

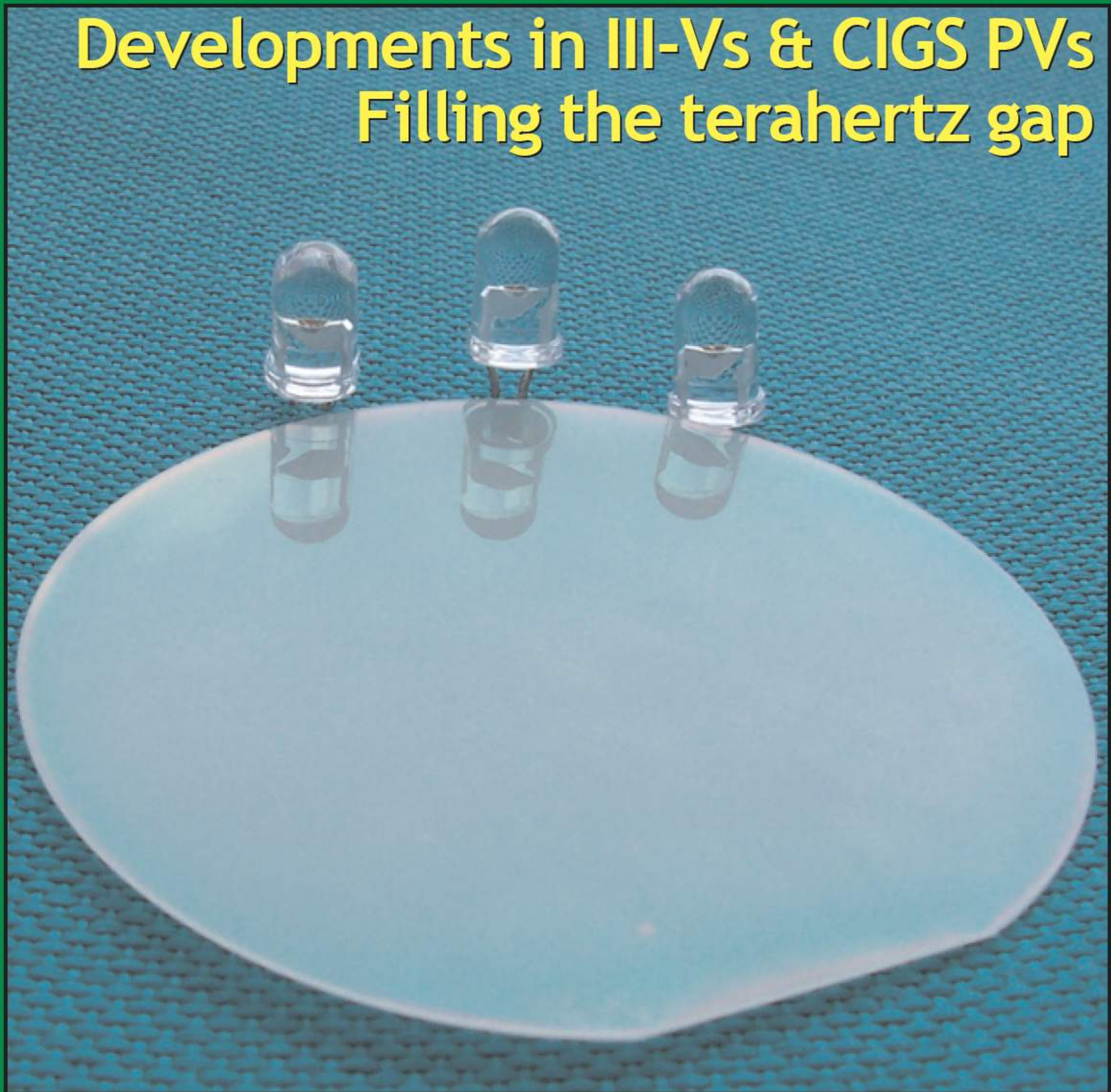
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C O M P O U N D S & A D V A N C E D S I L I C O N

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Developments in III-Vs & CIGS PVs Filling the terahertz gap



Nitronex launches 48V GaN-on-Si • RFMD's first GaN HEMT order
Cermet licenses GaN-on-ZnO LEDs • Cree LEDs qualified at 1A



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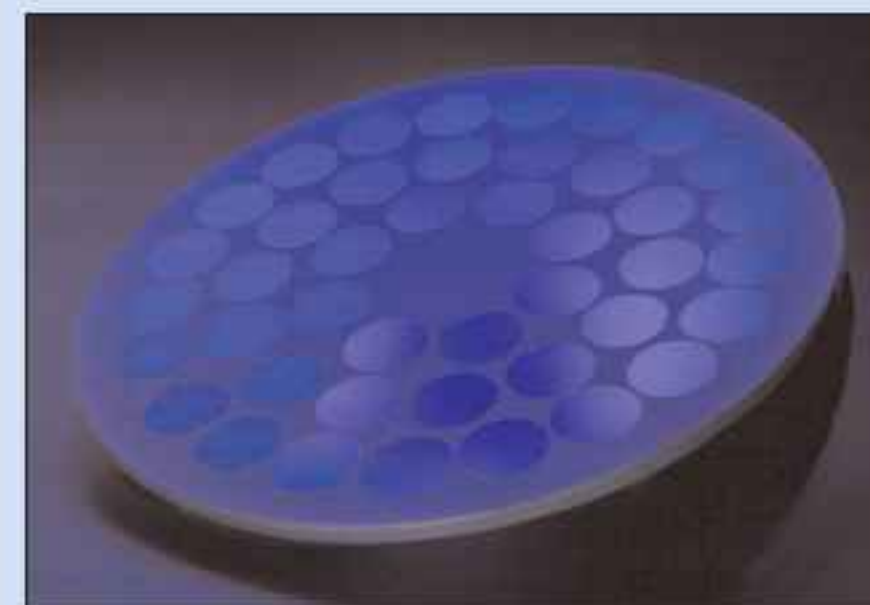
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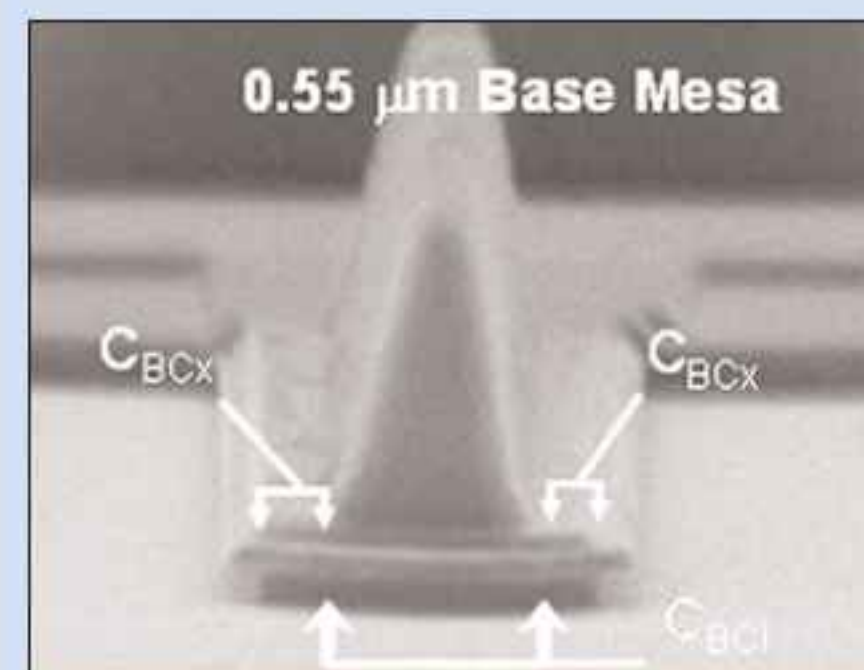
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p8 Wafer fabricated using Nitronex's 48V GaN-on-silicon platform for wireless infrastructure.



p10 Wafer carrier of Veeco's new 45x2"-capacity TurboDisc K465 GaN MOCVD system.



p38 SEM image of the base-collector mesa of the latest record-speed 845GHz transistor from UIUC's Milton Feng.



Cover: A 2" ZnO wafer made by Cermet, together with packaged LEDs. Cermet has licensed GaN-on-ZnO device technology, developed with the Georgia Institute of Technology, which enables the fabrication of LEDs that emit white light without the need for wave-length conversion by a phosphor. **p16**

Opto sees further growth prospects

In this issue we detail the latest transistor speed record (845GHz) reported at December's IEEE International Electron Devices Meeting by Milton Feng's group at the University of Illinois at Urbana-Champaign (p38) as they close steadily on the goal of a terahertz HBT. Furthermore, on pages 39-43 we elaborate on the 'terahertz gap' that has existed between high-frequency electronics and photonics technologies, and the developing applications such as terahertz imaging that are driving the investigation of the various device types and materials systems that can be used, such as GaN/AlGaIn or ZnSe/ZnCdSe double quantum well lasers and quantum cascade lasers.

Another application that is giving a big boost to the use of compound semiconductors is the ongoing shortage of silicon for solar cells. Following our overview of developments in copper indium gallium diselenide (CIGS) photovoltaic cells in our October/November 2006 issue, on pages 36-37 we give an update, including the specialist developers ramping up to full-scale commercial production in 2007/8 and collaborating with mainstream solar panel makers (especially in Germany, driven by government incentives), as well as silicon-based solar cell maker Q-Cells investing in Swedish CIGS university spin-off Solibro, and even car maker Honda establishing a CIGS solar cell manufacturing plant.

On page 35 we detail Spectrolab breaking the 40% barrier for terrestrial solar cells by incorporating a metamorphic InGaAs layer (rather than a lattice-matched GaAs layer) into its Ge-based triple-junction concentrator photovoltaic (CPV) cells. The firm is targeting 45% by 2010 using GaInNAs. Meanwhile, the world's biggest (silicon-based) solar cell maker, Sharp, entered the GaAs-on-Ge terrestrial CPV cell sector only last year, but has already achieved 36% efficiency, further boosting the prospects for non-silicon terrestrial PVs. Terrestrial applications also promise to boost Emcore, which recently invested in solar-power system supplier WorldWater & Power Corp, in exchange for a \$100m three-year CPV cell supply contract (see page 33). This should offset Emcore's reliance on satellite applications, which depressed revenues last quarter due to delays to satellite contracts.

However, last quarter Emcore's fiber-optic communications component sales rose, joined by JDSU, Avanex and Optium continuing the sustained recovery in the optical communications sector over the few years by reporting record quarterly revenues (see pages 26-31). Indeed, following Optium's \$97m IPO last November, as we closed for press Hitachi spin-off Opnext closed its IPO, raising \$254m (see next issue for details).

In contrast, Bookham's recovery has been thwarted by its Nortel supply contract ramping down and the growth in sales to non-Nortel customers stalling. This has led to further drastic cost-cutting measures, including closing its ex-Nortel plant near Ottawa and further job losses at Caswell, UK as it transfers more functions to Shenzhen, China. After its abandoned acquisition by Avanex (see p27) and the departure of CEO Georgio Anania, the pressures on Bookham to break even are more acute than ever.

Mark Telford

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Semiconductor Today covers the R&D and manufacturing of compound semiconductor and advanced silicon materials and devices (e.g. GaAs, InP and SiGe wafers, chips and modules for microelectronic and optoelectronic devices such as RFICs, lasers and LEDs in wireless and optical communications, etc).

Regular issues contain:

- news (funding, personnel, facilities, technology, applications and markets);
- feature articles (technology, markets, regional profiles);
- conference reports;
- event calendar and event previews;
- suppliers' directory.

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HB-LED lighting market \$1bn by 2011

In recent years, high-brightness LEDs (HB-LEDs) have demonstrated dramatic improvements in performance, as well as cost reduction, and the market for lighting applications is undergoing rapid growth, such that by 2011 it will approach \$1bn, according to a report by Strategies Unlimited, as the market grows beyond color and color-changing applications into residential, retail and off-grid applications, and ultimately into outdoor-area applications. By then it will only be the beginning for the ultimate replacement of conventional light sources, including high-efficiency fluorescent lamps.

Through 2006, HB-LED illumination applications included niche markets like architectural lighting, channel letter signs, machine vision, accent/decorative lighting, and landscape lights, taking advantage of the long lifetimes as well as the high brightness and efficiencies available from colored LEDs (relative to light sources such as filtered incandescent lamps and neon). Also, white LEDs have captured a strong market position in select

applications such as consumer portable lighting (e.g. flashlights, headlamps). More recently, white LEDs have begun to be used on a limited basis in applications such as retail display lighting.

Most general lighting applications require white light, so the market will begin to accelerate when white LED fixtures begin to offer energy savings compared to conventional light sources. This is likely to happen towards the end of 2007 with the introduction of high-performance white LEDs with efficiencies exceeding 100 lumens per watt, says Strategies Unlimited. However, many challenges face the LED industry to accomplish that goal, it adds.

White LEDs have captured a strong market position in select applications such as consumer portable lighting (e.g. flashlights, headlamps).

www.strategies-u.com

SOHO WLAN market to double

The small office, home office (SOHO) wireless LAN market is forecasted to double its 2006 levels to \$3.9bn by 2011, driven by increased shipments of higher-priced 802.11n products, according to a 5-Year Forecast Report by Dell'Oro Group.

"With the entrance of 802.11n in the SOHO market, revenue growth will remain robust as wireless LAN penetration into the broadband subscriber base rises to 75% in the next five years," says Elmer Choy,

analyst of WLAN research. "Broadband customer premise equipment with integrated wireless LAN will contribute most to this penetration, with almost 60% of the unit shipments in 2011," adds Choy.

Also, the market for wireless mesh nodes, which enable development of municipal Wi-Fi networks, will be the fastest-growing wireless LAN segment over the next five years, the report adds.

www.DellOro.com

Market for mobile WiMax & WCDMA infrastructure to offset CDMA and GSM declines through 2011

Mobile infrastructure equipment revenues are projected to grow steadily over the next five years, with a slight acceleration in 2008 due to increased mobile WiMax revenues, according to a 5-Year Forecast Report by Dell'Oro Group.

"We expect the mobile WiMax market to grow by a compounded annual growth rate exceeding of 50% through 2011," says Greg Collins, VP of Mobile Infrastructure research. "Despite this strong growth, we predict WiMax will account for less than 10% of the mobile infrastructure market in 2011 because of the lack of voice services available in the short term," he adds.

Also, the WCDMA market is expected to perform exceptionally well by 2011, capturing meaningful market share from the rival technologies GSM and CDMA. The CDMA market is projected to shrink as service providers in key growth regions — India, Brazil, and Korea — continue to migrate their subscriber bases to GSM- or WCDMA-based services. GSM service providers are also expected to start migrating to WCDMA.

"While growth in WCDMA remains tepid in the short term, we remain confident in its longer-term growth and potential to slowly displace GSM, because of the large percentage of mobile service providers that have committed to WCDMA technology and the expectation of increased subscriber adoption as handset prices drop in the future," says Collins.

www.DellOro.com

Record Q4 boosts handset shipments past 1bn in 2006

After 23 years of growth, annual mobile handset shipments reached 1 billion units during 2006, as predicted since last April by market research firm Strategy Analytics.

A record 300m cell phones were shipped in Q4/2006, up 22% on a year earlier. Nokia passed 100m units for the first time. Motorola gained market share, but saw tumbling average selling prices (ASP) and profit. Samsung's share was marginally down, as was LG's.

Attractive models and cool sub-brands yielded record shipments for Sony Ericsson which, in terms of revenues, is now the third largest vendor, overtaking Samsung.

For 2007, Strategy Analytics forecasts 1.1bn units (up 12% on 2006).

IDC's Worldwide Quarterly Mobile Phone Tracker reports shipments of 1.019bn units in 2006, 22.5% up on 2005's 832.8m. Q4 shipments totaled a record 294.9m units, 19.7% up on Q4/2005's 246.4m.

"Emerging markets contributed to the high volume sales," said Ramon Llamas, research analyst in IDC's Mobile Technology and Tracking team. "It was not long ago that shipments into mature markets, including Japan, North America, and Western Europe, consumed the majority of devices shipped worldwide. More recently, however, device shipments into emerging economies in Asia/Pacific, Central and Eastern Europe, the Middle East, Africa, and Latin America have surpassed shipments to mature markets, and the difference between the two continues to grow," he adds.

Shipments (in millions), market share and growth (IDC).

Vendor	Q4/06	Share	Q4/05	Share	Change
Nokia	105.5	35.8%	83.7	34%	26.0%
Motorola	65.7	22.3%	44.7	18.1%	47.0%
Samsung	32	10.9%	27.2	11.0%	17.6%
Sony Ericsson	26	8.8%	16.1	6.5%	61.5%
LG Electronics	17	5.8%	16.2	6.6%	4.9%
Others	48.7	16.5%	58.5	23.7%	-16.8%
Total	294.9	100%	246.4	100%	19.7%
Vendor	2006	Share	2005	Share	Change
Nokia	347.5	34.1%	264.9	31.8%	31.2%
Motorola	217.4	21.3%	146	17.5%	48.9%
Samsung	118	11.6%	102.8	12.3%	14.8%
Sony Ericsson	74.8	7.3%	51.1	6.1%	46.4%
LG Electronics	64.4	6.3%	54.9	6.6%	17.3%
Others	197.8	19.4%	213.1	25.6%	-7.2%
Total	1019.9	100%	832.8	100%	22.5%

N.B. Branded shipments, excluding OEM sales for all vendors.

"IDC expects this trend to continue as mature markets reach saturation and emerging markets, with much lower tele-density, provide ample opportunity for handset vendors to attract first-time users," he continues. Also, "the time to set up a mobile network is much shorter and less expensive than the time to set up a landline network, propelling cell-phone shipments further. Finally, mobile phones are seen as both a practical necessity and a status symbol in many emerging markets. Together, these economic, technological, and social conditions will continue to drive strong demand for mobile handsets in emerging markets for some time to come," concludes Llamas.

"Shipments of GPS-enabled handsets are certain to grow in most regions in 2007," says IDC research analyst Ryan Reith.

From a vendor perspective, Q4/2006 was similar to that of Q3, where some of the top-tier phone vendors reported record shipments yet declining profit margins, as follows:

1. Nokia shipped 105.5m units (up 26% year-on-year, from 34% to 35.8% market share) — a daily average of over a million units. But high volumes of entry-level devices depressed profits.

However, its converged mobile devices continued to outpace all other vendors, shipping 11.1m units.

2. Motorola shipped a record 65.7m units (up 47%, from 18.1% to 22.3% share), but 4.4% operating profit fell short of target due to late 3G launches and challenges in product

mix. It now aims to cut 3500 jobs.

3. Samsung shipped 32m units (up 17.6%) and exceeded its 2006 target, but its market share fell further behind Motorola. The launch of its Ultra Edition handsets buoyed shipments in Europe and Asia, and its Blackjack bolstered its converged mobile device lineup in Q4. The firm expects to ship 133m units in 2007.

4. Sony Ericsson shipped 26m units (growing the most, up 61.5%, from 6.5% to 8.8% share), closing on Samsung and pulling clear of LG. Sales of entry-level devices extended its reach in emerging markets.

5. LG shipped a record 17m units (up 4.9%, but down from 6.6% to 5.8% share). Profits for 2006 fell 72.9% from 2005 due to price cuts on leading models. It aims to launch more key devices, expand its presence in emerging markets, and enhance its brand in mature markets.

Other vendors shipped 58.5m units (down 16.8%, from 23.7% to 16.5% share) as the market consolidates on the big five.

www.idc.com

www.strategyanalytics.com

Filtronic curtails expansion on lower-than-expected demand

In its full interim results for first-half fiscal 2006/7 (to end-November), Filtronic plc of Shipley, UK (which makes microwave devices, components, and subsystems for electronic defense, point-to-point communication, and cell phones) reported revenue for continuing operations up 24% year-on-year (from £28.9m to £35.8m).

Filtronic Compound Semiconductors Ltd (FCSL) in Newton Aycliffe contributed £15.1m (up 44% year-on-year from £8.5m), rising from 29% to 42% of total revenues. This was mainly due to sales of GaAs pHEMT switches for cellular handsets to its US customers.

Excluding a profit of £82.6m from October's sale of the Wireless Infrastructure business to Powerwave Technologies, Filtronic's operating loss was cut from £8.6m to £5.9m. However, the break-even achieved by FCSL in the preceding half year to end-May was not sustained,

mainly due to product price reduction and exchange rate effects.

In early 2006 Filtronic announced an investment of £45m to triple FCSL's capacity. However, last June (after group losses of £6.7m for the half-year to end-May) the capital expenditure plan was cut to £15m.

Since then, Filtronic has experienced lower-than-expected demand for GaAs pHEMT switches on the merchant market.

Hence, as stated in mid-December's trading update for first-half fiscal 2006/7, the expansion plan has been curtailed 'within the limitations of contractual commitments and logical steps in installing equipment'. This will reduce the capital expenditure program by a further £5m to 'not exceeding £10m'. This incorporates a provision of £7m for charges related to cancelling contracts for chip manufacturing equipment that Filtronic ordered but now no longer needs.

Also, central R&D (mainly focused on the wireless infrastructure group) has been discontinued (saving £1m a year), with surplus property earmarked for disposal, including the main headquarters in Shipley.

"Progress has been made in reducing the losses in the continuing group and in taking actions to achieve the goal of a profitable and cash-positive performance," said chairman John Poulter.

However, for its fiscal second-half 2006/7 (to end-May), Filtronic's revenue is now forecast to be flat on the first half, with neither FCSL nor Point to Point expecting to show revenue growth. Losses in FCSL and the US Defence businesses, together with central costs, will exceed the operating profits from the UK Defence and Point to Point businesses. "The second-half outlook is still for the group to be loss-making," Poulter concludes.

www.filtronic.co.uk

Element Six collaborates on Diamond Microwave Devices

Element Six of Ascot, UK, which produces synthetic CVD diamond for industrial uses, has set up a Diamond Microwave Devices (DMD) subsidiary to develop materials and processing technology for high-power, high-temperature semiconductors for use in microwave power amplifiers and transmitters.

Element Six has also agreed to collaborate with Filtronic on technology development. The two firms have complementary strengths in materials, semiconductor device processing, and circuits that will be used in the development of diamond-based microwave technology, Element Six says. As well as having a GaAs fabrication plant at its Compound

Semiconductor division in Newton Aycliffe, Filtronic manufactures custom microwave subsystems at its Defence division in Shipley.

For high-power electronics, CVD diamond offers unique properties such as high breakdown voltage and high-temperature operation. If a practical semiconductor device can be demonstrated, it could provide superior microwave power and higher operating temperatures than existing devices and technologies, says Element Six.

Element Six has already been involved with research and industrial programs such as the UK Department of Trade and Industry sponsored CAPE (Carbon Power Electronics) program, aimed at overcoming the technical chal-

lenges of developing diamond-based electronics components.

"Whilst the technical challenges are high, a diamond MESFET could revolutionize the design of future microwave power modules," said DMD's general manager Richard Lang. "There is much work to be done in order to realize a practical device," he cautions.

"Diamond has the potential to be the ultimate semiconductor for high-frequency, high-power electronic applications," claims Element Six's CEO Christian Hultner. "The establishment of DMD provides greater momentum to our activities in this area and will accelerate the development of practical devices."

www.e6.com

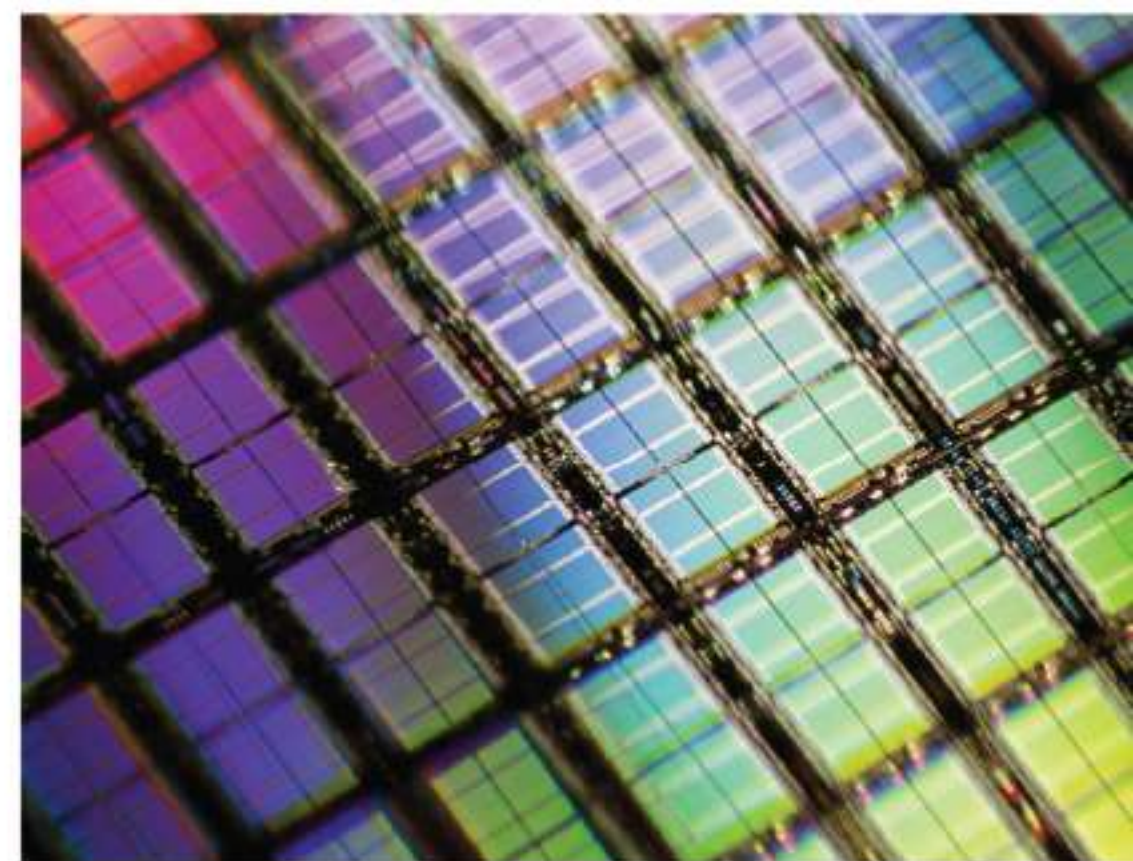


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IN BRIEF

GaN MMICs complete 8000 hours of testing

Defense electronics manufacturer Raytheon Company of Waltham, MA, USA says that GaN monolithic microwave integrated circuits developed by its Integrated Defense Systems (IDS) business have successfully completed 8000 hours of operational testing.

The tests were conducted at elevated temperatures and operating conditions in order to simulate performance over a period of 80,000 hours (about nine years of normal operation). Raytheon plans to continue accumulating test hours on the GaN MMICs into 2007. Concurrent independent validation will also continue into 2007.

"GaN semiconductors are capable of delivering up to 10-times higher power levels compared with the current [GaAs-based] technology," said Mark Russell, IDS' VP of engineering. "Combined with their enhanced thermal characteristics, they offer the potential for improved performance in current and future military applications."

The test demonstrates the reliability of Raytheon's GaN technology for high-power applications such as military radar, communications, electronic warfare and missile systems, the firm says. "It can significantly expand the warfighter's reach into the battlespace by trading off increases in range, sensitivity and search capability for same-sized antennas," adds Russell. "Alternatively, GaN technology can reduce the radar antenna size by half while more than doubling the search volume." This can improve the radar's transportability and reduce acquisition and lifecycle costs.

www.raytheon.com

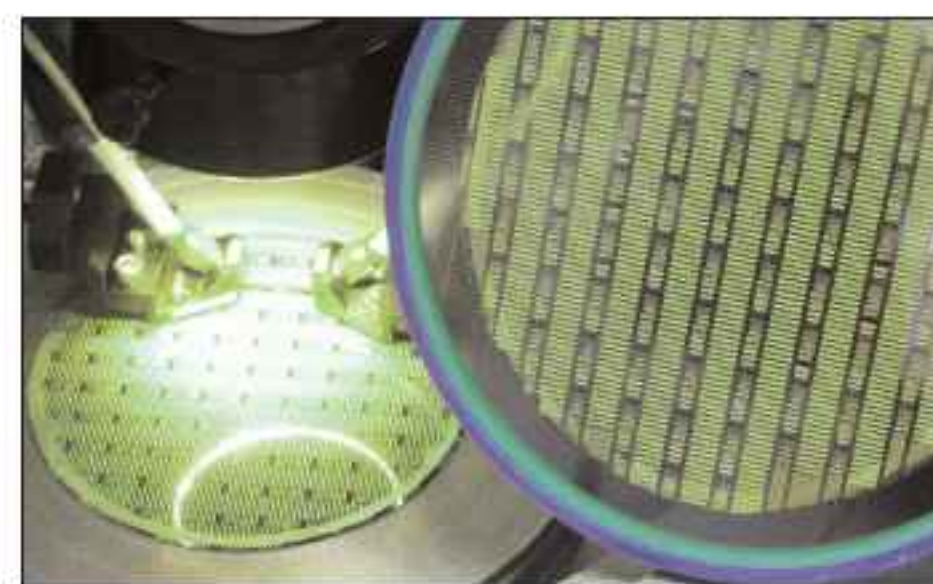
Nitronex launches 48V GaN-on-Si platform for wireless infrastructure

Nitronex of Raleigh, NC, USA has announced a 48V GaN-on-silicon platform for wireless infrastructure.

Based on its existing, qualified NRF1 SIGANTIC technology, the new platform exploits thermal enhancements in wafer processing, transistor design and packaging to support 48V operation under all waveforms and extreme flange temperatures.

"Designed to support high-power broadband operations, the high-voltage, thermally enhanced platform enables software-reconfigurable radios by giving RF power amplifier designers a power and bandwidth combination not available with other production technologies," claims Chris Rauh, VP Sales and Marketing.

"Supply voltages of 48V allow devices to operate with reduced memory effects, wider RF output bandwidth and easier matching. In a new RF power amplifier design, this translates into improved system efficiency and reduced number of prod-



Wafer fabricated using Nitronex's 48V GaN-on-silicon platform.

uct variants, resulting in reduced acquisition and operating costs. For existing designs, we see this product line helping to extend the service life of existing systems by improving efficiency and bandwidth."

Initial products will be for WiMAX and 3G/3G LTE cellular waveforms operating at 1.8–2.2GHz and 2.3–2.7GHz. Line-ups with outputs of 5–200W will be supported. Samples are expected in March, with full production qualification in Q3/2007.

www.nitronex.com

RFMD receives first GaN HEMT order

RF Micro Devices Inc of Greensboro, NC, USA has received its first purchase order for GaN HEMT power amplifiers (RF3825 PowerIC broadband power amplifiers for a "top-tier military supplier").

The 15W devices can operate from 200MHz to 1.9GHz (suited multiple band and broadband applications) and greatly enhance the bandwidth of software-defined radios for military communications, RFMD says.

RFMD's efforts to commercialize GaN technology began in 2000, and have been funded partly by the US government. This order represents "a significant step forward in terms of customer and market diversification," says president and CEO Bob Bruggeworth. "In addition, GaN technology is applicable to markets beyond military, including public mobile radio, WiMAX and wide-band-CDMA base-stations. The

combined revenue opportunity presented by these new markets is approximately \$1bn."

"GaN cost-effectively addresses the multiple bands required in WCDMA, WiMAX, military jammers and other markets with a single device, compared to the multiple devices required by competing process technologies, like LDMOS," says chief technical officer Bill Pratt.

RFMD manufactures its GaN technology on 3" SiC substrates in its high-volume fab, where it makes AlGaAs and InGaP HBTs and GaAs pHEMTs. It expects its first GaN product shipments in first-half 2007.

RFMD also expects to announce future advances in GaN technology in 2007, including the availability of high-power amplifiers featuring high linearity, wide bandwidth and power outputs of up to 200W.

www.rfmd.com

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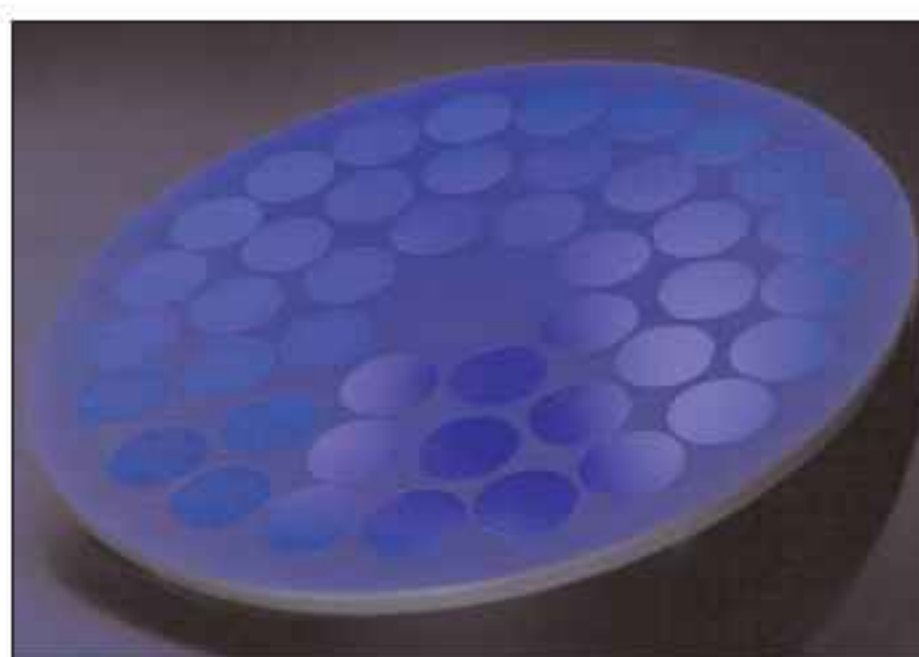


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New HB-LED MOCVD platform

Veeco Instruments Inc has introduced its new TurboDisc K-series GaN MOCVD platform for the production of high-brightness LEDs, and received orders for five new systems from three leading manufacturers totaling about \$10m.

The K-series includes the K300 and K465 models, offering a modular, upgradeable path to higher throughput, a larger-diameter reactor chamber and reduced cost of ownership. The K465 features the firm's most advanced reactor technology, offering about 50% greater throughput compared to currently available competitive MOCVD production tools, it is claimed. Veeco also claims that the K300 is the only MOCVD platform available with a fully automated, configurable, four-port expansion-ready hub for future multi-module processing and measurement modules. An automated



Wafer carrier of Veeco's TurboDisc K465 GaN MOCVD system, with a capacity of 45x2" wafers.

hot carrier transfer system that runs at about 300°C enables the wafer carrier to be loaded at any time during the process cycle while the reactor remains under vacuum, boosting throughput. No parts changes are needed between runs.

The new multi-generational platform and larger reactor capability will give HB-LED makers "a long-

term cost-of-ownership advantage plus the technology to achieve their LED brightness roadmap objectives," says chairman and CEO Edward H. Braun. Veeco continues to expect strong growth in this market as HB-LEDs experience adoption in applications such as automotive, architectural lighting and backlighting for laptops and LCD-TVs, he adds.

"Our new modular system, which is extendable to larger reactors, is the only platform capable of continuous operation available on the market," claims Piero Sferlazzo, VP and general manager of MOCVD operations. "Couple that with the excellent uniformity and repeatability of the TurboDisc technology, our customers now have a true, multi-generational, high-volume production MOCVD system."

www.veeco.com

Aviza's quarter revenues more than double year-on-year

For fiscal Q1/2007 (to end-December), process equipment maker Aviza Technology Inc of Scotts Valley, CA, USA had revenues of \$62.2m (up 19.6% sequentially and 114.9% year-on-year). The growth is due to increased demand from major DRAM customers and continued penetration of etch and PVD systems, the firm says, coupled with the conversion from 'new technology' to 'proven technology' of its Deep Silicon (DSi) etch module (for system-in-package, wafer-level packaging and conventional MEMS production).

Net income was \$1.1m, up from \$779,000 last quarter and a loss of \$4.6m a year ago, mainly due to an improvement in product mix.

"We once again exceeded our revenue guidance, and this marks the fourth consecutive quarter in which we have demonstrated an increase in revenue," said CEO Jerry Cutini.

"We achieved continued penet-

ration of our atomic layer deposition products and augmented our ALD relationships, as well as identified key opportunities in the power IC, wafer-level packaging and memory IC markets to increase our revenue channels," Cutini adds. During the quarter, Aviza received an order from a leading DRAM maker for its Celsior next-generation single-wafer ALD system, to be installed at its US facility for fabricating 90nm devices on 200mm wafers. Aviza also announced a joint development agreement to use its ALD hardware with the expertise of BOC Edwards (now The Linde Group) in chemical precursor formulation, in order to optimize deposition processes for high-k materials and metals.

"Additionally, we enhanced our R&D resources, both externally and internally," adds Cutini. Aviza was awarded a multi-year grant of about £1.2m (\$2.2m) from the Welsh Assembly Government's Regional

Selective Assistance program. This will enable Aviza to further develop and strengthen its plan to invest £6.4m over a multi-year period to enhance research, development and engineering capabilities at its facility in Newport, Wales, UK, complementing R&D work in Scotts Valley.

In January, Aviza filed a registration statement with the US Securities and Exchange Commission for a public offering of 4 million shares of its common stock. Aviza has granted Needham & Company LLC an option to purchase up to 600,000 further shares to cover over-allotments. Aviza intends to use the net proceeds for working capital, R&D and other general corporate purposes, which may include repaying borrowings under its mortgage and revolving lines of credit.

For its fiscal Q2/2007, Aviza expects revenues of \$60-64m, with operating income of \$2.5-3.0m.

www.avizatechnology.com

RF drives Ribber's 2006 sales up 14%

MBE reactor maker Ribber Group of Bezons, France has reported revenues for 2006 of €20.1m, up 14% from 2005's €17.7m. The firm billed 13 machines, including five production machines.

As a result of increased sales of 'nomadic communication products', production machine revenues rose 57% (from €6.1m to €9.6m). Ribber delivered one MBE 49 machine, one MBE 6000 machine and three MBE 7000 machines for microelectronic applications.

Research sales were down 24% (from €6.7m to €5.1m), comprising the delivery of eight machines compared to 11 in 2005, mainly due to reduced deliveries in Asia.

Component sales grew 10% (from €4.9m to €5.4m), generated by the development of maintenance and after sales service operations.

Sales in Europe fell 44% (from

€9.1m to €5.1m), since no production machines were delivered in that region. Sales in North America rose sharply by 97% (from €3.7m to €7.3m), with the sale of three production machines (compared to one in 2005). Sales in Asia rose 55% (from €4.9m to €7.6m), due to the sale of two production machines there (compared to none in 2005).

Ribber's sales backlog was €7.2m (down 43% on €12.5m a year ago), comprising five research machines and the machine of the high-k dielectric Ribber/IMEC oxide research program, which will be leased for three years (contributing to sale revenues).

Ribber's main goal for 2007 is to improve profitability, leading it to favor certain transactions over others, the firm says. It expects 2007 sales to be lower than 2006.

www.riber.com

Oxford Instruments delivers twin V100 MBE system to Asian user

Oxford Instruments Plasma Technology of Yatton, UK says it has delivered a twin V100 MBE system to a prestigious customer in Asia.

With an installed base of over 60 systems, the V100 is suited to high-volume production, being fully automated for handling multi-wafer platens with 4 x 4", 5 x 3" or 12 x 2" capacity. It is widely used in the manufacture of pHEMT, MESFET and HBT structures as well as the fabrication of laser diodes. The twin reactor also uses the firm's Therma-Cell effusion sources and the 3 litre version of the ECellAs valved arsenic cracker source (launched last November).

"The successful delivery of such a complex system further demonstrates the in-depth capability of



Oxford Instruments' twin V100 MBE system.

Oxford Instruments since acquiring the VG Semicon MBE business in October 2003", comments Tony Cornish, business manager for MBE and Ion Beam products.

www.oxford-instruments.com

Genesis orders six more Thomas Swan CCS systems for nitride HB-LEDs

Aixtron AG of Aachen, Germany says that in Q4/2006 it received purchase orders for six more Thomas Swan Close Coupled Showerhead MOCVD tools, as part of a long-term purchase agreement, from Genesis Photonics Inc (GPI) of Southern Taiwan Science-Base Industrial Park in Tainan. The reactors will be used for the production of nitride high-brightness LEDs (HB-LEDs).

Founded in January 2002, GPI provides InGaN-based blue and green LED epiwafers and chips (grown on sapphire substrates) for lighting, displays, backlights, and automotive applications as well as for scientific, industrial, and research applications. With over 36,300ft² of floorspace, GPI claims to be Taiwan's fastest-growing LED maker, and launched an initial public offering of 50 million shares in December.

"With this boost for our MOCVD production, Genesis will be in an excellent position to become one of the top suppliers for the LCD backlighting market," says GPI's chairman and CEO David Chung.

Display backlighting applications command about half of the total HB-LED market, says Aixtron. Newer applications such as backlights for camcorders, notebook and desktop PCs and high-definition TVs are continuing to provide good growth. However, while shipment volumes are increasing, the unit price per device is falling steeply, so LED makers are relying on high-yield manufacturing.

Aixtron had previously delivered a Thomas Swan Close Coupled Showerhead MOCVD reactor (with a capacity of 19x2" wafers) to Genesis Photonics in May 2005.

www.aixtron.com

www.g-photonics.com

Evans expands into France, Germany, Japan and UK by acquiring Cascade, Shiva and Nano Science

Evans Analytical Group LLC (EAG) of Sunnyvale, CA, USA, which provides microanalytical imaging, surface analysis and materials characterization services as well as semiconductor circuit repair and failure analysis testing, ended 2006 by acquiring five more companies:

- Cascade Scientific Ltd of London, UK and sister firm Cascade Scientific GmbH of Frankfurt, Germany;
- Shiva Technologies Inc of Syracuse, NY, USA and sister firm Shiva Technologies Europe SARL of Tournefeuille, France; and
- Nano Science Corp of Tokyo, Japan, which is a long-standing technical sales and customer service partner for EAG and Shiva.

EAG has also signed a letter of intent to acquire Shiva's affiliated lab in Bangalore, India.

Founded in 1988, Cascade focuses on the analysis of silicon-based and optoelectronic devices at all stages of fabrication. Capabilities include: secondary-ion mass spectrometry (SIMS), time-of-flight SIMS (TOF-SIMS), total reflection x-ray fluorescence (TXRF), x-ray spectroscopy (XPS), Auger electron spectroscopy (AES), atomic force microscopy and scanning tunneling microscopy (AFM-STM) and spreading resistance analysis (SRP).

Founded in 1990, Shiva is the largest analytical services provider of glow-discharge mass spectrometry (GDMS) for high-purity material research and production. GDMS is used for the depth-profiling of trace elements in inorganic solid materials including semiconductors, metals and alloys, as well as thin films and coatings. Shiva also offers services for laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), inductively coupled plasma optical emission spectrometry (ICP-OES) and interstitial gas analysis (IGA).

LA-ICP-MS can perform elemental characterization of items such as spots and stains etc as small as 5µm.

Also, since it samples materials directly, sample preparation issues are minimal and dilution effects, common to solution-based techniques, do not exist.

"With these transactions, we continue the strategic expansion plan we established early in 2006", said EAG's CEO Tom Pfeil:

- In May EAG acquired the operating assets and detector software of Thin Film Analysis Inc, a Silicon Valley-based analytical lab for material characterization using the ion-beam accelerator techniques of Rutherford Backscattering analysis (RBS), hydrogen forward scattering analysis (HFS or FRES), and ion channeling analysis.

- In August EAG acquired Applied Microanalysis Labs Inc of Santa Clara, CA, which provides static and dynamic SIMS techniques, boosting EAG's instrument capacity. It was founded by Dr Yumin Gao, a specialist in III-V surface analysis (particularly GaN-based LED structures).

- In November EAG acquired AMIA Labs of Leesburg, VA, which provides x-ray diffraction, fluorescence and reflectometry services (to be integrated into EAG's facility in Round Rock, near Austin, TX). AMIA has developed techniques for measuring texture, stress, composition and thickness on thin films, as well as micro-diffraction capabilities for patterned wafers.

"AMIA's x-ray based techniques are an excellent complement to EAG's existing suite of analytical methods by providing information on crystallographic phase, orientation and crystallite size of polycrystalline materials and epitaxial films", said Dr Richard S. Hockett, EAG's chief scientist. "Characterization of strained thin films such as SiGe, carbon-doped silicon, and AlGaIn is a significant semiconductor industry issue and EAG is well equipped to meet this need through the acquired x-ray services capabilities, coupled with our existing Raman expertise."

- In December, EAG acquired Advanced Materials Engineering Research (AMER) of Sunnyvale, CA, which provides a TEM, SEM, circuit repair and ESD service laboratory services. EAG says that AMER's lab in Shanghai allows it to better serve customers in the China region. "We have established a mainland China presence, added world-class TEM capabilities...and gained a significant failure analysis competency, including semiconductor circuit repair and electrostatic discharge and latch-up testing services," said Pfeil.

- Also in December, EAG acquired the semiconductor and microelectronics services operations of Materials Analytical Services (MAS), which has labs in Arizona, California and North Carolina and provides TEM, STEM, FIB, SIMS, AES, XPS, AFM, XRR/XRF and LEXES services.

The addition of TEM, scanning transmission electron microscopy (STEM), and associated focused ion beam (FIB) capabilities provides the enhanced-resolution imaging required as technologies trend to smaller devices, EAG says. The LEXES and XRR/XRF techniques also complemented its existing thin-film analysis capabilities (AES, RBS, XPS, and XRD).

The latest acquisitions expand EAG's analytical lab operations from six to 15 sites in seven countries, covering strategic regions in Asia, Europe and the USA, including Arizona, Massachusetts, Minnesota, New Jersey, New York, North Carolina, Texas, China, France, Germany, Japan, Taiwan, and the UK, as well as sales/support offices in Korea, and Singapore. "We now offer over 25 major surface analysis techniques, and have analytical service labs in the key global areas, allowing us to efficiently offer the complete suite of EAG analytical solutions through each location," says Pfeil. EAG's customer base is now over 2000 firms in more than 35 countries.

www.eaglabs.com

Ocean Optics launches benchtop spectroscopic ellipsometer for thin

The German-based Mikropack branch of Ocean Optics of Dunedin, FL, USA has introduced the SpecEL-2000-VIS benchtop spectroscopic ellipsometer for fast, precise thin-film measurement of layer thickness, refractive index, absorption and components ratio on semi-transparent flat samples such as wafers and glass plates.

The all-in-one system has a footprint of just 52cm x 33cm x 24cm and an integrated light source, spectrometer and two polarizers. It comes with a 32-bit Windows PC featuring easy-to-use software and measures polarized light reflected from the surface of the substrate to determine the thickness and the refractive index of the material as a function of wavelength.

Depending on the layer and substrate material, the SpecEl can detect layer thicknesses from 1nm to 5µm, and refractive indices over



Ocean Optics' SpecEL-2000-VIS benchtop spectroscopic ellipsometer.

the full 450-900nm spectral range. Analysis is carried out at the touch of a button within seconds of placing a sample on the wafer-chuck.

The software enables experiment methods to be configured and saved for one-step analysis. The analysis software provides a range of modeling possibilities, such as Cauchy, OJL, Tauc-Lorentz, Drude, EMA and different types of oscillators.

www.OceanOptics.com

IN BRIEF

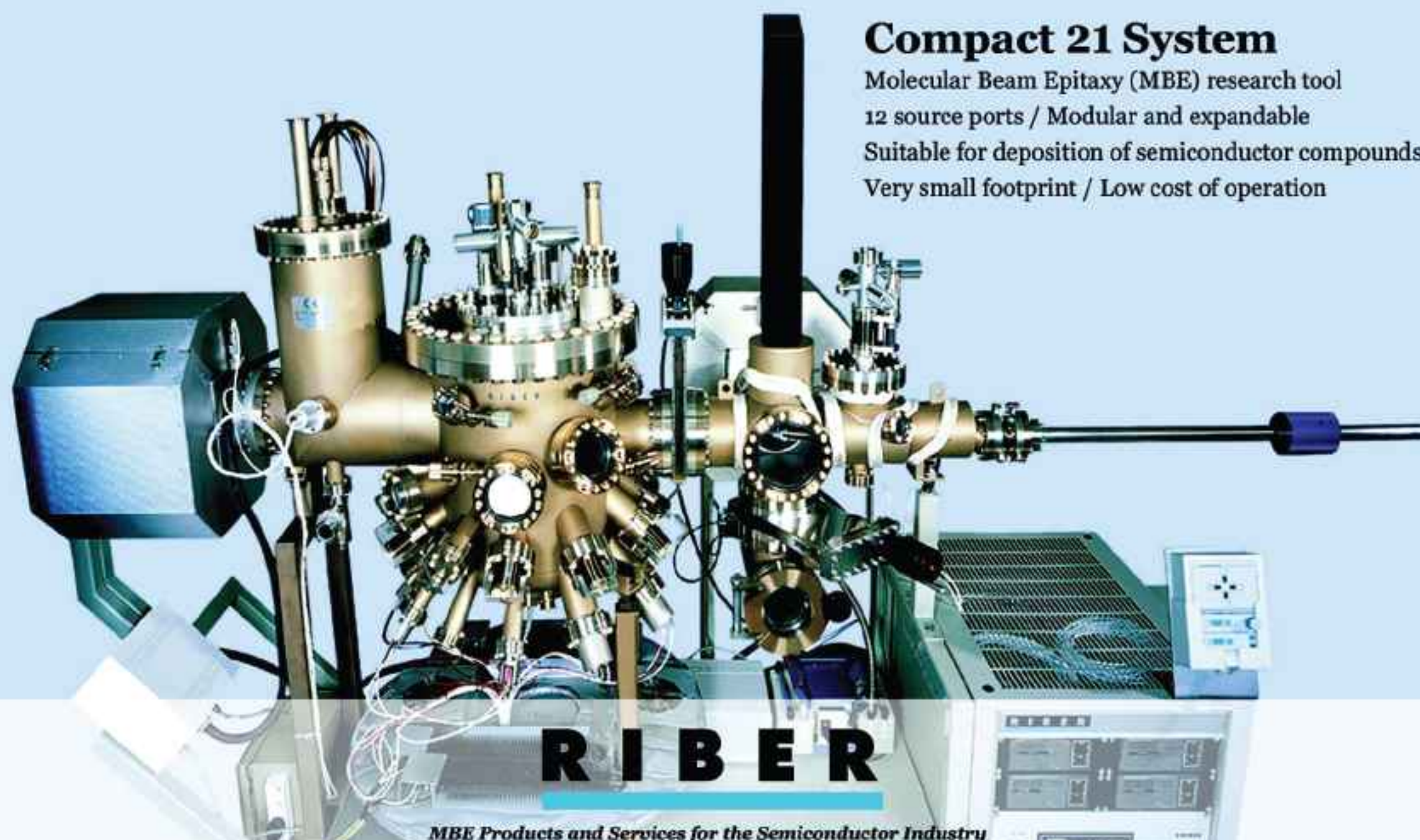
EVG distributing Sonix's SAM & NDT equipment

Sonix Inc of Springfield, VI, USA, a subsidiary of the Danaher Corp that makes scanning acoustic microscope and non-destructive testing equipment for bonded wafers and MEMS, has selected EV Group of St Florian, Austria, which supplies wafer-bonding and lithography equipment to packaging, MEMS and semiconductor markets, as its exclusive worldwide reseller/distributor of selected products, including Sonix Wafer Acoustic Microscopes. As strategic partners, the firms will provide solutions for bonding wafers and non-destructive acoustic inspection systems for all wafer-level integration and packaging, from R&D to production.

www.Sonix.com

www.EVGroup.com

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Picogiga samples SopSiC wafers for GaN RF power devices

Picogiga International of Les Ulis, France, a division of silicon-on-insulator (SOI) substrate maker SOITEC, has announced the availability of pre-production samples of its silicon-on-polysilicon-carbide (SopSiC) composite engineered substrates for low-cost GaN-based RF power devices.

Picogiga says that SopSiC bridges the compound epiwafer void between low-cost, low-power GaN-on-silicon and high-cost, high-power single-crystal SiC for GaN HEMT devices. SopSiC is designed to provide cost-efficient substrates for high-power devices used in wireless communication systems such as radar, satellite communications and base-stations, the firm adds.

"While GaN on both silicon and SiC is part of our existing epiwafer product line for high-power applications, SopSiC gives our customers a significantly better performing solution than silicon — and a considerably less expensive solution than SiC," says Picogiga's chief operating officer Jean-Luc Ledys.

The SopSiC structure is engineered using SOITEC's Smart Cut layer transfer and bonding technology, which it uses to make SOI wafers. It includes a bottom layer of polysilicon carbide, an insulating buried oxide layer, and a high-resistivity (1-1-1) silicon top layer, which acts as the seed layer for GaN epitaxial growth using either MBE or MOCVD. The bottom polysilicon carbide layer is designed to evacuate the heat generated by high-power HEMT devices. SopSiC marks the first industrialized compound epiwafer product combining both Smart Cut and MBE technologies, says Picogiga.

Samples are available in 3" and 4" diameters. But, since the fabrication process is not limited by the small diameters of bulk single-crystal SiC, the process is scalable to the larger wafer sizes standard for silicon — a 6" version is in development.

● At last November's 210th Meeting of The Electrochemical Society (ECS), as a participant in the three-year European Community-supported R&D project HYPHEN

(Hybrid Substrates for Competitive High Frequency Electronics), which started in 2005, Picogiga presented initial material characterization results for GaN grown on both SopSiC and SiCopSiC (SiC on polycrystalline SiC) compared with two standard materials: GaN on bulk Si and GaN on bulk SiC.

Using both MOCVD and MBE, the materials showed critical performance factors (e.g. crystal quality, mobility, and surface morphology) that equaled or exceeded standard materials, and superior results in terms of pilot production yield and repeatability.

In particular, the epitaxy of GaN HEMTs on SopSiC is more reliable than on silicon substrates. SopSiC is also much cheaper and better suited to high volumes than bulk SiC substrates for a frequency scale less than 10GHz.

HYPHEN's second phase, now underway, focuses on device processing.

www.picogiga.com

www.hyphen-eu.com

Picogiga's sales fall on weak demand for RF applications

SOITEC of Bernin, France, which manufactures silicon-on-insulator (SOI) wafers and other engineered substrates, has reported record sales of €99.6m for its fiscal Q3/2006–2007, up 11.1% sequentially and 40.4% year-on-year (compared with 41.5% growth in Q2 and 67.1% in Q1). Q3's growth was driven by 300mm wafer sales up 63.5% year-on-year and 17.3% sequentially. For Q1–Q3, sales were €274.9m, up 48.1% year-on-year.

SOITEC's Picogiga International division, which supplies MBE-grown composite substrates such as GaN-on-silicon, had sales of

€2.7m and €2.6m in Q1 and Q2, respectively (with Q1–Q2's €5.3m up 57% year-on-year, mainly due to its traditional market for RF applications). But Q3 sales fell to €1.7m (giving 9-month cumulative growth of 17.5% year-on-year), due to softness in RF markets.

In the light of short-term market considerations such as the anticipated weaker demand in Picogiga's traditional markets and recent uncertainties related to the customer inventory chain in the game consoles market, SOITEC says it has a cautious stance and now anticipates total Q4 revenues in line with Q3.

A good manufacturing performance for SOI despite the volume adjustment in Q4 is likely to be offset by the unfavorable exchange climate and weaker traditional Picogiga activity. However, SOITEC stresses that Picogiga continues its involvement in strategic R&D initiatives to develop new III-V products as well as materials for solid-state lightning. Strategic R&D programs, including official grant approval negotiations, are proceeding satisfactorily as planned, the company says.

Full-year sales for 2006–2007 will be reported on 16 April 2007.

www.soitec.com

DOD funds Kyma's native GaN

Kyma Technologies Inc of Raleigh, NC, USA has been awarded \$3.3m under a US Department of Defense multi-year contract, funded by the Missile Defense Agency (MDA) and Air Force Research Laboratory (AFRL).

Kyma will use its low-defect-density single-crystal native GaN substrate materials to develop GaN-based high-power high-frequency (HPHF) electronic device technology that can improve the performance of defense applications in radar, electronic warfare, communications and optoelectronics, says Kyma.

Kyma says that the contract leverages its existing work on cooperative research and development agreements (CRADAs) with the AFRL and the Naval Research Laboratory (NRL), as well as several MDA small business innovative research (SBIR) and small business technology transfer research (STTR) programs.

Drew Hanser, CTO and VP business development, is principal investigator. John Blevins of AFRL's Materials Directorate is technical monitor.

"While today's HPHF GaN device technology has reached impressive performance levels, reliability issues remain which we believe are tied to the current reliance on foreign substrates," says Hanser. "Kyma's native GaN has the potential to solve these problems by enabling a higher-quality device active region," he claims. "Our overall approach is to use the best materials possible, prove out the device benefits, while working in parallel to make these materials more readily available."

● In a reshuffle of senior management, former chief operating officer Mark Williams, who co-founded Kyma in 1998, has left the firm.

Edward Preble, VP of Engineering since 2005, is promoted to COO,

responsible for monitoring and improving operations and participating in long-term strategic planning. He reports directly to president and CEO Keith Evans.

Prior to working for General Electric Company then joining Kyma in 2003 as a senior engineer, Preble received his PhD in Materials Science and Engineering in professor Bob Davis' research group at North Carolina State University, which spun out Kyma in 1998, as well as Nitronex.

Terry Clites, who joined Kyma in 2003 as a crystal growth engineer, has been made operations manager, reporting to Preble. "Terry has done a great job in driving establishment of a quality-minded culture throughout Kyma," says Evans. Clites was formerly a manufacturing engineer at Sony Semiconductor.

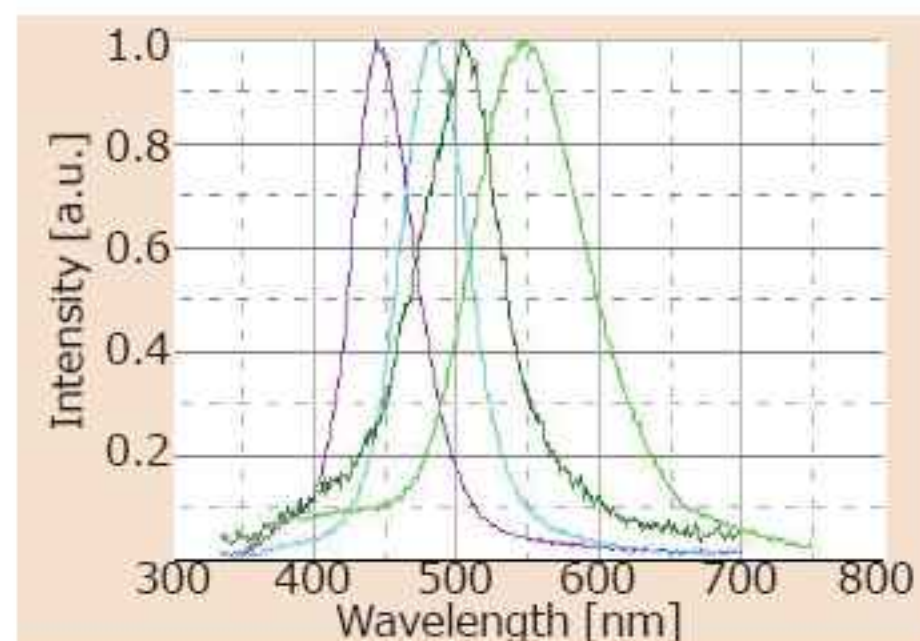
www.kymatech.com

TDI sampling InGaN epi, for small-scale production in Q3

Technologies and Devices International Inc of Silver Spring, MD, USA displayed InGaN epitaxial materials grown by hydride vapor phase epitaxial (HVPE) at the International Workshop on Nitride Semiconductors (IWNS) 2006 in Kyoto, Japan.

Depending on the material composition, devices containing InGaN can emit light over the whole range of the visible spectrum (from infrared from pure InN to UV from pure GaN). InGaN is used for the fabrication of violet, blue, and green LEDs, and could be used to develop yellow, red, and infrared LEDs. It is also used in laser diodes and high-frequency/high-power transistors, and is being considered for novel solar cell applications, for various types of sensors, and for very high-frequency transistors operating at thousands of gigahertz.

But currently the parameters and performance of existing InGaN-based devices, as well as prospects



PL spectra for violet-, blue- and green-emitting HVPE-grown InGaN layers,

for the fabrication of future devices, are limited by material properties, says TDI. New approaches to producing low-defect InGaN epi and substrate materials with improved composition control are needed to overcome these limitations.

"We fabricate InGaN materials using a novel HVPE process," says senior crystal growth specialist Alexander Syrkin. "This method is well known for fabricating very low-defect GaN and AlN materials including bulk

crystals." TDI can now demonstrate InGaN materials fabricated by HVPE.

"TDI is manufacturing and supplying a variety of nitride products including GaN, AlGaIn, and AlN template substrates for blue and UV LEDs, and for high power transistor applications. The development of TDI's HVPE technology for InGaN epitaxial materials [for the whole composition range] will help us to develop and commercialize novel advanced materials and device structures," says president and CEO Vladimir Dmitriev. "One of our first target products is InGaN template substrates for green LEDs, currently suffering from low light-emitting efficiency." TDI plans to start sampling InGaN epi products in early 2007, with small-scale production scheduled for Q3/2007.

InGaN epi work was supported by the US Department of Energy's Solid-State Lighting Program.

www.tdii.com

Avnet to distribute LEDs for Seoul

Seoul Semiconductor has chosen Avnet Electronics Marketing of Phoenix, AZ, USA to distribute its LED and solid-state illumination products in the Americas, via Avnet's illumination-focused business unit LightSpeed (launched in September).

In recent months, SSC (founded in 1987) has introduced the P4 (the brightest single-die white LED available, at 240lm) and Acriche (the world's only LED that can be driven directly from household AC mains current). Such LEDs can serve as lighting sources for automotive designers, commercial/residential lighting and tactical flashlight manufacturers, architects, traffic signaling and signage applications, says SSC.

Avnet says its LightSpeed unit works with users through a national team of dedicated illumination-focused engineers ('illumineers'), with experience in thermal, drive stage and optics design, who focus solely on LED-based lighting applications. "Taking a requirements-driven solution approach, LightSpeed develops complete solid-state lighting systems designed to accelerate the performance, cost and reliability benefits of LED light sources," says its director Cary Eskow. Avnet also has about 900 account managers and 200 field application engineers, who work on-site with local customers.

SSC's CEO C. H. Lee says that the first reason for the partnership is "their broad reach into many emerging illumination sectors; the LightSpeed team's unique technical knowledge of LEDs and the associated optical, thermal, and analog solutions; and Avnet's extensive offering of related semiconductors and supply chain services."

<http://em.avnet.com/lightspeed>

GaN-on-ZnO LED license for Cermet

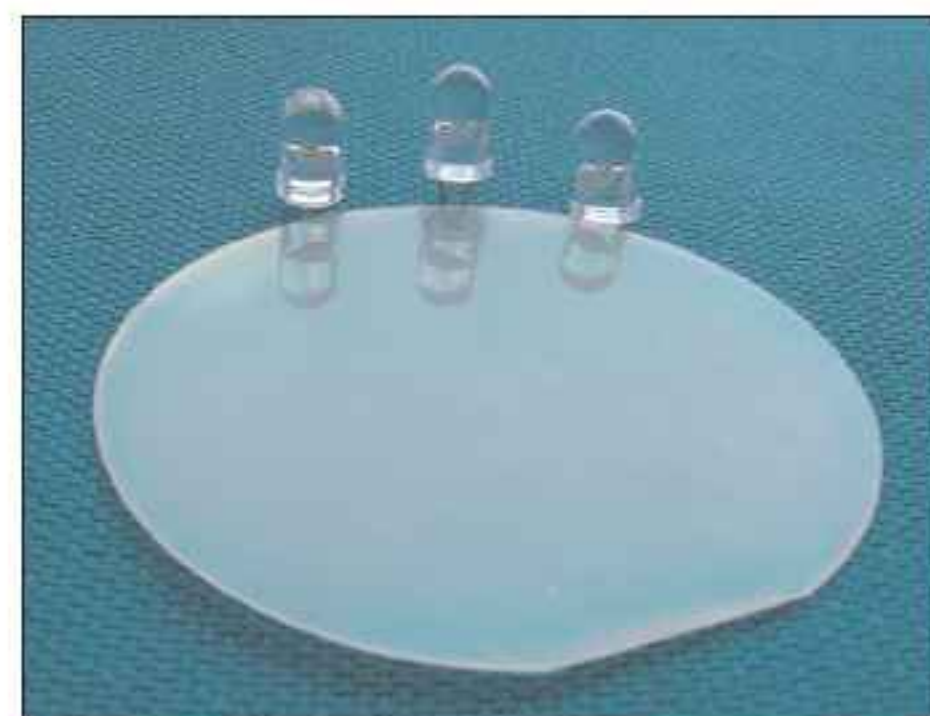
Wide-bandgap semiconductor substrate and device developer Cermet Inc of Atlanta, GA, USA has negotiated an exclusive, royalty-based license agreement to use phosphor-free white LED technology, developed with the Georgia Institute of Technology. The device concerned uses nitride emitter structures in combination with zinc oxide semiconductors, without the need for wavelength conversion by a phosphor.

Unlike current GaN-based white LEDs, which need a phosphor coating on the chip to convert its blue or near-ultraviolet light emission into white light, the GaN-on-ZnO white LEDs are phosphor-free and rely only on the interaction between the two semiconductor materials GaN and ZnO.

The development stems from a three-year \$3.8m US Department of Energy Solid State Lighting project 'Phosphor-Free Solid State Lighting Sources' lasting from October 2003 to November 2006, for which Cermet was the investigating organization and Georgia Tech was the subcontractor.

The firm's work focuses on growing conventional materials on novel substrates that possess unique physical properties with less internal strain. This process has the potential to increase efficiency, have emissions that can be adjusted by carefully applying potentials across the substrate, and can be made to behave like a phosphor, absorbing photons of one color and emitting new photons of a different color.

Cermet's goal was to implement large-area ZnO fluorescent substrate technology and lattice-matched nitride epitaxy technology to address substrate, epitaxy, and device limitations in solid-state lighting.



A 2-inch ZnO wafer made by Cermet, together with packaged LEDs.

- Targeted innovations included:
- MBE and MOCVD growth of truly lattice-matched, low-defect density (10^4cm^{-2}) nitride 330–420nm-wavelength LED structures on a ZnO substrate, resulting in reduced non-radiative recombination centers;
 - optical pumping by the integrated nitride emitter of the ZnO substrate, doped to self-fluoresce in the visible spectrum, yielding white light emission;
 - adjusting the color content of the white light by adjusting the substrate doping concentration.

In the first year of the program, Cermet demonstrated large-diameter doped bulk ZnO crystals, with greater than 80% transmission over the visible spectrum for a wafer thickness of 300 μm (and structural properties and defect densities unchanged by the addition of up to 10^{19}cm^{-3} dopants). Meanwhile, InGaN epilayers with excellent structural properties and very low etch pit densities (in the 10^6 range, lower than the densities seen in conventional devices grown on SiC or sapphire material) were grown by MBE and MOCVD.

Low-intensity phosphor-free white LEDs have since been fabricated. Cermet aims to improve the electro-optic efficiency and to develop a range of white color temperatures.

www.cermetinc.com

Lumileds claims white LED record of 115lm/W at 350mA

Philips Lumileds of San Jose, CA, USA is claiming performance records for high-power white LEDs: a luminous flux of 502lm from a 1x1 mm² power chip driven at 2A (an efficacy of 61lm/W) and 136lm when driven at 350mA (115lm/W) — the first high-power LEDs to exceed 100lm/W, it is claimed. Also, the correlated color temperature is 4685K (significantly lower than those typically reported, it is claimed).

In December, Seoul Semiconductor launched a single-chip white LED delivering 240lm with an efficacy of 100lm/W at 350mA. The first commercial versions of Seoul's chips produce a relatively harsh white

light rated at 6500K, although color temperatures as low as 2800K were in development. Last June Cree reported a white LED chip delivering 131lm/W, then in mid-December Nichia reported a 150lm/W white LED, but both were driven at 20mA.

Philips Lumileds says that, while performance numbers continue to increase for low-power LEDs operating at lower currents such as 20mA, high-power LEDs are required to deliver the quality and quantity of light required for lighting applications. The output of Philips Lumileds' latest LED technology is 17 times greater at the same power than was available in

1999 when the firm introduced the first high-power LED.

The company says it has achieved the results by combining several new technologies that it has developed. The first devices using these technologies will be introduced in a new generation of products this quarter. The technology will then continue to appear in both new and existing products throughout the next 12–18 months. Lumileds claims that such breakthroughs in epitaxy, device physics, phosphor, and packaging technologies are critical to delivering the performance required for light sources.

www.philipslumileds.com

Epistar seeks review of ITC ruling on Lumileds patent

Following a complaint filed with the US International Trade Commission (ITC) in November 2005 by Lumileds Lighting, in January an ITC administrative law judge ruled that the omni-directional mirror adhesion (OMA) AlGaInP LEDs of Taiwan's Epistar Corp and the glue bond (GB) and metal bond (MB) AlGaInP LEDs of UEC (acquired by Epistar in late 2005) do not infringe Lumileds' 'wafer bond' US patents 5,502,316 and 5,376,580, but that Epistar's MB and MB II products do infringe Lumileds' US patent 5,008,718. The judge recommends a limited exclusion order to prevent Epistar and others importing the chips, packaged LEDs, and boards containing them into the USA. However, the judge rejected Lumileds' request to extend the exclusion order to additional downstream products containing the MB LEDs (such as traffic signals, automobile brake lights and cell phones).

Epistar has petitioned the ITC to reject the determination (which it claims is based on an erroneous

interpretation of the '718 patent) and to state in its final determination (not expected until 8 May) that there is no infringement by any of its products.

After that, there will be a 60-day presidential review period during which any exclusion orders can be vetoed or modified. Epistar will have to post a bond based on the value of its infringing LEDs for any importation during the review period. It says that any exclusion order would only become effective after the review is over in early July.

In any case, Epistar claims the ruling will have little impact, since the MB line is a legacy product of the UEC merger, and only the older versions are affected; it has since revised the design to remove the feature claimed to infringe the '718 patent and is producing a new generation of MB LEDs. So, importers can use its updated MB LED and certify that their products do not infringe the patent.

Nevertheless, Lumileds remains confident that the ITC will also

exclude the OMA and GB LEDs, since the judge found that they also include the 'transparent window layer' that laterally spreads current away from the metal contact, and that this is the "critical feature of the claimed invention" of the '718 patent. Last July Epistar and UEC settled litigation with Lumileds by licensing its US patents 5,008,718, 5,164,798 and 5,233,204 covering absorbing substrate (AS) LEDs, but not its transparent substrate (TS) technology. Epistar and UEC developed their OMA, GB and MB LEDs using their counterpart 'mirror substrate' technology.

So, Lumileds aims to petition the ITC to adopt an interpretation consistent with the broad scope of the invention of the '718 patent (as well as its 5,376,580 and 5,502,316 wafer bonding patents) that covers not only the MB but also the OMA and GB LEDs. Lumileds is hence seeking an exclusion order against Epistar's MB, OMA and GB LEDs as well as downstream products including them.

Downlight sees XR-E LEDs chosen for LLF's first product

LED Lighting Fixtures Inc (LLF) of Morrisville, NC, USA has chosen Cree's XLamp XR-E LED for its first product, a downlight in a standard 6-inch recessed housing, which was demonstrated at February's NAHB 2007 International Builders' Show in Orlando, FL, USA in a full-scale comparison with incandescent and compact fluorescent lamps.

Delivering a luminous flux of 650lm at just 10–12W (an efficacy of about 60lm/W), LLF claims that they are the industry's most efficient general lighting fixtures for home and office use, and the first affordable fixtures powered by semiconductor emitters that can rival the output, appearance and lighting quality of a 65W incandescent bulb. It will be available in both 2700K and 3500K color temperatures for warm and cool white applications (shipping from Q2/2007).

"Our introduction of a viable LED product for general illumination will have historic implications for the lighting industry," claims CEO Neal Hunter (ex-chairman of Cree).

"This product takes maximum advantage of our new lighting-class LEDs," says Cree's chairman and CEO Chuck Swoboda. "This is the first LED downlight to deliver on the promise and capability of LEDs." Compared to typical incandescent and compact fluorescent lamps respectively, LLF's product is targeted to consume about 17% and 50% of the energy and last more than 20 times and 5 times longer.

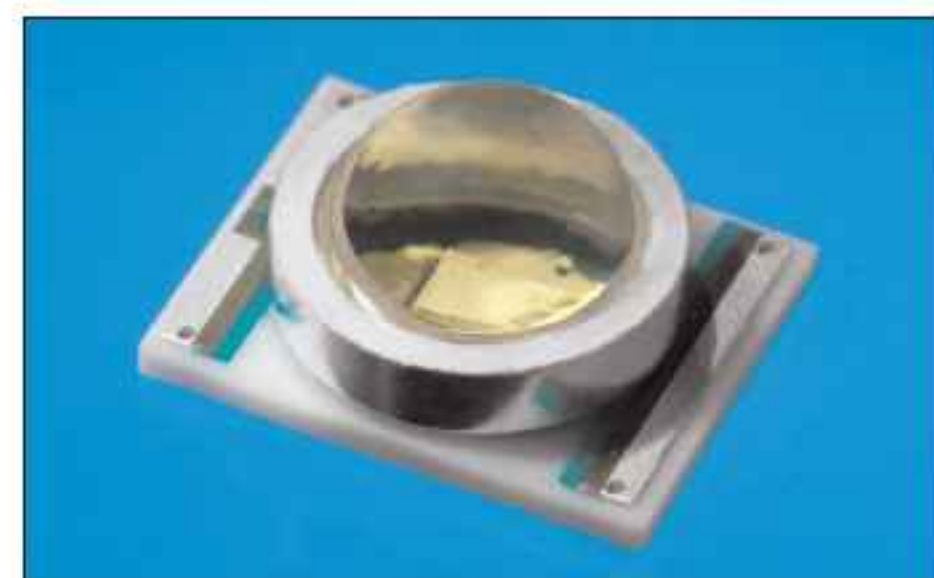
LLF tested a number of LEDs in developing its design. "Cree's performance is unmatched with the new XR-E design and recent advances in its power-package technology," says LLF's chief technology officer Gerry Negley.

www.llfinc.com

LEDs now qualified for use at 1A, 210lm

After additional testing, Cree says that its XLamp XR-E white LEDs are now qualified for use in high-power applications at a driving current of up to 1A, at which they produce luminous flux of up to 210lm (and typically 176lm). When launched last October, the XR-E was qualified for operation at 700mA. At 350mA, typical luminous flux is 80lm (an efficacy of 70lm/W).

"It is now qualified for extended performance in higher-power applications, such as portable lighting, where maximum light output is required," says Norbert Hiller, VP and general manager for



Cree's XLamp XR-E white LED.

XLamp LEDs.

"This qualification also applies to the millions of XR-E LEDs already in the field [which can now be driven at the higher rating]," Hiller adds.

www.cree.com/xlamp

XR-E LEDs selected for flashlights

Cree's XLamp XR-E power LEDs have been chosen by Favour Light Enterprise Ltd of Hong Kong (which employs 1500 people at its Shing Fung factory in Dongguan, China) for its LED camping lanterns and a number of new flashlight models.

"Cree power LEDs bring a whole new level of quality light to our practical, general-purpose personal lighting devices," says managing director Shiu Shing. "We can now provide our customers with extremely bright, LED-based products at reasonable prices."

The use of Cree's brightest LEDs by such a high-volume, value-priced flashlight manufacturer for camping lanterns and general-purpose flashlights at varying price points brings Cree's LED lights to a much larger customer base, says Norbert Hiller, general manager for XLamp LEDs.

XLamp XR-E power LEDs have also been chosen by Vortex Vision Corp of Temecula, CA, USA (which makes rechargeable-battery flashlights for military, law enforcement and professional markets) for five of its LED flashlight models.



LED flashlight from Vortex.

High brightness and efficiency are critical for battery-powered, portable lighting applications such as hand-held flashlights, says Cree. XR-E Series LEDs also produce the high-quality, uniform white light required, it adds.

The XR-E enables Vortex to make very bright flashlights featuring long run times, says managing director Arne Ogaard. "The rechargeable-battery flashlight market is focused on brightness and efficiency," said Hiller.

In the last month, Cree has also announced design-ins of XLamp XR-E power LEDs for flashlights and lanterns made by SureFire LLC of Fountain Valley, CA, USA and ASP Inc of Appleton, WI, USA.

www.favourlight.com

www.vortexvision.us

Cree's sales down on forecast due to lower LED chip sales

For fiscal Q2/2007 (to 24 December), Cree Inc of Durham, NC, USA has reported revenue of \$88.8m, down 15% on \$103.9m the previous quarter and 16% on \$105.6m a year ago. This was also lower than its forecast, which had already been revised from October's \$105–109m to \$90–92m in early December (see December/January issue, p24). Net income was \$16.5m (down from \$17.7m a year ago, but up from \$13.3m last quarter) — however, much of this was due to the sale of marketable securities.

Gross margin was 34% (down from 49% a year ago and 41% last quarter). This is mainly due to lower factory utilization associated with the decline in LED chip orders, increased pricing pressure for LED

chips, and higher start-up costs related to new product lines. Operating profit was just 3.5% of revenue (down from 16% last quarter). Cree's share price fell from a 52-week high of \$35.30 in May 2006 to a recent 52-week low of \$15.25.

"As announced in early December, the second quarter was more challenging than we had targeted, with lower LED chip sales," says chairman and CEO Chuck Swoboda.

"Despite the challenges in the LED chip business, we continued to make progress on our strategy to expand our business by leveraging our strengths in LED chip and SiC materials technology to broaden our product line with higher-value, component-level products for the emerging markets in LED lighting

and power," he adds. "Our new product lines delivered double-digit growth in Q2, with LED component sales [e.g. packaged XLamp LEDs] increasing to more than 10% of total LED revenue for the first time. The growth in these new product lines is an important, leading indicator of how we plan to grow the company over the next several years."

During the quarter, Cree began volume shipments of its newest white Cree XLamp 7090 power LED, which has luminous flux of up to 95lm (an efficacy of 85lm/W) at 350mA and up to 160lm at 700mA. New customer wins have already been secured, Cree says.

For its fiscal Q3/2007, Cree expects revenue level with Q2.

www.cree.com

Cree signs Asian LED distributor & expands sales team

Cree has signed up World Peace Industrial Co Ltd of Taiwan to sell and support its XLamp LED products in China, Asia Pacific and Japan. WPI is a member of WPG Holdings, an electronics distributor in Asia. Cree previously had a distribution agreement with World Peace Group Technology Ltd of Hong Kong.

"Expanding our distribution reach in Asia and Japan with WPI strengthens Cree's presence and ability to address the potential for high-power packaged LEDs in China, Japan and the Asia Pacific region," says Bob Pollock, Cree's senior VP, sales. "Our customers represent some of the most advanced and innovative lighting and backlighting manufacturers," adds WPI's CEO Mike Chang. WPI is one of the world's top three IC distributors.

The agreement gives WPI's customers access to Cree's family of high-power packaged LEDs. Among the XLamp products avail-

able will be the 210lm XR-E LED, the first commercially released power LED that is as efficient as fluorescent sources, claims Cree.

WPI will provide full system-solutions support for optical, thermal, and control electronics design.

Cree and WPI aim to work together to accelerate adoption of solid-state lighting in Asia by providing high-power packaged LED products and services to lighting and backlighting product makers.

Cree also recently signed multinational distribution agreements for XLamp products with Arrow Electronics and DigiKey, which the firm described as "an important piece of our strategy to expand sales of our component products". In October Cree also recruited Robert Pollock (VP of sales at rival LED maker Philips Lumileds) as its senior VP of worldwide sales to spearhead sales expansion (see November/December issue, p22).

Cree has since added four sales executives to its regional US and European sales teams:

- southern Europe — Giuliano Casatario (formerly with Tecnika Due);
- northern Europe — Derek Tibbitts (former European channel manager for HP and Agilent Technologies Semiconductor Products Group);
- eastern USA — Vince Feorenzo (former director of distribution and channels at Avago Technologies);
- western USA and Canada — Jerry Kolansky (former VP of sales at HP and Agilent Technologies Semiconductor Products Group).

"One of Cree's most important initiatives is focused on creating a world-class field sales and marketing organization," says Pollock. "We are now engaging expert direct sales professionals to help drive Cree's growth into the developing markets for energy-efficient lighting and SiC-based power devices," he adds.

Rohm develops smallest, thinnest full-color LED chip

Kyoto-based Rohm Co Ltd is sampling the SML-P12 series (PicoLED) chip, which has a record thickness of 0.2mm and a record small mounting area of 1.0mm x 0.6mm (1006 size). This is less than half the current standard product's 1.6mm x 0.8mm (1608 size), giving a volume about a quarter of that of the current product.

Rohm says that using original high-luminosity device and ultra-precise processing technologies has enabled it to develop the ultra-compact, ultra-thin chips in a full range of colors — previously thought impossible due to the significant loss in luminosity with traditional LEDs. The new units have the same level of brightness as conventional LED



Rohm's SML-P12 PicoLED chips.

chips, but in a package size 53% smaller in area and with 74% less volume than standard 1608-sized LEDs. This suits use in high-density applications with narrow spaces.

The series features a wide range of emitting colors (red, orange, yellow, green, blue and white), and includes InGaAlP models for appli-

cations requiring high reliability and InGaN models for applications requiring high luminosity.

The new LED can be used to create thinner mobile phone keypads, full-color high-density (1.5mm-pitch) dot-matrix units that can be used in car audio displays, and compact seven-segment displays with 0.2"-high characters (an industry first), broadening the possible applications of numerical displays.

Volume production (at 10m units per month) is scheduled for April at Rohm Wako Co Ltd in Okayama, Japan, Rohm Semiconductor (China) Co Ltd in Tianjin, China and Rohm-Wako Electronics (Malaysia) Sdn Bhd. in Kelantan, Malaysia.

www.rohm.com

Green flash LED for digital cameras

Avago Technologies of San Jose, CA, USA has introduced a high-brightness green (530nm) InGaN auto-focus auxiliary flash LED for digital camera auto-focusing in low ambient light conditions.

Conventional infrared sources in dark environments necessitate an extra sensor. So digital camera makers are moving to using visible LEDs instead as a lower-cost and more compact light source. Also, the cameras have twice the sensitivity to green than other colors due to the availability of more photodiodes allocated for green in each pixel.

With what is claimed to be the most compact package in the industry (4.8mm by 4.8mm by 5.33mm), the ASMT-FG10-NFJ00 green LED allows greater functionality per area of PCB. Based on the package for the ASMT-FJ10-ADH00 AlInGaP 612nm orange auto-focus LED, the encapsulated LED chip on an axial lead frame forms a molded epoxy lamp package with six



Green LEDs for auto-focusflashes.

bended leads for surface mounting. Avago says that the SMT package simplifies the assembly process, easing installation and cutting costs.

The dome LED lamp uses an untinted, non-diffused epoxy lens to provide high luminous intensity within a narrow-angle (6°) radiation pattern, suiting long-distance illumination. Avago says it offers the highest brightness auxiliary flash for digital camera auto-focusing as well as great luminous efficiency, reducing power consumption.

www.avagotech.com/led

Osram and Philips agree to cross-license LED patents

Osram GmbH of Munich Germany and Philips of The Netherlands, which are the world's two biggest lighting companies, have signed a cross-licensing agreement involving the mutual licensing of patents for all inorganic and organic LEDs.

The agreement relates to patents held by Philips, including its LED-making subsidiary Philips Lumileds Lighting Company of San Jose, CA, USA (which makes power LEDs), and by Osram, including its LED-making subsidiary Osram Opto Semiconductors GmbH of Regensburg, Germany.

"We expect this to put us in an even better position to use LED technology to serve the demands of the market," says Osram Opto's president and CEO, Dr Rüdiger Müller.

www.osram-os.com

www.lighting.philips.com

GELcore changes name to Lumination

GELcore LLC of Cleveland, OH, USA, which makes high-brightness white LED-based light systems, has been renamed Lumination LLC by parent company, GE Consumer & Industrial. GELcore was a joint venture of GE and Emcore Corp from 1999 until September 2006 when Emcore sold its 49% stake to GE for \$100m. In late 2006, GE invested \$100m in the business by forming a strategic alliance with GaN-based LED and laser diode maker Nichia Corp of Anan, Tokushima, Japan.

"Our name change emphasizes an important element of our growth strategy," says Lumination's president David Elien. "Our focus since our inception has been lighting applications that leverage the benefits of LEDs to drive real value for customers. We remain committed to delivering best-in-class LED lighting solutions in key segments such as signage, architecture, transportation signals and retail display, while

also setting our sights on global distinction in the emerging general illumination market segment."

The firm brought its first white LED solutions to market with its Tetra Power White LED solution for channel letter signage. Last year, Wal-Mart Stores Inc agreed to install its white LED refrigerated display case solution in over 500 North American stores- the world's single largest installation of white LEDs replacing fluorescent in a display lighting application. Eight of the top 10 U.S. supermarkets have reacted positively toward testing and use.

Lumination says it aims to introduce new white LED signage, commercial refrigeration, architectural and general illumination products in 2007, and a new white LED emitter for high-quality general illumination. Lumination's investment in new products will increase more than 50% this year over 2006.

www.geconsumerproducts.com

IN BRIEF

Nichia supplying UV-LEDs with output up to 250mW

Japan's Nichia has started supplying what it claims is the most powerful ultraviolet LED on the market. The model NCSU033A UV-LED, available in a 6.8mmx6.8mmx2.1mm package, has a typical peak emission wavelength of 365nm (matching the wavelength of i-line emission from mercury lamps).

Typical optical power is 250mW. The forward voltage is 3.8V (typical) and 4.4V (maximum). The lack of infrared emission suits use with heat-sensitive materials. The LED can operate at low temperature and is usable in a vacuum. Applications include UV-curing and photo-catalysts.

Nichia launched its first UV-LED in 2004, and up to now has supplied products emitting at 365nm, 380nm and, more recently, 375nm with optical power outputs up to 100mW.

www.nichia.co.jp

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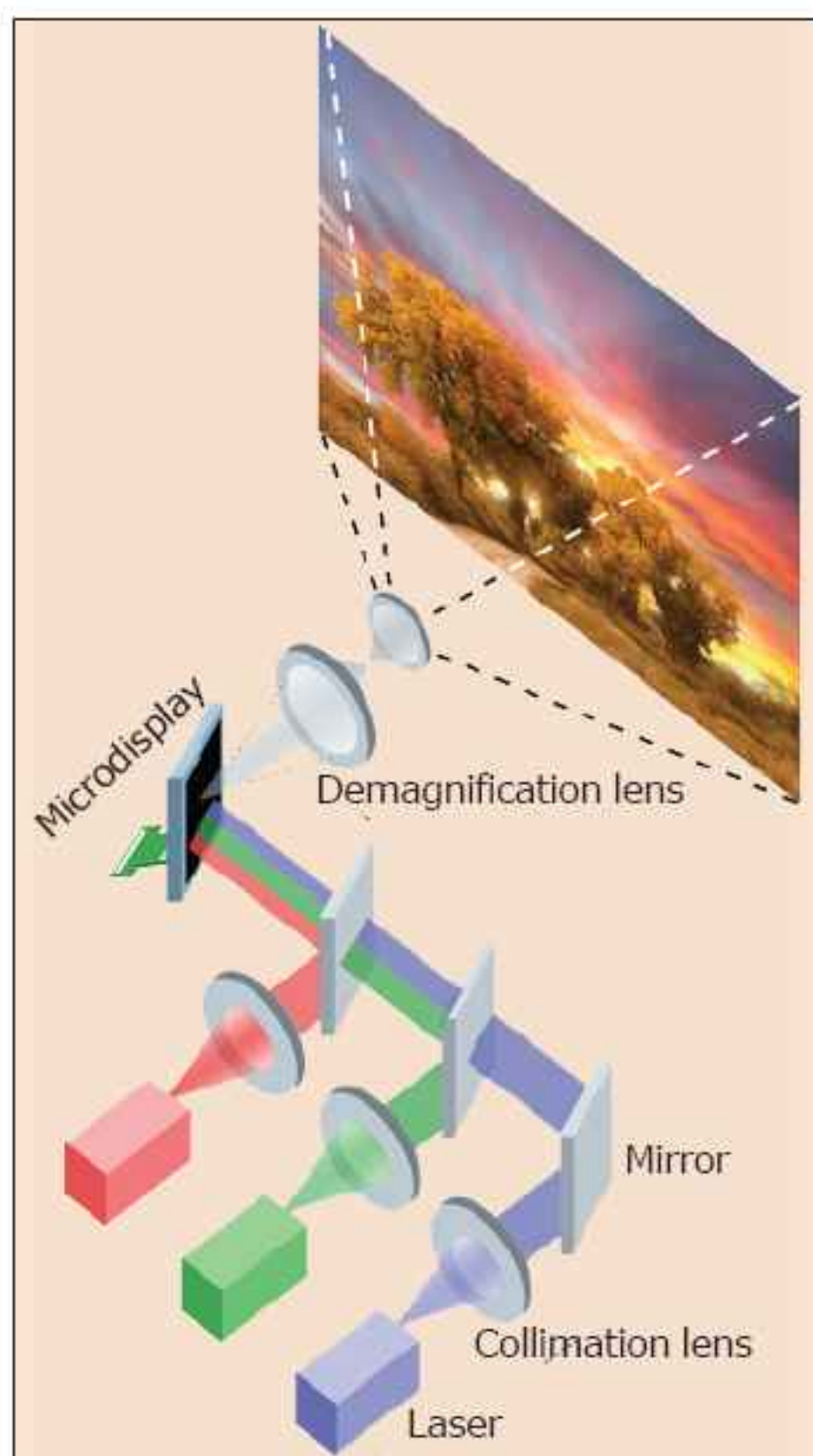
www.semiconductor-today.com

LBO secures extra \$1m & license for full-color laser projection

Light Blue Optics Ltd (LBO) of Cambridge, UK, a developer of miniature full-color laser projection technology founded in 2004, has closed a \$1m extension to last July's \$2.5m seed-funding round, again led by 3i plc but joined by the UK National Endowment for Science, Technology and the Arts (NESTA), the Cambridge Capital Group and business angels. The funds will enable it to accelerate its product development program.

LBO has also signed an exclusive licensing agreement with Cambridge Enterprise Ltd (the University of Cambridge's technology commercialization service) concerning a patent for real-time, full-color holographic laser projection (invented in 2003 by LBO's director of business development Edward Buckley and chief technology officer Adrian Cable while they were PhD students at the university). "We now have a strong, clear IP position," says CEO Dr Chris Harris.

LBO says that its projection system uses laser light sources and diffractive techniques to deliver high-quality, real-time, full-color video images in focus at all dis-



Schematic diagram of LBO's full-color laser projection system.

tances, even on curved or angled surfaces. A diode-pumped solid-state laser (DPSS) laser is used for green and semiconductor lasers for

red and blue colors. LBO says that, in their diffractive system, the lasers do not need a high modulation frequency, so the requirements upon them are less restrictive than those of competing technologies. Also, the system architecture is tolerant of deviations from ideal laser beam quality, the company claims.

LBO adds that the patented technology combines: compact size; focus-free operation; wide throw angle; robust design with no moving parts; low power consumption; and simple, low-cost manufacture. "The efficiency, robustness and cost advantages of our technology make it ideally suited for deployment in multiple markets; including automotive, digital signage and consumer electronics markets," claims Buckley.

Since July, LBO has been building relationships with strategic customers and development partners. "We have been very impressed by the traction that LBO has gained with launch customers," says 3i partner Laurence Garrett, who is also based in Cambridge.

www.lightblueoptics.com

LBO relocates to larger premises

In early January Light Blue Optics relocated from its former home in the St John's Innovation Centre in Cambridge to the Platinum Building in St John's Innovation Park. The 4000 square feet of space includes electronics and optical laboratory areas as well as increased meeting room capacity. The firm reckons that the new facilities should be able to satisfy its requirements for the next two years.





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(NASDAQ: AXTI)

Uncooled 20 & 25Gb/s 1310nm CWDM lasers for 100GbE

To support standards under development by the IEEE 802.3 Higher Speed Study Group (HSSG), Apogee Photonics of Allentown, PA, USA is developing uncooled externally modulated lasers (EMLs) for coarse wavelength division multiplexing (CWDM) supporting aggregate data rates of over 100Gb/s. Such high-speed optical data links enable cost-effective transmission of emerging 'triple-play' applications: Internet, voice-over-IP (VOIP) and interactive video services.

There are two product variants, both under consideration by the HSSG: a 20Gb/s 1310nm EML in a five-channel CWDM configuration and a 25Gb/s 1310nm EML in a four-channel configuration. These CWDM-based routes to 100Gb/s

data links build on the LX4 implementation of 10GbE transponders and the X40 1310nm CWDM solution for 40Gb/s links, says Apogee.

The lasers are based on Apogee's uncooled 10Gb/s 1310nm EML sources, which can operate uncooled over temperature ranges of -20 to 90°C. "The bandwidth can be significantly increased beyond 10Gb/s, unlike directly modulated DFBs that are challenged at data rates above 10Gb/s," says chief technology officer Milind Gokhale. "The 20Gb/s and 25Gb/s EML sources support the 10km link distance targeted by the 802.3 Study Group," he adds.

"Apogee Photonics' goal is to develop enabling photonics technologies that anticipate future customer needs," says CEO Mike

Decelle. "While the development of a 100GbE standard is only recently underway, our world-class indium phosphide technology portfolio is fully capable of supporting one of the candidate technologies for implementing the next advance in Ethernet transmission speeds," he claims. "Our 10Gb/s uncooled 1310nm EML is well established as the most reliable and highest performance laser source in its class, and it is upon this foundation that the next generation of Ethernet technology can be enabled."

The EML lasers will be available for sample evaluation in early 2007 and, subject to ratification of the 100GbE IEEE standard, generally available in second-half 2007.

www.apogee Photonics.com

Common platform for 10Gb/s transceiver development

Apogee is shipping samples of a single-platform approach, based on its 1310 and 1550nm telecom laser sources, for creating pluggable 10Gb/s transceivers, cutting development and qualification design cycles and speeding time to market.

Multi-source agreements for 10Gb/s transceivers have proliferated, from the first-generation 300-pin MSA and the XENPAK MSA (for datacoms) to the next-generation XPAK/X2 MSAs (for datacoms) and XFP (the first pluggable MSA to handle telecoms, datacoms and Fiber Channel). "The definition of new transceiver MSAs such as SFP+ [which is smaller and cheaper than XFP] requires many of our customers to make hard trade-offs in the number of transceiver products offered, given engineering resource constraints," says Scott Keller, VP of sales & marketing. The various MSA form-factors, and distance reaches (SR1, IR1, IR2, ER, LR, LR2) for each,



Apogee's pin-compatible uncooled 1310nm and cooled 1550nm EMLs.

requires a multitude of components to be designed-in and stocked by module makers and OEMs.

The combined 1310/1550nm architecture allows adoption of a standardized single platform serving the multiple 10Gb/s transceiver interfaces with a single XFP-type board and case. Transceiver-level design choices related to receptacles, flex guides, output pinning and driving only need to be made once. Apogee claims that the platform reduces the risks associated with new transceiver introductions and provides development cost

savings, decreasing the separate qualification cycles of each product.

The 1310 and 1550nm sources are both externally modulated lasers (EMLs) and are mechanically and pin compatible (e.g. the 10T3005 1310nm uncooled TOSA for LR and SR1 has a receptacle and flex guide compatible with the TLA10X 1550nm cooled XMD TOSA for ER, IR2 and LR2). For this, Apogee had to modify the 1310nm form factor to match the 1550nm source.

To support the single-platform approach, Apogee has made available evaluation boards supporting both the 1310 and 1550nm TOSAs: the T10-0120-021 for the Vitesse VSC7982 driver and the T10-0120-022 for the OKI 4195 driver.

Apogee's approach allows users to broaden their product range while reducing the cost, materials and resources involved in the design and qualification of separate platforms, claims Keller.

X40 MSA to improve multi-rate 40Gb/s transceiver reach & cost

The X40 Multi-Source Agreement Group has been formed by nine networking, system, optical module, semiconductor, and connector firms: Aeluros Inc, Broadcom Corp, Emcore Corp, Finisar Corp, Infinera Corp, Juniper Networks Inc, MergeOptics GmbH, Tyco Electronics Corp and Vitesse Semiconductor Inc.

The aim is to develop a new, integrated, data-agnostic, multi-rate optical transceiver, intended to support a range of 40Gb/s links for telecom (e.g. SONET/SDH and G.709) and datacom (e.g. packet switching) applications. The groups founding members invite companies from all sectors of the industry to express interest and submit views on requirements.

The X40 MSA is expected to enable network equipment makers to increase port density and system data throughput, extend link distances, and reduce power and cost per Gb/s compared to existing 40Gb/s solutions on the market.

The hot-pluggable transceiver module uses a mechanical form-factor similar to XENPAK to integ-

rate four transmit and four receive channels and optically multiplex them into a single pair of optical fibers (transmit and receive). Supported nominal per-channel data rates are 9.953–11.1Gb/s, providing an integrated data throughput range of 39.8–44.4Gb/s. The X40 module's electrical interface to the host board is based on four lanes of XFI, as defined by SFF-INF-8077i.

"The X40 transceiver module will make 40Gb/s networks more economical by bringing the cost points and maturity of 10Gb/s components to the 40Gb/s world," said Drew Perkins, chairman of the group and co-founder and chief technology officer of Infinera.

"The deployment of 40Gb/s networks has been limited by the high costs of many components and modules required for 40Gb/s systems," said Dr Daryl Inniss, VP of Ovum-RHK's Communication Components research. "Bringing together a broad group of leading industry players to focus on producing a standard X40 MSA can lead to greater deployment of

40Gb/s systems and lower costs."

The initial X40 physical media interface will be defined to meet the requirements for short-reach metro access links up to 10km. Current 40Gb/s transceivers based on the industry-standard 300-pin MSA are generally limited to 2km before chromatic dispersion necessitates compensation. X40 will use four uncooled CWDM wavelengths around 1310nm, and will carry 10Gb/s data per channel, with the same 10km reach as 10GBASE-LR interfaces. X40 will also feature digital diagnostic capability to monitor link performance.

The X40 MSA group will make details of the specification available so that other optical transceiver makers can produce compatible products and system vendors can begin to design equipment to use the transceivers.

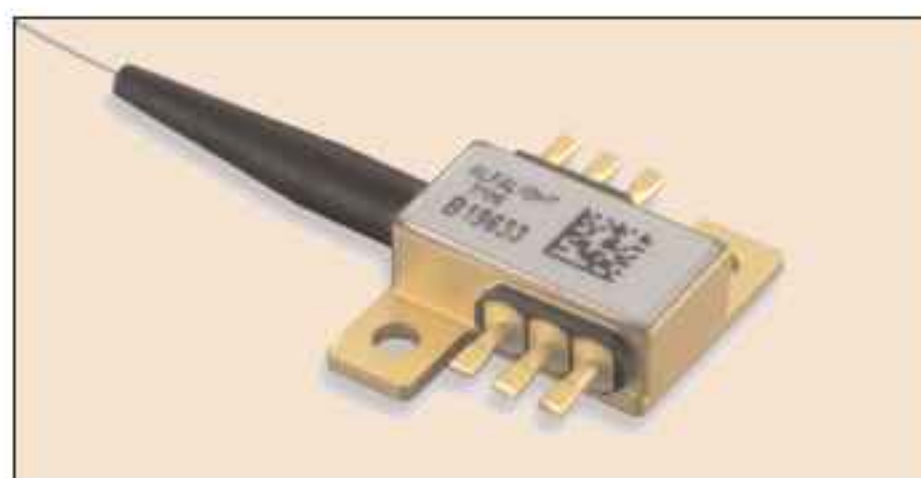
The group welcomes applications for membership from component, transceiver and network equipment manufacturers as well as carriers and other network operators.

www.x40msa.org

Alfalight boosts 976nm uncooled pump laser power to 6W

Alfalight Inc of Madison, WI, USA has made available a 6W fiber-coupled 976nm multimode laser diode (the AM6-976A-10-604). The increased output power and brightness are suited to driving pulsed fiber lasers, with applications ranging from industrial materials processing to laser radar (LIDAR). The laser diode and uncooled package are fully qualified for long lifetime and environmental ruggedness.

The higher brightness enables fiber laser systems with increased power, addressing the demands of new applications, says Ron Bechtold, VP of sales & marketing.



Alfalight's packaged 6-pin pump laser.

The hermetic 6-pin package has the smallest footprint on the market, claims Alfalight, has a built-in thermistor for temperature monitoring and is electrically isolated for ease of mounting.

Alfalight has also added to its family of thermoelectrically cooled mul-

timode pump lasers (with powers of up to 2.5W) by making available a 4W, 940nm multimode pump laser (the AM6-940A-20-408), suited for CATV and telecom applications, in an uncooled, electrically isolated hermetic package.

It operates over a wide operating temperature range, and provides a path to extend the performance and value of optical amplifiers.

Both lasers emit light via a 105µm fiber with 0.15 numerical aperture and are qualified in accordance with the requirements of the Telcordia GR-468 standard.

www.alfalight.com

JDSU's five-year revenue high drives return to profit

For fiscal Q2/2007 (to end-December 2006), JDSU of Milpitas, CA, USA has reported revenue of \$366.3m (up 15% on the prior quarter and 2% on a year ago). This exceeds its preliminary estimate of \$360-365m given in mid-January and far exceeds early November's guidance of \$332-352m. Revenues by region were: Americas, 57%; Europe, 27%; Asia-Pacific, 16%.

Benefiting from seasonal strength associated with customer spending patterns and improved execution relative to the previous quarter, sales for JDSU's Communications Test and Measurement segment grew sequentially by 44%. This more than offset a 4% fall in the Optical Communications segment associated with customer supply chain and inventory rationalization.

Results by segment were:

- Communications Test & Measurement, \$168.2m (46% of revenue), up 15% on a year ago and 44% on last quarter (with profit rising from \$26.5m a year ago to \$35.8m).
- Optical Communications, \$132.7m (36% of revenue), down 4% on last quarter but up 21% on a year ago (with loss being cut from \$10.2m to just \$0.1m).
- Advanced Optical Technologies, \$40.4m (11% of revenue), up 3% on last quarter but down 2% on a year ago (although profit has risen from \$9.4m to \$12.7m).
- 'All Other' (including the Commercial Lasers business), \$25.1m (7% of revenue), up 4% on last quarter and 39% on a year ago (improving from a loss of \$0.8m a year ago to a profit of \$2.2m).

JDSU's net income was \$23.2m, compared to a loss of \$17.4m the prior quarter and \$42.1m a year ago. Cash reserves at the end of December were \$1,228m.

"JDSU delivered the strongest revenue, gross margin, and net income results in more than five years," said CEO Kevin Kennedy. "Positive earnings per share results show marked improvement from previous quarters, highlighting the impact of our strategy to diversify our business and return to profitability, while continuing to deliver highly innovative products to market," he adds.

From a seasonally strong fiscal Q2, JDSU expects lower revenue for Q3 (to end-March) of \$333-353m (compared to \$312.9m a year ago).

www.jdsu.com

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Avanex reports record revenue

Optical network component, module and subsystem maker Avanex Corp of Fremont, CA, USA reported record revenue of \$55.6m for its fiscal Q2/2007 (to end-December 2006), up 9% on the prior quarter's \$50.9m and 54% on \$36.1m a year ago (and exceeding November's forecast of \$52–55m).

Gross margin rose to a record 19%, compared with 10% the previous quarter and 8% a year ago. This is due to the programs implemented two quarters ago aimed at reducing inventory charges, improving the supply chain, increasing manufacturing yields and managing the product portfolio, according to Marla Sanchez, senior VP and chief financial officer. "We expect to realize further improvements in our cost structure," Sanchez adds.

Although operating expenses rose from \$15.6m last quarter to \$19.9m, net loss has been cut from \$18.5m a year ago and \$9.7m last quarter to \$8.6m, despite including \$2.1m in 'due diligence expenses related to abandoned acquisition activity' (rumored to be a merger with rival Bookham, which is also headquartered in San Jose).

For its fiscal Q3/2007, Avanex expects revenue of \$54–57m and gross margin of 17–21%. "In the metro and long-haul markets we expect flat market demand in the first half of [calendar] 2007, due to the delay of certain capacity expansion projects and we anticipate the market to return to growth in the second half of the year," said chairman, president and CEO Jo Major.

www.avanex.com

1310nm FP laser chip for diplexers and triplexers in fiber-to-the-home

Avanex has unveiled the Power-Beam 1931FL, which it claims is the first 1310nm Fabry-Perot (FP) laser chip designed to minimize the cost of diplexers and triplexers—used in optical networking terminals (ONTs) for fiber-to-the-home (FTTH) broadband deployments—by enabling the use of fully automated and scalable passive alignment techniques. Traditional laser chip technology requires either active alignment or the use of additional components to couple the laser's optical power into the fiber, increasing the cost of FTTH components.

The 1931FL is the first laser chip integrating a spot size converter with special features for automated alignment, claims Avanex. The integration of these functions into a single chip enables users to

implement low-cost passive assembly processes on manufacturing lines.

"The PowerBeam 1931FL targets our advanced laser technology capabilities on extremely cost sensitive products such as those required in FTTH applications," said chief technology officer Giovanni Barbarossa. "Our solution brings significant advantages to our customers by enabling them to produce leading-edge low-cost products."

The 1931FL is for use in uncooled low-power-consumption applications up to 2.5Gb/s and meets Telcordia GR-468 standards.

The laser chip is currently in full production and has already secured several design wins with customers using planar lightwave circuit (PLC) technology.

IN BRIEF

Optium reports record revenue

For its fiscal Q1/2007 (to end-October 2006), Optium Corp of Chalfont, PA, USA, which makes optical subsystems (including transceivers and transmitters) for telecom and cable TV networks, reported record revenue of \$30m, up 31% on the prior quarter and up 114% on \$14m a year ago.

Net income was \$2.8m, up from \$1.7m the prior quarter, and \$377,000 a year ago.

"Our strong overall performance reflects growth in all major product areas," said chairman and CEO Eitan Gertel. "We continued to enhance our broad offering of products, especially in the area of 10G tunable transceivers and ROADMs."

For fiscal Q2 (to end-January), Optium expects revenue to rise to \$32–34m (to be announced on 25 February).

Founded in September 2000 (by management mostly from JDSU), Optium raised \$65.9m in four venture funding rounds. In addition, November's initial public offering on Nasdaq raised a further \$97m (compared to an expected \$66.6m).

This was despite a lawsuit filed in September by Emcore Corp and JDS Uniphase Corp alleging violation by Optium's Prisma II 1550nm transmitters of US patents 6,282,003 and 6,490,071. These describe a phase modulation method using two modulation tones to provide a more stable and reliable signal despite drift.

Both patents were originally owned by JDSU (awarded to Uniphase in 2001 and JDSU in 2002, respectively), but were transferred when Emcore bought JDSU's CATV business in May 2005. Optium has since filed a response to the allegations.

www.optium.com

Bookham slump forces extra cuts and CEO's resignation

Optical telecom component maker Bookham Inc of San Jose, CA, USA has reported fiscal Q2/2007 revenue (to end-December) at the low end of November's \$56–59m forecast: \$56.3m (level with last quarter and down 7.2% on \$60.7m a year ago).

Revenue from Nortel was \$14.5m (26% of total revenue), down from \$34.3m a year ago. Non-Nortel revenue was \$41.8m (58% up on a year ago, but flat on last quarter).

Net loss has more than doubled from \$8.3m a year ago then \$15.7m last quarter to \$18m. Adjusted earnings before interest, taxes, depreciation and amortization (EBITDA) has fallen from +\$0.7m a year ago and –\$7.7m last quarter to –\$10.4m (worse than the expected –\$6–10m).

Buying Nortel's optical components business in 2001 for just \$112m led to a long-term supply deal worth over \$120m with Nortel, which has since been Bookham's largest customer. The guaranteed purchase agreement was extended (albeit at a reduced level) to cover 2006. After end-2006, sales to Nortel were already expected to fall significantly in the March quarter. But, due to higher-than-expected inventory build-up at Nortel, Bookham now expects Nortel sales of no more than \$5m (just 5–10% of total revenue).

Due to normal seasonality and some inventory draw-down at some customers, Bookham expects only modest non-Nortel sequential sales growth. So, for fiscal Q3/2007 (to end-March), Bookham expects revenue to fall 15–22% from last quarter to just \$44–48m (the lowest in four years) and adjusted EBITDA to worsen to –\$12–16m.

Bookham is hence cutting costs further to save an extra \$6–7m per quarter in the September quarter, mainly through cuts to its workforce of 2100. This will include:

- closing the ex-Nortel facility in Kanata, Ottawa (transferring R&D functions to the facilities in Shenzhen, China and Caswell, UK). Staffing had already been cut from 300 to 100 in late 2003 (on transferring its 3" InP wafer processing line to Caswell) then to under 75 over the last 18 months.

- consolidation at the 183,000ft² InP fab in Caswell (including a shut-down of the obsolete 2" line and full transfer of products to the 3" line).

Previous cost cutting of \$10–12m per quarter (starting in May 2004) led to the closure of Caswell's GaAs fab (as it focused on optoelectronics) and migration of test & assembly from Paignton to Shenzhen.

But March 2006-quarter losses worsened from the expected near-breakeven to \$10–12m due to worse-than-expected costs related to the Shenzhen transition, impact of a shift in sales mix to lower-margin products, lower fab utilization at Caswell, and costs associated with introducing new products. So, last May Bookham initiated a 'focused recovery plan' of cost-cutting.

As well as the £13.8m sale and lease-back of the Caswell plant, this included transferring further development, manufacturing support and administrative functions to Shenzhen (including its laser prototype line), leading to more staff cuts, and November's sale of the Paignton plant for £5m (including a two-year option to lease back part of the site). Together with September's \$28.8m from a private placement of stock, the \$101m of funds raised have kept Bookham afloat (boosting cash reserves to \$58.2m after paying off long-term debt in early 2006).

Bookham expected quarterly savings of \$5–6m by the December quarter. But, in November it revised this to just \$4m plus a further \$1.5–2.5m by the March 2007 quarter.

Nevertheless, president and CEO Giorgio Anania believes that sales will rebound after the current March quarter, helped by Nortel working through its inventory. "Telecom market demand remains strong," said Anania, especially where Bookham has competitive product advantages. Last spring, Bookham launched new products including wideband tunable lasers, next-generation high-power 980nm pumps, optical amplifiers and extended-temperature XFPs and SFP DWDM transceivers. After much new design-in activity, Bookham has started ramping up production volumes, enabling it to diversify its customer mix.

After the extra cost cutting, Anania said Bookham could achieve adjusted EBITDA break-even by the end of the September quarter at a quarterly revenue of \$55–57m.

- Anania has since resigned as board member, president and CEO. Made CEO six years ago during the telecom downturn, Anania oversaw Bookham's IPO and transition from a niche supplier of silicon photonics to a maker of optical telecom components through acquiring the optical components businesses of Nortel and Marconi, as well as Ignis Optics, Cierra Photonics, New Focus in 2004, Onetta Inc and VCSEL maker Avalon Photonics of Zurich, Switzerland in March 2006 (with manufacturing transferred to Caswell and its industrial laser GaAs fab in Zurich). However, Bookham is yet to post a profitable quarter.

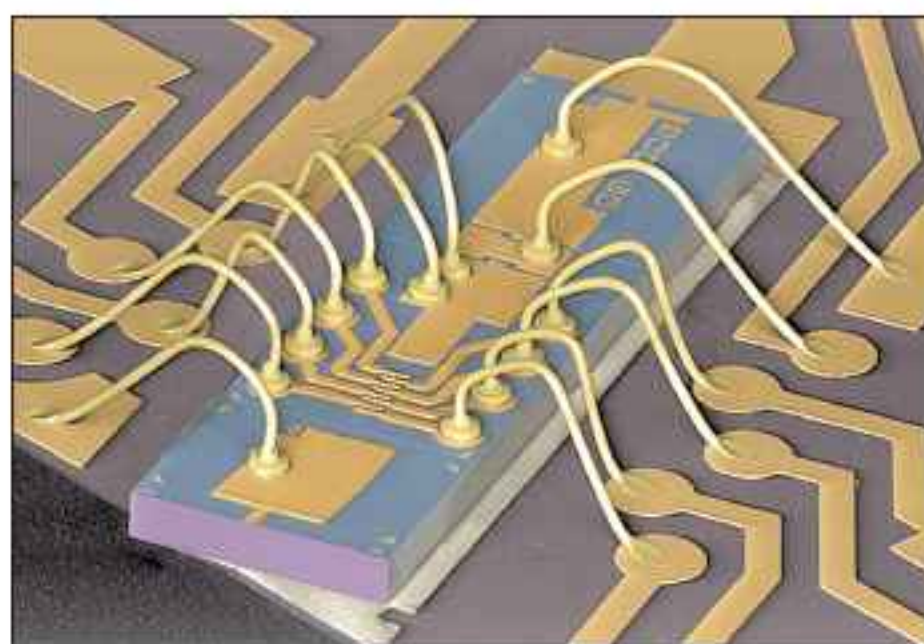
While Bookham seeks a permanent replacement, the interim president and CEO is now Peter Bordui, who became a director in 2004 (being a director of New Focus) then non-executive chairman in February 2005. Previously, he had senior-level roles at JDS Uniphase.

www.bookham.com

US patent for tunable laser

Bookham has been issued US patent 7145923 for its DS-DBR (digital supermode-distributed Bragg reflector) laser, which underpins its portfolio of tunable laser technology. The patent is one of several covering aspects of Bookham's tunable product range, and specifically protects its unique, monolithic, widely tunable laser design.

In the DS-DBR, a multi-contact chirped grating is used in conjunction with a grating that produces a comb of reflective peaks to give a broad tuning range. By tuning portions of the chirped grating to overlap in wavelength, a single peak from the comb can be selected to determine the lasing wavelength. Fine tuning can be achieved by injecting current into both gratings. By selecting peaks sequentially, tuning can be achieved over the full range.



Bookham's DS-DBR laser.

"Using the technology encapsulated in this patent, Bookham has developed wideband, InP-based tunable lasers for both C- and L-band operation with very fast tuning times and with excellent output powers, spectral purity and reliability," says Andy Carter, VP R&D.

"This DS-DBR laser design also provides a route towards further photonic integration, promising

increased functionality on a single InP chip, with the obvious benefits of low cost and small device size."

Bookham's DS-DBR technology is at the heart of its LambdaFlex tunable technology products, including an integrable tunable laser assembly (iTLA), and two new products, claimed to be the first of their kind. The wideband tunable transmitter assembly module (TTA) targets long-haul and regional metro applications and co-packages the wideband tunable laser with an InP Mach-Zehnder (MZ) modulator to provide transmitter functionality in a cost-effective, small, iTLA-sized footprint package. The tunable DS-DBR and InP MZ technologies are also being incorporated into a small-form-factor (SFF) 300-pin Wideband Tunable Transponder.

www.bookham.com

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OCP transitions to high-margin products and US FTTH market

For fiscal Q1/2007 (to end-December 2006), Optical Communication Products Inc of Woodland Hills, CA, USA reported revenue of \$17m (down 11% on \$19.1m last quarter and 4.1% on \$17.7m a year ago).

Gross margin has also fallen, from 35.6% a year ago and 22.9% last quarter to just 18.8%, mainly due to a higher proportion of sales being low-margin products, lower market average selling prices (ASPs), and increased direct labor cost. Net loss has risen from \$1.1m a year ago and \$1.4m last quarter to \$4.2m.

Cash reserves are expected to fall from \$124m at the end of December to \$105–110m at the end of September 2007 as OCP invests in initiatives to both improve margin and accelerate revenue growth as demand for fiber-optic components increases. These include:

- saving costs by integrating into its existing products lasers sourced from Taiwan's GigaComm (acquired last August), which also gives OCP a leading position in Japan's fiber-to-the-home (FTTH) market. Now, with large-scale development of FTTH in the USA, it aims to rapidly adapt the existing products.
- Partnering in October with vertically integrated contract manufacturer SAE Magnetics (H.K.) Ltd (a subsidiary of TDK Corp), which has a

workforce of over 30,000 occupying 2.5m ft² of manufacturing space, mainly in the Dongguan area of the Pearl River Delta. By summer this will establish lower-cost, higher-capacity, more flexible manufacturing in China for select product lines (augmenting OCP's short-run, specialized applications). OCP will retain the plants in Woodland Hills and Taiwan but reduce staffing by 150–180 and 70–80 respectively, while retaining qualified staff to develop new products. OCP will still fulfill low-volume, fast-delivery requirements from its US facilities.

- Accelerating product development and speed-to-market programs through the integration of an additional design center in Taiwan.
- Reducing the percentage of low-margin products from the product mix while bringing higher-ASP products to market, including high-performance XFP/SFP+ products supporting 10 Gigabit Ethernet applications (see the panel below).
- Creating integrated, close-to-market operations in Asia, North America and Europe to more closely align with global customers and participating directly in cost reduction and design activities in Asia.
- Instituting improved financial analysis and controls under the new chief financial officer.

CEO Philip F. Otto says that he expects to begin to see a measurable impact from the above initiatives in 2008.

Otto adds that OCP remains optimistic about broadband industry forecasts, which call for sustained growth in the optical components market, and is investing in process improvements and product development to address market resurgence. The planned level of such investments was not justifiable during the period of telecom market weakness over the past three years, the firm adds.

For fiscal 2007, OCP now expects revenues to be at the low end of December's \$80–90m forecast, and operating expenses to rise 40–45% year-on-year, mainly due to implementing Asia initiatives (including transition charges of \$3–3.5m for moving manufacturing to China), speed-to-market product strategies (which call for increased international market penetration, rapid product development, and flexible, turnkey manufacturing capacity), and global business development plans.

Gross margin should be about the same as Q1's 18.8%. OCP's long-term goal is sustainable gross margins of above 30%.

www.ocp-inc.com

OCP launches 10Gb/s XFP 10km temperature options

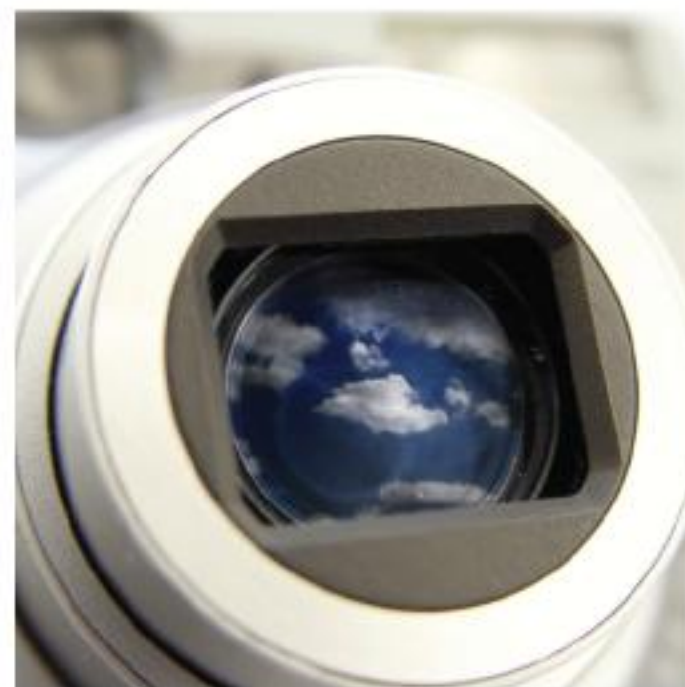
In December OCP started sampling industrial (–40 to +85°C) and extended (–5 to 85°C) temperature 10Gb/s XFP pluggable optical transceivers. The former will be exhibited at March's OFC 2007 event in Anaheim, CA, USA.

"We are addressing the expanded application requirements of the XFP market by offering additional operating temperature options," said

director of marketing Kirk Bovill.

The XFP transceiver is designed to provide multi-protocol support for the 10 Gigabit Ethernet, OC-192 SONET/SDH and 10 Gigabit Fiber Channel to distances of up to 10km. The multi-rate modules support data rates of 10.7–9.95Gb/s and are compatible with ITU-T G.691, ITU-T G.709, and Telcordia GR-253 standards.

The serial electrical interface and DDM functionality are based as per the XFP multi-source agreement (MSA). The DDM functionality enables monitoring of the internal temperature, DC supply voltage, transmitter bias current, transmitter output power, and receive optical signal level. Integrated DDM functionality also incorporates warnings and alarms.



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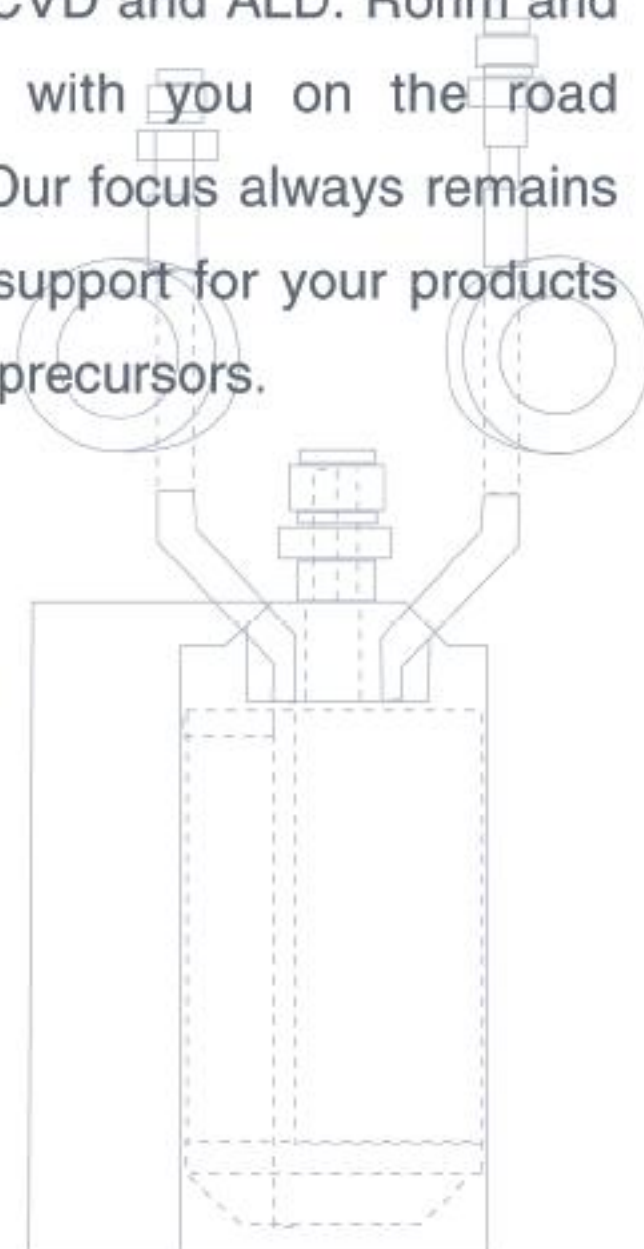
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Ortel manager promoted to Emcore chief operating officer

In December, Emcore Corp named Dr Hong Q Hou, VP and general manager of its Ortel fiber-optics division, as president and chief operating officer, as well as a director of the company, reporting to CEO Reuben F Richards Jr. Executive VP and COO Scott T. Massie resigned as an officer of Emcore and left the firm at the end of 2006.

Hou has also been offered the role of CEO when Richards becomes chairman after Emcore's annual shareholder meeting in 2008 (at which time the current chairman Dr Thomas Russell will become chairman emeritus and lead director).

Hou researched high-speed optoelectronics devices at AT&T Bell Laboratories, then from 1995 to 1998 was a principal member of the Technical Staff at Sandia National Laboratories before joining Emcore in 1998, co-starting the



Emcore's new president and chief operating officer, Dr Hong Q Hou, former general manager of its Ortel fiber-optics division.

Photovoltaics Division, and managing the Fiber Optics Division.

"Hou has been an invaluable contributor in virtually all aspects of Emcore's business over the past eight and a half years," Richards said. "His keen strategic vision and exemplary leadership have been critical in helping to position the company in today's technologies and markets."

Also, co-founder Dr Richard A Stall has resigned from the board after 10 years as a member, but continues

as chief technology officer, executive VP and general manager of Emcore's Solar Power Division. Like Hou, Stall was a member of the technical staff at AT&T Bell Laboratories, where he was responsible for the development of MBE technologies. Stall says that, in Hou, the board will continue to have a strong technically advanced director, enabling him to focus on his operating role.

● In connection with the changes, Emcore's board has amended provisions of the company's by-laws to immediately separate the positions of president and CEO and, after the annual shareholder meeting in 2008, to establish a corporate officer to hold the title of chairman, responsible for company strategy and policy and subject to the authority and supervision of the board. The CEO will be responsible for the business and affairs of the company.

Emcore and Finisar receive Nasdaq delisting notices

Emcore has received a Nasdaq Staff Determination letters stating that its stock is subject to delisting from the Nasdaq Global Market.

The firm is not in compliance with requirements in Nasdaq Marketplace Rule 4310(c)(14), after it missed the deadlines for filing its reports on Form 10-K (for the year to end September) and Form 10-Q (for the quarter to end December) with the Securities and Exchange Commission while the company reviews its past stock option grants.

A hearing before Nasdaq's Listing Qualifications Panel (to review the letters and Emcore's continued listing) took place on 15 February. The firm expects a verdict on its listing within 30 days after this.

Meanwhile, Emcore said it will file the forms "as soon as reasonably practicable".

In December fiber-optic component and subsystem maker Finisar Corp of Sunnyvale, CA, USA also said that it had received a Nasdaq Staff Determination notice stating that it is not in compliance with Marketplace Rule 4310(c)(14). Its common stock is subject to delisting from the Nasdaq Global Select Market.

Finisar had delayed filing a Form 10-Q report for its fiscal Q2 (to end-October), while reviewing its past stock option grant practices. It plans to file its Form 10-Q report "as soon as practicable" following the conclusion of the review.

Finisar has also requested a hearing before the Listing Qualifications Panel to review the Staff Determination.

Emcore and Finisar join GaAs HBT epiwafer supplier Kopin Corp of Taunton, MA, USA, which on 15 November received notice of delist-

ing (from the Nasdaq Global Market) after failing to file its Q3/2006 Form 10-Q report by the 10 November deadline due reviewing its stock option practices. On 21 November Kopin, likewise, also requested a hearing before the Listing Qualifications Panel.

Under Nasdaq Marketplace rules, the stock of all three companies continues to trade pending the issue of written determinations by the panel.

● As of 18 December, JDS Uniphase Corp of Milpitas, CA, USA is no longer part of the Nasdaq 100, the Nasdaq Stock Market's annual ranking of the 100 largest non-financial companies. However, this does not affect JDSU's regular Nasdaq stock listing.

JDSU's stock price fell from \$36 in March to about \$14 in November.

www.nasdaq.com

Emcore's digital fiber-optics products sales offset PV delays

Emcore Corp of Somerset, NJ, USA, which makes components and sub-systems for the broadband, fiber-optic, satellite, and solar power markets, has reported preliminary unaudited revenues from continuing operations of \$143.5m for fiscal 2006 (to end-September), up 24% on fiscal 2005.

This includes \$35.4m for fiscal Q4/2006 (up 6% year-on-year, but down 16% on the previous quarter). Fiber-optic revenues were \$28m, up 16% on a year ago and 8% on the previous quarter, due mainly to digital fiber-optics products. Photovoltaic revenues were \$7.3m, down 22% on a year ago and 30% on the previous quarter

due to a delay in the receipt of export licenses covering three satellite programs (now shipped).

For Q4/2006, net loss rose from \$5.1m a year ago to \$8.9m. However, after accounting for various charges as well as gains of \$87.4m and \$7.6m, respectively, on the sales of its 49% stake in GELcore (to joint venture partner General Electric for \$100m) and its EMD division (to IQE in August for \$16m), net profit was \$78.1m. Cash reserves rose by \$100m to \$124m. Fiscal 2006 yielded a net loss of \$23.5m (compared to \$24.3m in fiscal 2005), or a net income of \$58.7m including the above gains.

The GELcore and EMD disposals have provided capital to invest in terrestrial photovoltaics and in expanding the firm's fiber-optics business, says CEO Reuben F. Richards Jr. "Our [\$18m] strategic investment in WorldWater and Power and expansion into China are just two examples of these initiatives," he adds.

"In addition, we have obtained significant new satellite and terrestrial orders in our photovoltaic division that we believe will help improve operational performance in fiscal 2007," reckons Richards. Emcore expects fiscal Q1/2007 revenue to rise to \$38m.

www.emcore.com

Emcore buys \$18m stake in terrestrial solar-power firm WorldWater & Power and signs \$100m supply contract

In late November, Emcore said it was investing \$18m in a 31% equity stake (26.5% on a fully diluted basis) of WorldWater & Power Corp of Pennington, NJ, which was founded in 1984 to supply terrestrial solar-power systems to developing nations for applications such as water pumping.

Emcore has also formed a strategic alliance and supply agreement to be WorldWater's exclusive supplier of high-efficiency multi-junction solar cells, assemblies, and concentrator subsystems, with a contract valued at up to \$100m over the next three years.

Emcore has already invested \$13.5m in a first tranche. The closing of the remaining \$4.5m second tranche is expected by the end of this year, after the definitive strategic agreement is signed. Emcore will also gain two seats on WorldWater's board of directors.

"This strategic investment repre-

sents a shift in Emcore's terrestrial photovoltaic strategy by becoming, with WorldWater, a solution provider rather than just a component supplier," says Emcore's president and CEO Reuben F. Richards. "By connecting Emcore's space and terrestrial cell technology with WorldWater's specialized electrical drives for applications such as pumping water for water utilities and irrigation for farms, we should command a significant segment of the rapidly growing distributed solar energy market," he adds.

"A significant percentage of the world's electrical consumption is used to run pumps and motors," says Richards. "WorldWater's broad marketing experience and capabilities combined with Emcore's terrestrial solar cell and system technology will lead to significant market opportunities for utility-scale power as well as for markets on the retail side of the meter,

such as water pumping for agriculture and village-scale power."

"Concentrated photovoltaic systems are the keys to reducing the cost per watt of power generated," says WorldWater's founder and chairman Quentin T. Kelly. "This major financing from Emcore will enable WorldWater to substantially increase our core business of blending and/or replacing the electric grid with solar power and supplying solar electric drives able to operate motors and pumps up to 600hp for large commercial projects, whether in the agricultural, water utility or other industrial fields." In the last year, WorldWater revenues have risen from \$2m in 2005 to a projected \$17m for 2006. "Emcore's \$18m investment will help us to meet our working capital needs in expectation of achieving major growth in revenue next year," Kelly adds.

www.worldwater.com



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Spectrolab passes 40% efficiency barrier for terrestrial solar cells

In December, Spectrolab of Sylmar, CA, USA demonstrated record terrestrial solar cell efficiency of 40.7% from its multi-junction concentrator photovoltaic cells, as verified by the US Department of Energy's National Renewable Energy Laboratory (whose High Performance Photovoltaics program funded development).

The best commercial silicon solar cells are 22% efficient, and the theoretical maximum is about 26%. Compared to a single-junction silicon cell (which absorbs a limited part of the solar spectrum), maximum efficiency rose to 24% (in 1995) from a single-junction cell of GaAs on a Ge substrate, 27% (in 1997) from a dual-junction GaInP₂-GaAs-Ge cell, and 32% (in 1999) from a triple-junction GaInP₂-GaAs-Ge cell. As layers of various materials each absorb light from a different part of the solar spectrum, their individual efficiencies accumulate. Such cells are used by most satellites.

Current minimum average efficiencies for Spectrolab's production photovoltaic cells are:

- Single-Junction, 19%;
- Dual-Junction, 21.5%;

- Triple Junction, 25.1%;
- Improved Triple Junction (ITJ), 26.8%;
- Ultra Triple Junction (UTJ), 28.3%.

"The terrestrial cell we have developed uses the same technology base [GaAs-on-Ge] as our space-based cells. So, once qualified, they can be manufactured in very high volumes with minimal impact to production flow," says Spectrolab's president, Dr David Lillington.

In addition, conventional cells use sunlight that is incident directly ('one-sun insolation'). But terrestrial cells can use an optical concentrator (e.g. a Fresnel lens) to focus the sunlight's intensity, yielding higher efficiency and requiring fewer cells to achieve the same power output. Using AlGaInP rather than GaInP₂ as the top layer, Spectrolab and NREL achieved record concentrator triple-junction cell efficiency of 34.2% in 2001, then 36.9% in 2003 and 37.3% in 2004.

The 40.7% figure was achieved using a new class of metamorphic (rather than lattice-matched) semiconductor materials including a layer of GaInAs rather than GaAs, which allows much greater freedom in

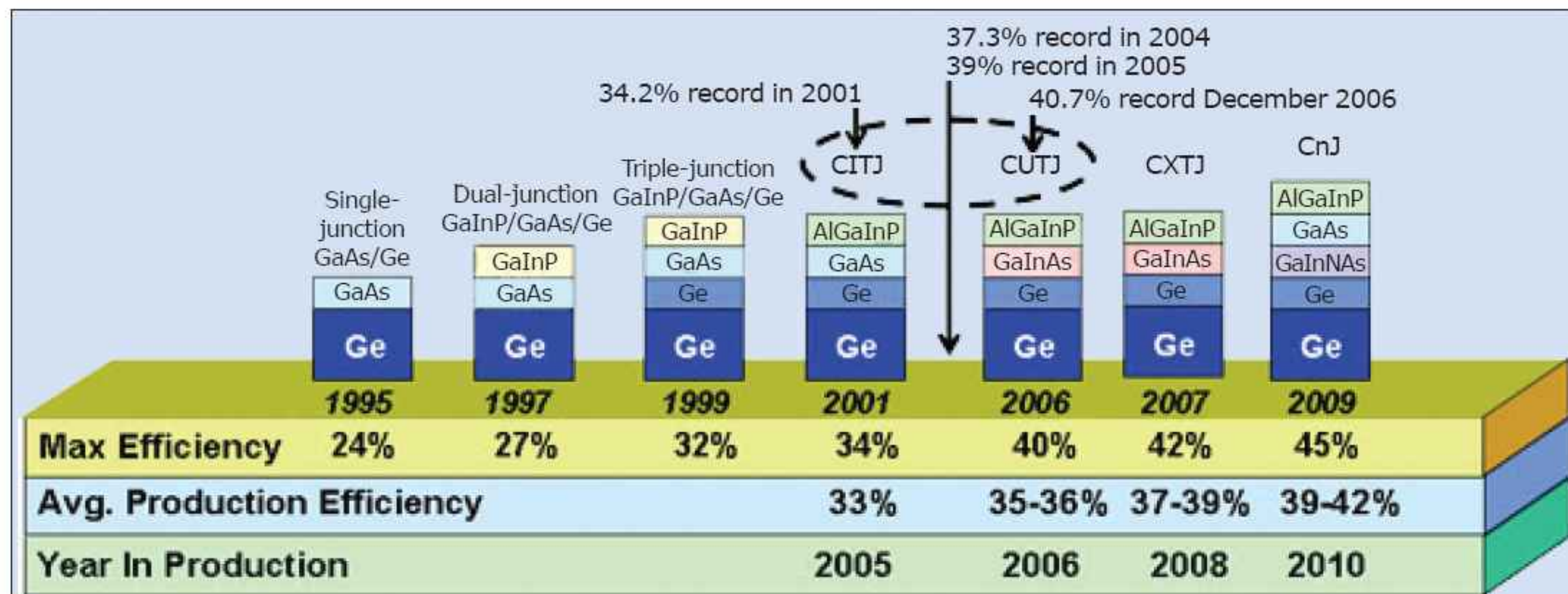
multi-junction cell design for optimal conversion of the solar spectrum, says Dr Richard R. King, principal investigator of the high-efficiency solar cell R&D effort. The solar cells are fabricated in a single epitaxial growth process using a Veeco TurboDisc As/P MOCVD system.

Spectrolab expects average production efficiencies to keep rising for CUTJ and its forthcoming CXTJ and CnJ cells, targeting 33% by 2009 and 40% in five years time.

According to the DOE's Alexander Karsner (assistant secretary for Energy Efficiency and Renewable Energy), a 40%-efficient concentrating solar cell could cut solar power installation costs to just \$3 a watt, producing electricity at 8-10 cents per kW/hr. Current silicon solar cells provide electricity at about \$8 a watt, before government rebates. The DOE's aim is to achieve \$1 a watt, without rebates or incentives.

● Sharp Solar, the biggest silicon solar cell maker, demonstrated a GaAs-on-Ge concentrator PV cell with 36% efficiency at October's Solar Power 2006 event in San Jose.

www.spectrolab.com



Spectrolab's terrestrial concentrator solar cell technology roadmap.

CIGS PV cells progress

Due to the solar industry's ongoing shortage of silicon source material, rapidly growing interest among both solar panel makers and investors in non-silicon-containing photovoltaic materials has driven developers of copper indium gallium diselenide (CuInGaSe₂, or CIGS) thin-film photovoltaic cells such as Nanosolar, Miasolé, HelioVolt, DayStar Technologies and Global Solar Energy to accelerate their production ramps (for delivery of production quantities in 2007 or early 2008)—see the October/November 2006 issue 4.

Since then, some firms have formed alliances with solar module makers. Meanwhile, they have been joined by university spin-off Flissom, silicon-based solar cell maker Q-Cells (forming a joint venture with university spin-off Solibro), and car maker Honda.

HelioVolt and Exeltech co-develop solar modules and building-integrated PVs

In late January, CIGS PV cell maker HelioVolt Corp of Austin, TX, USA announced a joint development agreement with Exeltech of Fort Worth, TX (which produces inverters for the power industry) to commercialize turnkey systems for solar energy generation.

The collaboration combines Exeltech's systems-level expertise in designing and manufacturing AC power systems with HelioVolt's FASST thin-film CIGS process technology (for rapid printing of coatings on substrates including conventional construction materials). The firms aim to develop systems for both conventional modules and building-integrated photovoltaic products.

"The flexibility of the HelioVolt design lends itself to integration with Exeltech's newest generation of grid-interactive products," says Exeltech's Kevin Parsons, VP and director of marketing. "The merging of these two very cost-effective designs can make a photovoltaic product deployable on a scale that will have a significant impact on the growing power needs of both residential and commercial customers and will reach a price parity with today's conventional generating methods."

"As HelioVolt's product development moves forward, this collaboration is perfectly in line with our strategy to partner with best-of-breed organizations that can speed thin-film-enabled product to market," says HelioVolt's CEO Dr B.J. Stanbery, who invented the FASST process and founded the firm in 2001.

GSE and Nansolar expand in US and Germany

CIGS solar cell maker Global Solar Energy Inc (GSE) of Tucson, AZ, USA said in November that it was spending \$75m over 18 months to renovate a building near the University of Arizona Science and Technology Park and

hire another 50 staff. It aims to increase production capacity from 2MW to at least 40MW by Q1/2008.

GSE says it has already sold 80% of its planned 2008 production. Its largest customer will be module maker Solon AG of Berlin, Germany, which last April bought a 19% stake in GSE (with a German venture capital investor buying the other 81%).

In late January GSE announced plans to invest about €30m (\$39m) to set up a plant at the Berlin-Adlershof science and technology park. Production is due to start in first-half 2008, and ramp up to an annual capacity of 30MW, giving a total capacity of 70MW in 2008.

GSE has hence founded a subsidiary Global Solar Energy Deutschland GmbH and recruited Dr Ilka Luck as its managing director. Luck developed copper indium sulfide thin-film PV technology and was co-founder (in 2001) and managing director of Berlin-based SULFURCELL Solartechnik GmbH (which, supported by the governments of Berlin and Brandenburg, started commercial production of modules in 2005). Her technical and commercial experience will accelerate growth, says GSE's CEO and president Mike Gering. "The geographical proximity to our technology partner Solon and other companies and research establishments working in the same field at the Berlin-Adlershof technology park provides the ideal environment," says Luck.

"This gives us the opportunity to strengthen our technical collaboration and gives us access to non-silicon-dependent solar cells, which will provide the foundation for the continuing growth of Solon," says its chief technology officer Dr Lars Podlowski.

Likewise, last August Nanosolar Inc (which was founded in 2002 in Palo Alto, CA, USA and makes CIGS PV cells printed on continuous rolls of thin flexible substrate) signed a long-term agreement with Conergy AG of Hamburg, Germany (the world's largest solar-electric system integrator), aiming to develop large-scale solar power systems. Previously, in June Nanosolar received \$75m in venture capital funding, which, together with government factory subsidies, brought its total cash to just over \$100m. Hence, in mid-December it chose a former Cisco manufacturing facility in San Jose, CA as its plant for solar cells and a facility in Luckenwalde in the Berlin capital region, Germany as its plant for solar panels (comprising 647,000ft² of space collectively).

Nanosolar is due to start commercial production this year, and expects ultimate annual capacities of about 200m solar cells (430MW) and more than 1m panels. It says that it already has arrangements to sell panels as stand-alone power plants and for use on the rooftops of commercial and residential buildings. ►

Flisson named a Technology Pioneer

Of 225 firms nominated by leading venture capital and technology companies, a panel appointed by the World Economic Forum in December selected 47 companies as Technology Pioneers 2007. The 15 in the 'Energy' category include NanoSolar and Flisom AG.

Based on research begun in 1980 at the Swiss Federal Institute of Technology (ETH Zurich), Flisom AG was spun off in 2005 with first-round funding of €1m, after CTO Ayodhya Nath Tiwari achieved the efficiency record for flexible solar cells on a plastic substrate (14.1%). ETH Zurich's Thin-Film Physics Group continues to act as the firm's research arm.

The use of commercially available polymer foil allows the use of low-cost roll-to-roll manufacturing technology, enabling high-speed, continuous thin-film deposition. Flisom is currently adding production expertise.

Q-Cells commercializing Solibro's technology

Q-Cells AG of Thalheim, Germany, which claims to be the second-largest solar cell maker after Sharp, said last November that it was taking a 67.5% stake in a joint venture, Solibro GmbH, formed to commercialize CIGS-on-glass PV technology developed by Solibro AB, a spin-off from the University of Uppsala's Ångström Solar Center that is supported by the Swedish Energy Agency. Q-Cells is initially paying Solibro AB €4m plus €20m against the achievement of technological milestones, and has committed €60m to the JV.

The Ångström Solar Center has realized efficiencies under laboratory conditions of up to 16.6% for mini-modules and 18.5% for solar cells. The pilot line, which has achieved modules with efficiencies exceeding 11.5%, is being transformed to a manufacturing development centre, operated as a subsidiary of Solibro GmbH, to provide technological support to production and to drive further CIGS development. The first full-size modules will be fabricated this year.

The plan is to build an initial factory in Thalheim with an annual production capacity of 25–30MW.

Honda establishes Soltec subsidiary

In early December, Honda Motor Co Ltd said it is investing 4bn yen in establishing a subsidiary, Honda Soltec Co Ltd, to produce and sell (in limited areas from March) CIGS PV cells developed by subsidiary Honda Engineering Co Ltd.

However, at the end of September Honda began constructing a 7bn yen, 11,080m² mass-production plant on the site of its Kumamoto factory, to become operational this autumn with an annual capacity of 27.5MW.

DayStar ramping up with GEN III line

Last November, DayStar Technologies Inc of Halfmoon, NY, USA, which make CIGS Photovoltaic Foil products on flexible metal sheets, appointed Dr Stephan DeLuca (COO since last April) as CEO, to steer the firm's transition to commercial manufacturing. He replaced founder Dr John R. Tuttle, who continues as chairman.

DayStar has been in pilot production on its GEN I and GEN II lines, but in 2007 expects to ramp-up production on its full-scale GEN III production line, from an initial capacity of 10MW to 20MW by end-2007. It aims to then fill its plant with up to 100MW of capacity, before replicating this elsewhere, up to 1GW in total.

MiaSolé expanding to modules

MiaSolé of Santa Clara, CA, USA, which makes CIGS cells on a flexible stainless-steel substrate, has been developing production lines with an annual capacity of 25MW each. It expects to expand from two lines at the end of 2006 to eight by end-2007 (200MW).

It will initially sell solar cells to module makers, and is working with module makers and building materials companies on flexible building-integrated PV products. It aims to launch its own modules in Q3/2007. ■

STF collaborates with RESI on manufacturing tools

In January, Solar Thin Films Inc (STF) of Somers, NY, USA signed a three-year agreement for Renewable Energy Solutions Inc (RESI) of Ewing, NJ, USA to develop equipment for manufacturing CIGS modules on glass substrates.

STF changed its name from American United Global Inc in July 2006 to reflect its new focus on PVs after acquiring Kraft Rt of Budapest, Hungary, which makes equipment for manufacturing thin-film PV modules (mainly silicon).

RESI was founded in 2001 as Terra Solar Development Corp and develops thin-film PV device fabrication processes and manufacturing technology. Dr Zoltan Kiss, a director, consultant and shareholder of STF, is also a shareholder, director and CTO of RESI.

STF aims to offer CIGS manufacturing equipment for sale this year and to provide turnkey facilities for CIGS PV modules.

STF is also participating in a contract proposal responding to the

Solar America Initiative (SAI) for a three-year optimization of RESI's CIGS technology. Also participating are the US National Renewable Energy Laboratories (NREL), the Institute of Energy Conversion, and Pacific Northwest National Laboratory (PNNL). STF's contribution is the development of a tunnel valve separating two different vacuum zones in the CIGS manufacturing equipment. SAI is expected to say in mid-2007 if it has accepted the proposal.

UIUC scales pHBT to new transistor record of 845GHz

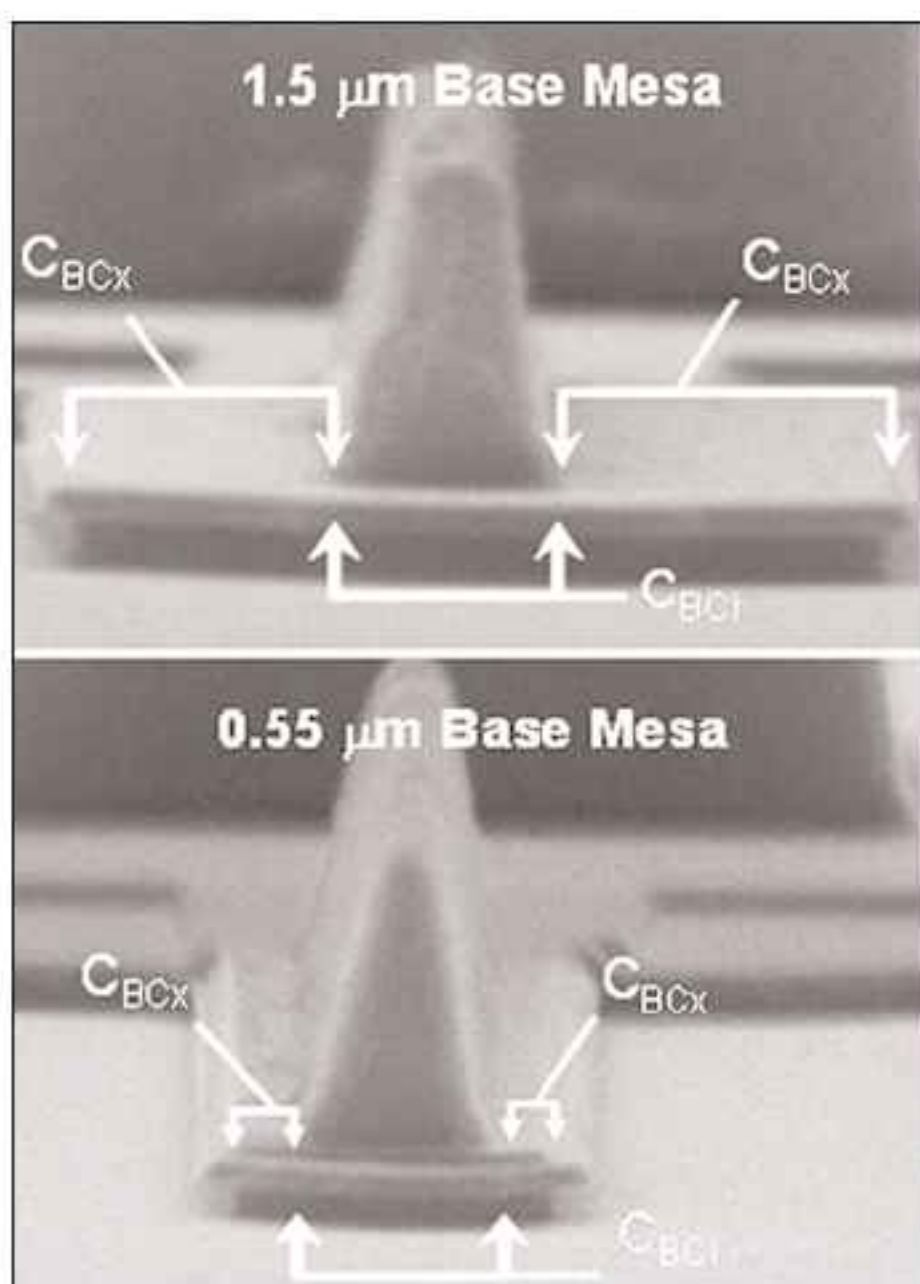
At December's IEEE International Electronics Device Meeting (IEDM) in San Francisco, CA, USA, the research group of Milton Feng, the Holonyak professor of Electrical and Computer Engineering at the University of Illinois at Urbana-Champaign (UIUC), reported that it had again broken its own speed record for the world's fastest transistor (fabricated in UIUC's Micro and Nanotechnology Laboratory).

With a cutoff frequency (f_T) of 765GHz at room temperature (25°C) and 845GHz when cooled to -55°C, the latest InP/InGaAs pseudomorphic heterostructure bipolar transistor (pHBT) is about 20% faster than the 710GHz record they reported in December 2005 and about 300GHz faster than transistors built by other research groups, it is claimed.

Faster transistors could facilitate faster computers, more flexible and secure wireless communications systems, and more rapid analog-to-digital conversion for use in radar and other electronic combat systems: the research is funded by the US Defense Advanced Research Projects Agency (DARPA); meanwhile, graduate student co-worker Walid Hafez now works for Intel Corp.

Feng's group has been working on high-speed transistors since 1995. "The steady rise in the speed of bipolar transistors has relied largely on vertical scaling of the epitaxial layer structure to reduce the carrier transit time," says Feng. "This comes at the cost of increasing the base-collector capacitance. To compensate for this unwanted effect, we have employed lateral scaling of both the emitter and the collector."

In October 2002, Feng received a \$2.1m five-year grant from DARPA



SEM images of original base-collector mesa (top); improved design (bottom).

with the target of a 500GHz transistor by spring 2004. The group reported a 382GHz transistor (with a 150nm collector) in January 2003, a 452GHz transistor (with a 25nm-thick base and a 100nm collector) that May, and a 509GHz transistor (with a 75nm collector) as soon as October 2003, using a typical HBT structure. Since then, funded by a \$5.9m DARPA contract, the goal has been to make a terahertz transistor.

However, "To achieve such speed in a typical HBT, the current density would become so large that it

would melt the components," Feng explains. The group therefore adopted an InP/InGaAs pseudomorphic HBT structure (with compositionally graded InGaAs base and collector regions).

"Pseudomorphic grading of the material structure allows us to lower the bandgap in selected areas," says Feng. This permits faster electron flow, reducing base and collector transit times. So, the compositional grading allows operation at higher current cutoff frequencies at lower current densities and junction temperatures than for traditional single HBT structures. "Unlike the previous HBT device structure, with this structure the goal of a terahertz transistor is now achievable."

Feng's group reported a 604GHz pHBT in April 2005 and a 710GHz pHBT (with a 12.5nm base and 55nm collector) that December. "By scaling the device vertically, we have reduced the distance electrons have to travel, resulting in an increase in transistor speed," said graduate student and co-worker William Snodgrass.

In the latest pHBT, the base-collector mesa has also been reduced laterally (from 1.5μm to 0.55μm): see the SEMs of the original (top) and improved (bottom) designs. The smaller area reduces the extrinsic base-collector junction capacitance, allowing quicker charging and discharging at the transistor's collector. This, combined with the reduced base and collector transit delays, gives a faster switching speed.

As well as further boosting the transistor speed, Feng aims to reduce current density further, which will reduce junction temperature and improve reliability.

www.news.uiuc.edu



Milton Feng (right) with William Snodgrass. (Photo: L. Brian Stauffer.)

Filling the THz gap with new applications

The electromagnetic spectral range **0.1–100THz** has many scientific uses for investigating the fundamental excitations in matter, but now new imaging opportunities are coming into view for medical and security applications that could launch terahertz technology into the public domain. Semiconductor technology is key to many of these developments, explains **Dr Mike Cooke**.

The electromagnetic spectrum, until recently, has been divided into two broad areas: radio/microwave and light/optics. Radio and microwave frequencies have been accessed directly with electronics (up to about 100GHz), while long-wavelength infrared radiation and beyond (say from 10THz) depends on 'photonics', the production of photons through quantum transitions (1THz corresponds to a photon energy of 4.1meV). In between is what is often called the 'terahertz gap', although the far infrared (FIR) covers some of the same territory.

But photonics and electronics have been steadily narrowing this gap in the electromagnetic spectrum (see Figure 1). On the electronics side, indium phosphide/indium gallium arsenide heterojunction bipolar transistors (HBTs) have reached a unity gain cut-off (f_T) of at least 845GHz at 220K (745GHz at room temperature) using a pseudomorphic (lattice-mismatched) grading of the base (12.5nm thick) and collector regions [1] (see facing page). The device (pictured opposite) has been scaled both vertically (reducing electron travel distance) and laterally (increasing speed of charge and discharge of the HBT). The lattice mismatch introduces a strain gradient, thereby enhancing electron velocities, giving further reductions in current density and charging times. The group that made the device, under Milton Feng at the University of Illinois at Urbana-Champaign, is no doubt working to improve this as I write. Among its aims, this group definitely has in its sights a 1THz transistor for faster computers, more flexible and secure wireless communications systems, and more effective combat systems.

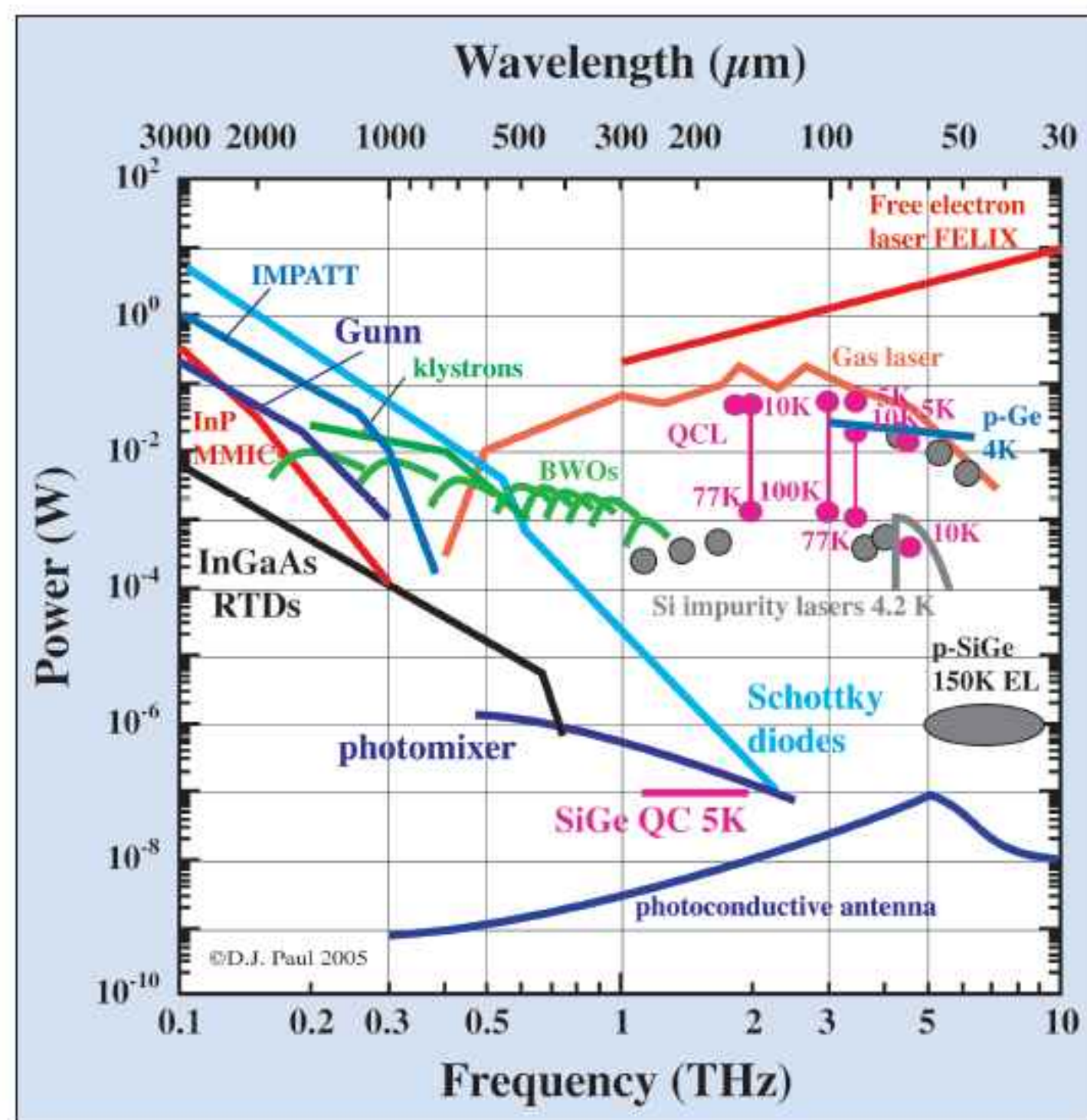


Figure 1: Graph showing output powers from THz sources in the literature up to June 2005 (from www.sp.phy.cam.ac.uk/~SiGe/THz.html), with thanks to Dr Douglas J Paul, senior researcher at the University of Cambridge, UK. Paul reports that the only major change since 2005 is that there are a few new GaAs QCL results at frequencies down to 1.7THz at low temperatures [e.g. Walther et al, *App. Phys. Lett.* vol. 89, p231121, 2006]. Magnetic-field-confined QCLs have pushed below 1.5THz [12].

Silicon germanium HBTs have also been produced at IBM and tested at Georgia Institute of Technology [2], with an f_T of 510GHz at 4.5K (352GHz at room temperature). These new gain devices are in addition to the two-terminal non-gain diodes (e.g. tunnel, resonant tunnelling, IMPATT, Gunn/TED, Schottky) developed and used at these frequencies for a number of years.

However, here we will focus on techniques that are optoelectronic in nature. The wavelength range from 1mm to 100 μ m (300GHz–3THz) corresponds to an approximate photon energy between 1.24–12.4meV or to an equivalent black-body temperature (E/k) in the range 14–140K, which is well below the ambient background on Earth (300K~26meV). Some authors extend the THz range to 100GHz–10THz.

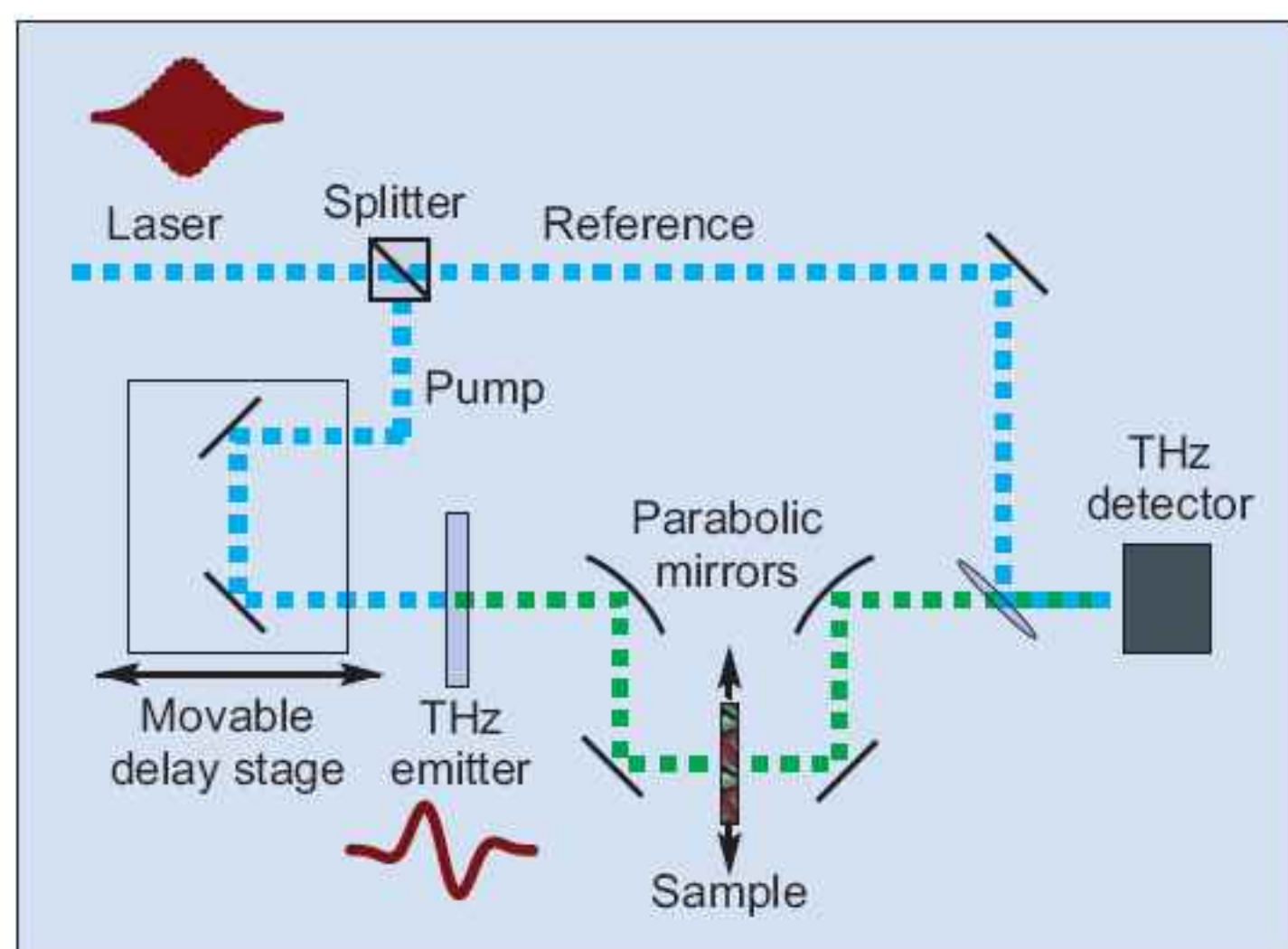


Figure 2: Typical time-domain spectroscopy system.

Imaging drive

T-ray imaging has been a major driver of recent interest in THz technology. Since T-rays can penetrate most materials except water and metal, such imaging provides opportunities in a number of areas such as the medical arena, where organic material can be penetrated without the damage of ionizing radiation (e.g. x-rays), albeit with a lower spatial resolution from the much longer wavelengths involved. The security industry is also interested in systems that can peek inside clothing for metal weapons without harm to the general public.

Unlike visible and infrared light, where often only intensity information is available, THz spectroscopy can measure the amplitude and phase of the electric field on a timescale that is shorter than the duration of a single oscillation. Time-domain spectroscopy (TDS) looks for system responses to pulsed signals that contain only a few cycles and hence are broadband in terms of frequency. From these studies, one can improve the understanding of condensed-matter and molecular-matter states (vibrations, charge density oscillations, excitons, superconducting gaps, spin waves, protein folding, etc) or enhance molecular recognition. But TDS can also be used to create T-ray imaging systems (Figure 2). Imaging technology that analyses the TDS response of objects moving in a focused beam was pioneered by Nuss and others at Bell Laboratories in the mid-1990s [3]. These systems operate close-in to the object.

T-ray focusing can be made reflectively or with lenses constructed from silicon, high-density polyethylene or a material called Picarin. Silicon has the advantages of low adsorption and chromatic aberration throughout the THz range, but a high refractive index (~ 3.42) leads to reflection losses at the air-glass interface (Fresnel losses). A technique for overcoming the latter problem is to use an anti-reflective coating (ARC). Polyethylene has less reflection loss, but a small amount of absorption above 1THz and a resonance at 2.2THz. Picarin is

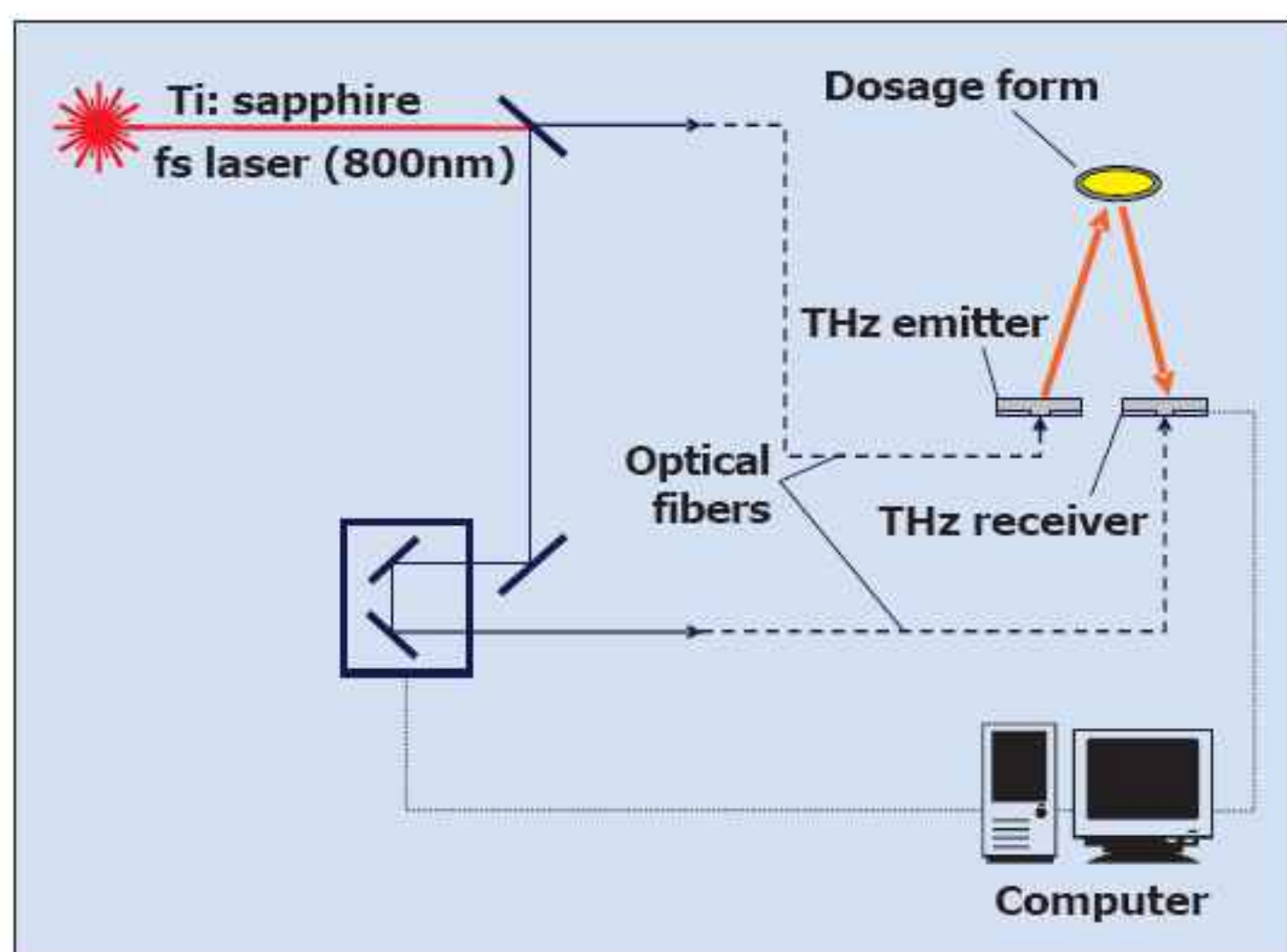


Figure 3: A pulsed imaging configuration.

another plastic material for THz lenses with a refractive index of 1.56 and small losses in the THz range.

Toshiba-owned TeraView (a spin-off of Toshiba Research Europe, Cambridge, UK) has developed THz techniques to detect cancerous cells using molecular markers, such as water, to provide spectral and absorption information to differentiate between cancerous and non-cancerous tissues, non-invasively. The aim is to greatly improve on conventional biopsy techniques and associated surgery by more precisely identifying areas to be excised, reducing the number of procedures and enabling earlier, more accurate diagnosis. The company also promotes THz technology (imaging and spectroscopy) for drug discovery and formulation, security screening/detection and material characterization (including electronic component analysis). TeraView uses measurements of transmitted or reflected terahertz radiation giving spectral, time-of-flight and direct signal strength to provide images (Figures 3 and 4). From the raw data, one can make inferences on refractive indices, amplitude and phase changes, and sample thickness (Figure 5).

Frequency domain

A more traditional THz application is spectroscopy. One such application has been the extension of radio astronomy to shorter wavelengths. NASA's Cosmic Background Explorer (COBE) indicated that approximately half of the total luminosity and 98% of the photons emitted since the Big Bang fall into the sub-millimeter and far-IR regions (600GHz–7.5THz) [4]. Interstellar and intergalactic spaces contain large quantities of singly ionized nitrogen, H_2D^+ , carbon monoxide, and many other species that have THz emission lines.

Geophysicists are also interested in many of the same gases in the earth's atmosphere and these can be accessed by satellite observations of water, oxygen, chlorine and nitrogen compounds, etc. THz emission lines from the Earth's stratosphere and upper troposphere give information on ozone destruction, global



Figure 4: TeraView's Imaga 2000 THz imaging platform.

warming, total radiation balance, and pollution processes [5]. For example, the five-year Earth observing system microwave limb sounder (EOS-MLS) [6] launched on Aura, 15 July 2004, measures thermal emission from broad spectral bands centered near 118, 190, 240, 640 and 2250GHz using high-resolution heterodyne receivers [7]. Further, the strong emission lines at 183 and 557GHz for water have been proposed as potential signals for planetary life detection.

Water T-ray absorption could also be used to distinguish materials with varying water content (e.g. fat vs lean meat). Further actual and proposed THz applications include screening for explosive related chemicals (ERC) at airports (even at a 'standoff' distance of 30m [8]), plasma fusion diagnostics and non-destructive evaluation (NDE).

Some proposals have also been made for THz radar and communications systems. However, the atmosphere is generally opaque to T-rays, although there are some potential frequency windows, particularly at higher altitudes (e.g. in the stratosphere) where there is lower scattering and greater penetrating power through aerosols and clouds compared with infrared and optical wavelengths. THz also has potential for the development of better radar scattering signatures for objects through the use of scale models of objects that can then be extrapolated to RF and microwave systems.

T-ray generation

A number of techniques are used and proposed for producing terahertz radiation. As is often the case for radiation-producing systems, there are continuous

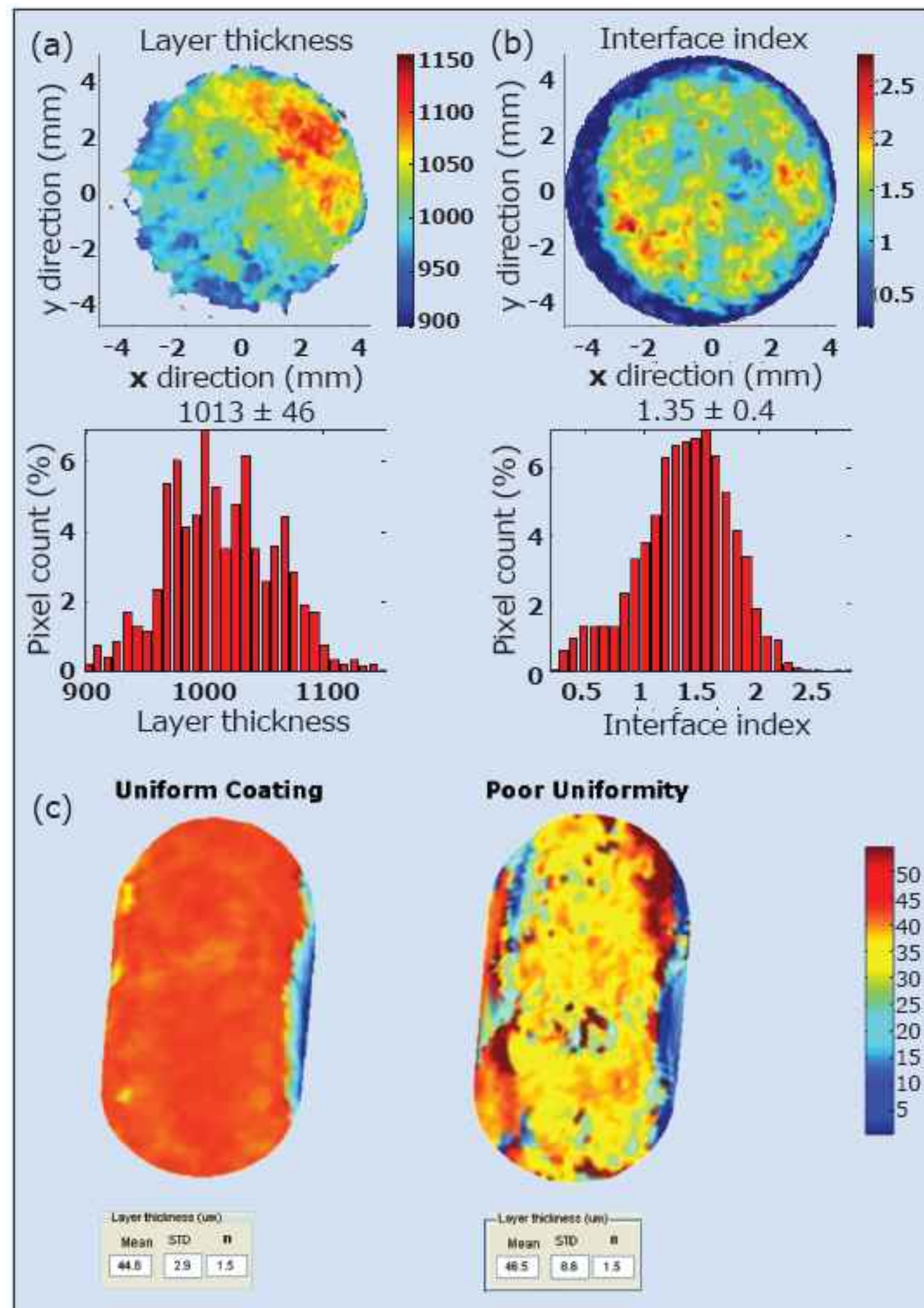


Figure 5: Images made with TeraView system on a buried layer in a pharmaceutical tablet coating. (a) Thickness map and histogram. (b) Interface index map and histogram give a view of the integrity of the interface between two layers. It shows there is some non-uniformity at the interface, particularly around the edges. (c) Color maps showing thickness variation in a coating applied to a tablet.

wave (CW) and pulsed systems with different characteristics and applications.

A typical CW source is the optically pumped terahertz laser (OPTL). These are often gas lasers of narrow bandwidth. Although hydrogen cyanide (HCN) or methyl fluoride (CH_3F) can be used to produce terahertz radiation, it is perhaps not surprising that the much more benign CO_2 is more popular, and there are commercial systems available aimed at the THz market.

There have also been some proposals for optical pumping of semiconductor materials to produce THz. Vukmirovi et al [9] present a design and simulations of an optically pumped laser using a GaN/AlGaIn double quantum well. The double-well structure sets up subband electron levels between which the transitions take place. The laser mechanism is based on a simple three-level scheme where the lower level is depopulated (creating the necessary population

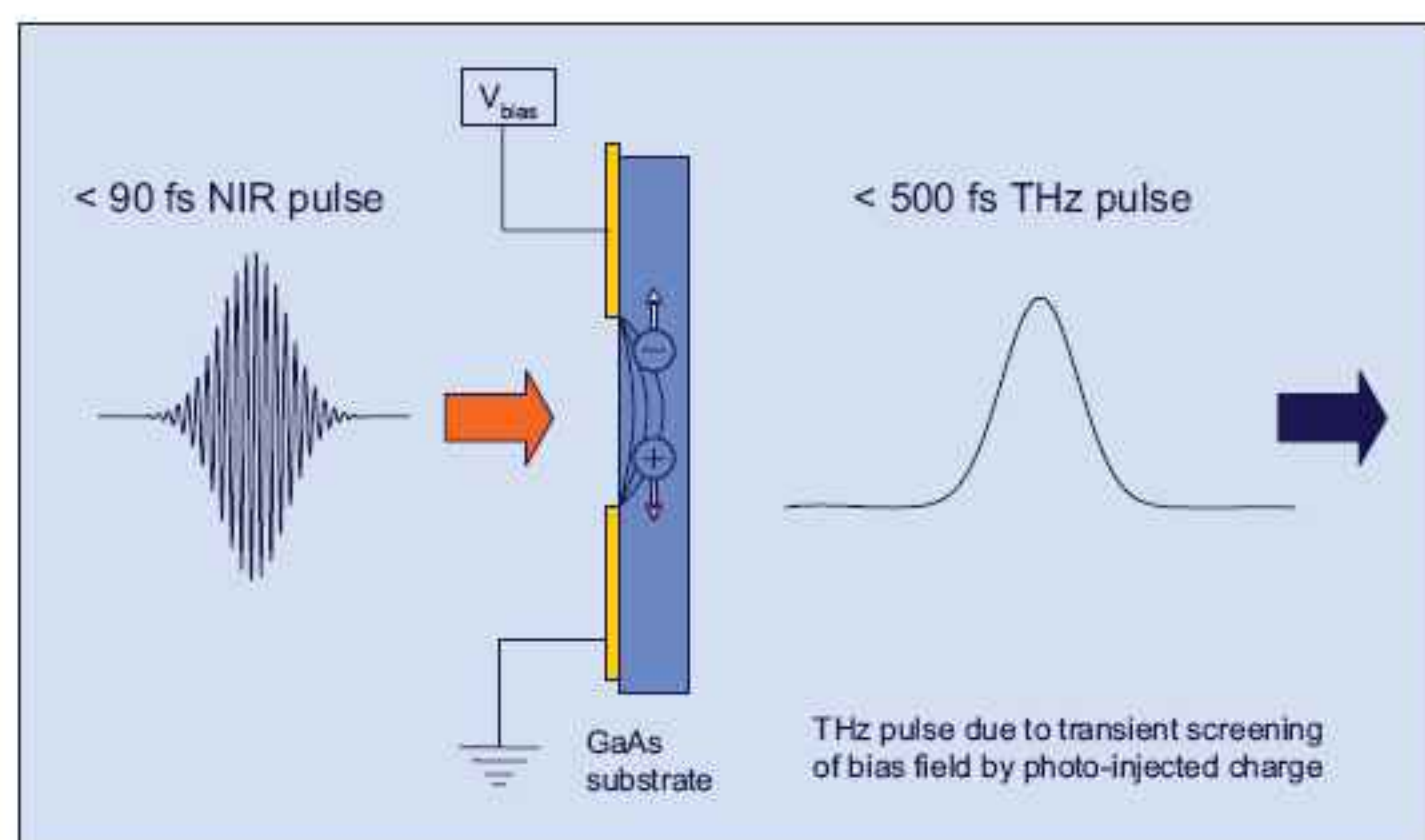


Figure 6: Laser gated photoconductive semiconductor for THz generation. Based on slide from TeraView.

inversion) via longitudinal optical phonon emission. An alternative material system, a ZnSe/Zn_{1-y}Cd_ySe double quantum well with a Zn_{1-x}Mn_xSe diluted magnetic semiconductor barrier, is presented by Popadi et al [10]. This OPTL (still theoretical) is also simulated. A giant Zeeman splitting takes place in the electron levels in the diluted magnetic semiconductor. An external magnetic field allows tunability of the laser in the range 60–72μm at low temperature.

A typical system for a pulse source consists of a gold split antenna switch structure fabricated on a GaAs substrate (Figure 6). TeraView uses such a system. A DC potential difference is set up across a gap in the structure. Pump laser pulses of duration less than 100fs are focused on the antenna gap. Photogenerated charge carriers jump the gap, with the current burst producing terahertz electromagnetic waves. Optical collection, collimation and focusing of the radiation produce a THz beam. Such sources give the broadband short-pulse radiation needed for time domain spectroscopy (TDS) and imaging, for example. Similar source systems use, instead of the GaAs photoconductive antenna, optical rectification (OR) in nonlinear media, where the high-frequency portion of the laser pulse is 'rectified' out to leave the THz radiation. OR materials include a number of patterned semiconductors (GaAs, GaP, ZnTe, GaSe), lithium niobate (LiNbO₃), and even metal surfaces. Photoconductive antennas can also be constructed out of (radiation-damaged) silicon or InP. Different pump lasers are suitable for different systems. For the GaAs antenna system, Ti:sapphire femtosecond lasers with a center wavelength of 800nm are often used, although a less expensive pump laser (e.g. laser diodes) would be desirable.

Another semiconductor system used to produce THz radiation is the quantum cascade laser (QCL). These have the advantage that they operate through current injection rather than optical pumping. Although QCLs were originally produced in the mid-infrared range (5.2μm) at Bell Laboratories [11], the principles can be extended to the terahertz range. QCL wavelengths

vary from 3.5μm infrared (~0.4eV, ~80THz, ~400K) up to 160μm THz wavelengths (~8meV, ~2THz, ~90K) and beyond. Pushing to the lower (THz) end, there are a number of differences and complications, since the inter-subband transitions used to create the laser radiation needs to be much narrower (of the order of 1–4meV). The material system is commonly GaAs/AlGaAs or AlInAs/InGaAs heterostructures, although there has also been work on Si/SiGe, along with some of the other usual suspects, such as GaN, AlGaIn, InP, GaSb, etc.

An advantage of the Si/SiGe combination is, of course, cost. However, another gain is possible higher-temperature operation, since there is no polar optical phonon to couple to in silicon and the coupling is negligible in SiGe, unlike with GaAs/AlGaAs systems. This is in contrast to normal laser diodes operating across the full bandgap, where Si and SiGe optical transitions are forbidden by the indirect bandgap of these materials and one is forced to use direct-bandgap materials such as GaAs/AlGaAs. However, it must also be remembered that, at present, these are theoretical considerations and, as yet, no working Si or SiGe QCL has been fabricated, although some non-lasing emission has been achieved.

Dr Douglas J Paul, senior researcher at the University of Cambridge, UK, is among those developing SiGe for QCL application. Paul comments: "With regard to the Si/SiGe cascades, we now have the waveguide losses down to a total value of 15cm⁻¹ (including free-carrier absorption and mirror losses), which is similar to GaAs devices. However, while we have designs for the active region that have enough gain to overcome this value, we are still struggling to find a grower who can grow the structures accurately enough to achieve high gain. As the two programmes we have funded for this are drawing to a close, it's difficult to know if we can achieve this in the near future without more funding."

All these different QCL systems are generally cooled to the extent needed by the particular frequency and material basis. Some achievements include operation down to 1.39THz (by applying magnetic confinement) [12], operating temperatures up to 164K (pulsed) and 117K (continuous) [13], and peak powers of the order of 248mW (pulsed) and 138mW (continuous) [14]. Various techniques are used to improve the waveguide/cavity structure of the laser, such as distributed feedback, metal gratings and waveguides, surface plasmons, etc.

With the THz field still very immature, there are many other techniques being explored to generate THz. Further semiconductor-based methods include photo-mixing of near-IR laser light and frequency multiplier systems. In photo-mixing, infrared laser diode light can be mixed with tunable Ti:sapphire laser radiation using low-temperature-grown GaAs with an antenna structure to produce THz. Virginia Diodes, starting from GaAs Schottky diodes, uses a variety of techniques to increase fre-

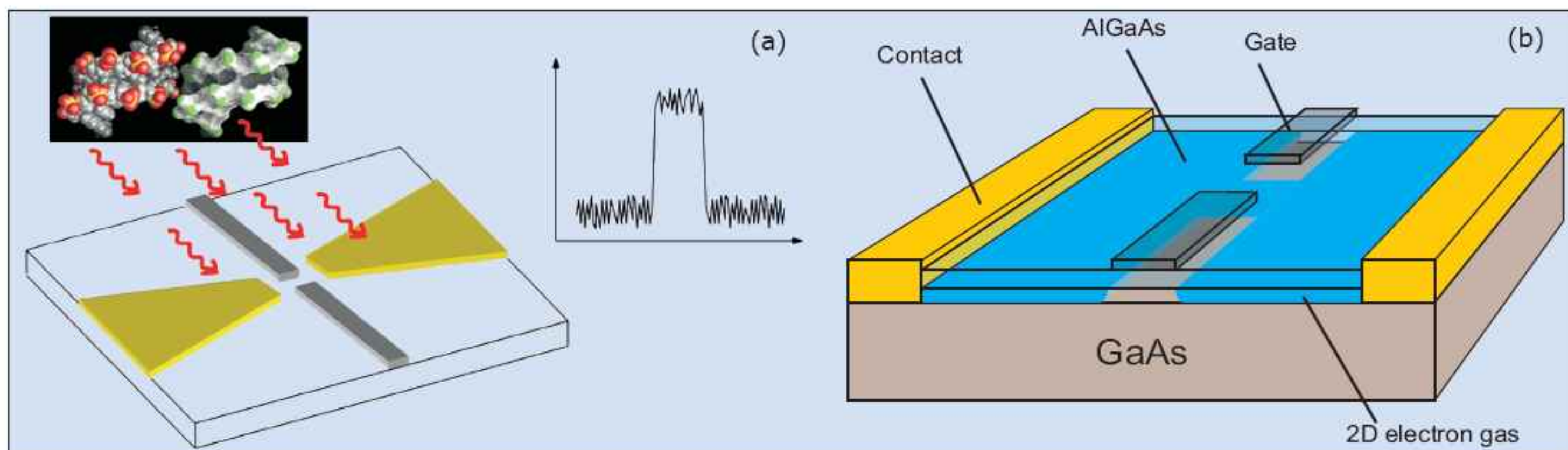


Figure 7: University at Buffalo's quantum point contact (QPC) detector: (a) grey and gold regions create a quantum point contact nanowire device that detects THz radiation emitted by targeted substance; (b) close-up.

quencies such as multiplier effects based on higher harmonics (up to x6). Non-semiconductor-based methods include backward-wave oscillators (BWOs), a sort of vacuum tube, and free-electron lasers that use high-energy electron beams to produce laser light.

Detectors


Many of the THz detection systems effectively use the above generation techniques in reverse. Hence, the photoconductive, optical rectification and inter-subband/quantum well (extending quantum well infrared photodetectors) technologies are often used. As with generation, one also finds non-semiconductor techniques such as detectors based on plasmonic techniques, and in addition many groups are researching superconducting detectors.

For spectral analysis, detection is often made through mixing the terahertz signal with a close known laser frequency (heterodyning) to produce a lower-frequency modulation that can be detected and then measured electronically. This requires a narrow-band CW laser such as the CO₂ OPTL.

Quantum point contacts (QPCs) are another semiconductor system being used to develop terahertz detectors by a team of scientists from the State University of New York at Buffalo, the University of California at Santa Barbara, and the Queens and Kingsborough Community colleges of the City University of New York [15]. These researchers hope that the confinement provided by the negatively biased metal contacts that raise barriers in the two-dimensional electron gas (2DEG) of a QPC and deplete the electron population in certain regions will enhance frequency resolution (Figure 7). The structure increases the coupling of the THz electromagnetic field to confined transitions in the 2DEG. A 2DEG, without such lateral confinement, normally has only weak coupling to electromagnetic waves that are incident perpendicular to the surface, since the fields are in the plane of the 2DEG. The carriers are then effectively free and the absorption is then 'bolometric' and lacks frequency resolution. ■


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Fax: +1 505 899 8172

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7 Wafer processing materials

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10 Process monitoring and control

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Fax: +49 30 3180 8237

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www.mrs.org

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www.shef.ac.uk/physics/plmcn7

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www.fis.cinvestav.mx/ldsd2007

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www.Blue-2007.com

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E-mail: miomd8@jku.at

www.hlphys.jku.at/miomd8

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E-mail: csmantech@csmantech.org

www.gaasmantech.org

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Matsue, Japan

E-mail: iprm07@ech.co.jp

www.iprm.jp

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Birmingham, UK

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