhibition. The repeater R320 transports dense wavelength-division multiplexing (DWDM) high-capacity signals over trans-oceanic distances providing a highly reliable solution for growing capacity demands. NEC says that when used in a DWDM system it enables transmission of up to 1.28 Tbit s^{-1} per fibre pair and thus can achieve up to 10.24 Tbit s^{-1} over a cable of eight fibre pairs at transmission distances up to 12,000 km. Equipped with erbium-doped optical amplifiers pumped by either 980-nm or 1,480-nm lasers or both, the repeater enables high-power signal amplification. NEC says that its broad and flat gain spectrum and low figure noise make it ideal for DWDM applications over long distances. Each repeater is designed to accommodate up to eight amplifier systems. According to the company, so far more than 3,000 units of repeatered submarine cable systems with a lifetime of almost 25 years have been sold with a null failure rate so far.

signals for SDN/SONET/OTN. The ONT-512 mainframe is equipped with 12 slots, which house modules of the ONT family that can perform tests simultaneously, and the ONT-506 has 6 slots. Another product at JDSU's stand was the MTS-8000, a test solution designed for metro networks that now incorporates a new feature — an optical spectrum analyser (OSA) platform module. The OSA enables measurements of the true optical signal-to-noise ratio in reconfigurable optical add–drop multiplexer networks and in the Agile Optical Network with a high degree of accuracy. The OSA covers wavelengths of 1,250 nm to 1,650 nm, which makes it suitable for both dense wavelength-division multiplexing and coarse wavelength-division multiplexing testing.

KDDI: Optical wireless transfer



www.kddilabs.jp

Optical wireless devices are a promising approach for high-capacity, short-range communication owing to their ultrahigh transmission speed, small size and low power consumption. KDDI has now developed a 1-Gbit s^{-1} handheld file-transfer system based on an optical wireless interface and performed a live demonstration at the event. The device consists of an optical wireless transceiver, 128 Mbyte SDRAM, 128 Mbyte non-volatile memory and a transmission flexible group protocol agent and controller. The transceiver uses a 1,310-nm Fabry–Pérot laser diode with an average output power of 9 mW as a light source and an InGaAs PIN photodetector as an optical receiver. The devices operate using 1.25 Gbit s^{-1} non-return-to-zero signals, and the bit-error-rate performance is measured to be 2^7–1. According to KDDI, the device can transmit data at distances from 20 mm to 100 mm and anticipates applications for future mobile terminals with high-speed interfaces.

ADVA: Efficient transmission

www.advaoptical.com

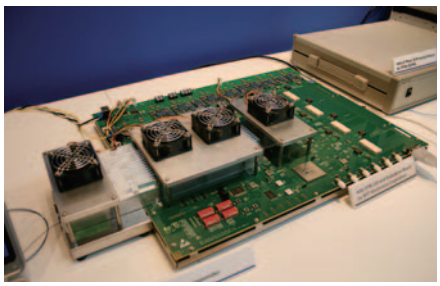
The Fiber Service Platform (FSP) product family showcased by ADVA of Germany focuses on the needs of enterprises and service providers deploying data, storage, voice and video applications. The optical-transmission system is designed with swappable modules that support coarse wavelength-division multiplexing, dense wavelength-division multiplexing, reconfigurable optical add–drop multiplexing and hybrid optical-layer configurations. ADVA says that its FSP 3000 offers cost-optimized transport of multiple services on a single wavelength at 2.5, 4, 10 and 40 Gbit s^{-1} and supports many protocols including Ethernet, SONET/SDH and G.709 OTN. ADVA also claims that the use of erbium and hybrid erbium/Raman amplification technology permits regenerator-free transmission over more than 1,000 km with 40 dB single span loss. The company also displayed its FSP 150CCs and FSP 150CCf Ethernet access platforms, which enable service providers to deliver profitable and differentiated Ethernet services.

Visible Light Communications Consortium: Lighting with a difference

www.vlcc.net

The visible light emitted by LED-based displays and lighting units can also be used for communication applications by modulating the intensity of the light output, according to the Visible Light Communications Consortium (VLCC). The consortium believes that this approach will be useful for many kinds of information transmission, human-interface technology, ultrahigh-speed wireless technology and high-precision positioning and navigation within buildings. The VLCC demonstrated various systems on its stand, including a wireless soundspot, image sensor and mobile file-transfer system. The soundspot consists of four LEDs in the wavelength range of 380–780 nm. Each emitting around 1 watt of power, these LEDs transmit data at a rate of 4.8 kbit s^{-1} by subcarrier four-pulse-position modulation at a frequency of 28.8 kHz. The coverage of each soundspot depends on the intensity of the LED but a typical scenario is a zone with a height of 10 m and spot diameter of 3 m. VLCC says that as LED light can be transmitted without causing any electromagnetic interference, the approach could be ideal for use in hospitals and airports where radiofrequency communication is not possible. VLCC is confident that the existing LED technology found in personal computers, advertising boards and mobile phones, as well as automobiles and traffic lights, could be used for visible light communication in the future.

Yokogawa: High-bit-rate expertise



www.yokogawa.com

Yokogawa demonstrated a state-of-the-art 40-Gbit s^{-1} DQPSK transponder at the exhibition. Exploiting the company's in-house expertise in compound semiconductor technology, the transponder helps extend the range of 40 Gbit s^{-1} systems by using a return-to-zero differential quadrature phase shift keying (RZ-DQPSK) modulation format. Measuring 320 × 110 × 40 mm^3, this transponder features a high-end transmitter and receiver. A full-band tunable

laser diode and 20 Gbit s^{-1} baud symbol rate RZ-DQPSK optical modulators are housed in the transmitter part whereas a delay interferometer, photodiodes and a clock recovery circuit constitute the receiver part. The transponder offers multi-rate capability (from 43.02 Gbit s^{-1} to 44.57 Gbit s^{-1}) and full C-band tunability (from 1,528.77 nm to 1,563.45 nm). Yokogawa also used the opportunity to display its optical phase-modulation analyser for DQPSK transmission, its optical packet interconnection technology, optical-router core subsystem, and core technologies for optical packet switching. The firm says that it is now developing a next-generation 100 Gbit s^{-1} transponder for DQPSK and QPSK transmission.

Trimatiz: Automatic optical amplifier

www.trimatiz.com

A prototype high-speed erbium-doped fibre amplifier with automatic gain control and a response time of within 1 μs was on display at the Trimatiz stand. According to the firm, the performance is due to a proprietary high-speed variable optical attenuator, which was also displayed at the exhibition. This amplifier can be customized to operate within wavelengths from 0.5 μm to 2 μm, including the C-band of the 1.5 μm telecom window. The erbium-doped fibre amplifier suits use for automatic gain control in both single-channel and multiple-channel wavelength-division multiplexing systems. Trimatiz says that it is scheduled to be mass-produced in the summer of 2008.

Nippon Signal: MEMS mirrors

www.ecoscan.jp

Nippon Signal was proudly showcasing laser finders and laser projectors based on its proprietary ECO SCAN resonant mirror technology. The resonant mirror is fabricated using microelectromechanical-system technology (MEMS) and is light-weight, scans at high speeds and has low noise and power consumption. It is available in versions that can tilt in either one dimension or two dimensions. The mirror is electromagnetically driven by the Lorentz force, which is used to tilt the mirror to perform large-amplitude scans with a small quantity of energy. Owing to its one-piece construction from single-crystal silicon, the mirror is extremely durable lending itself to a broad range of different optical products. For example, Nippon Signal demonstrated a laser projector based on a one-dimensional resonant mirror. The company plans to downsize this product to put it in use as a built-in projector for mobile phones, personal digital assistants, PCs and play stations.

Proximion: Dispersion compensation

www.proximion.com

By combining its in-house fibre-Bragg-grating technology with dispersion compensating fibre, Proximion has created a high-value dispersion compensation module (HDCM-CB) that it claims has the highest compensation effect available on the market at present. By integrating several fibre Bragg gratings in a single module, the HDCM-CB is able to compensate for transmission distances of up to 400 km and has an insertion loss of below 16 dB. Not only that, but the ratio of the dispersion distortion to the length of the compensated link is kept very low and can actually be optimized. With these properties, HDCM-CB is expected to be useful in high-speed-metro to long-haul networks, submarine networks and legacy systems, according to Proximion.

Tecdia: Tunable mirror filter

www.tecdia.com

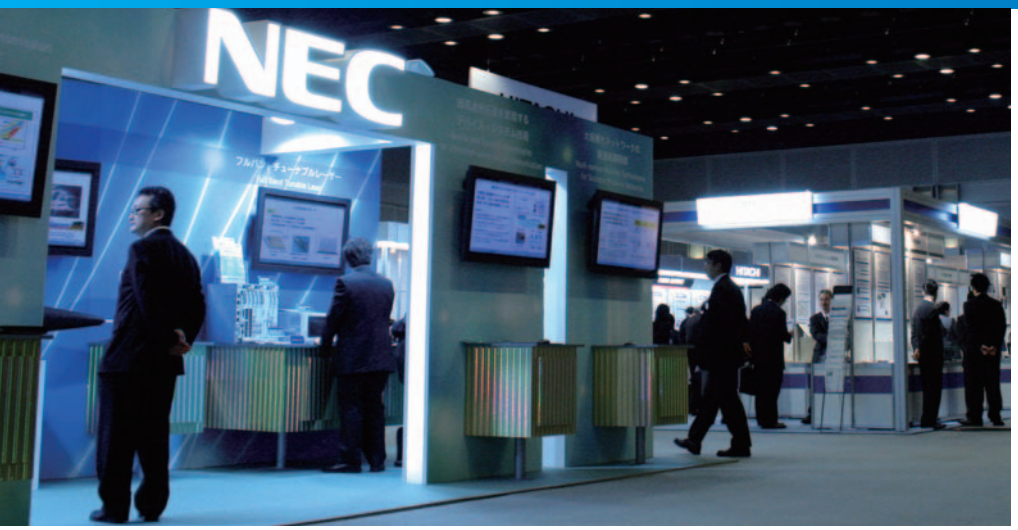
A liquid-crystal tunable mirror filter displayed by Tecdia is said to be highly useful for applications involving wavelength-division multiplexing (WDM) because of its broad bandwidth coverage and high reflectance. Conventionally, WDM communication requires a different transmitter module for each wavelength. However, Tecdia's liquid-crystal mirror filter enables two tunable laser modules to cover the entire C band or L band,

Hitachi: Y-00 quantum cryptography transceiver

www.hitachi-jiten.co.jp

The exciting potential of quantum cryptography was on display at Hitachi's stand. The company operated a live, real-time demonstration of the secure transmission of Hi-vision video data by a 2.5 Gbit s^{-1} Y-00 quantum cryptography system. Designed for next-generation, high-security communications, the Y-00 system is based on multilevel intensity modulation and the properties of quantum noise. The idea is to use quantum noise to prevent an eavesdropper from gathering knowledge about the encryption key, which is shared between the sender and the receiver. Hitachi's Y-00 transceivers suit transmission up to a distance of 50 km and feature a continuous-wave laser diode with an optical output power of 0 dBm and an external optical modulator. According to Hitachi, these transceivers will find applications in governmental,

banking and Hi-Vision/CATV networks. Hitachi also presented a prototype optical topography system that can be worn on the head, designed for observing activities in the prefrontal region of the brain. By using near-infrared spectroscopy to image changes in cerebral blood volume, scientists from Hitachi said that they can analyse the wearer's thoughts and actions. Potential applications are in the education and health-care sectors.



offering great flexibility and economy in WDM communication systems. The mirror filter is very stable and reliable as it does not rely on mechanical actuation and has well-controlled voltage operation. Owing to its small size, the module can fit into a butterfly package. According to Tecdia, the two models, TOF34C (C band) and TOF34L (L band) are still at the testing stage and the provisional release will be in 2008.

NICT: Terahertz technology

www.nict.go.jp

Promoting research and development from basic science to applications in the field of communications is the aim of the Japanese National Institute of Information and Communications Technology (NICT). At the event, the organization took the opportunity to exhibit its recent research activities. Among them were terahertz technology, real-time electro–optic imaging of microwave circuits, a quantum optical system and femtosecond-laser optical-frequency-comb generation. The goal of NICT's terahertz project is to achieve ultrahigh bit-rate wireless communication systems by developing semiconductor devices, such as terahertz quantum cascade lasers, terahertz-range quantum-well photodetectors and high-precision tunable continuous-wave sources. So far, a quantum cascade laser with a high peak-output power of around 30 mW at about 3.1 THz and threshold current density of less than 1 kA cm^{-2}, and a GaAs/AlGaAs terahertz detector with a peak frequency of 3 THz and responsivity of 10 mA W^{-1} at an electric bias of 40 mV have been achieved. NICT has also developed an ultrawideband terahertz time-domain spectroscopy system with a measurement range of from 0.5 THz to 15 THz and plans to make a terahertz spectra database for materials open to the public by the end of 2007. NICT has also developed an electro–optic imaging system for real-time analysis of electrical fields in a microwave circuit. The system is capable of imaging at a rate as high as 30 frames per second and the company expects that the system will be useful for determining the origins of unwanted radiowave emission or malfunctions in sophisticated microwave circuit boards.

NTT: Silicon photonics devices

www.ntt.com

Nippon Telegraph and Telephone (NTT) took the opportunity to showcase the diverse range of its research spanning from silicon photonics and nonlinear optics through to mid-infrared lasers. By combining silicon waveguides and electronic devices, NTT has successfully developed ultrasmall, low-cost modules for optical communications. For example, an add–drop wavelength filter at the communication wavelength of 1.55 μm, a thermo–optic switch and a wideband (1.2–1.7 μm) grating monochromator were displayed at the exhibition. According to NTT, the attraction of silicon photonics is that it enables highly compact and energy-efficient devices. Although many of the applications of silicon photonics are in the field of communications, NTT explained that the technology could also find applications in other applications, such as sensing. The company displayed a high-speed and compact electro–optic beam scanner based on nonlinear optics. The scanner steers an optical beam by applying an electrical signal to an electro–optic crystal KTN (potassium tantalate niobate). The optical deflection is induced by a voltage-dependent refractive-index change in KTN. With an efficiency 80 times better than conventional scanner designs, NTT anticipates that the scanner can be used in optical communications, sensing, optical recording and optical measurements. Another noteworthy product was NTT's mid-infrared laser, which is based on combining a $LiNbO_3$ wavelength converter with a telecom laser diode. NTT said that this 3-μm wavelength laser represents the first mid-infrared laser generated from a laser diode. Offering high sensitivity and *in situ* real-time measurement capability, this device is attractive for measuring the absorption spectrum of methane gas.

Fujitsu: Quantum photonics

www.fujitsu.com/global/

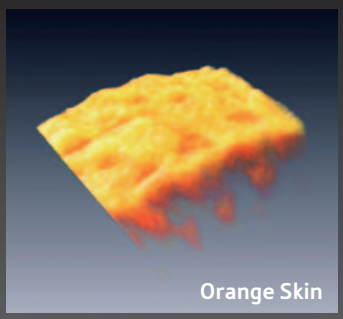
Fujitsu revealed its optical technology roadmap for the period from 2007 to 2020. Quantum-dot technology was among the highlighted technologies, in particular the development of a single-photon source for quantum cryptography and other photonic devices such as amplifiers. Still under patent application, Fujitsu's single-photon source is designed for quantum cryptography, which provides absolutely secure communications that can not be wiretapped. The single-photon source resembles a parabolic antenna that reflects the single-photon pulse emitted from the quantum dot into a beam that propagates in the direction of the substrate and can be coupled into an optical fibre. Fujitsu says that it has achieved a photon excitation efficiency of 11% — the highest value so far with semiconductor quantum dots. The company is now trying to miniaturize and stabilize the characteristics of the source and improve its performance. Fujitsu is also using its quantum-dot technology to make high-performance GaAs lasers for communication at a wavelength of 1.3 μm. For example, the company says that it has recently realized the world's first 1.3-μm-wavelength semiconductor laser for temperature independent 10-Gbit s^{-1} direct modulation. The company also presented a semiconductor optical amplifier with wide bandwidth (in excess of 100 nm) and high output power (in excess of 20 dB), which can amplify 10-Gbit s^{-1} signals to an output power as high as 23.1 dBm without distortion.

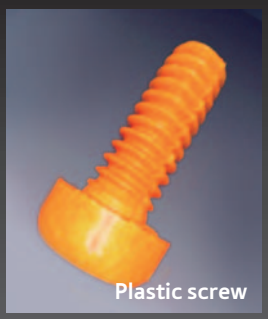
Inner Vision

Revealing inner space like you have never seen before.

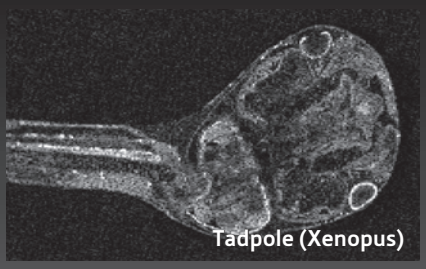
OCT image gallery

3D Inspection



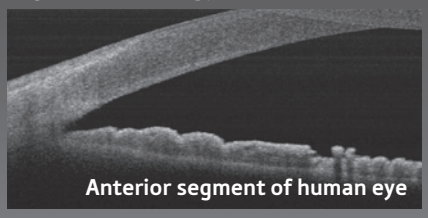


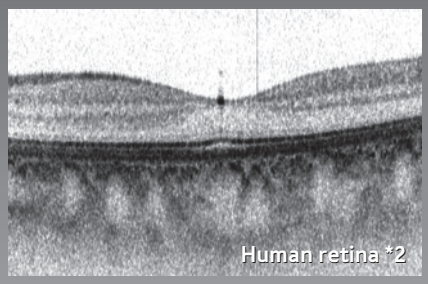
Biology



Endoscopy

Ophthalmology





References courtesy of *1 J. Su, J. Zhang, L. Yu, and Z. Chen (Univ. of California Irvine), *Optics Express*, **Vol. 15**, 10390 *2 Y.Yasuno (Tsukuba Univ.), *et al, Optics Express*, **Vol. 15**, 6121
(These two images were taken with their own developed SS-OCT system with using santec's HSL-series.)

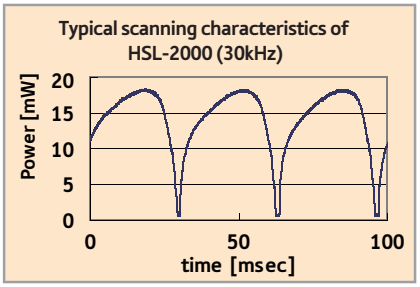
Swept-Source OCT system
Inner Vision IV-2000

Santec has developed a high speed scanning laser, HSL series that continuously scans over up to 150nm wavelength range at up to 30kHz. Swept-Source OCT, Inner Vision IV-2000, is a non-invasive imaging system that relies on analyzing the frequency components of backscattered light from the internal structure of an object or tissue using HSL. This new technology opens up various applications and creates new markets with significant benefits.

Santec Corporation is an established manufacturer of tunable semiconductor laser instruments and the leading manufacturer of scanning lasers for OCT.

Come visit BIOS booth#8008
and PhotonicWest booth#6157

High Speed Scanning Laser
HSL series



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