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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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Positive bandgap for graphene on silicon carbide opens up new horizons

RFMD buys Filtronic's GaAs fab • TriQuint launches BiHEMTs
Intel disposes of tunables • Terrestrial CPVs boost Emcore

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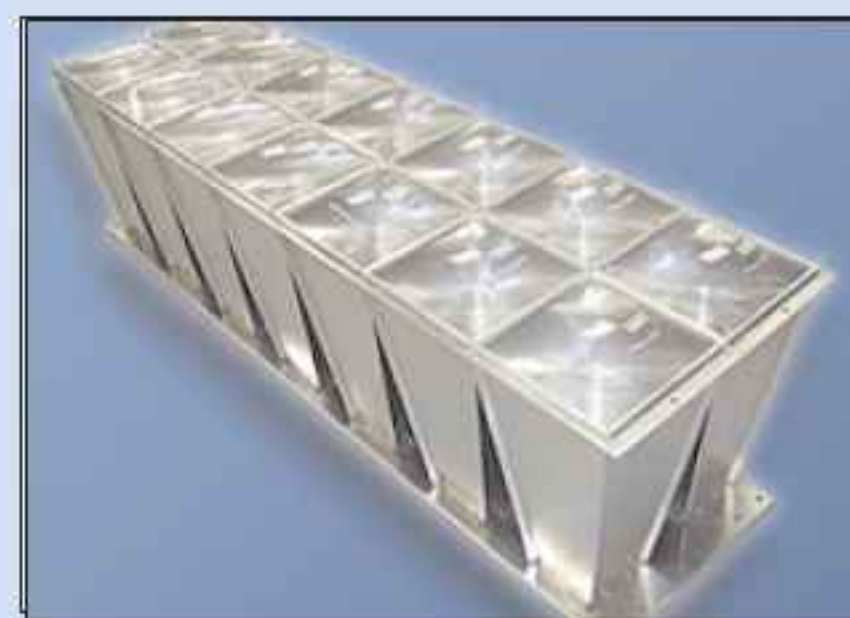
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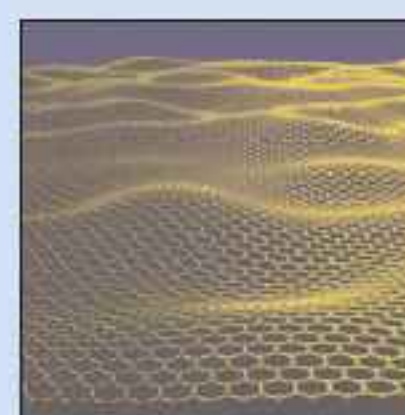
p5 The Cadillac Escalade Platinum is set to become the first series production SUV with full LED headlamps.



p33 Osram Opto's new white Diamond Dragon single-chip SMT LED, which can operate at a current of up to 2 Amps.



p43 Emcore's terrestrial concentrating photovoltaic (CPV) module, which is driving new solar contracts in both Canada and South Korea.



Cover: Artist's impression of a graphene sheet (by Jannik Meyer, Max Planck Institute for Solid State Research, Germany).

A positive bandgap has been found for graphene layers on silicon carbide, pushing the material into the semiconductor domain and opening up new applications for SiC. **p55**

RFMD diversifies as it expands

The Christmas holiday period saw welcome good news for staff at the Filtronic Compound Semiconductors Ltd GaAs fab in Newton Aycliffe, UK (who had been threatened with redundancy) when its main customer, RF Micro Devices (the world's largest GaAs RF component maker), agreed to acquire the business for £12.5m. Parent company Filtronic Ltd had previously been prepared to virtually give the business away (see page 8). The facility is now instead looking forward to the prospect of increasing its staffing as its new owner RFMD ramps up production.

The acquisition (due to complete at the end of February) should further increase RFMD's in-house capacity for manufacturing GaAs pHEMT switches and hence increase profit margins compared to outsourcing to foundries, as well as eliminating fears of capacity constraint in 2008 until the firm finishes construction of a new fab in Greensboro, NC. But, in addition, Filtronic's millimeter-wave RF semiconductor business should add to the continuing diversification of RFMD's product portfolio from its traditional GaAs HBT power amplifiers for cellular handsets to new growth areas, following November's acquisition of Sirenza Microdevices Inc and the formation of the Multi-Market Products Group.

At its analyst day in mid-November, RFMD announced its planned introduction of GaAs BiFET technology (joining rivals Skyworks and Anadigics, as well as Taiwanese foundry WIN Semiconductor, which already have BiFET technology in production — and joined by TriQuint, which has just announced its BiHEMT foundry process; see page 10). Filtronic could therefore gain not only increased volume but also new technology.

RFMD also announced at its analyst day that it had completed qualification of its first-generation GaN process, while it also discussed possibly developing LED technology as well as leveraging its GaAs manufacturing capacity expansions by entering the photovoltaic market. The latter is currently blossoming for terrestrial concentrator photovoltaic applications (driving Emcore to raise its expectations for 2008 revenues — see page 42).

Cadmium telluride PV manufacturing is also growing rapidly at First Solar, which has added a fourth plant at its Malaysia site as its shareprice has soared ten-fold in the last year or so, while CdTe material supplier 5N Plus has raised \$34.5m in its IPO to fund construction of a plant in Germany (see page 47). Meanwhile, copper indium gallium diselenide (CIGS) PV maker Nanosolar got widespread mainstream news coverage by selling its first flexible solar panels. The many and varied developments of CIGS PVs worldwide by both Nanosolar and its rivals will be covered in detail in an overview of the topic in our next issue.

Mark Telford, Editor (mark@semiconductor-today.com)

● It was with great sadness that we heard, shortly before going to press, that Vladimir Dmitriev, founder, president and CEO of pioneering nitride material maker TDI Inc of Silver Spring, MD, USA, had died suddenly from a heart attack on 6 January while he was traveling from the USA to Japan. A private memorial service was held in Bethesda, MD on 13 January. Semiconductor Today sends its condolences to Vladimir's family and all those who knew him. A full tribute will appear in our February issue.

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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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White LED revenues to fall 15% by 2011, despite shipments doubling

In 2006, white LED shipments rose 42.8% year-on-year (YoY) to 13.2bn units, says Fuji Chimera Research Institute in its survey on the global market for LED products, reports Nikkei Electronics. However, pricing fell by 20–30%, so revenue rose by just 5.2% to ¥184.9bn. For 2007, shipments are predicted to grow by 38% to 18.2bn units and revenue by 8% to ¥200.2bn.

The white LED market is currently being driven by cell phones, says Fuji Chimera. Also, through higher light-emitting efficiency and lower pricing, more white LEDs are being used in backlighting notebook PCs and medium and large LCD TVs. In contrast, the automotive and lighting system application markets are still small, with full-scale establishment expected for 2015 or later.

Fuji Chimera says that existing white LEDs must overcome challenges including cost and lifecycle (currently up to 40,000 hours, but this must be extended to 100,000 hours to increase demand).

The firm forecasts that shipments will rise by 115.9% on 2006 to 28.5bn units in 2011, but revenues will drop by 15.2% to ¥156.8bn.

Overall light-emitting device shipments — visible LEDs (including white LEDs), infrared LEDs, ultra-violet LEDs, organic LEDs (OLEDs) for lighting systems, and vertical-cavity surface-emitting lasers (VCSELs, excluding those for communication applications) — grew 2% YoY to ¥565.5bn in 2006.

Excluding white LEDs, overall shipments of visible LEDs grew by 27.4% YoY in 2006, with shipments of AlGaInP, high-luminance LEDs up in particular, says Fuji Chimera. Revenue, however, edged up only slightly, due to lower unit prices.

Regarding infrared LEDs, shipments of long-wavelength, short-wavelength and overall products remained flat, grew and slightly rose, respectively. The full-scale market for ultraviolet LEDs was only established in 2006, with products primarily shipped for application in banknote identification equipment.

Fuji Chimera predicts that overall shipments of light-emitting devices will reach ¥595.5bn in 2007 and rise 14% on 2006 to ¥644.4bn in 2011.

<http://techon.nikkeibp.co.jp>
www.fcr.co.jp/en



White LED market forecast (bars—revenue; line—number of units shipped).

Price erosion for notebook backlight LEDs just 20% in 2008

With demand growing rapidly, price erosion for LEDs used in notebook backlights is expected to fall from 30% in 2007 to just 20% in 2008, according to Taiwanese LED manufacturers.

Demand for white LEDs for use in notebook backlight applications started to pick up from second-quarter 2007, with Japan-based LED makers Toyoda Gosei and Nichia still the main suppliers of white LEDs, according to market research firm WitsView Technology. However, in second-half 2007, LED chip demand was running tight and prices remained high.

Average prices from Japanese manufacturers of LEDs for notebook backlights are about \$0.2 per unit, while the corresponding prices for LEDs for handset and high-brightness applications are \$0.1 and \$2.4 per unit, respectively.

Quotes for Taiwan-made LED chips are on average about 30% cheaper than Japan-made LED chips, claim Taiwan LED makers: about \$0.14 per unit for notebook backlights; \$0.06–0.07 per unit for handset backlights. LED chips for lighting application are priced at about \$1.8 per unit in Taiwan.

However, the manufacturers pointed out that prices of LED chips still need to drop further for LEDs to replace cold-cathode fluorescent lamp (CCFL) as the dominant technology for notebook backlighting. In 2008, they expect quotes to drop 20%, with prices for handset backlight-use LEDs expected to drop 30%.

In addition, prices for entry-level LEDs for use in Christmas lighting were forecast to drop 40–50% by the end of 2007 due to aggressive price cuts from China-based LED manufacturers.

www.digitimes.com/displays/a20071114PD215.html

Automotive demand to drive LED market to \$1bn by 2014

The automotive LED market is expected to grow to \$1bn by 2014, as new performance capabilities are expanding their use rapidly beyond simple switch illumination applications into automotive LCD backlighting and exterior lighting (most recently, fully LED-based front headlamps), forecasts market research firm Strategy Analytics in its report 'Automotive LED Market Demand: Exterior Lighting Driving Major Growth Opportunity'. Major LED suppliers, including Nichia, Osram and Lumileds are hence currently working with automotive partners to gain a major market share.

"Interior LED applications will continue to account for the majority of automotive LED volume demand," says Chris Webber, VP of Strategy Analytics' Global Automotive Practice. However,

the highest growth rates will be driven by vehicle lighting and driver information applications due to their use of higher-priced high-brightness LEDs in exterior lighting assemblies and LCD display backlighting.

"Regulatory barriers for the use of LEDs in front headlamps are in the process of being removed, which will lead to more LEDs for high- and low-beam headlight applications," adds Webber. "We believe, however,

that early implementation will be cost-limited and that it will be another two years before demand from exterior applications overtakes traditional lighting markets."

"Questions still remain regarding costs associated directly with LED device manufacturing, as well as the additional application costs of complex heat dissipating assemblies and electronic control," cautions Asif Anwar, director of Strategy Analytics' GaAs service. "This will hinder high-brightness LED deployment in low-margin volume vehicle segments."

www.strategyanalytics.net



This summer, the Cadillac Escalade Platinum will be the first series production sports utility vehicle (SUV) with a full LED headlamp (developed by Hella).

Five vertically stacked low-beam/daytime running lamp white LED units join two high-beam units, shown switched off (left inset) and switched on (right inset).

External lighting to double auto LED market in 10 years

The automotive LED market is set to double from \$650m in 2006 to \$1.3bn within 10 years as the LED becomes an alternative to incandescent light bulbs and halogen and xenon lamps in external lighting, reckons IMS Research's report 'LEDs in Automotive Applications'.

Currently, most of the value comes from interior applications such as backlighting dashboards and displays, as well as a wide range of indicator lamps. However, value from external lamps will rise from a third of the total market to over half by 2013. Most of the external LED lamps are at the rear (brake, tail and turning lights), but

daytime running lights (DRLs) will become much more widely used in the future, with the market growing from under \$5m last year to over \$100m by 2013, says analyst Jamie Fox, the author of the report.

Although daytime running lights are obligatory in countries such as Canada, Finland and Sweden, in some countries such as the USA they are used on many vehicles but not required, while in other countries such as the UK they are little used. However, usage of DRLs is growing overall. European Union studies have concluded that DRLs save lives, and a law requiring DRL use throughout the EU is widely anticipated.

Daytime running lights will offer a good opportunity for LEDs, says Fox. "LED DRLs have long lifetime and low power consumption as well as an attractive appearance." First introduced on the Audi A8 in 2004, they are currently used on less than 1% of vehicles. However, IMS says that, with very strong growth after 2009, revenues for LED DRLs in the next decade will be similar to current revenues for LEDs in rear lighting applications. "DRLs are the application that will lead the way for LEDs to move forward from the rear of the vehicle into front lighting," says the market research firm.

www.imsresearch.com

IN BRIEF

Handset LED market growth to slow in 2008

With 95% of handsets already using LED backlighting, LED manufacturers estimate that the growth in shipments of LEDs will slow next year to the 10% range, a growth rate just slightly ahead of the forecasted 9.1% growth for the overall global handset market, according to data from Digitimes Research.

Market analysts expect LED shipment growth in the handset market to be driven by the 'white-box' handset market, which will expand at a compound annual growth rate (CAGR) of about 25% between 2006 and 2010, with shipments of white-box handsets in the China market reaching 40–60 million units this year. The analysts explained that, while in the past China-based white-box handset manufacturers were pushing low-priced models, they are now seeing increased demand in China for higher-end products, which use LED backlights as well as LED-based flashes for camera phones.

With the market for LED backlighting for handset applications maturing, pricing for handset-use LEDs has been dropping and, according to the LED manufacturers, the overall production value of the handset LED market will decrease over the next two years, with related price quotes falling by about 30%.

However, despite the falling prices, Taiwan-based manufacturers will see increased opportunities for growth in shipments, as Japanese LED manufacturers are withdrawing from the handset-use LED market amid concerns about profit levels, reckons Digitimes Research.

www.digitimes.com:8080/displays/a20071217PD208.html

LED lighting market to grow at 35%

LED products in illumination applications constituted less than 10% of the \$2.8bn total LED market in 2006, but are expected to grow at a compound annual growth rate (CAGR) of 35.5% to nearly \$1.4bn by 2012, forecasts market research firm Databeans. This compares with a CAGR of just 11.8% for other applications (giving 14.6% overall).

The evolution of the lighting industry is underway, says Databeans, as indicated by plans to restructure traditional lighting businesses

(operating in a market estimated to be over \$100bn in 2006). GE has been moving aggressively into energy-efficient lighting technologies, as has Philips.

The market for LEDs for all applications (backlighting displays, indicator lamps in consumer and wireless electronics, and vertical illumination applications such as commercial signage and automotive) is growing at a record CAGR of 15%, Databeans adds.

www.databeans.net



Chinese GaN LEDs to outstrip Japan in 2010

The Chinese LED market grew at an average annual rate of 29% from 1997 to Rmb14.6bn (\$1.98bn) in 2006, and should reach Rmb32bn (\$4.34bn) in 2010, said Wu Ling of the China Solid State Lighting Alliance (CSA) at the First International Conference on White LEDs and Solid State Lighting (White LEDs-07) in late November.

Average annual growth from 2002 to 2006 was even higher (35%), boosted by the high-luminance LED market reaching Rmb9bn (\$1.22bn) in 2006. Of high-luminance LEDs, 40% are for backlight sources.

As the Chinese LED market has expanded, Chinese LED makers' technology has also improved, Ling claims, resulting in them capturing

a larger portion of the domestic market. In 2002, domestic LED makers used to depend on imported products, but in 2006 Chinese LEDs accounted for 43.9% of the domestic LED market.

Chinese products constituted 30% of the domestic market for high-value-added GaN LEDs (blue and white LEDs) in 2006, Ling reckons. GaN LED shipments in China grew from 65m units per month in 2003 to 600m units per month in 2006, and will grow to 1.65bn units per month in 2010, overtaking Japanese GaN LED output and making China the world's second largest GaN LED producing country, predicts Ling.

http://techon.nikkeibp.co.jp/english/NEWS_EN/20071129/143249

More LED power and efficiency needed for general lighting

In recent years LED component volumes have been driven mainly by mobile phone sales, showing a compound annual growth rate of more than 45%, yet revenue growth has grown at only 8% over the last two years due to the strong pressure on component prices, according to the report 'LED Manufacturing Technologies 08' from market research firm Yole Développement of Lyon, France in collaboration with the Paris-based European Photonics Industry Consortium (EPIC).

The overall LED market was forecast to produce 40bn devices and hit \$4.7bn in 2007, with low-end applications accounting for about 83% of the total, according to the report's author Philippe Roussel, Yole senior analyst for compound semiconductor activity. "The market is still dominated by portable device backlighting applications (e.g. mobile phones, PDAs, GPS, etc)... It is now clear that the LED market needs to expand into new and profitable sectors with higher margins," he adds. However, higher-brightness LEDs are expected to address other very promising markets. "We believe that this growth will come from three additional application areas: automotive lighting, architectural lighting, and [ultimately] general illumination, in addition to the LCD backlighting market."

But, to capture profits in these application sectors, much improvement is needed in LED performance, especially in dollars per lumen (\$/lm) and in lumens per Watt (lm/W) at full power. Recent announcements from LED manufacturers show impressive efficiency (150lm/W has been proved in the laboratory), but only for low-current (<20mA) low-power operation, says EPIC's secretary general, Tom Pearsall. To profit from the potential of ultra-high-brightness LEDs (UHB-LEDs),



Yole's regular, HB and UHB LED market forecast for 2005–2012.

Yole says, new approaches to manufacturing technologies are required at all stages (materials, design, front-end, back-end and packaging).

Currently, just 70lm/W has been demonstrated with high-power LEDs (>1W), so LEDs still lag behind the performance of fluorescent lamps for general lighting applications. LED efficiency is strongly linked to the input power: the higher the input power, the lower the efficiency. The difficulty in obtaining high power and high efficiency simultaneously underscores the immediate need for dramatic improvements in manufacturing technologies, Yole says. Existing high-power LEDs generate 75% heat versus only 25% light, so several parameters (e.g. internal quantum efficiency, electrical losses, extraction efficiency, and phosphor conversion and optics quality) must be improved greatly. To achieve this and create 150 lm/W LEDs that generate more than 50% light, key manufacturing technologies (either in use or under investigation) must be developed and implemented to considerably improve LED optical

output power: new substrate materials; laser lift-off; temporary bonding; flip-chip with reflecting back-contacts; transparent top contacts; photonic crystal and surface texturing, dicing/scribing, binning; surface texturing; and phosphor composition and deposition

Also, although LEDs have a natural advantage in automotive, outdoor and backlighting, a new business model is needed to penetrate the general lighting sector where fluorescent lighting remains a strong competitor, Yole believes. The incandescent lighting business currently generates revenues because 30% of the installed base is replaced every year and the manufacturing infrastructure has been amortized for many years. The industry needs to solve the challenge of building a growing market of lighting products with a quasi-infinite lifetime while developing mass-production methods for the next-generation of UHB-LEDs, the report concludes.

www.yole.fr

RFMD buys Filtronic compound semiconductor unit for £12.5m

Wireless electronics manufacturer Filtronic plc of Shipley, UK is selling its subsidiary Filtronic Compound Semiconductors Ltd (FCSL) in Newton Aycliffe, UK (Europe's only high-volume 6" GaAs wafer fab, which makes RF, microwave and millimeter-wave components and subsystems) to the world's biggest GaAs RFIC maker, RF Micro Devices Inc of Greensboro, NC, USA, for £12.5m (\$25m). The transaction is expected to complete on 29 February.

For its fiscal year to end-May 2007, Filtronic's underlying loss was £1.5m, but the headline loss (including exceptional items) grew from £5.1m the prior year to £29m. FCSL's gross assets were £23.5m. Its pension liabilities of £25-40m remain with Filtronic plc.

The sale price of £12.5m is higher than anticipated when Filtronic said in early November that it would sell FCSL for no initial payment (apart from the potential for deferred payment depending on the achievement of certain performance targets).

However, RFMD had outbid an unnamed third party to secure the deal. The firm entered negotiations just three weeks before the agreement, according to RFMD's chief financial officer Dean Priddy. "We decided that it was the right move and would help support our own growth," he added. "We believe it is a fair price for the business."

In October, in its report 'Filtronic — Life after RFMD', market research firm Strategy Analytics said that Filtronic was continuing to develop a sustainable position in both high-volume and high-value markets, placing the firm in mutually exclusive sectors. This gives the firm a balance that has been sought (or acquired) by leading RFIC makers such as RFMD and Skyworks and completely missing from other companies including Hittite and WJ.

The fab was opened in the mid-90s by Fujitsu Microelectronics as a DRAM memory silicon chip plant, but was closed in 1999 with the loss of 570 jobs. Filtronic then bought the fab in 2000 for £17.5m.

In 2006, Filtronic was the largest European GaAs device supplier, and 12th worldwide in Strategy Analytics' GaAs device vendor share rankings. But FCSL faced major challenges, given its scale of operation in a volatile and capital-intensive environment, set against the small size of its parent firm.

In early 2006, Filtronic had launched a £45m, two-year capital expenditure program to triple fab capacity. However, after half-year losses of £6.7m, this was scaled back to £15m, then again, in January 2007, to "not exceeding £10m" (including contract cancellation costs of £7m). In May, due to "continuing volatility in the cell-phone market", the expansion was cancelled, and 31 jobs were cut. Then, in late June RFMD, FCSL's biggest customer, announced the termination of its outsourcing deal for pHEMT switches (due in part to RFMD increasing in-house production). A thorough review of FCSL envisaged deep cuts in manufacturing or even closure, said CEO Charles Hindson at the time. Subsequently, Filtronic decided to cut the fab's staffing further, by 115, from 319 to about 200.

But in September, after winning a number of short-term orders for pHEMT switch wafers that created work through to March 2008, the firm postponed the redundancies. In its October report on Filtronic, Strategy Analytics pointed out that Filtronic was continuing to see strong demand from higher-value infrastructure and defense markets.

Now, after the RFMD deal, staff were told before Christmas that their jobs were safe in the short-term.

The sale agreement provides for the FCSL fab to remain in place, and for it to enter into a contract, lasting at least 3 years, for ongoing supply and lease (including the provision of support services) to Filtronic's Point to Point business (which makes transceiver modules and filters for backhaul microwave radios linking mobile basestations). Filtronic will cease its compound semiconductor manufacturing and supply activities, but maintain its broadband division (which employs 150) at the Newton Aycliffe plant.

RFMD expects the addition of the high-volume GaAs fab to greatly reduce its pHEMT sourcing costs (lowering its overall cost structure) and to provide extra manufacturing capacity, presenting the opportunity to capture incremental revenue that otherwise might be prone to capacity constraints in 2008 (until it completes another fab in Greensboro towards the end of the year). All this supports RFMD's aggressive growth expectations for cellular front-ends, says president & CEO Bob Bruggeworth.

Also, RFMD expects that FCSL's strong millimeter-wave RF semiconductor business will strengthen the product portfolio of its recently formed Multi-Market Products Group, enabling it to further diversify into new growth markets, as well as adding profitable, high-margin revenue and accreting to its target margin profile for the business.

"We intend to ramp up production and to do it very aggressively. We want to explore the potential of the factory and expect to see very strong growth," says Priddy. "We will be adding new positions in the new year. We will need at least 50 staff and possibly as many as 100." RFMD says it will train non-skilled workers, if necessary.

www.filtronic.co.uk

www.rfmd.com

RFMD appoints Sirenza's Ocampo and Skrzypczak to board

RF Micro Devices Inc has increased its board of directors to 11 members by appointing John Ocampo and Casimir Skrzypczak, former board members of RF component supplier Sirenza Microdevices Inc of Broomfield, CO, USA (acquired in November for \$900m).

"The composition of RFMD's new board of directors reflects the evolution of RFMD following its recent acquisition of Sirenza, which we believe created the world's largest, most diversified and best positioned RF company," says president and CEO Bob Bruggeworth. "These individuals' extensive industry experience and broad range of expertise should be of great value as we continue to grow RFMD."

With over three decades of RF experience, Ocampo had been a director of Sirenza since co-founding the firm in 1985, as well as chairman since December 1998.

From May 1999 to September 2002, he was chief technology officer and, from 1984 to May 1999, president and CEO. Previously, from 1980 to 1982 he was engineering manager at telecoms engineering firm AvanteK (now Hewlett-Packard/AvanteK) then general manager at RF component maker Magnum Microwave Corp of San Jose, CA, USA until 1984.

Skrzypczak has been a director of Sirenza since January 2000, and is also a director of optoelectronic chip and module maker JDS Uniphase. From 1985 to 1997 he was president of NYNEX Science & Technology Inc (a subsidiary of telecoms firm NYNEX Corp). With over 30 years of experience, Skrzypczak was also group president at telecoms firm Telcordia Technologies from 1997 to October 1999, then senior VP at networking equipment maker Cisco Systems until July 2001.

www.rfmd.com

Raytheon sues RFMD for HEMT patent infringement

In late November, US defense contractor Raytheon Co filed a complaint in the US District Court of Central California against RF Micro Devices Inc of Greensboro, NC, USA, according to a report from Reuters. Raytheon alleges that RFMD's RF3866 two-stage low-noise amplifier infringes one of its patents (issued in 1992).

Raytheon is seeking damages "adequate to compensate Raytheon for infringement" of the firm's high-electron-mobility transistor (HEMT) technology.

RFMD responds that it will defend itself against the charges. "We feel that the claim is without merit and that it will result in a favorable disposition for RFMD," says chief financial officer Dean Priddy.

http://dockets.justia.com/docket/court-cacdce/case_no-8:2007cv01360/case_id-401093

Huawei ramps RFMD's RF3161 EDGE PAs in its U120E 3G multi-mode handsets and Skyworks' RF solutions in its base-stations

RF Micro Devices says it has started shipping its RF3161 quad-band large signal polar modulation (LSPM) EDGE power amplifier (PA) module to Huawei to support the ramp of its U120E 3G multi-mode (UMTS/EDGE) handset.

The highly integrated RF3161 is packaged in a compact 6mm x 6mm x 1mm package, making it the industry's smallest and thinnest EDGE PA module in production, RFMD claims. The module is designed to support all major merchant market 3G multi-mode handset platforms implementing LSPM EDGE transmit architectures.

The RF3161 helps handset makers like Huawei to progress quickly and efficiently from layout to mass production of complex, next-generation handsets, claims Eric Creviston, corporate VP of RFMD's cellular handset products group.

The U120E is the successor to Huawei's high-volume U120 handset, which featured RFMD's RF3166 PowerStar PA. "We look forward to supporting Huawei with new and innovative front-ends in future 3G multimode devices," adds Paul Augustine, general manager of the component solutions business unit at RFMD. The firm anticipates that new, incremental EDGE-enabled handsets will feature its RF3161 as well as its high-efficiency RF3159 linear EDGE PA.

Meanwhile, Skyworks Solutions Inc of Woburn, MA, USA says that Huawei is leveraging multiple devices from its portfolio, including downconverters, front-end modules, power amplifiers, attenuators and switches, for both GSM and WCDMA base-station platforms.

Over the last several years, Huawei has partnered with some of

the world's top telecoms operators and gained market share. As a result, Skyworks' sales to Huawei have tripled since 2004 and continue to grow, based on Huawei's increasing traction among worldwide carriers as it expands its domestic footprint in China to the broader global infrastructure market, says Liam K. Griffin, Skyworks' senior VP sales & marketing. "Based on their business momentum, Huawei is becoming one of our largest infrastructure accounts as they leverage our highly integrated base-station solutions."

Skyworks reckons that, on aggregate, it can capture up to \$35 per base-station with RF-intensive WCDMA solutions compared to about \$10 of content in a 2G base-station.

www.huawei.com

www.rfmd.com

www.skyworksinc.com

IN BRIEF

Rochester distributing 'end-of-life' products for Anadigics

Anadigics Inc of Warren, NJ, USA, which makes GaAs-based wireless and broadband communications components and modules, has selected Rochester Electronics LLC of Newburyport, MA, USA as its authorized distributor of discontinued products. Rochester already works with 30 semiconductor manufacturers to provide an aftermarket source for such 'end-of-life' products.

Rochester will continue to fill orders from Anadigics customers when products reach end-of-life status and beyond. All Anadigics products distributed by Rochester Electronics are 100% factory direct.

"Long program life cycles tend to have two schedules, one for the manufacturer and another for the customer," says Jennifer Palella, Anadigics' senior director of worldwide distribution.

"Partnering with Rochester will enhance our end-of-life strategy, allowing Anadigics to better serve its customers," she adds.

"Anadigics brings us the ability to provide a more complete package of discontinued semiconductors. Customers can now fill most requirements with one call," says Rochester's founder and CEO, Curt Gerrish.

Last September, Rochester was also selected as an authorized distributor by Avago Technologies Inc of San Jose, CA, USA, which manufactures analog interface components for communications, industrial and consumer applications, to help its customers continue to fill orders when products reach end-of-life status.

Rochester claims to be the world's most comprehensive source for discontinued semiconductors.

www.anadigics.com
www.rocelec.com

TriQuint launches BiHEMT process

TriQuint Semiconductor Inc of Hillsboro, OR, USA, the world's largest GaAs foundry supplier, has introduced TQBiHEMT, its latest foundry process for wireless/RF design engineers, fabricated on 150mm (6-inch) GaAs wafers.

The new manufacturing capability combines two of TriQuint's existing processes, offering a single technology for integrating previously incompatible functional blocks onto a single die. This reduces part count, saves board space and improves overall system costs, the firm says.

TQBiHEMT is suited to highly integrated front-end radio modules typically found in wireless applications with high data rates and frequencies, TriQuint reckons, since these types of applications require a process that allows front-end functional blocks to be optimized individually. The new process enables optimal integration of high-power amplifiers based on heterojunction bipolar transistors (HBTs) on the same die as low-noise amplifiers and switches based on pseudomorphic high-electron-mobility transistors (pHEMTs), while remaining a cost-effective design solution, the firm claims.

"TriQuint's TQBiHEMT process represents an evolutionary step-up from earlier BiFET technologies by offering increased functionality," comments Asif Anwar of market research firm Strategy Analytics. "The GaAs industry is dispelling the myth that integration is an advantage offered by silicon processes alone and continues to increase the value-add to customers," he adds.

Demand for 3G, 4G wireless and other high-frequency wireless applications is growing, and TriQuint's customers are looking to tap into the burgeoning market, says Glen Riley, VP and general manager for TriQuint's Commercial Foundry. The

TQBiHEMT process is being delivered at a competitive price point relative to discrete solutions, he adds.

TriQuint uses its TQHBT3 high-volume InGaP HBT process (with an emitter width of 2µm and an F_{max} frequency of 65GHz, designed for high-power, high-efficiency and linear power amplifiers) in its own products for the cell-phone handset market.

Likewise, its TQPED InGaAs E/D (enhancement/depletion-mode) pHEMT process (with gate lengths of 0.7µm and F_{max} frequencies of 65GHz and 57GHz for enhancement-mode and depletion-mode pHEMTs, respectively) is used to make high-isolation switches and low-noise amplifiers for the handset and wireless data markets.

The TQBiHEMT process, incorporating HBTs and pHEMTs, enables the creation of single-chip products, and gives the optimum combination of power amplifiers and switch low-noise amplifier components, TriQuint claims.

These active device types are complemented by high-Q passive circuit elements: precision 500ohms/sq thin-film nichrome (NiCr) resistors, high-value (400Ω/sq) bulk epitaxial resistors, and small-area/high-value (1200pF/sq-mm) MIM capacitors. Three interconnecting metal layers (two global, one local) and optional backside grounding via technology complete the available circuit component suite.

"TQBiHEMT provides wireless communications system designers the circuit component and three-layer interconnect technology required to optimize performance goals for next-generation RFICs," says Mike Peters, director of marketing for TriQuint's Commercial Foundry.

Device samples and design kits will be available in first-quarter 2008.

www.triquint.com

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Nasdaq gives WJ six months to recover to \$1 share price

WJ Communications Inc of San Jose, CA, USA, which designs and supplies RF products for wireless infrastructure, RFID and WiMAX markets, has received notice from the Nasdaq Stock Market that, for 30 consecutive business days, the bid price of its common stock closed below the minimum \$1 per share required for continued listing under Marketplace Rule 4450(a)(5). WJ last traded above \$1 in intraday trading on 21 November, and had not closed above \$1 since 5 November.

The notice has no immediate effect on the listing of WJ's stock, which will continue to trade on the Nasdaq Global Market.

In accordance with Marketplace Rule 4450(e)(2), WJ will be given 180 calendar days (until 17 June) to regain compliance (for which the bid price must close at or above \$1 per share for a minimum of 10 consecutive business days).

If compliance is not regained by 17 June, WJ will receive a written notification from Nasdaq that its securities will be delisted. WJ can then appeal that determination to a Listing Qualifications Panel, or apply to transfer its securities to the Nasdaq Capital Market if it satisfies the requirements for inclusion set forth in Marketplace Rule 4310(c), other than the minimum bid price rule. If the application is approved, WJ will be afforded the remainder of the Nasdaq Capital Market's second 180 calendar day compliance period to regain compliance with the minimum bid price rule while on the Nasdaq Capital Market.

WJ says that it continues to assess opportunities to maximize shareholder value, including its previously announced engagement of Thomas Weisel Partners LLC to evaluate strategic alternatives.

www.wj.com

RRFC wins \$8.85m AFRL contract for ALD hermetic coating of MMICs

Raytheon RF Components (RRFC) of Andover, MA, USA has won a \$8.85m Defense Production Act (DPA) Title III Program award to develop a dedicated, long-term domestic foundry source for atomic layer deposition (ALD) hermetic coating of monolithic microwave integrated circuits (MMICs) at the wafer level. Such devices are intended for use in radar systems. The US Department of Defense contract is being managed by the Air Force Research Laboratory (AFRL/PKMD) at Wright-Patterson Air Force Base, Ohio.

Currently, most MMICs are coated using plasma-enhanced chemical vapor deposition (PE-CVD), but ALD allows more precise control.

The Department of Defense (DoD) presolicitation notice issued in May stated that the 33-month contract involves: procuring ALD equipment for depositing environmental coat-

ings in RRFC's MMIC production wafer fabrication plant; replicating the existing wafer-level dielectric deposition process and films; optimizing the ALD process and deposition materials for manufacturability; qualifying, validating, and demonstrating the hermetic coating process in the production of microwave and millimeter MMICs.

Also, the production demonstration release should include establishing, demonstrating and documenting: complete computer-aided manufacturing (CAM) instructions; statistical process control and process control limits; device and component models; and device, components, and MMIC reliability and environmental integrity.

www.raytheon.com/products/rf_components

www.defenselink.mil/contracts/contract.aspx?contractid=3658

Microsemi acquiring MDT for \$7.8m

Microsemi Corp of Irvine, CA, USA, is acquiring most of the assets of Microwave Device Technology Corp of Westford, MA, USA for \$7.8m.

The takeover will enable Microsemi to both enter into the sensor market and expand its portfolio of microwave semiconductors by adding GaAs microwave diodes. "By adding GaAs devices to our present silicon product line, we will increase our frequency band of coverage from 24GHz to 110GHz," says John Caruso, VP and general manager of Microsemi's Lowell Division. "Additionally, we have added millimeter components to our existing silicon product line, thus utilizing our GaAs capability for high-frequency transceivers that support such products as intrusion alarms, motions and speed detectors and other sophisticated sensor products." MDT is MIL-S-19500 qualified, and customers include Raytheon, Lockheed Martin, Honeywell, Ericsson, Nokia, and Fujitsu.

"We see this combined business providing sound value for all our customers, employees and Microsemi investors alike," says president Dr T.B. Ramachandran, who founded MDT in 1988.

"We saw significant synergy with MDT," says Microsemi's VP of business development, Rob Adams. "MDT is a sole-source supplier to many of Microsemi's existing high-reliability semiconductor customers and its business model matches our gross margin profile for this market." MDT had sales of just over \$7m in the past 12 months.

"Microsemi has a long history of successfully integrating and leveraging private high-reliability suppliers," says president and CEO James J. Peterson. Significant efficiency gains are possible on the operational level as well as on the business opportunity level, he believes.

www.microsemi.com

NEC combining Kansai front-end and Fukui back-end facilities

NEC Electronics Corp has unveiled plans to reorganize its manufacturing facilities in Japan, aiming to improve efficiency in semiconductor development and production, and to promote synergy between manufacturing companies and business units. This involves realigning six of its manufacturing facilities to better support the firm's three core business units.

Also, NEC Electronics aims to boost collaboration between its manufacturing companies by aligning them directly with its three business units: Discrete & IC, Microcomputer (MCU), and System-on-Chip (SoC).

The NEC Kansai Ltd front-end processing plant and the NEC Fukui Ltd back-end processing plant (which have about 2300 and 850 staff, respectively) will also be integrated, and serve as the main manufacturing facility for compound semiconductor devices (as well as power management devices and display drivers) for the Discrete & IC business unit.

Also, the NEC Kyushu Ltd and NEC Yamaguchi Ltd front-end processing plants and the NEC Semicon Package Solutions Ltd back-end processing plant (which have about 2200, 1200 and 1500 staff, respectively) will be integrated into one company, which will be the flagship manufac-

turing facility for the MCU business.

NEC Electronics reckons that, as a result of the mergers, the MCU and Discrete & IC business units will have the benefit of 'seamless' front-end and back-end manufacturing, helping to improve quality management, reduce costs, bring added value to products, and improve profitability.

NEC Electronics is also transferring leading-edge silicon development and prototyping functions from its Sagamihara manufacturing plant (which has a production capacity of 2000 300mm wafers per month) to a new location on the premises of NEC Yamagata Ltd (NEC Electronics' most advanced manufacturing subsidiary) by March 2009, allowing a seamless continuation from product development to manufacturing for the System-on-Chip (SoC) business unit. Most of the 700 or so staff at the 300mm line in Sagamihara will be transferred to Yamagata, the site of the recently announced 32nm joint development in Yokohama, or NEC Electronics' headquarters in Kawasaki.

NEC Electronics says that the realignment of the above six manufacturing units into a three-pronged model is expected to occur in April.

www.necel.com

Nasdaq extends Kopin deadline

Nasdaq has extended the deadline from 17 December to 11 February for Kopin Corp of Taunton, MA, USA to file all delayed periodic reports with the US Securities and Exchange Commission, necessary to regain compliance with Nasdaq Marketplace Rule 4310(c)(14).

Kopin, which makes heterojunction bipolar transistor (HBT) wafers and liquid-crystal CyberDisplays, has previously received Nasdaq notifications for failing to file its Q3/2006 Form 10-Q, 2006 Form 10-K, and Q1, Q2 and Q3/2007 Form 10-Q financial reports. The delays are due to an investigation into the firm's past stock option granting practices and related accounting by a special investigative committee (appointed by Kopin's board).

In May, the committee issued preliminary findings and recommendations that financial statements for 1995 through 2006 should be restated. Kopin is now working to complete any necessary restatements.

However, if Kopin has not regained compliance by 4 February, the Nasdaq board will instruct its staff to discuss the reason with the firm and to update it on whether the stock should remain listed.

www.kopin.com

RFMD ships 100 millionth Polaris RF solution

RFMD has shipped its 100 millionth Polaris Total Radio RF solution to a 'leading handset manufacturer', about three years after it began shipping Polaris 1, its first cellular RF solution.

"This achievement is especially gratifying, as it occurs concurrently with the production ramp of our newest RF solution, Polaris 3, which we forecast will extend multiple years and support meaningful revenue and earnings growth for RFMD,"

says president and CEO Bob Bruggeworth. "Based on current customer forecasts for our Polaris 2 and Polaris 3 RF solutions, we expect the next 100 million Polaris shipments will happen significantly faster than the first 100 million."

Polaris RF solutions include the power amplifier, switch, filter, DC-to-DC converter, transceiver and other functions critical to the performance of a cellular handset.

RFMD claims that Polaris 3 delivers the industry's highest levels of RF functionality, and production volumes of Polaris 3 are expected to increase sequentially throughout 2008. RFMD adds that, with the ramp of Polaris 3, it is increasing its dollar content in cellular RF, since Polaris RF solutions command about three times the dollar content of EDGE cellular front ends.

www.rfmd.com

Micromem makes first foundry-grade fully functioning MRAM

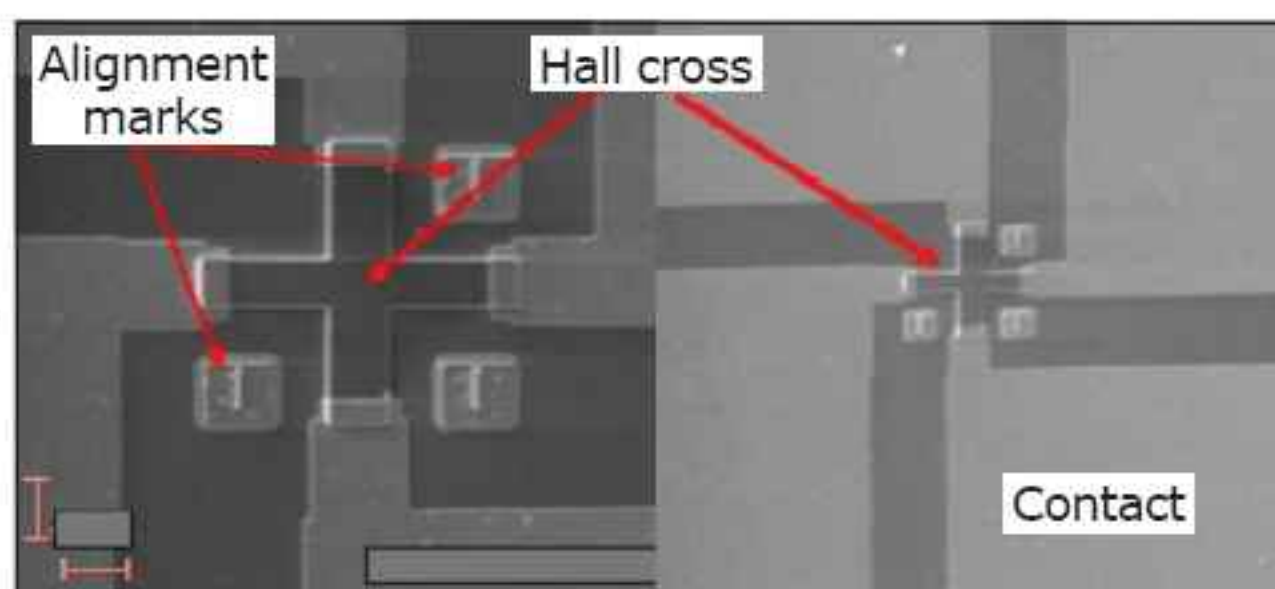
Fabless GaAs firm Micromem Technologies Inc of Toronto, Canada claims it has made the first foundry-grade fully functioning magnetic random access memory (MRAM) cells. This concludes a three-year R&D proof-of-concept phase, which is being followed by a foundry phase focused on manufacturability and scalability.

In late summer Micromem contracted engineering firm Strategic Solutions of Grass Valley, CA, USA as a partner to design and implement its MRAM technology. To orchestrate a knowledge transfer of work by Dr Harry Ruda and his team at the University of Toronto, Strategic Solutions created a manufacturing design-of-experiment and a reticle design (consisting of thousands of MRAM bit cells in various configurations) plus a test plan document, in order to communicate manufacturing requirements to a GaAs foundry.

In September Micromem contracted Global Communication Services Inc (GCS) of Torrance, CA, USA as its partner foundry. Phase One of the contract aims to establish the manufacturability of the MRAM design, via tests to determine the optimum configuration for memory performance and foundry manufacturing costs.

Micromem says that the development team at Strategic Solutions and GCS has worked closely to meet the aggressive schedule initiated last autumn. The initial foundry phase has now generated much statistically validated MRAM performance data, which Micromem is analyzing in January. The firm's initial data review indicated that the test plan was successful and that the data set is rich with scalable data that indicates a clear path to an optimized MRAM cell design.

Also in January, Micromem aims to deliver functioning MRAM cells in



Hall cross-sensor (in detail, left; larger view, right).

specific package formats for third-party radiation-hard testing, focused on medical device sterilization radiation requirements, galactic radiation test protocols for space-based applications, and weapons radiation protocols. Phase One should complete with the manufacture of working multi-bit MRAM cells. The firm plans to then release MRAM performance data in early February.

With Phase One foundry work ahead of schedule, Micromem has now contracted Strategic Solutions to provide a reticle design and test plan for a 64-bit MRAM cell. These arrays will be transistorized and packaged to allow third parties to test and validate standard memory test protocols, including power, speed and robustness. In that same foundry run, driven by the Phase One test plan data set, Micromem will take the necessary steps to further optimize the fundamental MRAM bit cell architecture. The 64-bit MRAM arrays should be available for client testing in 3–4 months.

With the progress of Phase One, the availability of foundry-grade MRAM cells packaged for third-party testing, and release of the 64-bit MRAM array into the next foundry phase, Micromem says that it will be equipped to engage clients with targeted product development and integration requirements. Such steps are mandatory for holding discussions with clients that have expressed interest in partnering.

Micromem claims that, compared with competing MRAM cell architectures with multiple thin-film layers, Phase One has proven that the memory is simple to manufacture and robust in design.

A further outcome of the initial foundry phase is the high-sensitivity performance of the thin-film Hall cross-sensor

component of the MRAM cell, says program director Steven Van Fleet. This enables the firm to increase its product portfolio with a high-sensitivity, low-cost Hall cross-sensor. The February 2006 Frost & Sullivan report on 'Extremely Sensitive Magnetic Sensors' projected a 2010 market of \$2bn (with Hall sensors about 80%). In 2005 the total magnetic sensor market was about \$1bn.

Micromem has held preliminary market discussions with targeted clients and found that there appears to be a good revenue opportunity to supply standalone Hall cross-sensors for various applications. In January it will deliver evaluation packages to several clients that have agreed to test and provide performance and cost/benefit feedback.

CEO Joe Fuda adds that Micromem is now focusing on its client capture strategy, via three parallel market streams, aiming to secure:

- a developmental and market development partner for MRAM, focusing mainly on military, health-care and automotive applications;
- end-user clients for Hall cross-sensor applications requiring high sensitivity in thin-film solutions;
- a developmental and market development partner for conversion of the GaAs memory technology to silicon germanium, allowing the firm to participate in the larger silicon-based memory space (focusing on lower cost and higher-density).

www.micromeminc.com

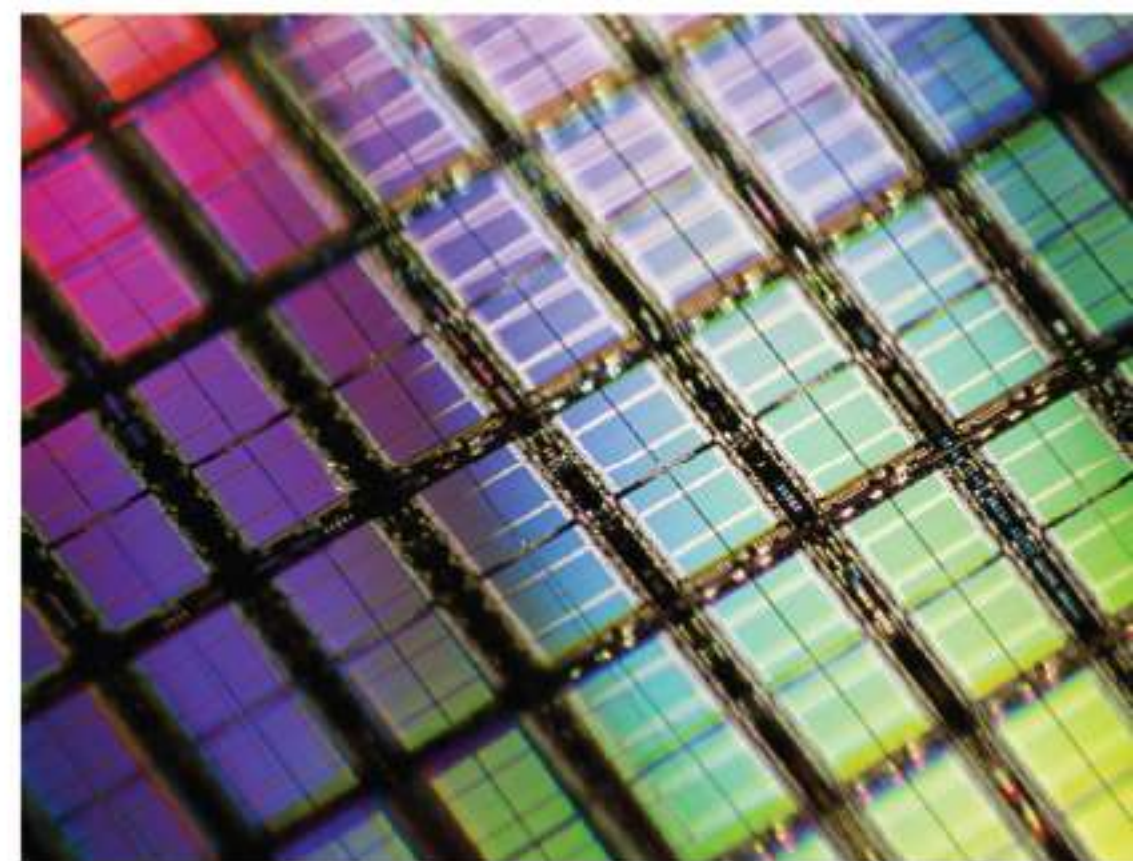


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SURFACE TECHNOLOGY SYSTEMS

SRC awards Glasgow \$2.5m for 8nm-gate p-channel MOSFETs

The university-research consortium Semiconductor Research Corp (SRC) of Research Triangle Park, NC, USA is funding Scotland's University of Glasgow in a \$2.5m, three-year project (from 1 January) to identify the best p-channel material to scale minimum MOSFET feature sizes in CMOS devices (including gate length) down to the 8nm technology generation.

Exploiting compound semiconductor materials for the p-type channel is expected to enable the shrinking of silicon chips for a further 4–6 years beyond previous projections for the miniaturization roadmap.

Driving the research is the fact that continued scaling of silicon may lead to curbed chip performance. The University of Glasgow will team with SRC to extend silicon's capabilities, facilitating continued improvements in chip performance while a replacement device is found.

"Being able to utilize MOSFETs in compound semiconductors has been the elusive Holy Grail of scaling for 30 years. With what we expect to accomplish with the University of Glasgow, we may be only 2–3 years away from achieving that breakthrough," says Dr Jim Hutchby, senior scientist for the Global Research Collaboration (GRC), the unit of the SRC responsible for narrowing the options for carrying CMOS to its ultimate limit.

"When the day comes that Moore's Law scaling of classical silicon CMOS slows, the benefits from our extending the silicon chip using compound semiconductors could be profound for the electronics industry," he adds. "At that point, we'll have developed with compound semiconductors a new set of materials and devices to improve both the power dissipation and speed of the historically successful CMOS technology."

Switching speeds have increased nearly 20% each year, sustaining Moore's Law's aggressive pace of increasing IC functionality. However, the capability to continue this will eventually slow down without the implementation of compound semiconductor materials such as indium gallium arsenide (InGaAs) to replace silicon as the channel region of the MOSFET, says the SRC.

To improve carrier velocities, a goal of Glasgow's work will be to strain p-type compound semiconductors in much the same way that performance enhancements have been realized in silicon. Strained compound semiconductor solutions are expected to yield mobilities of 6,000–50,000cm²/Vs, more than 10 times the values achievable in silicon. This has the potential to significantly reduce switching times, yielding faster chips.

Glasgow will work closely with the Non-Classical Research Center (NCRC), launched in 2006 by SRC-GRC and led by University of California-Santa Barbara. The NCRC is working on providing a sharp increase in carrier velocities in the n-channel. The aim of the new work at Glasgow

Exploiting compound semiconductor materials for the p-type channel is expected to enable the shrinking of silicon chips for a further 4–6 years

To improve carrier velocities, a goal of Glasgow's work will be to strain p-type compound semiconductors

will be to significantly improve velocities in the p-channel, also using compound semiconductors (initially, strained InGaAs structures, before increasing the indium concentration).

"We're on our way to proving a new class of compound semiconductors that will provide better peak carrier velocities and lower voltages and allow the industry to supplement silicon's critical paths for speed and power," says professor Iain Thayne, who is project leader for the Glasgow team in the Ultrafast Systems Group of the Department of Electrical and Electronic Engineering.

In addition to applications using digital logic such as microprocessors, this technology is expected to be of more general use, in areas such as sensors and photonics for medical, safety, imaging and communications applications.

The research will complement and enhance work that the University of Glasgow is already undertaking in this area, supported by the UK government's Engineering and Physical Sciences Research Council (EPSRC). For the last 3 years Glasgow has been working closely with Freescale Semiconductors to develop III-V MOSFET technology.

Combined with the new research funding at Glasgow, SRC-GRC has committed \$10m to non-classical semiconductor advances. With a goal of scaling the CMOS critical dimension (i.e. the gate length) down to 8nm, SRC-GRC conducts what is claimed to be the world's largest and most comprehensive industry research program for the development of n- and p-type channels using compound semiconductor materials.

www.elec.gla.ac.uk/groups/nano/UFS/mosfet.html
www.src.org

InGaAs emerging as material for future NMOS channels

The Austin, TX-based industry research consortium SEMATECH says that the high electron mobilities of III-V compounds make them prime candidates for future NMOS channel materials. Specifically, indium gallium arsenide (InGaAs) is likely to be the material of choice, according to the consensus of more than 60 industry and university researchers in the invitational workshop 'III-V CMOS on Si: Technical and Manufacturing Needs' (organized by SEMATECH and sponsored by deposition equipment maker Aixtron) at December's IEEE International Electron Devices Meeting (IEDM) in Washington DC.

InGaAs, with a mobility performance of 6-10 times that of silicon, has emerged as a leading candidate channel material in dual-channel devices that may consist of germanium-based PMOS and III-V-based NMOS field-effect transistors (FETs), with proponents of III-V expressing optimism over the manufacturability.

However, some delegates expressed concern that such materials-based solutions for performance enhancement may not be brought to manufacturing in time, and that issues that need to be addressed to realize performance improvement would not be resolved in time for use in devices at the 22nm technology node.

Delegates also agreed that inserting III-V materials on Si devices poses several challenges, including lattice mismatch, poor interface quality, high-k dielectric growth and off-state current leakage. However, the scalability of MOCVD attracted consensus as the most promising manufacturing process, with clustered chambers for III-V and high-k suggested as an effective tool configuration for increased throughput. "By 2012 we should have a real working solution for III-V," said opening speaker Robert Chau of Intel.

● In IEDM's technical sessions that followed, SEMATECH's Front-End Processes division presented five papers detailing progress in developing a manufacturable high-k metal gate-stack solution for 32-22nm device technology generations.

1. In 'Impact of Flash Annealing on Performance and Reliability of High-k/Metal-Gate MOSFETs for sub-45nm CMOS', lead author Pankaj Kalra reported the use of millisecond annealing on scaled high-k metal gated devices to form ultra-shallow junctions that meet requirements for sub-45nm CMOS technology.

Wafers were ramped up to an intermediate temperature followed by using flash lamps to heat the device side of the wafer to the peak anneal temperature of 1300°C. Subsequent testing revealed that, unlike spike annealing, dopant diffusion (which causes excessive junction depths) is minimized and dopant activation is actually improved.

Also, the process does not significantly affect bulk charge trapping (a major performance/reliability issue in high-k dielectrics). The flash process can achieve junction depths of about 12-15nm with low effective sheet resistance (meeting 32nm technology targets).

2. Rusty Harris reported that high-k/metal gates on NMOS FETs fabricated on the 110 silicon crystal plane demonstrate respectable output performance due to velocity saturation of electrons. "High-k seems to be an important element in making the 110 channel very realistic," he noted.

Also, it seems that off-state current can be controlled in Si(110) in the same way as the more conventional Si(100) orientation, allowing Si(110) NMOS and PMOS structures to be used effectively in low-standby-power (LTSP) devices. So, Si(110) may provide a significant improvement for high-performance (HP) and

LTSP devices without the process complexity that is typical of mixed-orientation CMOS approaches.

3. Sagar Suthram discussed SiGe with strained quantum wells (QWs), which could offer a replacement for Si channels for 22nm and beyond, meeting future low-power and high-performance requirements that are probably too great for Si-based materials. These devices (which use the quantum well effect of confining charge carriers to a two-dimensional plane, improving their transport characteristics) exhibit a low band-to-band tunneling current and provide significant mobility enhancements. The devices display a strain response similar to that of Si, indicating that scaling pathways with Ge-based devices exist.

In two more papers, SEMATECH gave details on enabling approaches for dual metal gate technology:

4. Enriching high-k materials with oxygen in a low-temperature process is an effective way to diminish flat-band roll-off (V_{fb}), which is the main challenge to achieving low PMOS threshold voltage (V_t) and thin EOT simultaneously. S.C. Song et al discovered that progressive oxygen vacancy generation causes V_{fb} roll-off, shedding light on a little-understood phenomenon.

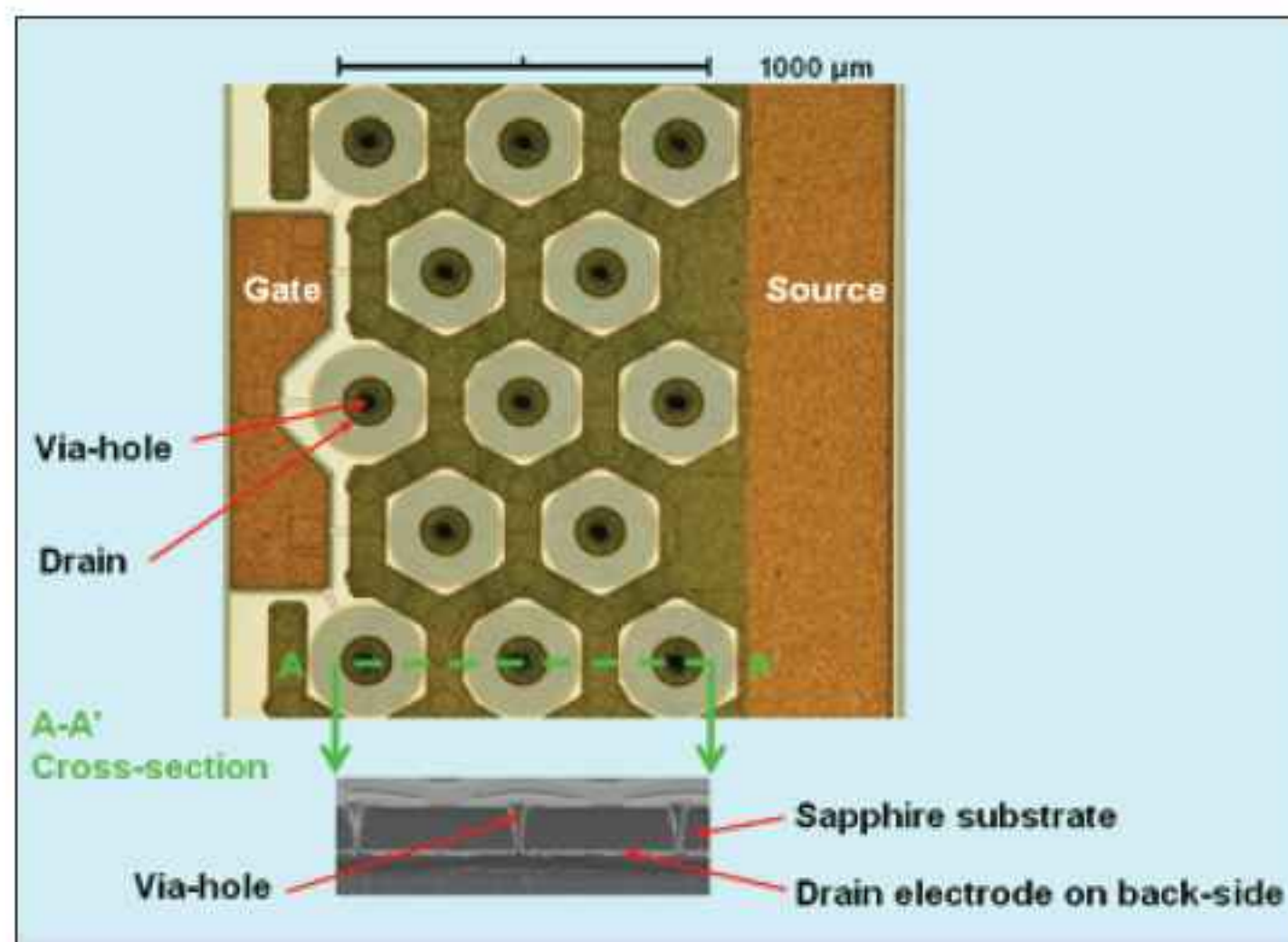
5. A second-generation high-k gate stack material, HfTiSiON, has been demonstrated as a successor to first-generation HfSiON dielectric. With an aggressively scaled dielectric constant (k) of about 40, and low leakage, HfTiSiON seems to answer gate stack manufacturability needs for the 32nm generation and beyond. "For the first time, we addressed the thermodynamic instability of TiO_2 -containing dielectrics," says Prasanna Sivasubramani. "This may enable gate stack scaling beyond HfO_2 ."

www.sematech.org

GaN power transistor with 10,000V breakdown voltage

At the IEEE International Electron Devices Meeting (IEDM 2007) in Washington DC (10–12 December), Panasonic of Osaka, Japan presented a gallium nitride power transistor with an ultra-high breakdown voltage of over 10,000V, more than five times higher than the previous record.

Matsushita Electric Industrial Co Ltd (the firm behind the Panasonic brand) says that a novel device structure and a high-quality GaN film on a highly resistive sapphire substrate were used to realize a high breakdown voltage (BV_{off}) of 10,400V with a low on-state resistance (R_{on}) of $186\Omega\text{cm}^2$. Overlap of the electrodes via insulating film on the



Panasonic's 10,400V breakdown-voltage GaN transistor, showing via hole and back-side drain electrode.

surface side is eliminated by using a back-side electrode with through-holes in the sapphire, resulting in the ultra-high breakdown voltage.

The through-hole in the chemically stable sapphire is formed by a novel laser drilling technique using a high-power pico-second laser. Also, Panasonic says that its proprietary epitaxial growth technology helps to extract GaN's inherently superior material properties, resulting in the high breakdown voltage and the low on-state resistance.

The new GaN transistor is applicable to high-voltage and low-loss power switching devices for industrial and electrical power systems.

The firm has applied for 110 domestic and 69 international patents on the technology.

<http://panasonic.net>

www.hyarc.nagoya-u.ac.jp/hyarc

Semiconductor-based weather radar enters operation

Tokyo-based Toshiba Corp has delivered what it claims is the world's first operational weather radar system that replaces electron tubes in the transmitter with a high-power semiconductor module (which uses GaN power field effect transistors). The first unit has been installed at the Hydrospheric Atmospheric Research Center at Nagoya University, Japan.

The new radar is only one sixth the size of conventional equipment (with a minimum installation size of 2m x 2m) but offers comparable output power (over 200W, giving coverage of 64km), along with improved waveband efficiency and enhanced features. The Nagoya radar operates in the 9GHz frequency band (X-band).

While the new weather radar is much more compact and offers much higher performance than

conventional systems, it maintains the same level of output power by adopting a combination of GaN power FETs and pulse compression technology, which strengthens peak output power. Implementation of fully digital data processing suppresses spurious levels, allowing the frequency separation required for interference suppression to be shortened to one fourth. This contributes to efficient use of crowded radio frequencies.

The new radar reinforces performance by adding innovative features such as dual polarization observation (which enhances the precision of rainfall estimation by capturing the shape and size of raindrops and cloud) and clear-air turbulence observation (which detects very low levels of signal scattering, enabling observation of air conditions including wind speed even in

clear weather - a very difficult task for most weather radars).

As the new radar does not use electron tubes, which have to be periodically replaced and disposed of, it reduces environmental loads, meeting Toshiba's goal of maximizing the eco-efficiency of its products and systems, the firm says.

Because of the limitation of bandwidth availability with increasing use of radio wave frequency resources, steady demand for solid-state radars is expected, as they can contribute to more efficient use of frequencies. Toshiba says that it will market the new high-power semiconductor-based weather radar in both 9GHz band (X-band) and 5GHz band (C-band) versions, both in Japan and overseas, including sales of individual modules that build the system.

www.toshiba.co.jp

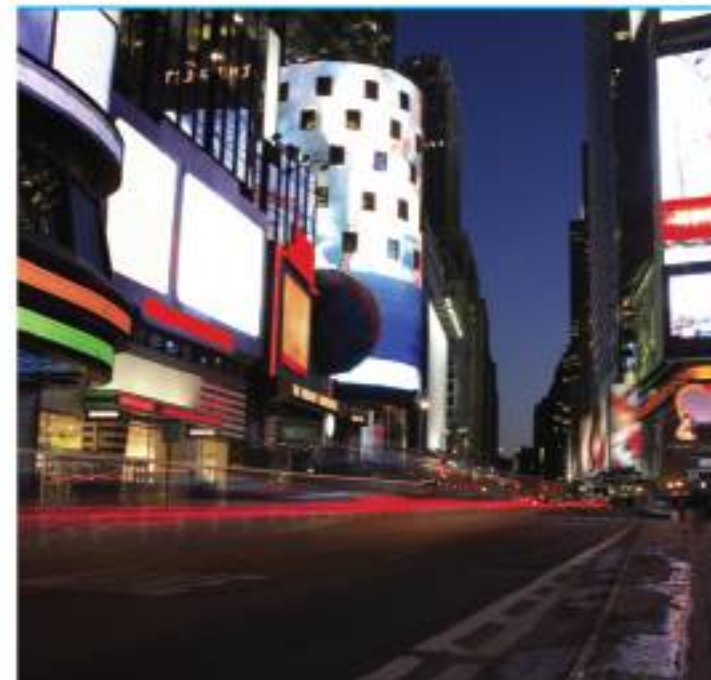


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AXT wins \$18.6m IQE order

Substrate and raw material supplier AXT Inc of Fremont, CA, USA has been awarded a production order from epiwafer foundry IQE plc for its global 2008 semi-insulating gallium arsenide substrate requirements, valued at about \$15.1m (with an option to purchase a further \$3.5m worth).

IQE has six epiwafer manufacturing facilities in Cardiff in the UK; Bethlehem, PA and Somerset, NJ in the USA; and in Singapore. All substrates (mainly 6" semi-insulat-

ing GaAs) will be shipped by the end of 2008.

"AXT is well positioned to be able to accommodate IQE's increasing demand, particularly in larger-diameter GaAs substrates," says IQE's president & CEO Drew Nelson. "Its expansive manufacturing capacity, unique raw

AXT is well positioned to be able to accommodate IQE's increasing demand

material capability and broad product portfolio make it an ideal partner to support our strong growth plans for 2008," he adds.

IQE's choice of AXT as a major supplier is a result of close collaboration on qualifying on various wireless related requirements, says AXT's chairman & CEO Phil Yin. "This agreement recognizes our unique capability to scale our manufacturing in order to meet the needs of our customers."

www.axt.com

AXT promotes senior director of technology Wei to CTO

AXT has promoted Chia-Li Wei to chief technology officer (CTO), as part of its on-going focus on technology development (particularly in the LED and solar markets).

Wei joined AXT in May as senior director of technology, and will continue to direct the firm's technical vision, including further refinement of its proprietary VGF process, research into alternative crystal growth processes, and development of products using complimentary materials such as GaN, GaP, and SiC. Based mainly at AXT's manufacturing facility in Beijing, China, Wei will now report to chairman and CEO Phil Yin.

Prior to joining AXT, Wei spent more than 25 years in epitaxial process engineering positions with

HP-OED (which was acquired by Lumileds and later became Philips Lumileds). Previously, Wei spent three years in process engineering

development in LEC growth of both InP and low-defect GaAs with the central research lab of Varian Associates.

"His experience in liquid-encapsulated Czochralski (LEC) crystal growth technology will allow us to provide lower-cost alternatives to



AXT's CTO Chia-Li Wei.

VGF-grown semiconducting substrates," says Yin. "It will also allow us to broaden our product offering and increase our total market opportunity by providing an alternative technology for certain applications that will enhance AXT's current market base such as new applications for LEDs, including GaP and small-diameter semiconducting GaAs," he adds.

"Chia-Li's expertise in MOCVD further enhances our understanding of the epitaxial and device parameters and thus strengthens our partnerships with our LED customers," says Yin. "The Czochralski crystal growth technology also provides us with an alternative method to grow germanium for concentrator photovoltaic applications."

Gold Canyon boosts private placement from \$1m to \$3m

Mineral exploration firm Gold Canyon Resources Inc of Vancouver, British Columbia, Canada has increased the size of its private placement of common shares (announced on 7 November) from \$1m to \$3m.

Proceeds will be used mainly for further work to follow up results from drill campaigns at the firm's Cordero Gallium Project in Humboldt County, NV, USA (owned via US subsidiary

Gold Canyon Resources USA Inc), at its Springpole Gold Project in the Red Lake area of Ontario, and for general corporate purposes.

Gold Canyon plans a core drilling program at Cordero in January to further test the new high-grade model that returned up to 245g/ton of gallium over 25 feet during the last drill program. The large-diameter core will also provide a mini

bulk sample for metallurgical testing and support for an economic scoping study. At least \$1m is budgeted to meet objectives and take Cordero to the next stage, the firm says.

Gold Canyon says that its exploration and development team will also continue to research new projects to ensure a steady pipeline of new opportunities.

www.goldcanyon.ca

Dow Corning wins further Navy funds to develop 4" SiC wafers

Dow Corning Compound Semiconductor Solutions (DCCSS) of Midland, MI, USA has been awarded a \$4.2m contract from the US Office of Naval Research to develop silicon carbide (SiC) materials technology. This follows a \$3.6m contract awarded in December 2005, and allows DCCSS to continue developing its ability to manufacture device-quality SiC substrates up to 100mm (4-inches) in diameter.

Because of its unique thermal and electrical properties as a substrate, SiC technology is becoming increasingly important in the development of new high-frequency and more-efficient high-power electronics products. Emerging applications include radar systems, cell-phone base-stations, hybrid electric

vehicles, and power grid networks. Dow Corning is using the funding, together with its own silicon manufacturing expertise, to accelerate SiC substrate development.

"The first phase of this program has met all its key objectives and advanced the technology of SiC significantly," says James Helwick, global director of new business development programs for Dow Corning's Advanced Technologies & Ventures Business. "We're expecting the second and later phases to help us further increase quality and reduce costs, which should pave the way for better-performing, more affordable SiC-based products that use even less energy."

"SiC technology's ultimate market success requires more than raw

materials. Additional research and systems development also will be essential," says DCCSS' chief scientist Mark Loboda. "This program provides an ideal platform for government, leading academic research institutions and commercial organizations to collaborate and share resources to improve this promising technology."

Dow Corning has been developing SiC technology since 2003, when it acquired SiC substrate maker Sterling Semiconductor Inc. Dow Corning's SiC development is underway at the firm's manufacturing site in Auburn, MI, which it dedicated in 2004 following the launch of the DCCSS business.

www.dowcorning.com/content/compsemi

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IN BRIEF

Entrepix marketing Rudolph AutoEL Series ellipsometers

Rudolph Technologies of Flanders, NJ, USA has granted Entrepix Inc of Tempe, AZ, USA an exclusive global license (excluding the region of Japan) to manufacture, sell, service and support its AutoEL series of thin-film ellipsometers (the first microprocessor-based automated ellipsometer), labeled 'Rudolph Technologies AutoEL—provided and supported by Entrepix'. The transfer of assets and inventory was due to be completed in fourth-quarter 2007.

Rudolph, which designs, manufactures and supports process control metrology, defect inspection and data analysis systems, says that thousands of AutoEL tools have been placed in universities, research labs and production lines since the system was commercialized in 1977, with many still in use today. "AutoEL technology was the foundation of our overwhelming success in thin-film metrology," says Rudolph's chairman and CEO Paul McLaughlin.

Entrepix provides chemical mechanical polishing (CMP) process outsourcing and equipment services, including refurbishment of CMP, post-CMP cleaning and thin-film metrology equipment.

"The AutoEL is a perfect complement to our existing CMP and metrology equipment business," says Entrepix's CEO Tim Tobin. "We have the infrastructure in place to continue development and refinement plus expand support of the tool to meet our customers' needs well into the future."

www.rudolphtech.com

www.entrepix.com/Rudolph/AutoEL/AutoEL-3.html

Plasma Accelerator launched for die etch failure analysis de-processing

Etch and deposition system maker Oxford Instruments Plasma Technology (OIPT) Ltd of Yatton, UK has launched the Plasma Accelerator for advanced die processing, its latest upgrade for dry etch de-processing in semiconductor failure analysis (FA).

The Plasma Accelerator delivers increased etching speeds, better duplication rates, straightforward operation and low damage, while supporting a full range of dry-etch FA processes including passivation removal and IMD (inter-metallic dielectric) and ILD (inter-layer dielectric) etch, ensuring that a clean, smooth etched surface is produced with no metal de-lamination or erosion, claims OIPT.

The upgrade also enhances process throughput by delivering up to 20 times faster etch rates, increasing overall tool utilization and decreasing process gas usage by 90% while ensuring rapid investigation of the suspected failure. Typical process times are reduced to less than 5 minutes to expose four metal layers — eight times faster than conventional ICP

Plasma Accelerator for die processing



(inductively coupled plasma) mode processes and 20 times faster than RIE (reactive ion etching), claims OIPT.

The Plasma Accelerator upgrade can be used with both new and existing Plasmalab μ Etch300 and Plasmalab μ Etch200 systems, which allow a range of processes from passivation removal to anisotropic oxide removal, from small die or packaged device through to full 300mm wafers. Also, at the end of October, OIPT added to its failure analysis product line with the launch of the entry-level Plasmalab μ EtchEL, which has switchable dual-mode PE/RIE (plasma etch/reactive ion etch) capability.

www.oxford-instruments.com

OIPT appoints head of sales & customer support for Asia

OIPT has appointed Jeffrey Seah as head of sales & customer support in Asia.

Prior to joining OIPT, Seah was the Asia-Pacific business manager at March Plasma Systems. Previously, he has held senior positions in the Asian semiconductor industry, including regional manager with German company Multitest and regional sales & service manager at both US firms KNS and AMI.

"Jeffrey brings a wealth of business experience from the Asia-Pacific semiconductor market, the largest and most important geographical semiconductor region in the world, and naturally a key market for Oxford Instruments,"



Jeffrey Seah.

says sales & customer support director Mark Vosloo. "He will contribute enormously as we continue to develop our products and customer support offerings."

"Oxford Instruments has a strong and highly experienced sales & customer support team in Asia, addressing both production and R&D customers, and I am very pleased to join them," says Seah, adding that new products are being launched and gathering momentum in the market.

OIPT wins £2.5m order for new Southampton facility

Etch and deposition equipment maker Oxford Instruments Plasma Technology (OIPT) Ltd of Yatton, UK has won an order for nine process tools, worth a total of more than £2.5m (\$5m), to equip a new clean-room facility at the University of Southampton, UK. The new £55m, 10,000m² Mountbatten research complex will serve the research of the School of Electronics and Computer Science (ECS) and the Optoelectronics Research Centre (ORC), and contains a large purpose-built interdisciplinary cleanroom and associated laboratories.

Last month the university celebrated completion of the structural framework of the new four-storey concrete-framed building, just over two years after fire destroyed the original Mountbatten Building. Completion of the building is anticipated for summer 2008, when the



Artist's impression of Southampton's Mountbatten research complex. Courtesy of Jestico + Whiles.

tools will be installed (in time for the start of the new academic year).

The systems will provide R&D capabilities for nanoelectronic, MEMS and photonic devices. The order includes both plasma etch and deposition tools, with two Plasmalab-System 100 ICP (inductively coupled plasma) etch tools, two Plasmalab 80Plus open-loading RIE (reactive

ion etching) tools and two PlasmalabSystem100 PECVD (plasma-enhanced chemical vapor deposition) tools, plus the firm's newest products: a FlexAL plasma/thermal atomic layer deposition (ALD) tool, a Nanofab nanowire and nanotube growth tool, and a large-chamber Ionfab ion beam system.

Oxford Instruments had already supplied the ORC with three systems in 2006–2007, as part of a £1.2m order.

"This is a very significant order for us, not only commercially, but also as an endorsement of Oxford Instruments' position at the forefront of providing high-quality, innovative process tools which are enabling the next generation of electronic and nanotechnology devices," says OIPT's managing director Andy Matthews.

www.oxford-instruments.com

Etch tool boosts LED/laser throughput

Ulvac Inc of Chigasaki, Kanagawa, Japan has added to its APIOS NE Series of dry etching systems with the launch of the NE-950 system for the mass production of LEDs and laser diodes. Shipments of the APIOS NE-950 started in December, with the aim of selling 30–40 units in 2008 (at ¥120m each).

Compared to Ulvac's existing systems, improved operation has boosted productivity by up to five-fold, accommodating five 100mm (four-inch) wafers rather than just one, 21 two-inch wafers rather than just eight, or nine three-inch wafers rather than just four. Also, automated wafer transfer equipment from cassettes to trays is available as an option.

The NE-950 can provide hardware and processes to process GaN, InP and GaAs materials, as well as other materials such as sapphire, SiC, noble metals, and oxide films.

Ulvac says it achieves high relia-

bility through using star electrodes (patent no. 3429391) to avoid depositions accumulating on the RF charging windows and through surface treatment of the inner walls of the chamber, temperature control, and deposition measures for vacuum exits.

For application to laser diode processing, Ulvac says that its magnetic-field-assisted magnetron ICP plasma source (Inductive Super Magnetron: patent no. 3188353) is capable of high-precision and anisotropic etching while controlling the plasma density and evenness.

The NE-950 can select either single-wafer or multi-wafer operation and can also control etch depth to a high precision through optical interferometer. Moreover, the star electrodes also prevent the optical interferometer window from becoming dirty, aiding the stability and reproducibility of etching.

www.ulvac.co.jp/eng

LED makers buy hydrogen purifiers

Via its Taiwanese sales & service agent Pionics Technology Corp, Johnson Matthey Gas Purification Technology (GPT) of West Chester, PA, USA has supplied two Model PSH-60 hydrogen purifiers (with flows of 60Nm³/hr) to high-brightness LED epiwafer and chip maker Tekcore Co Ltd of Nantou, Taiwan.

GPT has now supplied Tekcore with five bulk hydrogen purifiers. The new systems, along with others already in place, will supply Tekcore's growing number of high-volume MOCVD reactors.

Also, in late November, GPT supplied a Model PSH-30 (30Nm³/hr) hydrogen purifier to Chi Mei Entech Co Ltd (CMLT) of Taipei, Taiwan, a division of thin-film-transistor liquid-crystal display (TFT-LCD) maker Chi Mei Optoelectronics (CMO) that manufactures LEDs for backlighting LCD screens.

www.pureguard.net

IN BRIEF

Genus founder Elder retires from Aixtron

William 'Bill' Elder OBE has retired from the executive board of deposition equipment maker Aixtron. In 1981 Elder founded Genus of Sunnyvale, CA, USA, which in 2005 was acquired by Aixtron for its silicon-related technology, including atomic layer deposition (ALD), atomic vapor deposition (AVD) and chemical vapor deposition (CVD).

Aixtron's COO Dr Bernd Schulte will extend his responsibilities to include the development of the firm's silicon interests.

"Bill's extensive knowledge and huge semiconductor experience has been a key factor in the completion of the integration process of Genus into Aixtron," says president & CEO Paul Hyland.

www.aixtron.com

QinetiQ orders CCS system for nitrides

UK-based defence and security technology firm QinetiQ has ordered a Close Coupled Showerhead (CCS) 6x2" Flip Top configuration MOCVD system from Aixtron.

The reactor will be installed at QinetiQ's Micro and Nano Technology laboratories in Malvern, alongside its existing epitaxy systems (which include a CCS 3x2" reactor). The new system will be used to develop GaN devices, initially in support of a program to develop low-cost LEDs for solid-state lighting that is sponsored by the UK department of Business Enterprise and Regulatory Reform (BERR).

"This new larger-scale reactor is the best tool for our new development plans for nitride-based devices," says QinetiQ's Dr Trevor Martin, who will supervise the tool. "It will also serve us well for small-scale prototype runs of epiwafers for our international customers."

www.qinetiq.com

Aixtron sells 300mm laser-on-Si reactor

Aixtron AG of Aachen, Germany has sold a Close Coupled Showerhead (CCS) 300mm CRIUS cluster system that includes two silicon- and III/V-based MOCVD modules, for installation in the Central Technology Laboratory of Philipps-University of Marburg's Material Sciences Center in Germany.

This is Aixtron's first sale of a CRIUS CCS system in 300mm configuration, says Aixtron's director of marketing Dr Rainer Beccard. Applications are particularly suited to the growth of III/V compound semiconductors on commercially available silicon wafers.

Dr Wolfgang Stolz, head of the Central Technology Laboratory, says that the new system will be used for a collaborative research project funded by the BMBF (Germany's Federal Ministry for Education and Research) that will bring together several industry and research institutions to explore diode lasers fabricated from the

dilute nitride Ga(NAsP) material system deposited on silicon.

Ga(NAsP) is particularly suited to the realization of next-generation 850nm diode lasers for data communications. Researchers are working towards their practical growth on lower-cost wafers. This has the extra advantage of providing a way to monolithically integrate optoelectronics with silicon-based control microelectronics. Hence, high-bandwidth intra-chip and inter-chip optical interconnects could be made that would open-up new fields of applications.

Beccard comments that, in addition to laser-on-silicon integration, this type of equipment will play a very important role in the future, in particular when looking at applications like III/V on silicon for CMOS. The Ga(NAsP) material system will also become very important for high-efficiency III/V-solar cells on silicon, adds Stolz.

<http://web.uni-marburg.de/wzmw/ctl>

Forepi orders Aixtron G4 systems and Yield+ retrofits

Aixtron has received an order for several AIX 2800G4 high-capacity MOCVD reactors from Forepi Formosa Epitaxy Inc of Lung-Tan, Taoyuan, Taiwan. Forepi also ordered the Yield+ package to retrofit several of their existing systems. The combination will doubly augment Forepi's manufacturing capacities for GaN-based epitaxial wafers, chips and ultra-high-brightness LED chip related products.

The new Yield+ package can improve Forepi's results, believes the firm's president Dr Fen Ren Chien. "It was therefore natural that, when we came to order additional new G4 systems already

including it, we should at the same time bring several of our existing reactors up to the same process performance," he adds.

The Yield+ package features improved robustness and reproducibility for epitaxial growth, and provides better wavelength uniformity tuning due to an actively cooled gas inlet (which minimizes pre-reactions) and a triple gas injector (which offers an enhanced range of tuning parameters). These features guarantee higher throughput, better yield and cost per wafer for higher LED performance, says Aixtron.

www.forepi.com.tw

First MBE production reactor for GaN-based electronic components

Riber of Bezons, France has installed its new MBE49GaN system at an unnamed industrial site, where it is undergoing production qualification.

Riber claims that the MBE49GaN is the first MBE production machine capable of producing GaN-based electronic components, combining high-performance epiwafers with high productivity. It is also the first MBE production machine for handling either multiple 100mm nitride wafers or one 200mm wafer, and complements Riber's range of research reactors (joining the Compact12GaN, Compact21GaN and EpineatGaN).

The GaN processes stem from development work carried out with Riber's industrial partner, as well as research at the joint Riber/CNRS lab in Sophia-Antipolis, France. Using a Compact21GaN system, the lab works on two main processes:

- RF components (e.g. HEMTs).
- Opto devices (e.g. LEDs or lasers).

Riber claims that the research into RF devices enabled state-of-the-art performance to be achieved for HEMT processes, leading to the technical specifications of the MBE49GaN.

Also, the lab's research into opto-electronic devices is part of a program founded by ANR (Agence National de la Recherche). The DEMONI project started at the beginning of 2007, focused on developing a process to produce white monolithic LEDs.

As well as its R&D work, the lab is used for demonstrating GaN processes to Riber's customers.

"With this new advance, we have all the R&D resources, the applications, and the epitaxy machines to assist our customers in progressing more rapidly in their research work, or to penetrate new applications," reckons Riber's chairman Michel Picault.

www.riber.com

Riber's 2007 sales fall 15% to €17m, but orders boost 2008

Molecular beam epitaxy (MBE) equipment maker Riber has received an order for two Compact21 research MBE systems from an unnamed European research institute. One will be used for nitride compounds. The other will be used for zinc oxide.

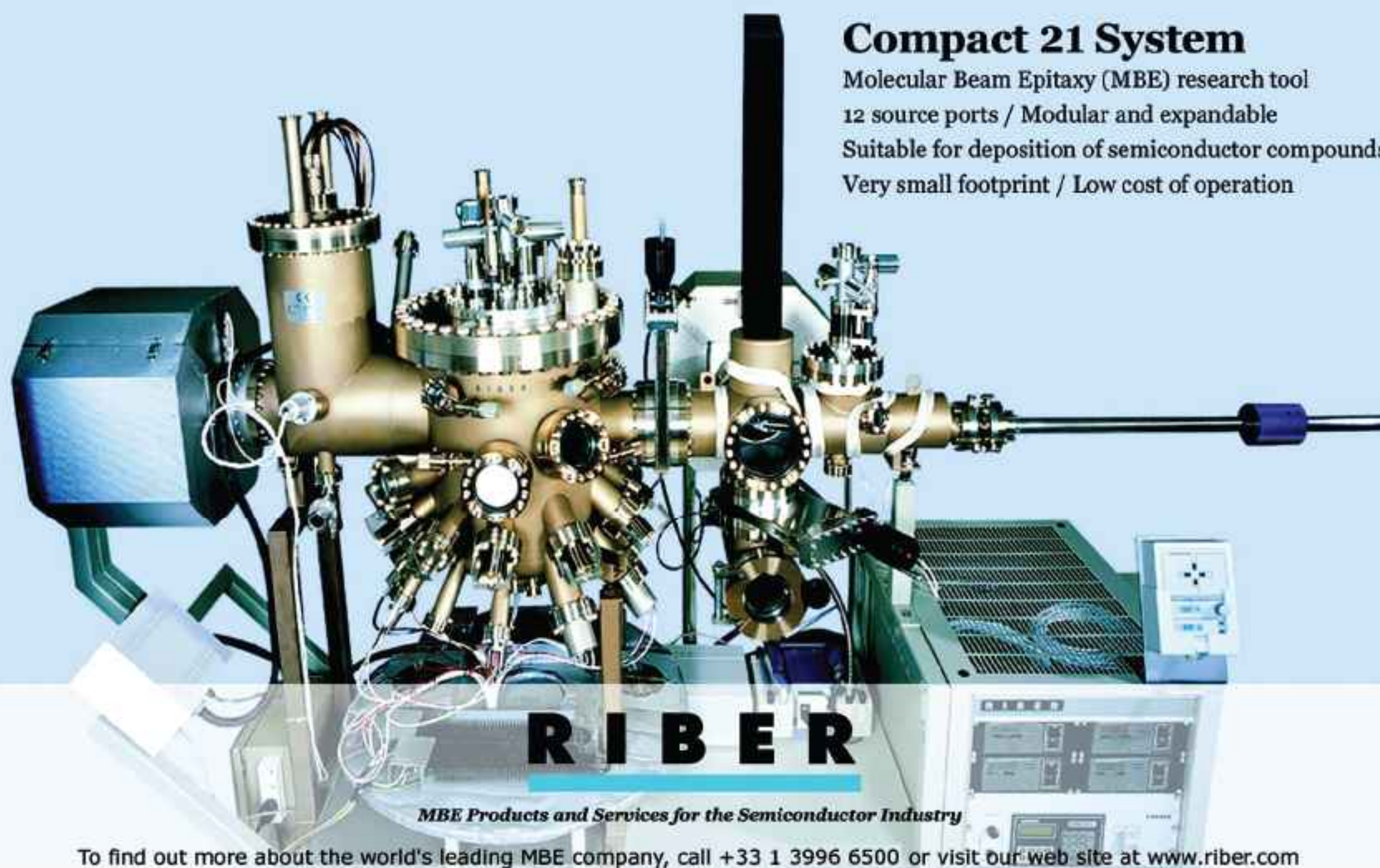
Also, Riber has signed a contract for the sale of an MBE production reactor to an undisclosed recipient in Asia.

Riber now forecasts that full-year 2007 sales should be about €17m (down 15% on 2006's €20.1m, but level with 2005). However, due to ongoing sales negotiations for several contracts, it expects good order flow during first-half 2008, so full-year 2008 revenue should be slightly higher than for 2007 (due mainly to sales of production reactors).

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Kyma agrees CRADA with Naval Surface Warfare Center

Nitride substrate maker Kyma Technologies Inc of Raleigh, NC, USA has signed a Cooperative Research & Development Agreement (CRADA) with the Naval Surface Warfare Center—Crane Division (NSWC Crane) in Indiana (a shore command of the US Navy under the Naval Sea Systems Command in Washington).

The three-year CRADA formalizes and expands upon an ongoing effort between Kyma and NSWC Crane, who have been informally collaborating for over a year on advanced materials characterization analyses of Kyma's native GaN products. The CRADA's principal investigators are NSWC Crane's Chuck Pagel and Kyma's chief technology officer and VP of business development Dr Drew Hanser.

"NSWC Crane's capabilities include a number of advanced materials and device characterization and analysis tools and associated expertise," says Hanser. "Formalization of this important collaboration represents an important step for Kyma towards furthering our understanding of how to bring better materials solutions to our customers."

Kyma's CEO, Dr Keith Evans, adds, "We have already benefited in several ways from this collaboration. A very recent example is the characterization of impurity concentrations within our GaN crystalline boules. This represents important feedback for Kyma's native GaN crystal growth effort."

Kyma was spun out of North Carolina State University in 1998, and

sells ultra-low-defect-density native (free-standing) GaN in customer-defined orientation including polar (c-plane Ga-face or N-face) and non-polar (a-plane and m-plane), and GaN and AlN templates grown on sapphire and other substrates.

It is expected that, by 2010, the nitride device market will surpass \$9bn, and the combined addressable market for GaN and AlN substrates will surpass \$500m.

● Kyma's chief scientist, Dr Tanya Paskova, will present recent characterization results from the collaboration with NSWC Crane in the Opto 2008 Symposium at Photonics West (San Jose, CA, USA, 19–24 January).

www.crane.navy.mil

www.kymatech.com

TDI awarded HVPE patent for low-cost bulk GaN and AlGaIn substrates

Technologies and Devices International Inc (TDI) of Silver Spring, MD, USA has been awarded US Patent 7,279,047 B2, the latest in a series of patents covering production equipment for manufacturing low-defect nitride semiconductor materials, particularly bulk GaN and AlGaIn substrates.

The new patent 'Reactor for extended duration growth of gallium containing single crystals' relates to crystal growth equipment for fabricating GaN and AlGaIn single-crystal materials using a modified hydride vapor phase epitaxial (HVPE) process.

The new production tool facilitates a long-lasting high-growth-rate process for high-quality GaN and AlGaIn single-crystal materials (for fabricating blue and green LEDs and laser diodes, and optoelectronic devices operating in the ultraviolet spectral region, respectively).

"This equipment will enable significant improvements in quality, stability and efficiency of crystal growth technology," says president and CEO Vladimir Dmitriev. "It will be applied to fabrication of a variety of products, including multi-wafer manufacturing of free-standing and bulk GaN substrates... Fabrication of low-cost low-defect GaN substrates is the key for rapid penetration of solid-state lighting," he adds.

The patent adds to TDI's intellectual property portfolio, which includes more than 30 issued and pending US and international patents and covers crystal growth methods, growth equipment, and materials invented at TDI for various types of compound semiconductor as well as epitaxial device structures.

www.tdii.com

FBH buys CV wafer profiler for nitrides

WEP of Furtwangen im Schwarzwald, Germany has sold a CVP21 electrochemical capacitance-voltage (ECV) wafer profiler to the Ferdinand-Braun-Institut für Höchstfrequenztechnik (FBH) in Berlin, Germany, which conducts research on III/V devices.

The CVP21 fully automates the entire measurement process for carrier concentration profiling (including fluid handling, movement of the electrochemical cell, in-situ imaging, and CV scan analysis).

The system monitors the quality of semiconductor layers and includes comprehensive self-calibration algorithms. It also contains a patented process for (Al,In)GaIn samples in full-automation mode.

The CVP21 will be installed in a cleanroom in the vicinity of nitride growth equipment for direct feedback to the epi reactor operators.

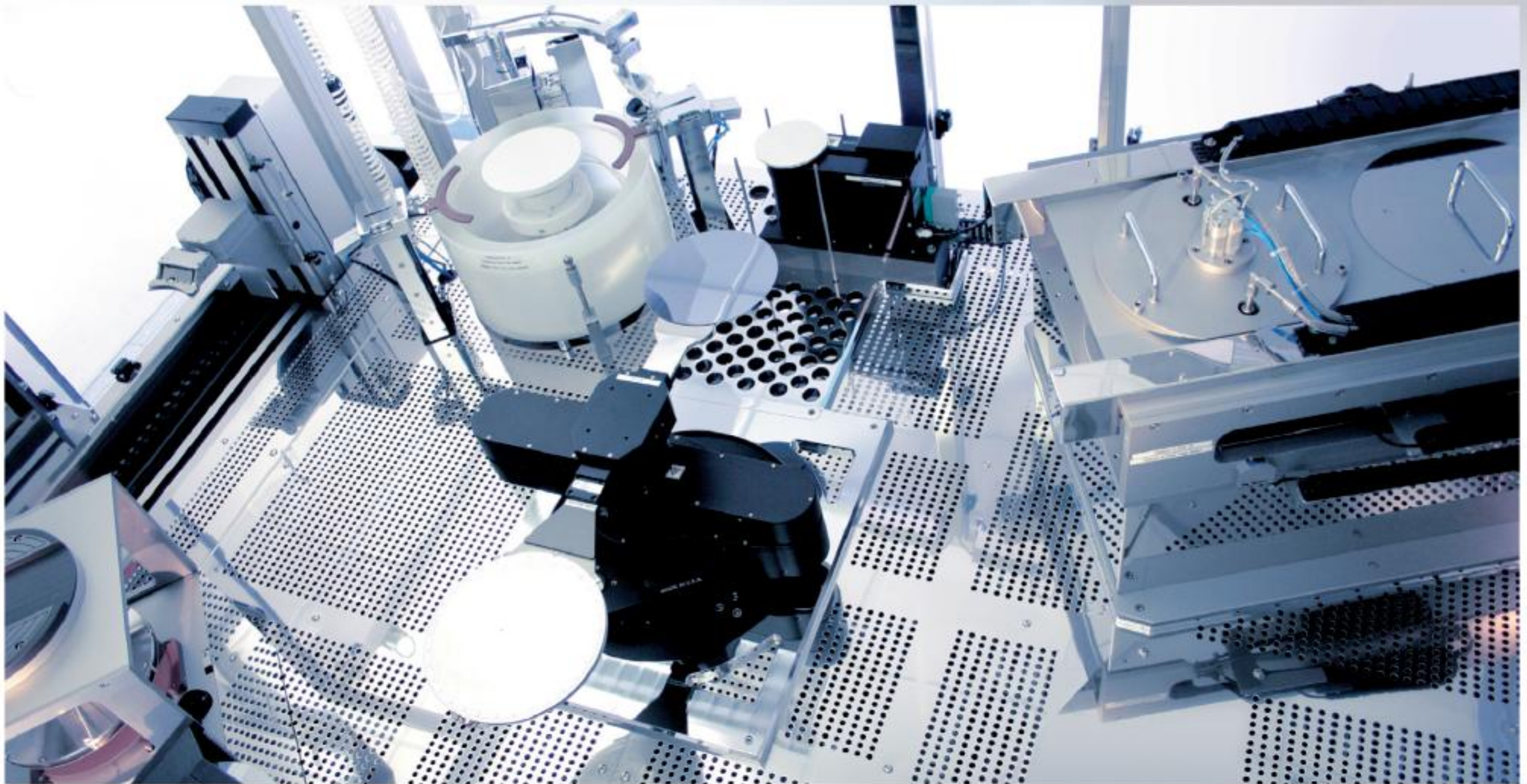
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SDK doubling R/Y chip capacity

Tokyo-based Showa Denko K.K. (SDK) has decided to invest ¥1.2bn to further increase production capacity for AlGaInP ultrabright LED chips at its Chichibu plant, from the current 100m units per month to 200m units per month by the end of 2008. The aim is to meet the growing demand for applications in outdoor displays and automotive parts. The latest expansion is in addition to the earlier expansion from 30m to 100m units per month (completed in October).

The firm supplies AlGaInP ultrabright LED chips in colors including red, orange, yellow, and yellowish green. The main applications are

outdoor displays. However, new applications are being developed, including automotive parts (rear lights, interior lighting) and LCD backlighting for flat-panel TVs and PCs. Demand is therefore expected to grow 30% or more annually.

Under its Passion Project (a consolidated business plan that runs from 2006 through 2008), SDK is expanding its ultrabright LED business as a 'new growth-driver'. In July, the firm announced that it was investing ¥5bn to expand its capacity for GaN-based blue/green LED chips at its Chiba site ahead of schedule, to 200m units per month by June 2008. This extended an

existing expansion (announced only in February) from 30 million to 100m units per month by the end of 2007. While GaN-based blue LEDs are currently used in mobile phones and displays, demand is expected to grow at an annual rate of nearly 20% in the next five years, due mainly to the development of applications such as LCD backlighting, says SDK.

With a collective capacity of 400 million units per month, SDK is aiming to increase sales of ultrabright LED chips (AlGaInP red/yellow LED chips and GaN blue/green LED chips) to ¥15bn in 2008.

www.sdk.co.jp/html/english

Arima is launch customer for AIX 2800G4-R system

Aixtron has received the first order for its new AIX 2800G4-R MOCVD reactor, designed for high-volume production of AlGaInP-based devices, from Arima Optoelectronics Corp (AOC) of Taoyuan, Taiwan.

Founded in September 1998, AOC mass produces UHB-LEDs and lasers in chip and epiwafer form. AOC will qualify the new system for high-volume production of AlGaInP-based red/orange/yellow UHB-LEDs.

Equipped with an automated wafer handler, the 60x2" or 15x4" capacity AIX 2800G4-R is designed to maximize throughput and uptime.

Arima's president, Dr P.J. Wang, said: "Its new features will provide us with large production capacity at a high number of runs per day and the implemented design innovations will optimize the uptime for AlGaInP, a very demanding material system in MOCVD. Arima staff will therefore once again work closely with Aixtron engineers to rapidly qualify the system in high-volume mass production."

www.aixtron.com

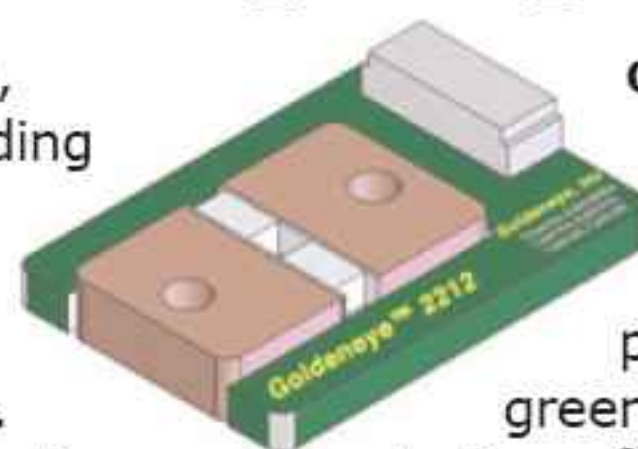
Goldeneye unveils EpiChip LED

Goldeneye Inc of Carlsbad, CA, USA has developed a freestanding 'epi-only' LED that will power the firm's future high-brightness light sources for general lighting and other applications.

Using a patent-pending fabrication process, the firm claims it has simplified manufacturing while enhancing device performance. "The 'EpiChip' is the ultimate simplification in LED design, in that it is simply all epi", says VP of Technology Scott Zimmerman. "It provides the lowest thermal resistance, highest extraction efficiency, lowest cost of manufacturing, and maximum flexibility in packaging," he claims.

The new device marks the introduction of several innovations, including the use of an economical, proprietary thick epitaxial layer. Combined with the elimination of the need for expensive wafer-bonded submounts and other process steps, this enables the production of a versatile high-power LED at a fraction of the cost of existing devices, the firm reckons.

A wide range of die configurations, sizes and colors (including amber and white) are being developed.



Goldeneye's EpiChip LED light source.

Goldeneye has produced blue and green EpiChip LEDs up to 1 mm². In particular, for 200µm x 200µm emitters, typical output power at a driving current of 20mA exceeds 5mW at 520nm. Devices emitting at wavelengths of 350–585nm have been demonstrated. The firm expects to have select products ready for commercial introduction by Q3/2008.

The EpiChip technology platform was developed initially for use in Goldeneye's patented light recycling systems. However, the firm now has patents pending covering other applications, including automotive, architectural, and general lighting.

"We have spent the last several years putting a wide range of technologies together, both from an IP and process standpoint", says CEO Bill Livesay. Over the next 12–18 months, the firm aims to roll out a series of EpiChip-based products for the solid-state lighting and display industries, he adds.

www.goldeneyeled.com

Epistar doubling AlGaInP UHB-LED capacity and expanding GaN by 45%

Taiwanese LED chipmaker Epistar expects to nearly double its monthly capacity for AlGaInP ultra-high-brightness (UHB) LED, from 80m units in 2007 to 150–160m units in 2008, says executive VP Jou Ming-Jun according to the Chinese-language Economic Daily News (EDN), reported via Digitimes. Epistar's overall AlGaInP capacity also includes 1.6bn standard-brightness LED chips, making it the world's biggest AlGaInP LED maker, it is claimed (ahead of Arima).

The firm is also expanding its monthly capacity of nitride LEDs by 45%, from 800m units to 1.1–1.2bn units in 2008, adds Jou. He also pointed out that LED backlighting used in handsets, especially in low-priced handsets in newly emerging markets, will grow by 40%. The penetration rate of LED backlighting used in notebooks

will rise from 3% in 2007 to 10–15% in 2008, while the penetration rate for use in 7–10" panels will rise from 45% in 2007 to 65% in 2008, Jou reckons.

Epistar also sees strong potential for the use of high-power LEDs in street lamps and special lighting products, with growth of 70–80% expected in 2008.

Despite having a positive outlook for LED applications, Jou notes some risks and uncertainties in the LED industry, such as immature LED backlight technology and problems with standards and regulations for LEDs used in street lamps.

● Epistar has received orders for its Aquarius and Phoenix lines of AlGaInP UHB-LEDs from two manufacturers, for use in public displays.

www.digitimes.com/displays/a20080102PD214.html

www.epistar.com.tw

Acriche receives global product safety certification

Seoul Semiconductor says that its Acriche LED, which it claims is the world's first semiconductor lighting source that can be driven directly from an AC outlet without a converter, has received CE Marking and German TUV certification, confirming that it conforms to stringent global standards for product safety. Acriche is the world's first LED package to receive the CE Marking.

In August, the European Union will implement the Energy-using Products (EuP) Directive, which will require specific electrical and electronic devices to attain CE Marking certification before they can be traded in the EU.

Acriche can be used in power systems ranging from 100–120V and 220–230V.

www.seoulsemicon.com

Production solutions for HB LEDs

Systems and processes with industry-leading batch capability

Oxford Instruments' process tools offer industry-leading production solutions for HB LEDs; high throughput and high yield with excellent in-wafer, wafer-to-wafer and run-to-run uniformity.

Substrate preparation

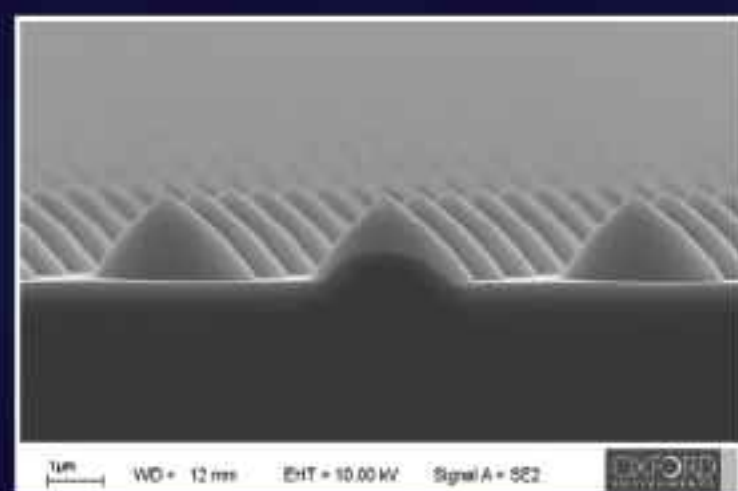
Sapphire, SiC, GaN etching
20 x 2" up to 4 x 4"

GaN, AlGaIn, AlGaInP and related materials etching

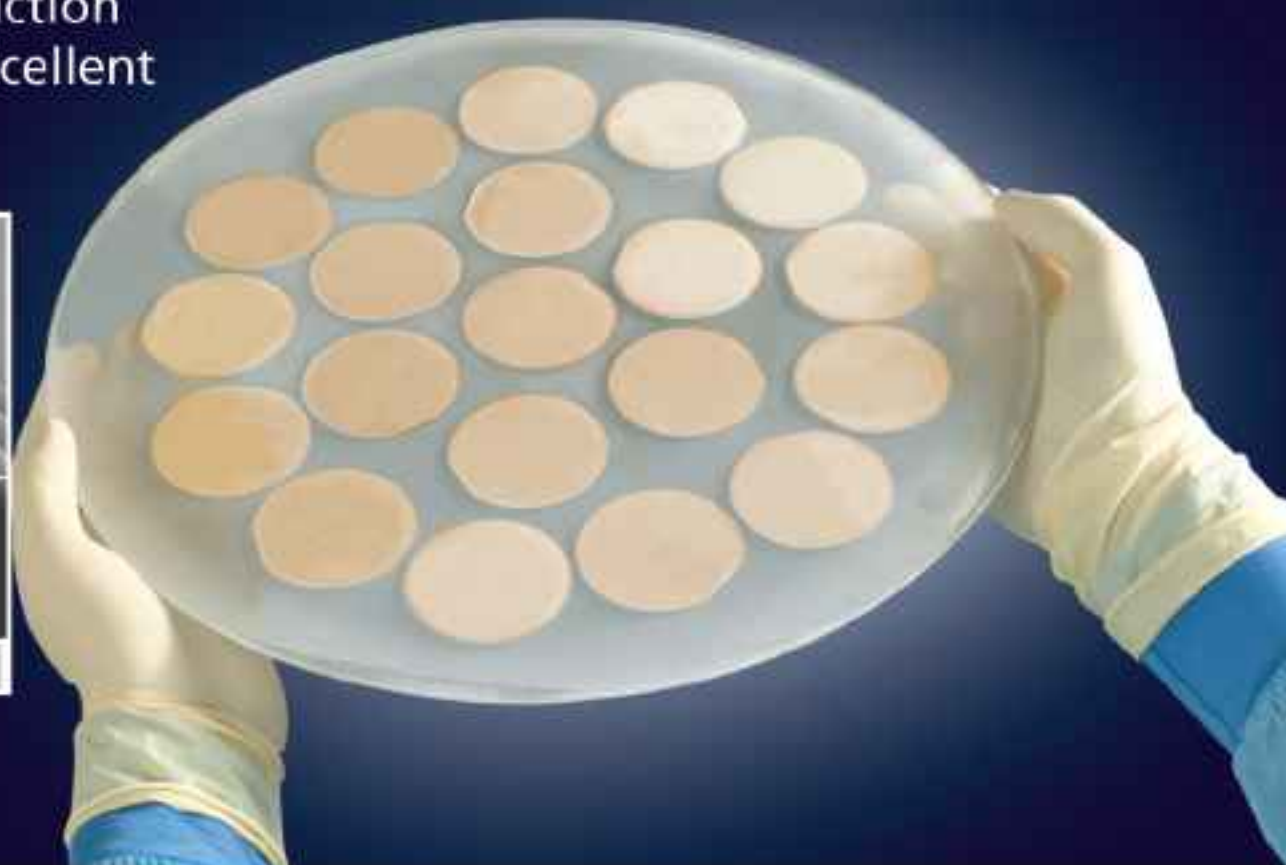
20 x 2" up to 4 x 4" (GaN, AlGaIn)
10 x 2" up to 3 X 4" (AlGaInP)

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www.oxford-instruments.com/HBLED

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Seoul claims thinnest HB-LED chip

Korean LED maker Seoul Semiconductor has filed a patent application for what it claims is the world's thinnest LED chip. The WH108 measures 1.6mm in width, 0.8mm in length and 0.17mm in height, 15% less than the industry's thinnest LED chips currently (0.2mm).

The LED's wafer-type substrate, which has been structurally precision-processed to improve optical efficiency, enables the chip to realize high luminous intensity and thermal characteristic. The WH108 delivers a luminous intensity of 240mcd, more than twice the brightness of existing LED chips at a current of 5mA.

Also, the WH108 is capable of producing the same brightness at a lower power, helping to extend the battery life of portable devices such as cell phones, digital cameras and laptops.

The ultra-thin package and high brightness suit applications in cell-phone keypad modules or touch pads, ultimately leading to thinner cell phones. However, enhanced thermal characteristic mean that the WH108 can also withstand and perform reliably in demanding environments including: small lights (inner lighting of refrigerator, automobile reading lamps); special illumination devices (endoscope illumination); and automobile dashboard lighting.

"The WH108 is a result of our continuous commitment to meet our customers' demand for thinner and brighter LED chips," says Jeong Su Park, head of Seoul's LED chip business division.

Prototype models in white, blue and green are available to cell-phone makers this month. Mass-production on a scale of more than 10 million LEDs per month will begin in first-quarter 2008.

www.seoulsemicon.com

LLF claims efficiency record from high-CRI warm-white LED lamp

LED Lighting Fixtures Inc (LLF) of Morrisville, NC, USA, which develops LED-based light fixtures for general illumination, says that its LRP-38 lamp has set a new standard for energy-efficient lighting by producing 659lm while consuming just 5.8W of wall-plug power (113.6 delivered lumens per watt), compared with 60W for an equally bright incandescent bulb, according to results of steady-state tests by the US National Institute of Standards and Technology (NIST) on LLF's prototype PAR 38 self-ballasted lamp.

The lamp uses less than 9% and 30% of the energy consumed by incandescent and fluorescent sources, respectively. The lamp emitted a warm-white incandescent-like color of 2760K with a high color rendering index (CRI) of 91.2.

"The results of this prototype clearly demonstrate that LLF's LED technology will surpass all existing forms of lighting in terms of performance," says chief technology officer Gerry Negley. "The prototype lamp verifies that the LLF

platform can be deployed in any form factor, which will allow full penetration of the global lighting market," he adds. "We used Cree XLamp and Osram Opto Semiconductors Golden Dragon products in the lamp, which we believe are the best LEDs available to maximize our proprietary system performance."

The LRP-38 demonstration is the most energy-efficient, high-CRI white lighting solution ever developed, claims LLF's Hong Kong managing director, Tony van de Ven.

"While there is currently no timetable for a production release, this result shows that LLF's technology with LED light sources has the ability to surpass 100 lumens per watt from a fixture, which is a revolutionary milestone."

Currently, via 65 lighting sales agents across the USA and Canada (representing over 300 distributors), LLF sells its LR6 six-inch downlight product (designed for 50,000 hours of lifetime) in warm (2700K) and neutral (3500K) white colors.

www.llfinc.com

PVI extends presence to epiwafers

Prime View International Co Ltd (PVI) of Hsinchu Science-based Industrial Park, Taiwan, which manufactures thin-film transistor liquid-crystal displays (TFT-LCDs), has confirmed that it is extending its presence to upstream LED epiwafer production, according to a report in Digitimes.

As a subsidiary of the Yuen Foong Yu Group, in November PVI said in a Taiwan Stock Exchange filing that, through affiliated company Yuen Foong Yupaper Investment, it is investing US\$3m in its China-based subsidiary Darewin Chip Inc in Yangzhou City, Jiangsu Province.

PVI originally positioned Darewin as an LED chip packaging house, but production will now extend to blue LED epiwafers, with volume production starting early this year.

PVI's Stephen Chen confirmed that, in the initial stages, epiwafers will be used to feed in-house demand for small- and medium-size panels, but the firm has not ruled out the possibility of boosting capacity in the future, or to bid for related orders from third parties.

As PVI focuses on the deployment of small- and medium-size panels, which require a brightness specification of just 1200mcd for the corresponding LED-powered backlighting unit (BLU) versus the 1800mcd for notebook BLUs, this implies a relatively low entry barrier to starting manufacturing.

www.pvi.com.tw

www.darewinchip.com

www.digitimes.com/displays/a20071227PD223.html

Ostar LED research team wins German Future Prize

A research team from Osram Opto Semiconductors GmbH of Regensburg and the Fraunhofer Institute for Applied Optics and Precision Engineering in Jena has been awarded the German Future Prize for 2007 for its development of thin-film chip technology and its application in Osram's high-power Ostar family of LEDs. Development was supported by the German Federal Ministry of Education and Research (BMBF).

Osram Opto's Dr Klaus Streubel and Dr Stefan Illek, together with Dr Andreas Bräuer of Fraunhofer-Institut für Angewandte Optik und Feinmechanik (IOF), received the €250,000 prize for technology and innovation in Berlin from German Federal President Horst Köhler.

The German Future Prize (now in its eleventh year) is Germany's most prestigious award for R&D. Osram Opto says that, for 2007, the judges were looking not only for exceptional technical, engineering and scientific achievements but also for practical applications, marketability and job creation.

According to Osram Opto, thin-film technology is the key to producing extremely high-brightness LED chips, as well as enabling them



Future Prize 2007 winners (from right to left): Osram Opto's Streubel and Illek and Fraunhofer IOF's Bräuer. (Photo © Ansgar Pudenz.)

to be packed tightly together to create a large illuminating surface.

In the past, the substrate remained in place after wafer fabrication, where it absorbed much of the light generated by the chip, but with Osram's thin-film technology the original substrate is removed. The process involves coating the top surface of the light-generating layer with metal. The metallized side is then soldered onto a thin carrier material, which acts as a reflector). Then the original substrate is removed, leaving just a thin, light-generating layer that is so close to the surface that the LED emits almost all of its light upward, boosting brightness enormously.

Osram Opto says that Ostar's technical innovation lies in the combination of the new thin-film manufacturing process for high-power chips, a matched package platform that has been designed to take full advantage of the thin-film chips, and tailored optics developed in cooperation with Fraunhofer IOF. "With these technologies we have achieved a particularly high luminance for LEDs in all colors, and also for infrared light", says Streubel.

The resulting high-efficiency LEDs should open up new applications, ranging from mini-projectors and rear-projection TV to night-vision systems in vehicles and general room lighting, the firm reckons. LEDs are already being used in car headlights and tail-lights, giving manufacturers greater freedom to create new designs. A version of Ostar will be launched in 2008 for use in car headlights.

● In July, Osram Opto received the 'Best Innovator 2007' award presented jointly by A.T. Kearney and Wirtschaftswoche.

www.osram-os.com/

german-future-prize-2007

www.deutscher-zukunftspreis.de

Osram LED lighting illuminates Regensburg's World Heritage Site charter presentation

In late November, Golden Dragon LEDs manufactured by Osram Opto Semiconductors of Regensburg, Germany bathed three historical monuments in Regensburg's official municipal color of bright red to celebrate the town receiving its charter as a World Heritage Site. The town is said to be the only one in Germany that retains its medieval structures (with approximately 1000 historic



Golden Dragon LEDs in the windows of the Salzstadel. (Picture: Osram.)

monuments packed into a small area).

Regensburg-based lighting designers LI-EX (LED Light Design Expert) sited red Golden Dragon LEDs in the 85 windows of the Dollingersaal, the Salzstadel and the Runtingersäle.

The red LEDs, which have a wavelength of 625nm, were designed to blend in with the architecture.

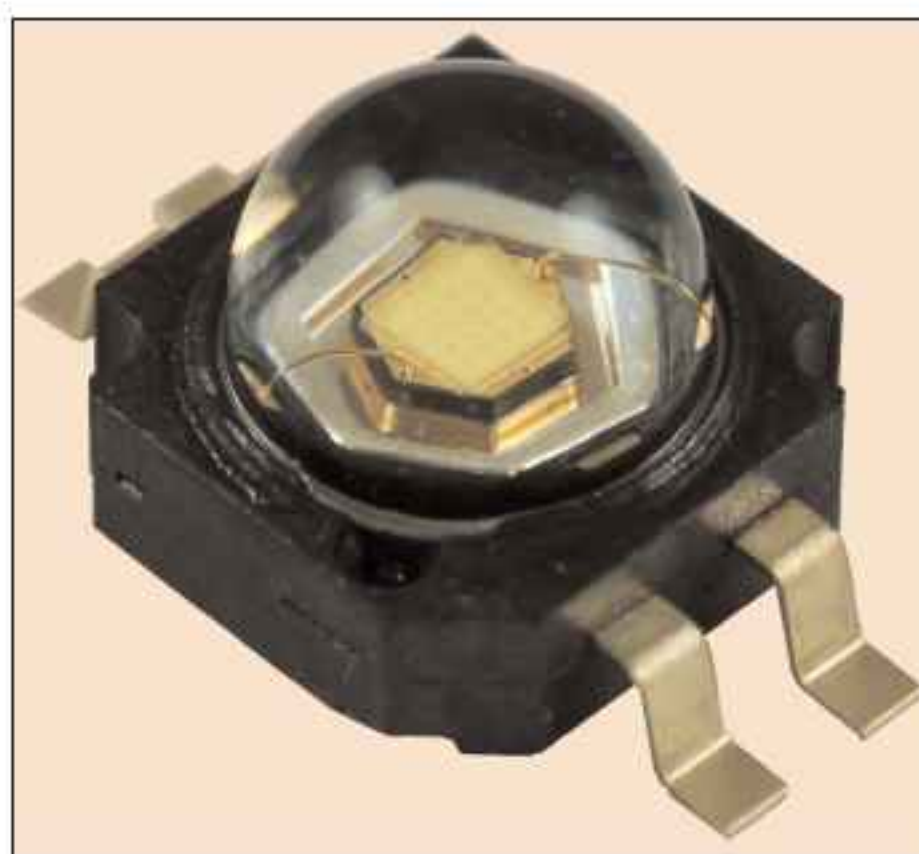
www.li-ex.com

Lumileds launches first 1A LED

Philips Lumileds of San Jose, CA, USA has launched its new cool-white Luxeon K2 with TFFC LED, the only LED designed, binned and tested for standard operation at 1000mA and capable of being driven at 1500mA, the firm claims.

Thin Film Flip Chip (TFFC) technology contributes to improvements in overall light output, optical performance and thermal capability. Meanwhile, new packaging advances improve what is claimed to be already the industry's most rugged and capable package and deliver the lowest thermal resistance, 5.5°C/W, of any power LED. This allows it to be driven at higher currents, as well as lowering thermal management engineering effort and cost. Light output performance from a Luxeon K2 with TFFC part that has been binned and tested for 160lm minimum and a 1A drive current can easily exceed 220lm at higher drive currents, Lumileds says.

At its rated drive current, the LED operates at only 66% of its maximum power rating and delivers what is claimed to be unprecedented performance for a single 1mm² chip. More than two dozen LED drivers available from Future Lighting Solutions are already capable of providing drive currents of 1000mA and more, enabling engineers to take advantage of the LED's high drive capability.



Lumileds' Luxeon K2 with TFFC LED.

Currently, most power LED manufacturers have introduced products at 350mA, but none of these devices can be driven reliably at higher currents without sacrificing lumen maintenance or causing junction temperature to exceed published maximum values, says Lumileds, and none can be operated at 1A for extended periods of time. Even when datasheets indicate typical values at higher drive currents, they are not achievable in actual applications, the firm claims.

In contrast, for applications like security lighting, roadway lighting, automotive lighting 'architainment' or spot lighting, where maximum light and robustness are required while still delivering improved efficiency, the new LED's high drive current allows engineering of the most cost-effective solutions,

considering all costs including the thermal management system, drive electronics, optics and LED count. The ability to increase current without increasing thermal management size or cost to the same degree ultimately results in a lower cost of light, says Lumileds.

"Customers are already making the move to 1000mA drive currents and higher to take advantage of higher light output and improved efficacies," says product manager Erik Milz.

"Incorporating TFFC technology and package improvements gives us the best LED for the most demanding applications and environments such as automotive, signaling, general lighting and architectural applications. Using a single chip allows for the smallest optical source size, making it easier to design optics such as reflectors, diffusers and lenses that are essential for most applications." The new LED is also compatible with much of the complementary infrastructure for electronics, optics and thermal solutions already in place for Luxeon K2 LEDs.

The Luxeon K2 with TFFC is available from Future Lighting Solutions in cool-white form. Lumileds says it is also preparing for volume production of neutral-white and warm-white versions, to be followed by royal blue, blue, cyan and green types.

www.philipslumileds.com

www.futurelightingsolutions.com

Nichia and Seoul sue each other for defamation

In late December, Nichia Corp of Anan, Tokushima, Japan filed a lawsuit against South Korean LED maker Seoul Semiconductor Co Ltd in the Seoul Central District Court seeking compensation of KRW500m (about JPY60m) in damages for defamation, as well as remedies necessary for the restoration of its reputation.

In January 2006, Nichia filed a lawsuit in the US District Court, Northern District of California,

alleging that Seoul Semiconductor's 902 series side-view LEDs (which are mostly used for liquid-crystal display backlight units) infringed its US design patents D491,538, D490,784, D499,385 and D503,388. Nichia says that, on 8 November 2007, a jury rendered a verdict stating that Seoul Semiconductor willfully infringed the four US design rights.

Nichia claims that Seoul Semiconductor is therefore damaging

Nichia's reputation by distributing false statements in connection with the jury verdict, including stating on its home page that 'Seoul Semiconductor has substantially prevailed in the litigation' and that the products at issue are 'actually non-infringing'.

Nichia expects the court to enter a judgment, based on the jury verdict, later this month.

www.nichia.com

www.seoulsemicon.com

Osram to launch 2A Diamond Dragon single-chip LED

This month Osram Opto Semiconductors GmbH of Regensburg, Germany is launching what it claims is the brightest single-chip SMT LED: the white super-bright Diamond Dragon, which is based on a single 2mm x 2mm chip manufactured in ThinGaN technology with chip-level coating.

The new LED has a brightness of 250 lumens at a typical (binning) operating current in continuous operation of 1.4A (2A maximum). It will be available in white correlated color temperatures (CCTs) of 2700–6500K as well as in all monochromatic colors.

The package incorporates a silicone lens that can be handled using standard SMT processes without any change of process. The very low specific thermal resistance (R_{th}) of 2.5K/W allows heat produced in the chip to be removed efficiently. A maximum junction temperature of 175°C makes the LED extremely



robust (with a typical expected lifetime of 50,000 hours) and enables application where it cannot be cooled easily.

The new product will enable use in applications where heat and thermal management issues were once barriers to adoption of such technology, says Ellen Sizemore, director of LED/IR marketing at Osram Opto Semiconductors Inc in Santa Clara, CA, USA. The combination of low thermal resistance and high junc-

tion temperature capability allows the LED to be easily integrated, for example in small spotlights such as MR-16 bulb retrofits and recessed downlight ceiling luminaires, where they can even replace small halogen lamps, the firm claims.

Rated for 5–8W input power, the Diamond Dragon forms a bridge between Osram Opto's established 1–3W Golden and Platinum Dragon LEDs and its 10W Ostar LEDs. The Diamond Dragon footprint is compatible with previous devices, allowing integration into existing designs without modification and therefore upgradability for existing Golden and Platinum Dragon users. The new LEDs will suit both indoor and outdoor general lighting applications as well as for the automotive sector in daytime running lights or rear fog lights, says Osram.

www.osram-os.com

Luxeon Rebel LEDs to appear in lighting designs

Philips Lumileds is highlighting the launch of lighting designs by both Chromatica and IST enabled by its Luxeon Rebel LED's high output per mm² and small package size (3mm x 4.5mm, giving a footprint 75% smaller than other surface-mount power LEDs, it is claimed).

Each design has features that were not possible before, since previous generations of power LEDs had too large a footprint. From high-power outdoor display screens to small residential luminaires, the products extend the range of applications of power LEDs, says Lumileds.

Chromatica is using Rebel LEDs in a new tri-color (RGB) module for applications such as color-changing architectural lighting. The large package sizes of other power LEDs prevent the close mounting needed to achieve effective colour mixing at a usable focal length, Lumileds claims, whereas Luxeon Rebel LEDs allow much closer packing, boosting



Lighting effect created by Chromatica using Luxeon Rebel LEDs.

light density and maximizing light output in the smallest possible area. Previously, close packing of red, green and blue LEDs required the use of low-power LEDs, which give a relatively feeble light output. Now, due to the smaller optical system, optical engineering and colour mixing are simpler and potentially less costly.

Likewise, in Chromatica's road traffic signs, the Rebel's reduced

dimensions enable compliance with strict standards for uniformity and brightness. "Precise board mounting was the key to meeting our specification," says Chromatica director Kevin Clark.

IST's design is for a compact fluorescent light replacement. "CFL replacements fit a 160mm fixture, and must be produced with aggressive pricing while exceeding the requirements of energy regulations," says director Matt Fitzpatrick. Luxeon Rebels can also be densely placed to fit a compact form factor, he adds. "Our SCILS (Scattering Cold Illuminating Light Source) downlighter uses a patented technique to evenly disperse this light and make full use of the LED light output."

Luxeon Rebel LEDs are available in versions delivering minimum flux levels of 70, 80, 90 and 100lm.

www.philipslumileds.com

www.chromatica-led.com

www.istl.com

Arizona State wins \$800,000 DARPA grant for green lasers

Physics professor Fernando Ponce of the Center for Nanophotonics (part of the Arizona Institute for Nano-Electronics at Arizona State University) has been awarded a three-year, \$800,000 grant by the US Defense Advanced Research Projects Agency (DARPA) to conduct research on green lasers.

The grant is part of the 'Visible InGaN Injection Laser' (VIGIL) program, managed by Henryk Temkin (electrical engineering professor at Texas Tech), which aims to develop lasers based on the InGaN/GaN system operating at wavelengths equal to or longer than 500nm.

InGaN/GaN-based injection lasers with emission in the 400nm spectral region have been developed for commercial applications, primarily information storage and retrieval. However, extension of the emission wavelength to the blue and green regions of the visible spectrum has been challenging. Lasers emitting at wavelengths beyond 400nm suffer from rapidly increasing threshold

current densities and lower output powers. A related problem is the rapid decrease in the internal quantum efficiency of InGaN in InN-rich alloys, from about 50% in purple-emitting LEDs to about 20% in green-emitting devices. VIGIL's aim is to achieve InGaN injection lasers of at least 500nm with performance levels similar or superior to those already demonstrated at 400nm.

VIGIL should end with the demonstration of a high-power ($\geq 1W$) injection laser operating continuous-wave (CW) at room temperature with good stability (> 1000 hrs) and wall-plug efficiency (30%).

Wafer yield of 20% on 2" diameter substrates should assure low cost.

High-efficiency visible lasers would enable a variety of military photonic systems, ranging from monitoring water purity, providing effective pumps to mode-locked lasers with ultra-short pulse response, enabling compact and power efficient display engines, to detection systems based on differential absorption LIDAR.

The effectiveness of such systems is a strong function of the laser source's capabilities with regard to emission wavelength, power, efficiency, and cost. Achievement of VIGIL's objectives should result in great improvement in the size, weight, performance and cost of future military systems, DARPA says.

Using the new funding, Ponce's group will develop the fundamental understanding of the physics of growth, materials properties, and device performance of nitride heterostructures for injection lasers operating in the blue-green region.

An important task is to establish a correlation on the nanoscale between atomic structure and the electrical and optical properties of the nanostructures, as well as to determine how this atomic structure is related to the crystal growth process and parameters, and how it affects light emission leading to lasing.

www.fulton.asu.edu/fulton/news/bulletins.php

www.darpa.mil/BAA/BAA07-28.html

US facility to speed LBO's projection system development

After closing a \$26m Series A funding round in October, Light Blue Optics (LBO) of Cambridge, UK has opened a US operation with an Engineering and Business Development facility in Colorado Springs, CO, USA. The facility should accelerate the firm's product development and commercialization program to bring its miniature holographic laser projection systems to high-volume markets.

Product development activities are led by Dr David Bolt in Colorado Springs, who joined LBO recently as VP of Engineering. Having previously worked for Philips Electronics and Plasmon, Bolt has 20 years of experience with global partners and managing large, multi-disciplinary

teams of engineers to deliver electro-optic products to volume production. "We have quickly managed to recruit a highly experienced development team in Colorado that I believe can deliver our product roadmap to high-volume market," he says.

As part of a reorganization for growth, LBO's director of Business Development, Dr Edward Buckley, has been promoted to VP of Business Development. Based in the Colorado Springs facility, Buckley will be responsible for all business development in North America and Asia. "My relocation is in response to our customers' requirements and will strengthen LBO's ability to build strategic relationships and key

development partnerships across North America and Asia," he says.

"Our new engineering and business development operations in Colorado Springs bring great additional strength to the group, enabling us to better support our customers in North America and execute our fast-paced product roadmap," says CEO Dr Chris Harris. "The Colorado-based engineering team complements our UK facility in Cambridge, which remains the centre for innovation, new product concepts and European business development," he adds. "The establishment of LBO's US operations is a critical step in the development of the company."

www.lightblueoptics.com

Nichia achieves 420mW pulsed operation of violet laser diode

Japan's Nichia Corp has developed a violet laser diode operating at an output power of 420mW in pulsed mode, with an estimated lifetime exceeding 10,000 hours and stable operation for 1000 hours at a case temperature of 80°C.

The performance is sufficient for next-generation DVD recorders with a double-layer disc operating at more than 12x record speed, or a quad-layer disc at 2x record speed.

Nichia has been mass producing

lasers with pulsed-mode output powers of 130mW since April and 180mW since June. In May it said it planned to mass produce a 250mW model (for 8x speed recording) this January and a 320mW model (for 10x speed recording) in first-half 2008.

Nichia adds that it is aiming to expand its production capacity as well as improve product quality in order to meet demand for the next-generation DVD market.

www.nichia.com

Nichia to sample first 1W cw pure-blue laser

Nichia says that in March it will start to ship engineering samples of what it claims is the world's first 1W multimode pure-blue GaN-based laser diode operating in continuous-wave mode at room temperature. Emitting at a wavelength of 445nm, the laser will be made available as a blue light source for application in displays.

Nichia says the new laser takes advantage of its experience with 405nm GaN-based lasers for next-generation optical disk systems, but is based on extensive R&D of

longer-wavelength (440–460nm) devices for full-color display

The device's power conversion efficiency (i.e. wall-plug efficiency, or WPE) when operated at 1W is above 20%. The estimated half-lifetime exceeds 30,000 hours.

Nichia says that the highly reliable laser therefore provides key features such as high power, high efficiency and long life, suiting use as a blue light source in displays. The new laser therefore should enable the realization of a full-color laser display, the firm reckons.

Seoul files ITC complaint against Nichia for GaN laser patent infringement

Korea's Seoul Semiconductor Co Ltd has filed a complaint with the US International Trade Commission (ITC) alleging that Nichia engaged in unfair trade practices through the importation and sales of GaN-based laser diode products that infringe its US patent 5,321,713 ('Aluminum gallium nitride laser', filed in June 1992 and granted in June 1994).

Seoul Semiconductor says that it has invested more than \$10m in R&D of laser diode and LED related technologies by US-based universities and companies, and that it has obtained rights to numerous laser diode and LED related patents.

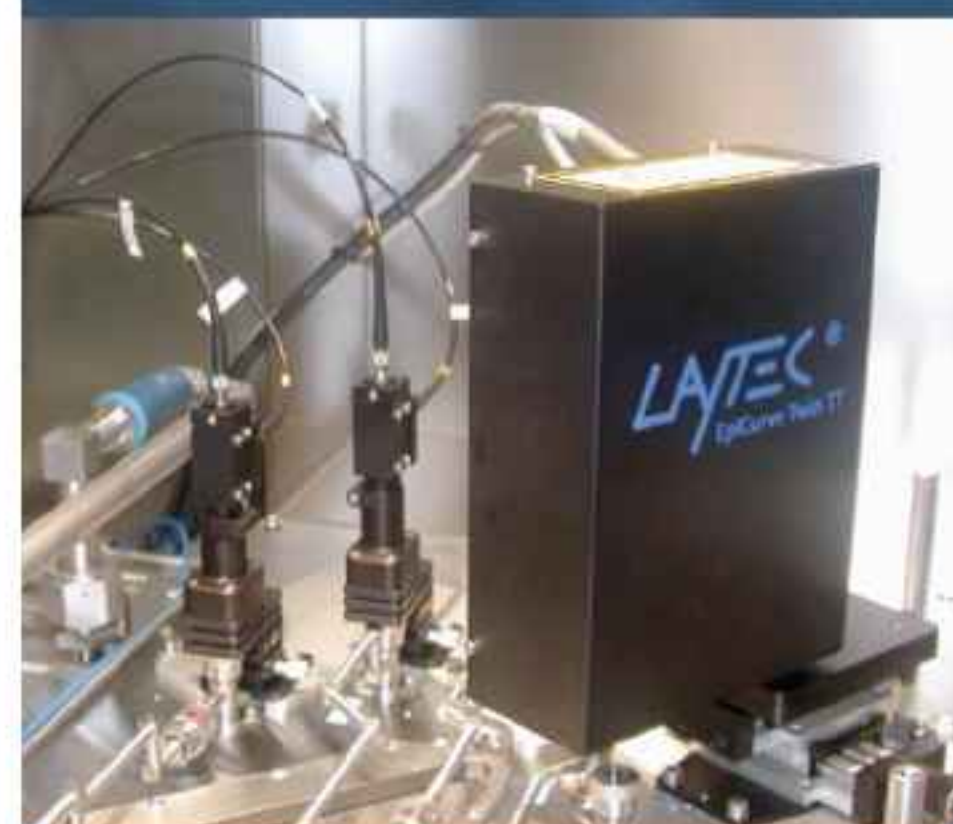
Seoul Semiconductor also has another pending lawsuit, filed in the US District Court for the Eastern District of Texas on 6 November, alleging that Nichia's sale of LEDs infringe its US patent 5,075,742 ('Semiconductor structure for optoelectronic components with inclusions', filed in January 1991 and granted in December 1991) covering technologies related to white, blue, green and UV LEDs and laser diodes.

Seoul Semiconductor anticipates that the ITC's investigation of Nichia will start in January and be tried in fall 2008.

www.seoulsemicon.com

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QPC launches 425W high-power laser

QPC has launched its Ultra-500 family of high-brightness lasers, offering up to 425W of output.

The Ultra-500 expands QPC's high-brightness laser product line to offer more than 400W from a compact module, and addresses power-hungry use in the industrial, defense and surgical markets.

"We have seen strong market demand for the Ultra-500 in both the near-infrared and eye-safe wavelength regime, and have received multiple orders from both US and international customers," says VP of marketing & sales Paul Rudy. BrightLock Ultra-500 lasers began shipping in November to defense customers, and BrightLase Ultra-500 lasers in December to medical customers.

QPC says that the Ultra-500 range offers high power delivered in a narrow core diameter fiber at application-specific wavelengths. For medical use, the BrightLase has a compact, easy-to-use source for eye-safe wavelengths targeting high water absorption peaks for precise surgical applications such as cancerous tumor treatment, benign prostrate hyperplasia, and emerging applications in cardiology. For industrial use, it provides over 400W at near-infrared wavelengths for micro-welding, engraving and marking. For defense use, the BrightLock is a laser pump engine with up to 180W in a compact, lightweight footprint with a narrow stable emission spectrum for solid-state and fiber-laser systems.

BrightLase Ultra-500 lasers deliver up to 425W from 200, 400 and 800µm fibers and are available at wavelengths of 792, 808, 976, 1064, 1320 and 1470nm.

BrightLock Ultra-500 Lasers deliver up to 180W and have on-chip internal grating wavelength stabilization at 976 and 1532nm from a 200 and 400µm fiber.

www.qpclasers.com

QPC wins \$12m development and production order for laser TV

QPC Lasers Inc of Sylmar, CA, USA, which makes high-power lasers for the industrial, defense and medical markets, has won a contract from a consumer electronics manufacturer to develop and deliver its proprietary BrightLase lasers for use in rear-projection TVs based on digital light processing (DLP) and liquid crystal on silicon (LCOS) technologies. The contract also provides for an exclusive supply relationship that could be worth up to \$230m over the 10 year term of the contract (depending on the size of the rear-projection TV market).

QPC expects to receive development milestone payments of up to \$1.15m over the next 90 days. The firm also received an order (which becomes non-cancellable once product specifications have been met) totaling about \$11m for products to be delivered through June 2011. QPC expected to start recognizing initial milestone revenues from the contract in fourth-quarter 2007, elaborated co-founder and chief financial officer George Lintz.

"This contract marks the successful expansion of QPC's technology into the large and growing market for visible wavelength technology," says co-founder and CEO Dr Jeffrey Ungar. "Rear-projection laser televisions will offer a dramatically improved viewing experience compared to other older and/or more expensive technologies available today, such as those based on lamps, plasma, LCDs, and conventional cathode ray tubes." Laser TVs should provide more vibrant, life-like colors with high resolution and wide viewing angles from a lightweight, less expensive, slimmer-profile unit, he adds.

"Major consumer electronics manufacturers such as Sony Corp and Mitsubishi have exhibited laser TV prototypes in the recent past, however we are not aware of any laser TVs that are currently available for

consumer purchase," said Dr Paul Rudy, senior VP of marketing & sales at the end of November. "QPC's laser technology should enable a more rapid ramp to production and availability to consumers."

BrightLase lasers achieve high power in a single beam from an energy-efficient, low-cost chip, claims Ungar. QPC's compact and efficient laser design can replace the expensive, short-lived, and inefficient UHP lamps that are common engines in conventional display technology, the firm claims.

Alternative laser approaches based on conventional multi-stage lasers and lower-power multiple-beam diode lasers are also costly, inefficient, and difficult to manufacture in high volume

"While LEDs have also been used for this application, we believe lasers offer higher brightness and improved energy efficiency," Ungar says. "Alternative laser approaches based on conventional multi-stage lasers and lower-power multiple-beam diode lasers are also costly,

inefficient, and difficult to manufacture in high volume," he adds.

"This contract award not only signals QPC's entry into the multi-billion-dollar high-growth consumer electronics sector for laser TV, but opens up numerous possibilities for utilization in a wide variety of display applications including miniature mobile projectors for mobile phones, PDAs, and laptops, along with displays for automobiles and cockpits," adds Ungar. "Our technology offers high-speed direct modulation, low power consumption, and low cost in high-volume production," he claims.

www.QPCLasers.com

Novalux sells fab and outsources wafer processing for high-volume consumer display applications

Novalux has sold its wafer fab to an undisclosed Silicon Valley company. It is still growing epiwafers for its Novalux extended-cavity surface-emitting laser (NECSEL) devices at its main facility in Sunnyvale, CA, but they are then shipped to two large-capacity contract manufacturers in Taiwan: one that processes the wafer through dicing and another that attaches the die to sub-mounts and performs the final testing.

"We've qualified and frozen our chip design and processes," says chief operating officer William Mackenzie. "This has enabled us to move our NECSEL wafer processing from our prototype quick-turn fab, with its very limited capacity, to much larger contract manufac-

turing facilities in Taiwan," he adds. Novalux then provides the resulting laser array to partner companies who finish and package the visible red/green/blue lasers for delivery to consumer electronics companies.

Founded in 1998, Novalux says that outsourcing wafer processing is a key step in transition from low-volume prototype manufacturing to mass-producing lasers for high-volume consumer electronics use.

NECSEL lasers are set to be used in lighting and display devices ranging from laser high-definition projection TV (HDTV) to embedded projectors in cell phones and PDAs. The firm has also demonstrated the first laser LCD-TV back-light unit and prototype laser architectural tube lighting.

"As per our business roadmap, Novalux is evolving into a fabless, high-volume, low-cost NECSEL laser producer for consumer electronics applications," says Mackenzie. "The contract manufacturers we've chosen for wafer processing are sophisticated operations that can mass-produce higher-quality, more consistent lasers at a lower cost than we could do locally. This is a critical step toward meeting customer demands for NECSEL production parts in early 2008," he adds. "We're preparing to ramp up laser production very quickly and efficiently."

● As we closed for press, Novalux was acquired by Arasor International Ltd. See next issue for details.

www.novalux.com

JDSU launches 10W diode laser

Broadband and optical communications component maker JDSU of Milpitas, CA, USA has launched what it claims is the most powerful fiber-coupled diode laser, its next-generation L4 platform.

The telecom-grade L4 Series uses a new chip design to generate 10W of output power. Also, its package takes up less space compared to previous designs, enabling OEMs to pack more diode lasers into a smaller space within a system.

The lasers are designed for use in a range of industrial, medical and dental applications, including fiber-laser pumping, material processing, and dental soft-tissue surgery.

"With the new L4 platform, JDSU has increased the performance, power and efficiency of our diode lasers, all within a smaller footprint," says Alex Schoenfelder, VP and general manager of Integrated Photonics. "Our customers benefit by getting higher-performance diode laser solutions that aren't more expensive than previous offerings, thanks to our high-volume manufacturing capabilities."



New features of the L4 include:

- Expanded fiber delivery options (highest power in the industry, and a package with potential scalability; 100µm fiber delivery at 0.22 or 0.15 NA, allowing higher brightness in the fiber or focusing in a smaller diameter for specific applications);
- Smaller, more efficient package (taking up less space compared to previous designs and allowing more units to be packed in a smaller area);
- New electrical format (a simplified electrical design removes the need for additional parts, easing integration into OEM systems);
- Improved wavelength flexibility (available at 910–980nm).

www.jdsu.com

BKtel named EMEA distributor of the year

JDSU has named Germany-based fiber-optic component and sub-system distributor BKtel Components as 2007 Distributor of the Year for Europe, Middle East and Africa (EMEA). This is the second consecutive year that BKtel has been recognized for driving sales of JDSU optical communication products in the region.

JDSU's products are widely used in the cable TV and fibre-access segments in EMEA, where high-speed interconnectivity is becoming increasingly widespread.

By offering 'improved support, aggressive pricing and quality products', BKtel secured optical communications business from Andrew Wireless Systems GmbH, the German division of Andrew Corp, which uses JDSU components in 'in-building' and 'distributed' antenna systems (to transfer signals between cell-phone system antennas and base-stations within a fiber-optic system).

www.bktel.com

Finisar files delayed reports and retains Nasdaq listing

Fiber-optic component and subsystem maker Finisar Corp of Sunnyvale, CA, USA has completed and filed with the Securities and Exchange Commission (SEC) its Form 10-K annual report for the fiscal year to end-April 2007, as well as its delayed Form 10-Q quarterly reports for fiscal Q2 and Q3/2007 and Q1/2008 (including restated financial statements due to the investigation of the firm's historical stock option granting practices conducted by the audit committee of its board).

Consequently, on 10 December, the Nasdaq Listing and Hearing Council confirmed that Finisar had demonstrated compliance with Nasdaq's filing requirements under its Marketplace Rules. Accordingly, Finisar's common stock remains listed on the Nasdaq Global Select Market.

In late August 2006, Finisar's management started a preliminary voluntarily internal review of stock options granted since its initial public offering in November 1999. After the initial review, the audit committee undertook a more comprehensive investigation of practices for granting and accounting for stock options up to 8 September 2006.

The audit committee found that measurement dates used by the firm when accounting for certain stock option grants were incorrect due to process-related deficiencies, and that the individuals involved in the option granting process lacked a thorough understanding of the relevant accounting rules. However, it found no evidence of intentional misconduct or malfeasance on the part of personnel involved in selecting and approving the grant dates or administering the stock option granting process.

It was found that a broad-based annual performance grant of options to purchase 2,540,000 shares made in June 2000 by the CEO, acting as

the stock plan committee, had erroneously included grants of options to purchase a total of 235,000 shares to three of Finisar's officers (including its chief financial officer). The measurement dates for these grants have been revised, along with the grants to non-officers with which they were included. None of the three officers exercised the options related to these grants.

The revisions have resulted in an additional non-cash stock-based compensation expense of \$107.6m, to be recognized in fiscal 2000-2006. About 85% (\$91.1m) is due to six key granting actions between November 1999 and August 2003, representing 21 million shares (20% of all options granted during the review period). About 82% of the additional expense was recognized prior to fiscal 2004. Also, the firm identified modifications to certain stock options related to extended leaves of absence that resulted in further expense of \$5.0m.

For stock option grants awarded at less than fair market value and vested after 2004, Finisar's board is to reduce or eliminate the excise tax of up to 40% and comparable state tax provisions to which staff may be liable. This will result in further charges of about \$7m (to be recognized in fiscal Q3/2008).

● After reporting preliminary fiscal Q2/2008 revenues in early November, Finisar confirmed revenue of \$100.7m, down 4.8% on Q1 due to: excess inventory of SAN transceivers at a large customer; 10-40Gbps product revenues of \$18.2m being flat on Q1, with shipments of both the recently qualified 10Gbps X2-SR transceiver and certain 40Gbps transponders being limited by the need to make firmware changes (completed at the end of the quarter), and supplier issues limiting production of 10Gbps 40/80km XFP transceivers.

Finisar has now also reported net loss of \$9.8m, up from \$7.3m in Q1.

The revenue drop was due to a mix of product- and customer-specific issues at a small number of large customers, not lack of demand, said chairman, president and CEO Jerry Rawls. "Customers continue to be optimistic about the prospects for growth for our 10 and 40Gbps product lines." Finisar is hence continuing to invest heavily in high-speed optical communication devices, e.g. 40 and 100 Gigabit Ethernet transponders and the recently announced 10 Gigabit Laserwire active optical link (which replaces bulky and power hungry copper-based connections in data centers).

www.finisar.com

StorIT appointed as Middle East distributor

Finisar has selected StorIT of Dubai, United Arab Emirates as an authorized distributor for the Middle East, including UAE, Saudi Arabia, Qatar and Egypt. StorIT provides solutions and services that enable enterprises to efficiently store, protect and manage business-critical data.

"We look forward to working with StorIT to extend Finisar's leading market share in pluggable optical

modules to this important marketplace," says Federico Zanotti, Finisar's sales director for Europe, the Middle East and Africa (EMEA).

"This opportunity enables us to broaden our extensive spectrum of solutions to better serve our large customer base of value-added resellers and system integrators," says StorIT's managing director Suren Vedantham.

Optium's record revenue driven by 10Gb/s rebound and new growth platforms

For its fiscal Q1/2008 (ended 3 November 2007), optical subsystem manufacturer Optium Corp of Horsham, PA, USA reported record revenue of \$36.1m, up 20.4% on \$30.0m a year ago and up 34.9% on \$26.8m last quarter.

As well as continued momentum in the firm's new 40Gb/s and ROADM (reconfigurable optical add/drop multiplexer) product lines, the results reflect record sales of 10Gb/s products. This demonstrates Optium's ability to respond to a rebound in demand for shipments of higher-end 10Gb/s products during the quarter, says chairman and CEO Eitan Gertel. "The flexibility of Optium's manufacturing model allowed us to achieve these results, even as our focus in the quarter was directed toward capacity expansion goals and the integration of a number of new customers and products we'll be introducing over the course of fiscal 2008," he adds.

In accordance with US generally accepted accounting principles (GAAP), Optium made a net loss of \$1.1m, compared to net income of \$1.2m last quarter and \$2.8m a year ago. However, on a non-GAAP basis, the firm reported net income of \$2.1m, an improvement on a net loss of \$359,000 last quarter (though down on \$3.2m a year ago).

"We executed to our long-term growth plan in the quarter," says Gertel. "For fiscal 2008, our priorities involve strategies that expand our market reach in both the telecommunications and cable TV markets, bring our new technologies to market faster, and build relationships with new customers around the world," he adds.

"During the first quarter, we made solid progress in each of these areas," he said, citing several examples:

- Gertel says the firm has made important advances in the development of its 10Gb/s 300-pin small-form-factor tunable transceiver (initiating shipments in Q2).

- In the firm's analog & cable TV business, despite encountering some demand slowness compared to the prior quarter, Optium expects revenue growth in Q2. Plus, in the first quarter the firm qualified new cable TV transmission technology that should continue to expand the addressable market.

- For the new 40Gb/s product line, demand continued to build at a solid pace as Optium ramped capacity, with revenues in Q1 four times more than the prior quarter. Also, the firm

has been gearing up for production shipments of what it believes will be the industry's first 40Gb/s DPSK transceiver in a 300-pin module.

- During the quarter, the ROADM product line continued to perform to the firm's aggressive growth expectations, as it continued to ramp capacity to meet demand from existing customers, as well as new customers in Asia and Europe.

"The momentum we are experiencing for these growth platforms gives us added confidence that we are well on track for meeting our growth objectives for fiscal 2008," says Gertel. "Our record revenues and improved non-GAAP profitability reflect the benefits of a balanced strategy to position Optium for long-term growth," he concludes.

For its fiscal second-quarter 2008 (ending 2 February), Optium expects revenue to rise again to \$38–39m.

www.optium.com

40Gb/s revenues were four times the prior quarter's

Opnext ships 500,000 10G transceivers

Optical communications module and component manufacturer Opnext Inc of Eatontown, NJ, USA says that it has shipped more than 500,000 10G transceivers. Opnext had previously announced that it had shipped a quarter of a million 10G transceivers earlier in 2007.

"Overall IP or data traffic in North America continues to expand at a pace over 40% year over year. Service providers are investing to prevent a bandwidth crunch from their emerging video services," says Daryl Inniss, vice president of market research firm Ovum RHK. "Equipment vendors in all segments are reporting strong revenue gains, suggesting that the market is continuing to expand," he adds. "Opnext, a leading 10G supplier, continues to post the strongest sequential growth among the top ten OC suppliers."

Opnext offers a broad portfolio of products in the 10G family, including 300-pin, XENPAK, X2, XPAK, XFP and SFP+, encompassing all port types within these form factors. The firm's modules support SONET OC-192, SDH STM-64 and 10GbE protocols, enabling long-reach terrestrial transmission, metropolitan area network, optical add-drop multiplexer (OADM), access, enterprise switching, high-speed data and storage communications.

The firm says that its 10G module transceivers fully comply with industry standards from ITU-T G.691, G.709, and IEEE 802.3, as well as OIF recommendations, supporting electrical interfaces including SFI-4, XAUI and XFI (easing integration onto system host boards).

www.opnext.com

Avanex files complaint against 3S and cuts revenue guidance

Optical communications component and module maker Avanex Corp of Fremont, CA, USA has filed an arbitration complaint in New York alleging breaches by 3S Photonics of its obligations, including prematurely terminating an exclusive distribution agreement.

Telecom laser chip and module maker 3S was founded in 1994 as Alcatel Optronics S.A. (a subsidiary of the Alcatel group) and was

acquired in 2003 by Avanex, becoming Avanex France S.A. Last April, it was bought by Alexandre Krivine and Didier Sauvage and renamed 3S Photonics.

Avanex expects that, as a result of the termination of the distribution agreement, revenue for its fiscal Q2/2008 (to end-December 2007) will be \$51–53m, down on \$54.7m last quarter and \$55.6m a year ago, and below the low end of its

guidance given in early November of \$56–58m. Avanex believes that gross margin will generally be consistent with last quarter.

Avanex does not expect to receive future distribution revenue associated with 3S, which will also reduce its fiscal Q3 revenue (to flat to slightly lower than fiscal Q2).

Avanex plans to release its full fiscal Q2 results by early February.

www.avanex.com

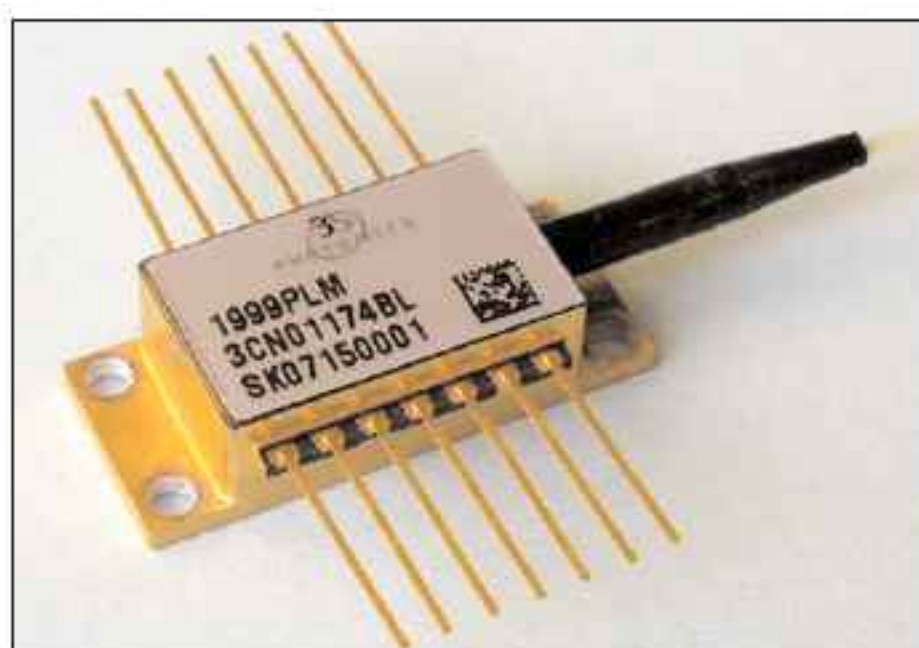
3S expands from submarine to terrestrial pump laser module market

3S Photonics of Marcoussis, Essonne near Paris, France has launched a complete product line of 980nm terrestrial pump laser modules.

3S supplies submarine modules, but is now aiming to break into the terrestrial market as well. In-house chip technology that is fully qualified for submarine use ensures performance levels and reliability in the new range, the firm says. Also, new packaging technology based on a direct coupling approach has been implemented to adjust optimally to terrestrial market demands.

Chairman & CEO Alexandre Krivine says that 3S is targeting all telecom market segments, from low power to high power. The product line hence consists of three complementary models adapted to specific demands: the 1999 PLU (in an uncooled mini-DIL package: low power, outputting up to 275mW); the 1999 PLM (in a low-profile cooled butterfly package: medium and high power, outputting up to 365mW); and the 1999 CHP (in a low-profile cooled butterfly package: ultra-high power, outputting up to 660mW).

Low-power modules are typically intended for the metropolitan market (urban networks with a reach of



3S' 1999 PLM pump laser module.

200–300km), whereas the ultra-high-power module is mainly dedicated to the long-haul market (inter-urban connections).

The new modules are targeted mainly at Asian erbium-doped fiber amplifier (EDFA) manufacturers (for integration into their own products and re-sale of the sub-system to optical network vendors globally). 3S aims to capture 15% of the terrestrial pump laser module market by the end of 2008 (representing about 20,000 units, generating \$7m).

3S has hence also increased its mass-production capacity by contracting new partnerships with Asian manufacturers, and designating an assembly line fully dedicated to terrestrial pump laser modules.

www.3sphotronics.com

Bookham appoints general counsel

Optical component, module and subsystem maker Bookham Inc of San Jose, CA, USA has appointed Kate Rundle as executive VP and general counsel, succeeding Tom Kelley and reporting to president and CEO Alain Couder.

Rundle has nearly 25 years of legal experience in Silicon Valley, with expertise in intellectual property, marketing, technology licensing and corporate law. "Kate's in-depth knowledge of the technology industry and extensive legal experience with global companies in areas important to our business will allow her to play a pivotal role in Bookham's continued growth," says Couder.

Rundle joins from MIPS Technologies Inc of Mountain View, CA, USA, where she was general counsel. Previously, she was an attorney at Wilson, Sonsini, Goodrich & Rosati for 11 years (providing IP licensing and protection and other services to technology firms), then IP counsel at The 3DO Company, before spending more than eight years at Sun Microsystems Inc (most recently as deputy general counsel and managing senior director of the Global Law Network for Shared Services).

www.bookham.com

Infinera's Welch and Nagarajan named IEEE Fellows

Infinera of Sunnyvale, CA, USA says that co-founder Dr Dave Welch, currently its chief marketing and strategy officer, has received two industry honors, recognizing his key role in the development of what the firm claims are the world's first commercial large-scale photonic integrated circuits (PICs).

Welch has been elected to the board of directors of the Optical Society of America (OSA), the non-profit association that promotes the study of optics and photonics. His three-year term begins on 1 January. Welch will contribute to shaping current efforts and building future programs and initiatives for OSA. "His industry experience, history and technical knowledge undoubtedly will be an asset to the board," says OSA executive director Elizabeth Rogan.

Welch has also been named a Fellow of the Institute of Electrical and Electronic Engineers (IEEE) for 2008, citing his "contributions to semiconductor lasers and photonic integrated circuits".

With the commercial launch of its DTN digital optical networking system in 2004, Infinera claims to have pioneered the first large-scale PICs deployed in commercial telecom networks. The firm's PICs integrate more than 60 optical devices on a pair of monolithic indium phosphide chips, enabling it to develop optical systems with a data rate of 100Gb/s per line-card. Infinera optical systems have since won deployments in telecom and Internet service provider networks worldwide.

From 1985 to 2001, Welch was responsible for many of the products and technical developments made at optical component maker SDL Inc, the world's largest manufacturer of pump lasers for optical telecom networks (acquired by JDS Uniphase in 2001 for \$41bn). Welch has more than 80 patents and more than 250 published articles to his credit.

Infinera's director of Advanced Optical Technologies, Dr Radha Nagarajan, has also been made an IEEE Fellow for his key role in the development of Infinera's large-scale

PICs, citing "contributions to high-bandwidth semiconductor laser and photonic integrated circuit technologies". Infinera says that Nagarajan has played a leading role in the development of its PICs.

The recognition comes two years after Nagarajan was named an OSA Fellow for 2006. Also, in October 2006, Nagarajan (along with colleagues Drs Charles Joyner and Richard Schneider) received the Aron Kressel Award from the Laser and Electro-Optical Society (LEOS).

Nagarajan obtained his undergraduate degree in Electrical Engineering at the National University of Singapore, a Masters in Electrical Engineering at the University of Tokyo, and a Ph.D. at the University of California, Santa Barbara in 1992, and then joined SDL in 1995. In 2000, he won a Photonics Circle of Excellence award for the design of an efficient, high-power, single-mode pump module for erbium-doped fiber amplifier (EDFA) applications.

www.infinera.com

Firecomms launches Gigabit transceiver for low-cost POF links

Firecomms Ltd of Cork, Ireland, which develops high-speed plastic optical fiber (POF) transceivers and surface-emitting lasers (VCSELs), has launched the EDL1000G-510, a fully integrated Gigabit transceiver that will enable low-cost, gigabit links over POF. Based on the firm's proprietary VCSEL technology, the low-power transceiver is capable of delivering data over POF at rates of 1.25Gbps, and is pin compatible with 1x9 optical transceivers for glass fiber.

Fitted with OptoLock, a plugless interconnect that allows for quick connection of bare POF, the new transceiver consists of a red VCSEL and a receiver designed specifically for POF applications. Because it emits visible light, the transceiver enhances safety and simplifies setup and test procedures, while its

industry-standard transceiver footprint provides an easy drop-in replacement solution to enable communication over POF with low-cost, consumer-friendly connectors.

"This is the first time a Gigabit transceiver which emits visible light (the preferred wavelength for POF) is available on the market," says CEO Declan O'Mahoney. "Because POF is as easy to work with as speaker wire and is immune to electrical interference, we expect to see a major demand for this transceiver in 1394 FireWire networks and in Gigabit Ethernet networks worldwide."

Firecomms demonstrated the EDL1000G-510 transceiver in an IEEE 1394 home networking application on the HANA booth at the Consumer Electronics Show in Las Vegas, NV, USA (7-10 January).

● Firecomms has signed two US representative agreements for its POF transceivers (being adopted by developers of equipment for consumer electronics, industrial and automotive networks) to be marketed and sold in the New York metro area by Sylvester Sales Associates of Milford, NJ and in the Southeast USA by WaveLink Associates of Orlando, FL.

POF is now used in millions of small-area networks (e.g. in cars) and is rapidly gaining ground in home network and point-to-point interconnection, says Firecomms, but there is a substantial unrealized market in telecoms/datacoms, point-of-sale, security, and medical instrumentation. The POF market is forecast to be worth over \$1bn per year by the end of 2008.

www.firecomms.com

Emcore raises fiscal '08 guidance after PV revenue doubles

For fiscal 2007 (to end September), Emcore Corp of Albuquerque, NM, USA, which makes components and subsystems for the broadband, fiber-optic and solar power markets, reported higher-than-expected revenue of \$170.1m, up 18% on \$143.5m for fiscal 2006:

- Fiber Optics revenue rose 5% to \$110.4m, due mainly to a significant increase in sales of CATV products, FTTN components and revenues associated with April's acquisition of Opticomm Corp of San Diego, CA;

- Photovoltaics revenue rose a huge 54%, from \$38.7m to \$59.7m.

For fiscal Q4, revenue was \$47.0m, up 6% on \$44.5m the prior quarter and 33% on \$35.4m a year ago:

- Fiber Optics revenue was \$31.3m, up 11% on \$28.0m a year ago and up 13% on \$27.6m the prior quarter despite lower revenue from legacy datacom products serving the digital fiber-optics sector;

- Photovoltaics revenue was \$15.8m, down 7% on \$16.9m the prior quar-

ter due to the timing of certain order shipments, but more than doubling (up 116%) on \$7.3m a year ago due mainly to increased demand for solar cells and panels for commercial satellites, government engineering programs, and the emerging business of concentrator solar cells for terrestrial power applications.

Operating expenses for fiscal 2007 were \$86.8m, including \$23.7m for Q4 (up from \$20.5m a year ago). This rise was largely due to investment in the new terrestrial Solar Power Systems division, professional fees from the review of past stock option granting practices, \$0.6m from the new manufacturing facility in Langfang, China and \$0.4m from the acquisition of Opticomm.

Net loss was \$57.3m for the year (versus a \$55m profit the prior year). This included \$16.2m in Q4 (versus a profit of \$75m a year previously).

"Fiscal 2007 was a year of transition at Emcore," says CEO Reuben F. Richards Jr. "We consolidated oper-

ations, transferred product manufacturing to our new facility in China, extended our industry-leading satellite photovoltaics product line to serve the terrestrial solar power market and experienced continued growth in our broadband CATV product line."

During the year, order backlog tripled, from \$48m to \$149m (just \$22m for Fiber Optics, but \$127m for Solar Power: \$57m for satellites and \$70m for terrestrial). The rise is due to the receipt of long-term PV-related sales contracts, of which \$45m is scheduled for shipment after calendar 2008. This has contributed to Emcore raising fiscal 2008 revenue guidance to above its initial guidance of \$210-230m.

"We are well positioned in each of our core product markets and foresee continued improvement in our competitive position across all segments," says Richards. "Our primary objective for the coming year is to achieve positive earnings per share."

www.emcore.com

Intel disposes of its tunable telecom assets

Emcore has agreed the \$85m acquisition of the telecom-related assets of Intel's Optical Platform Division (including intellectual property, assets and technology relating to tunable lasers, tunable transponders, 300-pin transponders and integrable tunable laser assemblies). The transaction is expected to close in first-quarter 2008.

Emcore reckons that the acquisition will enhance its presence in the telecoms market segment and expand its fiber-optics product portfolio, allowing it to provide a more complete product offering. It also presents an opportunity to build upon Intel's leading tunable laser technology, strong product

quality and history of customer service and satisfaction, says CEO Reuben Richards. "The acquired assets should drive substantial product cost reduction, and the combined product portfolio should enable Emcore to gain a greater share of customer spending."

Emcore reckons that the assets will generate \$65m of revenue in 2008, and accelerate its path to earnings per share profitability in mid-2008.

"The optical telecom components business continues to be an attractive market opportunity, but we believe this business and its assets are an optimal fit with Emcore," says Doug Davis, VP of Intel's Digital Enterprise Group and

general manager of its Embedded and Communications Group.

"The two companies will work together following the close of the transaction to complete a smooth transition of the business."

Disposal of these telecom-related assets enables Intel to focus its investments on core communications and embedded market segments in line with its platform strategies, the firm says.

Intel is also said to be exploring strategic alternatives regarding the portion of its Optical Platform Division which manufactures lasers and transceivers for enterprise data centers and storage applications.

www.intel.com

Emcore to supply 80MW of CPV systems to Ontario and Korea

Emcore has received an order from South Korea for 5.7MW of concentrating photovoltaic (CPV) systems, as well as a letter of intent for follow-on projects of 14.3MW (expected to be released in first-half 2008), making 20MW in total.

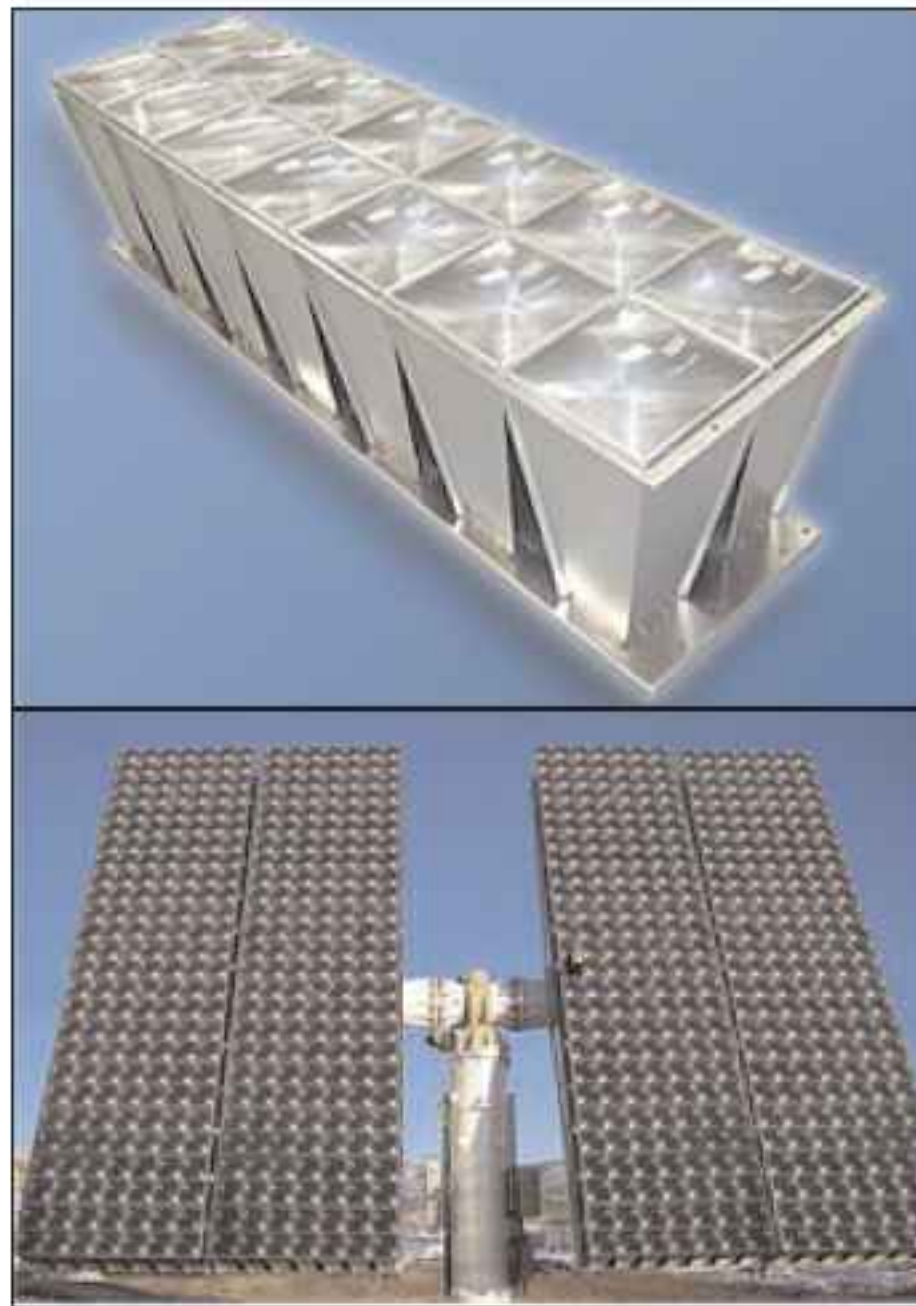
The firm has also signed an agreement to form a joint venture with Seoul-based semiconductor packaging firm DI Semicon to manufacture CPV systems in Korea for Emcore, including systems for the 14.3MW of follow-up projects and involving a minimum purchase commitment from DI Semicon of 15MW of CPV systems annually (for deployment in South Korea).

"This purchase order and the opportunity to establish a joint venture in South Korea is an important step in the development of Emcore's Solar Power business," says Earl Fuller, VP and general manager of Emcore's Solar Power division.

"The Korean market has excellent renewable energy support with one of the highest feed-in tariffs in the world at this time. We are very pleased to work with DI Semicon in this opportunity to establish CPV as a utility-scale terrestrial power technology in Korea," Fuller adds. "This order also marks an important milestone of the acceptance of CPV technology and product solutions as the lowest cost-per-watt of any utility-scale solar power system."

Emcore has also signed a memorandum of understanding to supply and install 60MW of turnkey CPV solar power systems in the Sault Ste Marie area of Ontario, Canada over the next three years. Emcore also has the right to substitute other solar technologies in portions of the projects.

Local firm Pod Generating Group (PGG), a developer of photovoltaics-based power generation



Emcore's CPV module (top) and Generation I CPV array (bottom).

facilities in Northern Ontario, Canada (and a sister company of Los Angeles-based Pod Consulting Group), has secured the licenses and permits for the project through the Ontario Power Authority's Standard Offer Program. System deployment is expected to begin in mid-2008.

In addition, Emcore says that it is in discussions to set up a manufacturing plant in the Sault Ste Marie area to supply local demand as volume ramps up, instead of making the panels at its plant in Albuquerque.

According to a report in the local web-based publication SooNews.ca, the cost of transporting the triple-

junction panels and the cost of having support for the project off-site makes setting up a plant and support team at the location more economically feasible.

Earl Fuller, VP and general manager of Emcore's Solar Power Systems division, is quoted as saying that Emcore will need local manufacturing and support for the solar panel installation for the 60MW project within the next 18-24 months. Initially, the plant will supply panels to the Ontario area but, because of its geographic location, it will later supply panels to the North Eastern and Eastern regions of North America. Fuller added that the Ontario Government's Standard Offer Program offers the most economic support for the expensive start-up costs of solar power component manufacturing and distribution compared to most other areas of the world.

Emcore says that its CPV systems incorporate high-efficiency multi-junction solar cells that operate with 500x concentration. In August, the firm said that it obtained 39% peak conversion efficiency under 1000x concentration on its current volume-production terrestrial CPV products, compared to typically 15-21% for silicon-based solar cells and 35% on average for competing multi-junction cells.

"Emcore's CPV systems are optimized for the lowest cost-per-watt of any utility-scale photovoltaic power system," claims Fuller. "CPV improves the performance of compound semiconductor-based solar cells, avoids the supply constraint that currently exists with silicon-based solar modules, and provides a lower cost-per-watt," adds Fuller.

www.soonews.ca/viewarticle.php?id=15205
www.emcore.com

Bandwidth renamed Spire Semiconductor to focus on CPVs

Bandwidth Semiconductor LLC of Hudson, NH, USA is to be renamed Spire Semiconductor from 1 January to better align it with the overall focus of its parent company Spire Corp of Bedford, MA, USA on providing photovoltaic module manufacturing equipment and turnkey solar factories. Bandwidth currently provides Spire with crystalline silicon solar-cell process technology and has recently re-entered the fast-growing GaAs concentrator solar cell market.

"GaAs solar cell activities are growing at Spire Semiconductor and are supplementing revenue growth from its portfolio of defense, biomedical and consumer products," says Spire's chairman and CEO Roger G. Little. "This operation has held a pioneering position in the field, and in the future we intend to place even more emphasis on the [terrestrial] solar concentrator cell market.

As Spire Semiconductor, this operation will be better integrated with Spire Corp," he adds.

Bandwidth's general manager Edward D. Gagnon adds that the subsidiary should be able to capitalize on the growing market opportunity for custom GaAs-based solar cells and thermophotovoltaic power cells, while continuing to support its growing number of foundry customers with compound semiconductor epitaxial wafers and device processing services.

Bandwidth Semiconductor was formed in 1999 when Spire sold its optoelectronics division to Methode Electronics. Methode Electronics then included Bandwidth in its Stratos Lightwave spin off in 2000. Proceeds from the offering were used in part to relocate the operation, build extensive cleanrooms and add new fabrication equipment. In 2003, Spire reacquired Bandwidth from Stratos Lightwave

when the firm's focus shifted from telecoms.

Spire's original optoelectronics division was an early pioneer in using GaAs for both concentrator solar arrays and space system solar cells. The firm developed and fabricated GaAs solar cells with record levels of efficiency as early as 1985.

During its transitional periods, Bandwidth Semiconductor retained its solar cell intellectual property portfolio. It has recently been awarded research contracts from the US National Aeronautics and Space Administration, the Department of Energy and the Air Force to develop GaAs cells for both terrestrial and outer-space applications. Due to its expanded manufacturing facilities and the growing market interest in terrestrial concentrator systems, Bandwidth is now offering its custom solar-cell solutions to solar system integrators worldwide.

www.spirecorp.com

Spire chooses EPP as Germany rep and sets up regional test center

Spire Corp of Bedford, MA, USA, which supplies photovoltaic module manufacturing equipment and turnkey solar factories, has selected Munich-based Electronic Production Partners GmbH (EPP) as its exclusive representative in Germany, Austria, Switzerland and the Benelux countries, and as a non-exclusive distribution partner in Eastern Europe and beyond. Spire also supplies crystalline silicon solar-cell process technology and recently started to supply gallium arsenide solar concentrator cells to system makers through its subsidiary Bandwidth Semiconductor LLC of Hudson, NH, USA (which became Spire Semiconductor on 1 January).

"Europe is the focal point of photovoltaic (PV) demand and we recognize the need to expand Spire's reach and exposure in this critical marketplace," says chairman and CEO Roger Little. "EPP is an excel-

lent firm with a deep background in semiconductor capital equipment and complex electronic systems," he adds. "EPP is at the hub of the world's largest PV market and well positioned to respond quickly to sales and service requests. With strong technical capabilities and years of experience in capital equipment service, EPP can handle the needs of solar production companies throughout the world," reckons Little.

"EPP brings the local expertise and attention needed to grow market share here and serve the European-based solar manufacturers," says EPP's managing director Bryan Burton.

Spire says it will also establish a regional test and demonstration center highlighting its SPI-Sun Simulator 4600SLP (introduced earlier this year), which is suited to both crystalline silicon and thin-film applications.

"The single long pulse of the 4600SLP allows for full saturation of the newest thin-film modules and results in a high production rate for module testing," says Mark Willingham, who is Spire's vice president of corporate marketing.

"The simulator is the brain of the production line and defines the power at which a module can be sold," he adds. "A fully functional 4600SLP will be on site in Munich and available for testing by our customers. It will be invaluable in testing new module designs as well as inspecting imported modules."

Verifying the power rating of modules from many countries is critical at this stage for PVs, as demand in Europe pulls in modules from across the world and less developed suppliers, Willingham points out.

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Rochester's NanoPower Labs receive \$3.2m in PV funding

Rochester Institute of Technology is expanding its research and technology transfer efforts in renewable energy development and sustainability due to recent funding awards from the US Departments of Energy and Defense.

RIT's NanoPower Research Labs has received two awards (out of 25 given nationally) from the Department of Energy's Future Generation Photovoltaic Devices and Processes Program.

The first award (for \$1.1m) is for a three-year project aimed at providing higher-efficiency solar cells for the growing concentrator photovoltaic (CPV) market. "This work will build on our previous efforts in efficiency and design to create a higher-quality solar cell," says principal investigator and NanoPower Labs member Seth Hubbard.

The second award (for \$2.1m over three years) is for a university-industry collaboration with Wakonda Technologies Inc of Fair-

port, near Rochester, NY, USA designed to enhance the integration of III-V materials onto thin films used in solar cell production. The project was also selected for a matching grant from the New York State Energy Research and Development Authority. The work will build on Wakonda's efforts to produce more energy-efficient and cost-effective solar cells for commercial use. Wakonda is commercializing Virtual Single Crystal (VSC) thin-film technology related to III-V triple-junction terrestrial solar cells fabricated on Ge film on flexible metal foil about 2 mils (0.0508mm) thick, rather than on expensive germanium crystal wafer substrate (the PV cell can therefore be integrated into buildings, infrastructure and personal power applications).

"Our collaboration with RIT will promote the continued development of alternative energy industries in New York," adds Wakonda's CEO Les Fritzemeier.

The research should also ultimately expand RIT's education and research goals through the newly created Golisano Institute for Sustainability. "Our efforts will build upon and enhance the sustainable transportation research being undertaken by the Golisano Institute and assist in the development of sustainable energy systems that provide cost-effective energy with no negative environmental impacts," says NanoPower Labs director Ryne Raffaele, professor of physics and microsystems engineering.

"Research will also provide hands-on training for students in the institute's proposed doctoral program in sustainability, helping to educate our next generation of engineers, designers and policy makers."

Over the past three years, RIT's NanoPower Research Labs have received over \$5m in competitive awards for solar energy and battery research.

www.rit.edu

Wakonda named Clean Energy Entrepreneur of the Year and awarded \$900,000 Department of Energy funding

In Denver, CO, USA at November's 20th Industry Growth Forum of the US Department of Energy's (DOE) National Renewable Energy Laboratory (NREL), Wakonda Technologies Inc of Fairport, near Rochester, NY, USA beat 31 competitors to be named Clean Energy Entrepreneur of the Year. The \$10,000 prize is sponsored by electricity and natural gas provider Xcel Energy of Minneapolis, MN.

Wakonda is commercializing high-efficiency Virtual Single Crystal (VSC) thin-film technology related to III-V triple-junction terrestrial solar cells but fabricated on Ge film on flexible metal foil about 2 mils

(0.0508mm) thick, rather than on expensive germanium crystal wafer substrate. The photovoltaic (PV) cell can also therefore be aesthetically integrated into buildings, infrastructure and personal power applications. The technology promises to bring lower costs because of its higher efficiency, lighter weight and flexibility, says the firm.

"Our investor panel was impressed with Wakonda's novel approach to producing high-efficiency PV products—this could be a step-change for the solar industry," said L. Marty Murphy, Forum chairman and NREL's manager of Enterprise Development.

● Also, in the Funding Opportunity Announcement 'Next Generation Photovoltaic Devices & Processes' (as part of President Bush's Solar America Initiative, which aims to make solar energy cost-competitive with conventional sources by 2015), the DOE said it is investing \$21.7m in 25 projects at 15 universities and six companies, averaging \$900,000 over three years (fiscal 2008–2010). This includes \$892,735 awarded to Wakonda for a \$2.1m project "to apply low-cost conventional thin-film manufacturing techniques to the production of large-area, high-efficiency multi-junction PV".

www.wakondatech.com

5N completes \$34.5m IPO to fund German CdTe plant

High-purity metals and alloy producer 5N Plus Inc of Montreal, Canada completed its initial public offering on the Toronto Stock Exchange in December at a price of \$3.00 per share, yielding proceeds of \$34.5m. Also, in a parallel secondary offering, minority shareholder II-VI Inc of Saxonburg, PA, USA sold its stake in 5N for gross proceeds of \$32m.

5N Plus was founded in June 2000 after developing electronic materials within Canadian natural resource company Noranda Inc (one of the world's largest mining firms). It draws its name from the purity of its products (99.999%, or five nines, and above), which include metals such as tellurium, cadmium, selenium, and zinc. It also produces related II-VI and III-V compounds such as

cadmium telluride (CdTe) and cadmium sulphide (CdS) as precursors for the growth of crystals for electronic applications, including infrared detectors for night vision, for medical imaging detectors, thermoelectric modules, and thin-film photovoltaic cells. The firm is an integrated producer, with both primary and secondary refining capabilities, and also provides recycling services.

In the IPO, 5N Plus issued 10m common shares, for gross proceeds of \$30m, plus 1.5m further shares following the exercise in full of an over-allotment option by the underwriters, for additional proceeds of \$4.5m (totaling \$34.5m from 11.5m shares).

The net proceeds will be used primarily to:

- fund the construction of German subsidiary 5N PV GmbH's 40,000ft² plant in Eisenhüttenstadt (announced in November, for operation in July 2008), which will boost capacity for CdTe production (particularly for First Solar Inc of Phoenix, AZ, USA, which has a second solar module manufacturing plant in Frankfurt an der Oder, Germany);
- fund capital expenditure at its Montreal facility; and
- repay the firm's bank loan and a portion of its long-term debt.

The rest will be used for general corporate purposes and working capital.

On the first day of trading after the IPO and the secondary offering, about 7.7m shares changed hands, raising the share price to over \$5.20.

www.5nplus.com

First Solar adds fourth CdTe PV plant in Malaysia following new long-term module supply agreements

First Solar Inc of Phoenix, AZ, USA, which manufactures thin-film photovoltaic modules based on cadmium telluride, has entered into new long-term module supply agreements with a subsidiary of Babcock & Brown (a global investment fund and asset management firm based in Australia) and Ecostream Switzerland GmbH (a subsidiary of Netherlands-based Econcern BV that focuses on developing solutions for sustainable energy supply).

The new agreements, which are structured on terms similar to First Solar's existing long-term supply agreements, expand contracted module volume by a total of 557MW, allowing for additional sales of about \$1bn (at an assumed exchange rate of \$1.30/€1.00 over the period 2008–2012).

To meet the demand expected from the sales contracts, First Solar's board of directors has approved the construction of a fourth manufacturing plant with four production lines in Kulim Hi Tech Park, Kedah, Malaysia. This will bring the total number of lines at its Malaysian Manufacturing Center to 16. The new plant is scheduled to start production in second-half 2009 and will be built adjacent to the three previously announced plants currently under construction, which will each have annual production capacities of 120MW of solar modules (totaling 480MW together).

The announcement came just over five weeks after First Solar said that it was adding the third plant

The announcement came just over five weeks after First Solar said that it was adding the third plant, which is expected to cost about \$150m and to start production in first-half 2009 (see October issue, page 53). That followed the announcement in July of several new long-term supply agreements with solar energy system makers in Europe. First Solar announced the first of the four-line solar module plants in January and broke ground in April (expecting completion by late 2007 and full volume production by end 2008).

First Solar already operates factories in Perrysburg, near Toledo, OH, as well as Frankfurt an der Oder, Germany (inaugurated in July), with collective annual production capacity of 210MW.

www.firstsolar.com

Are silicon technologies poised to displace GaAs?

Asif Anwar of Strategy Analytics thinks not, and points out that GaAs technologies remain cost competitive in high-volume markets such as cellular handsets and are now also addressing the challenge of integration with new processes.

Low cost and higher levels of integration have allowed silicon technologies to displace gallium arsenide from prime markets in the past, displacing it completely from the digital IC market (remember Vitesse) as well as the cellular handset transceiver (as testified by TriQuint, M/A-COM, etc).

Current and future silicon technology capabilities, combined with cited advantages of a lower cost base and integration capabilities, are steadily improving to encompass millimeter-wave capabilities as well as aiming to displace the dominant position currently enjoyed by GaAs technologies in the cellular handset front-end. Given the historical precedent, are silicon technologies poised to displace GaAs?

Past trends and current status for GaAs

Lower costs and higher levels of integration achievable on silicon technologies have driven GaAs out of mainstream markets in the past. In the mid to late 90s, GaAs ICs for CDMA and TDMA handsets from companies such as M/A-COM, RF Micro Devices and TriQuint addressed the transmit/receive chain by integrating mixers, LNAs and gains blocks on chip. As the radio moved toward addressing multiple bands, GaAs processes were simply not able to match the complex integration offered by silicon processes. The superior integration capabilities of silicon completely displaced GaAs from the segment, effectively confining GaAs devices to the radio front-end, in which these devices are currently still the incumbent technology for both power amplifiers and switches.

Another example was the rapid decline of GaAs for use in digital ICs. In 2000, Vitesse was the largest GaAs device manufacturer in the world. When silicon CMOS performance caught up to GaAs while offering cheaper manufacturing costs and higher levels of integration, Vitesse's move to silicon CMOS effectively killed off the GaAs digital IC market. While it is reasonable to argue that this is an exceptional case (in which the market was effectively encompassed by one firm), this does not preclude similar trends being repeated in the current mainstream markets for GaAs.

Currently, GaAs industry revenues are dictated by wireless markets, with the total market for GaAs devices totalling \$3.1bn in 2006, of which 84% was centred on MMIC devices. The cellular handset has been the main driver for GaAs MMICs, requiring greater numbers of heterojunction bipolar transistor (HBT) power amplifiers (PAs) and pseudomorphic high-electron mobility transistor (pHEMT) switches as the market moves towards multi-mode and multi-band architectures.

Infrastructure markets such as point-to-point radios and VSAT, where high frequency and high power are the desirable attributes, are also key markets for GaAs. Also, phased-array technology continues to drive demand for GaAs from the military sector, especially in the areas of radar and communications.

The challenge from silicon technologies

Integration has always been the unique selling point for silicon technologies and continues to be the primary argument used by companies looking to displace GaAs from the radio front-end of cellular handsets and other markets, including millimeter-wave applications such as automotive radar and point-to-point radio.

Companies such as Axiom Microdevices and Jazz Semiconductor are targeting the cellular handset front-end, with the aim of taking market share from GaAs-based multi-chip module solutions.

Axiom Microdevices claims to be on track to ship 10 million units of its 0.13µm Si CMOS AX502 quad-band GPRS PA in 2007. The AX502 is approved on a number of major semiconductor platforms and is selling to handset manufacturers such as ZTE for low-cost handset solutions. The company is also looking at developing solutions for EDGE and WCDMA platforms and cites the future potential for one-chip solutions (with the PA integrated with the transceiver and the base-band).

Jazz recently announced its 'Silicon Radio' platform, which is again aiming for a single-chip solution in the future that will encompass the transceiver, PA, antenna switch and power controller. In the shorter term, the company is introducing a solution that integrates the

PA, power controller and antenna switch on a single die, effectively looking to replace GaAs-based discrete technology (GaAs HBT PAs and pHEMT switches) solutions from the radio front-end of cellular handsets. The initial solution targets extended GSM (EGSM), but the firm also has EDGE and WCDMA solutions on its product development roadmap.

Both of these companies have targeted the cellular front-end largely on the basis of integration, but cost is also an integral part of the argument.

Axiom cites a typical cost of \$1000 for an 8-inch 0.13µm CMOS foundry wafer, compared to a GaAs 6-inch foundry wafer that

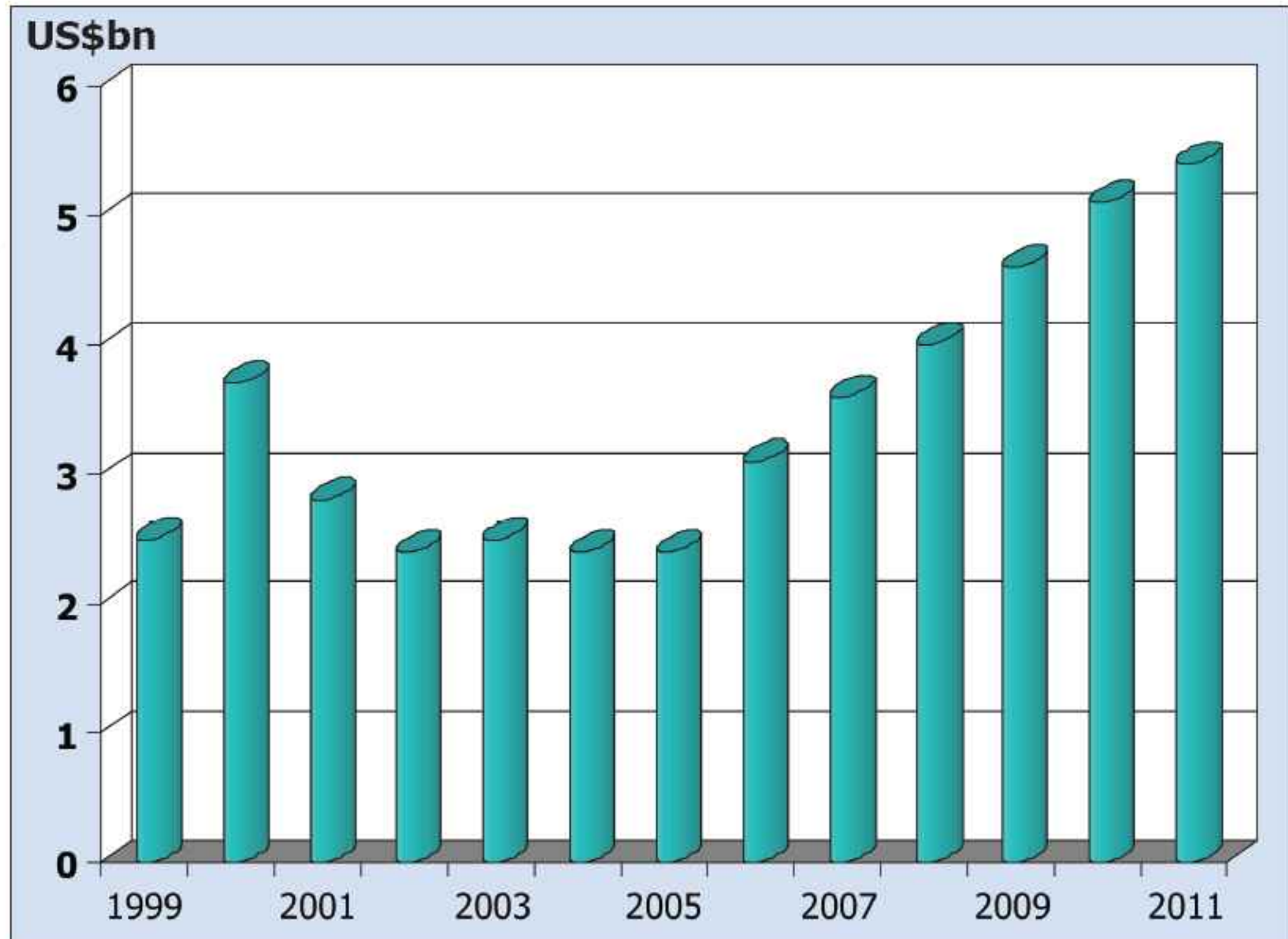
could be as costly as \$2500. Jazz also cites a similar sliding scale for silicon wafers from about \$1000 for CMOS, rising to \$2500 depending upon the layers of metallization and additional processes added to the original CMOS.

Peregrine Semiconductor has targeted the handset switch market with its UltraCMOS silicon-on-sapphire process, based on integration and performance and not necessarily cost. The key to the firm's success was the initial superior performance of its parts in meeting and exceeding the 3GPP IM3 specifications for WCDMA/GSM operation. Coupled with the advantages of integration, Peregrine's switches are rapidly displacing silicon-based p-i-n diodes in antenna-switch modules and have also been used in PA-switch modules, displacing the pHEMT switches normally used in these products.

The GaAs response

As new cellular standards come to the fore, handset makers look for a proven technology that can meet their requirements across the spectrum of leading-edge to ultra-low-cost platforms. In this context, it is clear that GaAs HBT PA and pHEMT switch technologies currently meet handset OEM requirements for performance, time to market, packaging and even cost (though some myths abound in this last area, which are addressed below).

GaAs also remains the key technology for infrastructure markets requiring high frequency and/or high power performance, where the technology has a strong heritage derived from a military background.



GaAs device market, 1999–2011 (in \$bn). Source: Strategy Analytics.

While GaAs technology performance and multi-mode and multi-band architectures have served to increase the overall GaAs content being used over the years, GaAs device makers have also continued to improve the integration capabilities of GaAs technology, increasing the value-add to their customers.

Anadigics' BiFET process combines HBT and FET structures on one substrate and forms the basis for the firm's cellular handset PA modules, which are designed to lower/minimize current consumption while maximizing power added efficiencies, especially in the 16dBm regime where handsets are typically operating for the majority of the time. Using its BiFET technology, Anadigics has also showcased a fully integrated 802.11 a/b/g WLAN front-end IC that integrates the high- and low-band PAs and low-noise amplifiers (LNAs), the RF switches, filters and all other associated circuitry on a single die, with the final product measuring 4.0mm x 4.0mm.

Skyworks' BiFET process also combines a FET on a HBT substrate to offer biasing and power output on a single chip for both cellular handset and Wi-Fi front-ends. The power output stage of its BiFET process outperforms conventional GaAs HBT PAs, while the addition of the FET on the same chip eliminates the need for separate silicon ICs used for biasing control and offers the handset maker a smaller-footprint solution.

Other companies are following suit with their own variations of the BiFET processes. The early implementation by Anadigics and Skyworks has focused on using an HBT wafer with the FET grown on top or alongside using etch stops to separate the different devices. ➤

Other firms such as WIN Semiconductor are starting with a HEMT wafer with an HBT and E/D-mode pHEMT device optimized separately on the same wafer, again using etch stops. Adding a more complex E/D-mode pHEMT device gives the potential to offer both switch and power amplification on the same die, plus associated logic control, which would enable another function typically performed by a separate Si CMOS-based die. Other companies are following suit with their own variations of the BiFET processes. TriQuint's TQBiHEMT process combines TriQuint's high volume InGaP HBT process, TQHBT3 with its InGaAs E/D pHEMT process, TQPED, to enable the creation of single chip products, incorporating the best possible PA, switch and LNA components. RFMD is also working on the development of BiFET processes.

Finally, enhancement mode pHEMT technology has also been demonstrated as a viable tool for achieving greater levels of integration on GaAs. Avago Technologies has demonstrated a fully integrated front-end IC for 802.11 a/b/g that integrates high- and low-band PAs and LNAs, the RF switches, filters and all other associated circuitry on a single die, with the final solution occupying a footprint of just 1.5mm x 2.6mm.

Exposing the true cost of GaAs

One of the key arguments from the silicon camp is that GaAs is an expensive, exotic technology that is tolerated by end-users as it currently offers the best performance.

Si or SiGe-based PA foundry wafers cost between \$1000 for a Si CMOS process and around \$2500 for a SiGe-based product. Furthermore, production is on an 8-inch substrate platform, so the die cost is significantly cheaper, with the potential to yield almost double the product from one wafer. If we compare commercial wafer foundry costs, then clearly GaAs is at a disadvantage, with commercial foundry wafers potentially costing up to \$2500 for an HBT cellular handset PA wafer.

However, it must be remembered that more than 95% of GaAs HBT PA and pHEMT switch manufacturing for cellular handsets is performed by integrated device manufacturers (IDMs) such as RFMD, Skyworks, TriQuint and Anadigics, who have their own manufacturing facilities. We estimate that the cost of an internally manufactured HBT PA wafer is closer to \$800, which significantly reduces the silicon cost advantage, especially compared to a SiGe foundry wafer. Another way to consider this argument is that GaAs technology is successfully competing against silicon CMOS-based solutions for ultra-low-cost handsets (for example, TriQuint recently announced the start of volume production shipments to China's ZTE for Vodafone's ultra-low-cost handsets) as well as being the technology of choice in emerging areas.

Considering infrastructure markets, while we argue

that there is still a potential performance gap in most markets (with the exception of automotive radar), a review of technical papers confirms that silicon technologies are capable of millimeter-wave performance, which suggests that silicon technologies should be able to displace GaAs on the basis of cost from low-volume markets such as wireless infrastructure, cellular backhaul (point-to-point radio), satcoms, military and automotive radar.

However, closer analysis reveals that silicon technologies can actually be significantly more expensive than GaAs when considered for these low-volume markets when the cost of mask-sets is taken into account. We estimate that GaAs mask-set costs typically range from \$25,000 to \$50,000 per mask-set compared to \$50,000 to \$300,000 (and, in extreme cases, more than \$1m) for silicon processes.

Tie this in with longer design cycle times (which can exceed 8 weeks) and silicon solutions become a much more costly option for a fabless design house targeting these aforementioned low-volume markets, as it will take significantly longer to amortize costs. We believe that silicon solutions can only be cost effective for low-volume markets such as millimeter-wave radios or automotive radar with silicon IDMs at the helm, e.g. Infineon, NXP Semiconductor, Freescale, M/A-COM etc, which can run specialized processes on conventional high-volume manufacturing lines (thus offsetting the higher cost associated with supplying low-volume markets). The automotive radar market is one example where this model is being applied by M/A-COM and Infineon and is an area where SiGe-based solutions will potentially displace GaAs in both long- and short-range platforms.

Ultimately, however, GaAs technologies remain the most cost-effective solution for high-power, high-frequency applications.

GaAs market forecast through 2011

Demand from cellular handsets will continue to be the primary growth engine for the GaAs industry. We estimate that 3G platforms accounted for 13% of the global market in 2006, and this will rise to 61% of global market shipments by 2011. WCDMA/EDGE-based handsets will account for 42%, while EDGE/GPRS will still account for over 37% in 2011. Simply put, the bulk of unit growth will be in the high-end of the market, where complex multi-mode, multi-band front-ends will be required.

While there will be a mix of approaches used in the cellular handset front-end, we forecast that GaAs will dominate this function and will be used in a variety of modules, including PA modules, PA-filter modules and PA-switch modules.

GaAs technologies will also dominate the millimeter-wave markets, including military applications, satellite

communications (space and ground) as well as cellular backhaul. Not only does GaAs technology offer the best performance for these applications, but we maintain that GaAs technologies are also the most cost-effective solutions for these markets.

Coupled with demand from other markets such as cable TV (CATV), direct broadcast satellite (DBS), telecoms and datacoms, the overall market for GaAs devices will exceed \$5bn in 2011.

Implications

- For high-volume markets such as cellular handsets, GaAs currently offers the best performance and fastest time to market, which is essential as new standards come to the fore and handset makers look for a proven technology that can meet their requirements. This strength is recognized by handset OEMs such as Nokia who, while continuing to actively assess alternative technologies including SiGe, see GaAs as the mainstream technology for the future.
- Silicon technologies are steadily improving to encompass millimeter-wave capabilities as well as aiming to displace GaAs technologies from the dominant position in the mainstream radio front-end of the cellular handset. Integration capabilities and cost remain the primary arguments for adoption of silicon technologies.
- The integration capabilities of GaAs technology are improving, with single-die front-end modules demonstrated for Wi-Fi applications and BiFET technologies also being used to displace silicon-based biasing circuitry in cellular handset PAs.
- Silicon is cheaper than GaAs in high volume. How-

ever, GaAs offers the most cost-effective solution at millimeter-wave frequencies, where unit shipments are measured in tens of thousands rather than tens of millions. Mask-set costs for silicon processes can be more than 10x those for GaAs.

- Even though Si CMOS PAs are winning design slots in low-cost GPRS/GSM markets, this is not necessarily at the expense of GaAs PAs. Conversely, Si technologies are still working to catch up to GaAs for EDGE and WCDMA capabilities and are typically two generations behind GaAs, especially when considering raw performance.
- If it can be done in silicon, then it WILL be done in silicon, but radio performance requirements from the cellular handset market are still a moving target. The market continues to demand greater linearity, higher frequencies and multi-mode, multi-band capabilities, which are not necessarily going to be achievable in a single-chip solution in the short-term.
- Longer term, the laws of physics dictate that silicon technologies will have to give way to alternative technologies as the limits of electron mobility (among other factors) are reached. One way around these limits in the future may be to integrate compound semiconductors into silicon circuit designs, in order to provide the performance enhancements of compound semiconductors and the manufacturing scale and cost advantages of silicon. ■

This article stems from a presentation given by Strategy Analytics at European Microwave Week 2007. For accompanying presentation slides, see:

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MMICs making gains in terahertz range

As well as its core GaAs content, the CSIC 2007 saw reports of advances in InP-based submillimeter-wave ICs as well as GaN-based power amplifiers.

The 2007 IEEE Compound Semiconductor IC (CSIC) Symposium last October returned to Portland, OR, USA for the first time in 15 years, and naturally drew a large attendance from nearby GaAs RFIC maker TriQuint Semiconductor in Hillsboro. However, as pointed out by symposium chair Mohammad Madihan of NEC Corporation of America, attendance has dwindled from 780 people 20 years ago in 1987 (as the GaAs IC Symposium, when digital GaAs ICs were the focus) to 295 now (with MMICs now predominant), due partly to GaAs IC technology reaching maturity. Nevertheless, technical progress abounded in many areas.

DARPA reports swift progress

In an invited presentation 'Frontiers of Compound Semiconductors', John Zolper, who is director of the Microsystems Technology Office (MTO) of the US Defense Advanced Research Projects Agency (DARPA), emphasized that, while silicon technology dominates in applications where a high level of integration can be exploited, compared to compound semiconductors it cannot provide the power-bandwidth product for military applications. This is particularly the case for applications that stress linearity, dynamic range, noise figure, power efficiency or maximum speed. Zolper highlighted progress covering narrow-bandgap antimony (Sb)-based compound semiconductor (ABCS) devices (following completion of the ABCS program in 2005), wide-bandgap GaN- and SiC-based electronics (WBG-RF) and super-scaled InP heterojunction bipolar transistors (the TFAST and SWIFT programs).

Regarding antimonides, Zolper noted that the first InAs/AlSb HEMT low-noise amplifiers (LNAs) were recently demonstrated (0.25µm HEMTs on a GaAs substrate). The two-stage LNA achieved a noise figure of 2.1dB at 34–36GHz, but while dissipating just 1.5mW per stage or 4.5mW in total DC power. Advances in integration complexity for ABSC materials are being continued in DARPA programs such as the 'Integrated Sensor Is system Critical Technology Demonstration' (ISIS-CTD) program.

The 'Sub-millimeter Wave Imaging Focal-plane Technology' (SWIFT) program has developed InP devices with values of cutoff frequency (f_T) much greater than 500GHz. The three-year end-of-program goals include developing 50mW sources and low-noise amplifiers (LNAs) with noise figures below 8dB at 340GHz by 2009.

While these devices have been developed for operation in the sub-millimeter wave region, the cost and performance impact of the technology for lower-frequency regimes including the millimeter wave (MMW) region, and possibly the microwave region, will be profound, says Zolper. In particular, with Northrop Grumman having demonstrated LNA MMICs operating at 270GHz with 11.5dB of gain and a noise figure of 7.5dB, future T/R (transmit/receive) modules for small mobile platforms may benefit from the migration of low noise figure and high dynamic range to increasing frequencies, he adds.

Zolper reckons that achieving an f_T and an f_{max} of 1 Terahertz is 'straightforward', but devices can be operated at lower frequencies to optimize trade-offs.

Submillimeter-wave ICs with record gain

Much development work has been done on MMICs operating at 140–220GHz (the G-band). However, for applications such as radiometry and atmospheric sensing, the next 'window' in atmospheric attenuation is centered at 340GHz (where 300GHz denotes the lower end of the 'terahertz' regime, with wavelengths less than 1mm). This requires the development of submillimeter-wave IC (S-MMIC) technology.

Using an InP HEMT with a 35nm gate on an InP substrate, Northrop Grumman reported the first single-stage amplifier to realize gain above 300GHz in a submillimeter-wave IC at CSIC in November 2006 and, last May, a three-stage MMIC amplifier with ~12dB of gain at 270GHz and positive gain well above 300GHz (measured in July to have a noise figure of 7.5dB). However, the researchers believed that the noise figure was limited by the successive stage noise contribution and that increasing gain per stage should result in lower cumulative noise figure.

At October's CSIC 2007 symposium, researchers from Northrop Grumman and NASA's Jet Propulsion Laboratory (JPL) in Pasadena, CA, USA reported what was claimed to be the first amplifier with a significant amount of gain at submillimeter-wave frequencies

(i.e. frequencies that are greater than 300GHz): an InP HEMT-based three-stage amplifier with gain across the entire WR-3 waveguide band (210–325GHz), specifically gain of >20dB from 250–290GHz (>6.7dB per stage), plus 16dB gain (>5dB per stage) at 340GHz (the limit of the measurement setup).

As well as record gain in an MMIC and record gain per stage above the G-band, this represents a much improved operating bandwidth (for a gain of more than >10dB) of >100GHz. This demonstrates that existing HEMT-based amplifiers are viable for operation well into the submillimeter-wave (S-MMW) regime.

As well as demonstrating the first submillimeter-wave (S-MMW) low-noise amplifiers (LNAs), the researchers also claimed the first fixtured results, yielding the first measured noise performance (a minimum noise figure of 8.7dB at 330GHz — which the researchers expected to improve further as package and designs are iterated).

The improvements were achieved by using:

- an InP HEMT epi profile with an $\text{In}_{0.75}\text{Ga}_{0.2}\text{As}$ channel;
- an advanced gate process to reduce the gate capacitance (critical for achieving useable gain at these frequencies);
- a modified device layout to minimize inductances and extrinsic capacitances (more useful in MMW power amplifiers than LNAs, since the short wavelength and conductor losses require that combining networks are kept as compact as possible).

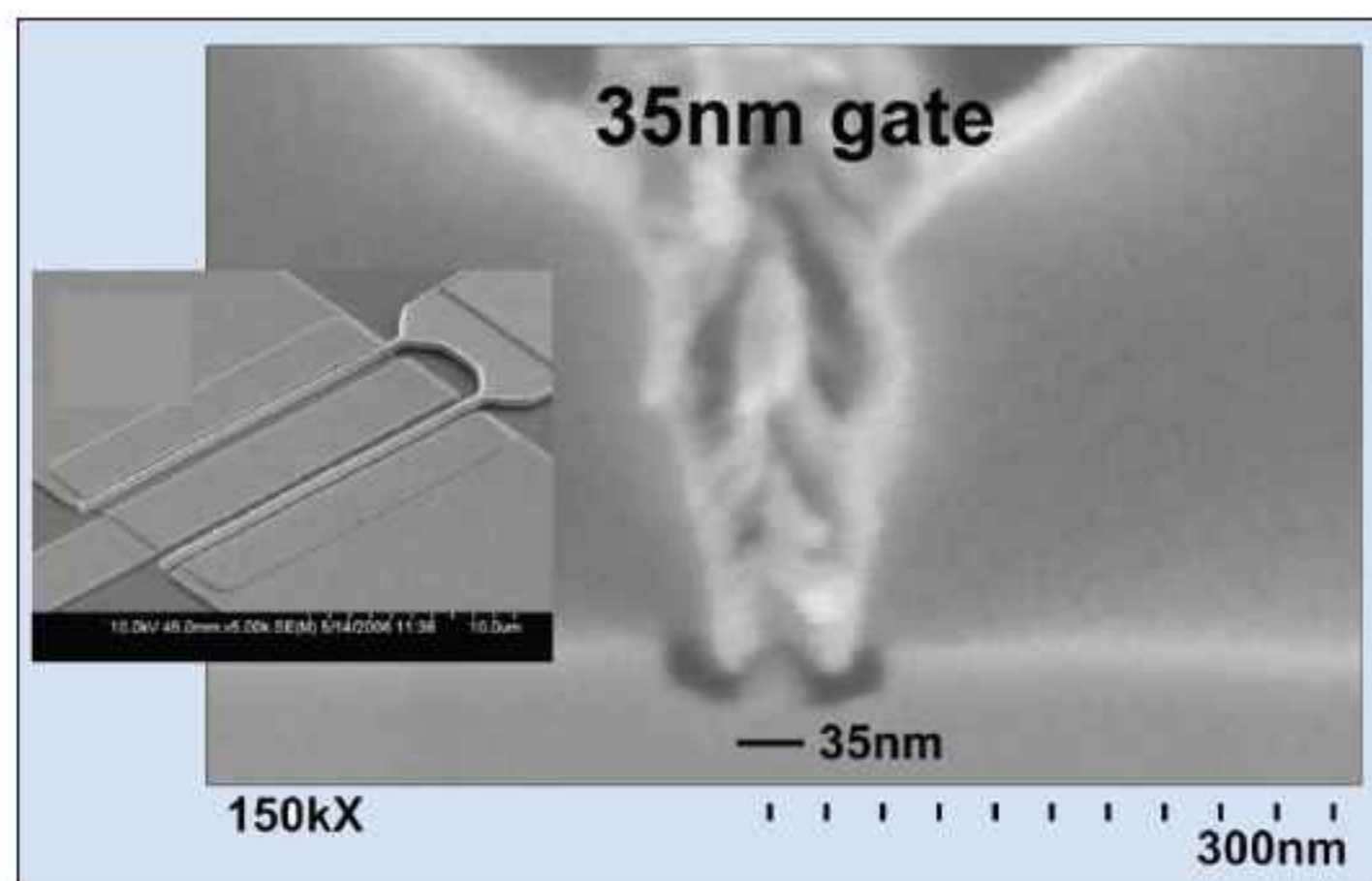


Figure 1. Micrograph showing the 35nm gate length of Northrop Grumman's S-MMW InP HEMT transistor.

The transistor also demonstrates a high f_T of ~400GHz (which is essential for the proposed operating frequencies).

The researchers expect that the upper frequency operating limits of low-noise amplifiers will push further into the submillimeter regime over the next few years, with far-reaching impacts in radiometry and imaging. Indeed, at the subsequent IEEE International Electron Devices Meeting (IEDM 2007) in Washington DC in December, Northrop Grumman presented results extrapolating the maximum oscillation frequency (f_{max}) to over 1THz (see panel below).

IEDM sees first transistor with extrapolated f_{max} of 1THz

At December's 53rd annual IEEE International Electron Devices Meeting (IEDM 2007) in Washington DC, researchers led by Richard Lai of Northrop Grumman detailed what is claimed to be the first transistor with a maximum oscillation frequency (f_{max}) of over 1THz: a sub-50nm InGaAs/InAlAs/InP HEMT with an extrapolated f_{max} based on unilateral gain to 1.2THz and maximum stable gain (MSG)/maximum available gain (MAG) to 1.1THz (with an associated extrapolated peak cutoff frequency, f_T , of 385GHz).

In on-wafer measurements at JPL, a three-stage low-noise amplifier (LNA) MMIC exhibited gain of 21dB (7dB per stage) at 285GHz, 18dB (6dB per stage) at 300GHz, and 15dB (5dB per stage) at 340GHz. These results not only closely match the predicted computer circuit simulation values but are also consistent with the extrapolated MSG at these frequencies based on 1–110GHz device S-parameter measurements.

To achieve the improved performance, modifications of the baseline InP HEMT process included using electron-beam lithography to reduce the transistor's gate length from 70nm to less than 50nm (with a T-shaped gate footprint as short as 35nm). Also, a more highly doped

cap layer, coupled with an MBE-grown InAs/InGaAs composite channel, yields a reduction in the sheet resistance of the epitaxial layers from 110 Ω /sq to 75 Ω /sq and an improvement in mobility from 12,000cm²/Vs to as much as 15,000cm²/Vs.

The researchers reckon that the extrapolated 1THz f_{max} and 15dB gain at 340GHz represent the state-of-art in high-frequency transistor and RF amplifier capability. With next-generation designs, the technology may be sufficient to realize multi-stage MMIC gain amplifiers up to 600–700GHz. Further device enhancements, such as gate length reduction and scaling should enable the first gain amplifiers at 1THz.

Such transistors should provide much higher frequency and bandwidth for a new generation of military, commercial and research applications, such as radar, intelligence, telecoms and radio astronomy applications operating from 200GHz to 1THz.

● Development was supported by the 'Sub-millimeter Wave Imaging Focal-plane Technology' (SWIFT) program of the US Defense Advanced Research Projects Agency (DARPA), as well as the US Army Research Laboratory, and internal company funds.

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CMOS to near 1THz f_{\max} by 2018?

In another invited presentation, Changhua Cao of the Silicon Microwave Integrated Circuits and System Research Group (SiMICS) in the University of Florida's Department of Electrical and Computer Engineering gave an overview of how, using a mainstream foundry, the feasibility of CMOS circuits operating at frequencies of 100GHz up to nearly 200GHz has been demonstrated (a 140GHz fundamental mode VCO in 90nm CMOS, as well as a 192GHz push-push VCO and a 180GHz detector circuit in 130nm CMOS logic).

Using such 45nm CMOS technology (available shortly in manufacturing), it should be possible to realize practical circuits operating at 200–300GHz, Cao reckons. Long term, according to the International Roadmap for Semiconductor, by 2018 the f_T and f_{\max} of NMOS transistors required in production are 0.7 and ~1THz, and with such transistors it should be possible to implement circuits operating at near to 1THz.

GaN HEMT with high breakdown and high f_{\max}

In 'High f_{\max} GaN-HEMT with High Breakdown Voltage for Millimeter-wave Applications' Toshihide Kikkawa et al of Fujitsu Laboratories Ltd reported the demonstration of GaN HEMT technology for millimeter-wave (W-band) amplifiers with a high f_{\max} of 180GHz as well as a high breakdown voltage (BV_{gd}) of 190V (see Figure 2), with the aim of improving gain, efficiency, and reliability in wideband amplifiers.

First-generation GaN HEMTs have already been transferred to Eudyna, and second-generation GaN power amplifiers for mobile WiMAX are now in commercialization, but third- and fourth-generation GaN is intended for millimeter-wave operation.

Previous reports have focused mainly on achieving a high current cut-off frequency (f_T) to verify GaN's high saturation velocity. To obtain a high-gain millimeter-wave power amplifier with high reliability, both f_{\max} and a high BV_{gd} are important. However, for Schottky gate GaN HEMTs, a high BV_{gd} is important for improving

efficiency, but there have been no reports on high- f_{\max} Schottky gate devices with a BV_{gd} of over 150V.

The realization of a highly reliable W-band power amplifier (with target of obtaining 1W when operating at 70–90 GHz), requires both:

- a BV_{gd} of over 100V (for 20V operation); and
- an f_{\max} of over 180GHz (for a gain of over 6dB).

Kikkawa says that obtaining a high BV_{gd} is easy, but obtaining low gate leakage is difficult.

The researchers demonstrated an f_{\max} of 180GHz (and an f_T of 85GHz) with a BV_{gd} of over 190V by using:

- a novel Y-shaped Schottky gate electrode (instead of the conventional T-shaped gate) fabricated using additional simple heat treatment (increasing the mechanical strength between the fine gate and the over-gate when the gate length is 0.15 μ m or less, and decreasing the gate resistance in the area between the fine gate and the over-gate by 30%); and
- an n-type doped GaN/SiN cap structure (rather than an AlGaN cap layer), suppressing the built-in electric field below the breakdown field strength through piezo charge between the n-GaN cap layer and AlGaN (improving device reliability without current collapse and increasing the Schottky barrier height).

To obtain a higher transconductance g_m (to improve gain and f_{\max}) and a higher output resistance R_{ds} (to decrease the drain conductance) with a high BV_{gd} , the thickness and Al content of the n-type $Al_xGa_{1-x}N$ electron-supplying layer was optimized to 11.5nm and $x=0.3$ ($Al_{0.3}Ga_{0.7}N$) for a 0.1 μ m gate electrode.

Also, a moderate sheet resistance is important for determining the epi structure with the highest breakdown voltage. In addition, the gain and BV can be optimized by changing gate-drain length (L_{gd}).

Kikkawa claims that their GaN HEMTs are the first to achieve high f_{\max} and high BV_{gd} simultaneously.

Highest-power solid-state power amplifier over 20GHz

What was claimed to be the highest output power for any solid-state power amplifier (based on GaN, GaAs or any other material) at over 20GHz was presented by Y Murase et al of Japan's R&D Association for Future Electron Devices (now of Nano Electronics Research Laboratories, NEC Corp): an AlGaN/GaN FET power amplifier module delivering continuous wave (CW) output power of 20.7W at 26GHz, as well as linear gain of 5.4dB and power-aided efficiency of 21.3%.

To achieve high breakdown characteristics with reduced current collapse and high gain, the researchers say that they developed a 0.2 μ m-long recessed-gate AlGaN/GaN FET with a field-modulating plate (FP). This resulted in a high operation voltage of 25V, even at quasi-millimeter wave frequencies.

In addition, the researchers claim that this is the first time that a single-ended AlGaN/GaN FP-FET amplifier module for quasi-millimeter-wave frequencies (20–30GHz) has been fabricated. ■

• CSIC 2008 will take place in the Portola Plaza Hotel, Monterey, CA, USA on 12–15 October.

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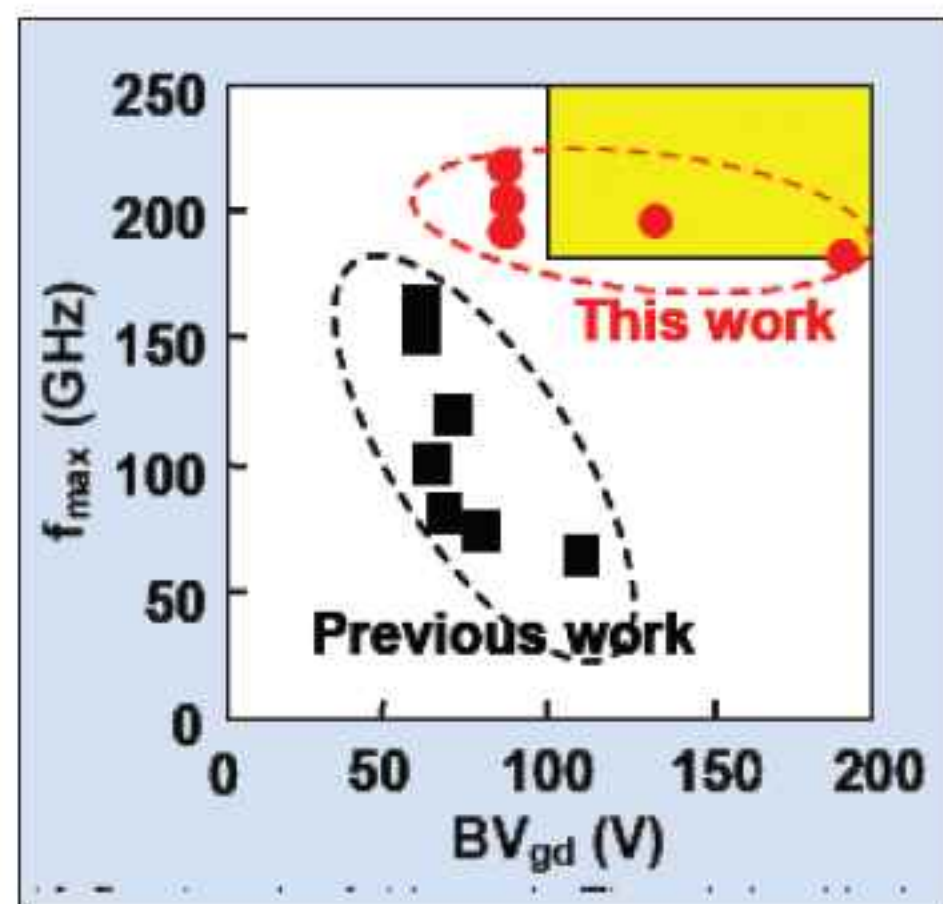


Figure 2. f_{\max} vs BV_{gd} for W-band GaN HEMT power amplifiers.

Graphene opens up to new possibilities on SiC

Structures made up of a few or even single layers of carbon in hexagonal sheets (graphene) have exciting possibilities for electronics. Until recently, these structures have been measured to have zero bandgap putting them on the border line between metal and semiconductor. Now, a positive gap has been found for graphene layers on silicon carbide, pushing the material into the semiconductor domain.

Dr Mike Cooke reports.

When physicists started producing flakes of single- and few-layer graphene from graphite in 2004 [1], it was contrary to theoretical expectations that said two-dimensional structures would not be thermodynamically stable. At the same time, the electronic structure of single-layer graphene was found to have the form of the relativistic Dirac equation (with zero effective mass) where the 'speed of light' is 10^6m/s rather than $3 \times 10^8\text{m/s}$. The 'spin' of the graphene 'Dirac' equation is in addition to the usual angular-momentum spin and is related to there being two carbon atoms per unit cell in the hexagonal 'chicken-wire' lattice (see Figure 1).

This behavior gives single-layer graphene a zero energy gap, putting it on the border between a metal and an insulator. Multiple layers of graphene have overlapping conduction and valence bands, giving these materials semi-metal electronic behavior.

While this behavior could create experimental analogues of difficult-to-access high-energy physics theoretical structures such as two-dimensional quantum electrodynamics and, it has been suggested, string theory, as well as opportunities for interconnects and normally-on transistors (using electric-field-induced band gaps), for practical use of graphene in transistors one really needs normally-off transistors, as provided by semiconductor (positive band-gap) materials to produce integrated circuits.

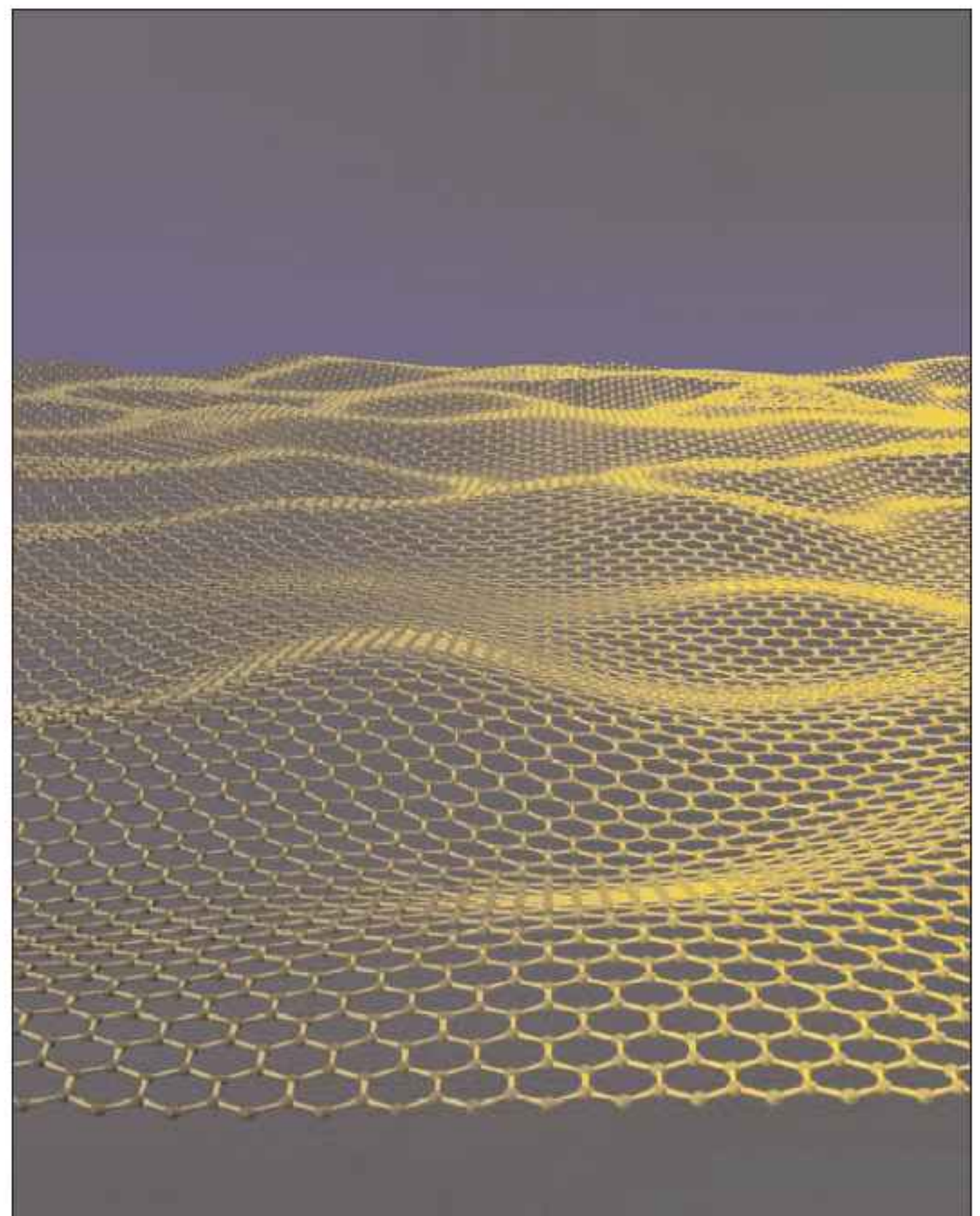


Figure 1. Artistic impression of a graphene sheet by Jannik Meyer, Max Planck Institute for Solid State Research, Germany.

So it is with some excitement that one reads of the development of epitaxial graphene layers with positive band gaps deposited on silicon carbide substrates [2], reported by US and Spanish scientists at the universities of California-Berkeley, California-Santa Cruz and Boston, the Georgia Institute of Technology, the US Lawrence Berkeley National Laboratory and Instituto de Ciencia de Materiales de Madrid in Spain. The graphene layers are produced by thermal decomposition of a Si-terminated n-type SiC wafer surface.

The researchers have measured a band gap of the order of 0.26eV. This gap reduces as the number of layers increases and closes beyond four layers. For bilayer graphene the gap is given as 0.14eV, and for a trilayer it is 0.066eV (Figure 2). The scientists theorize that the gap is the result of sublattice symmetry breaking from the graphene-substrate interactions. ➤

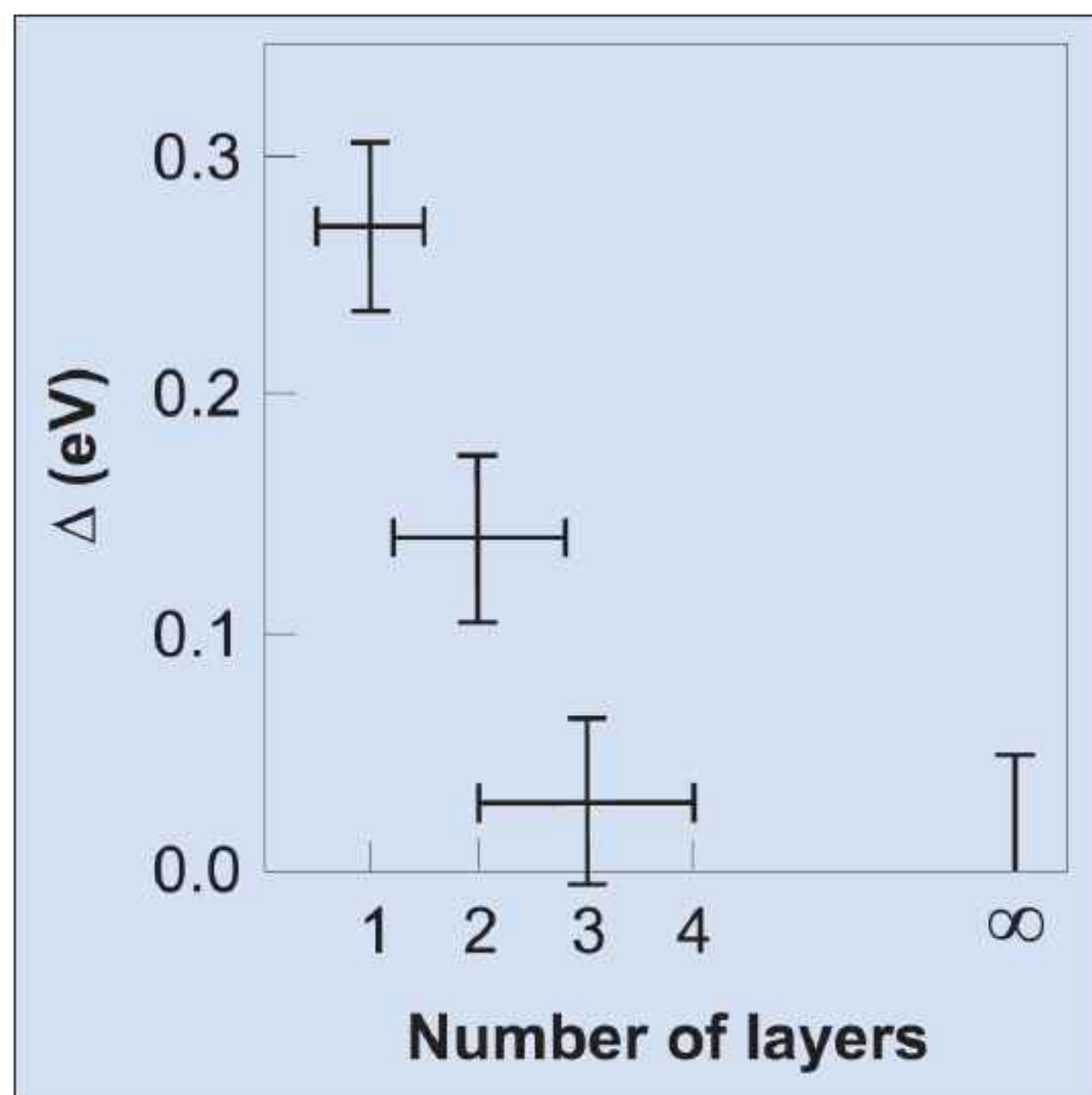


Figure 2. Induced gap of graphene on SiC versus the number of layers.

Electron energy (EDC) and momentum (MDC) distribution curves found using angle-resolved photoemission spectroscopy (ARPES) were used to derive dispersion relations near the band gap (Figure 3). The ARPES measurements were carried out at the Advanced Light Source (synchrotron) at Lawrence Berkeley.

The gap can be seen within the Dirac model as giving the electron a small effective mass — small enough so that, away from the gap, the dispersion relation becomes linear (as for the zero gap case) rather than quadratic (as for normal 'non-relativistic' fermions in semiconductors); see Figure 4.

The EDC peaks are broad, giving finite photoemission in the gap. Why the peaks are so broad and how this would affect attempts to construct devices are important unanswered questions. The article's authors point out that ARPES measurements tend to underestimate transport lifetimes by up to two orders of magnitude. As one approaches the Fermi level, the peaks become sharper (indicating longer lifetimes), giving hope for device applications.

The position of the Fermi level is such that the graphene layers are usually electron doped. Among the next key steps for this research is to attempt hole doping or to apply a gate voltage to move the Fermi level into the gap. The researchers also plan to investigate layers on other substrates in the hope of controlling the gap.

The researchers prefer a model where symmetry breaking occurs between the two sublattices making up the hexagonal graphene structure due to interaction with the SiC crystal surface structure. Previously, attempts to create a band gap in graphene have

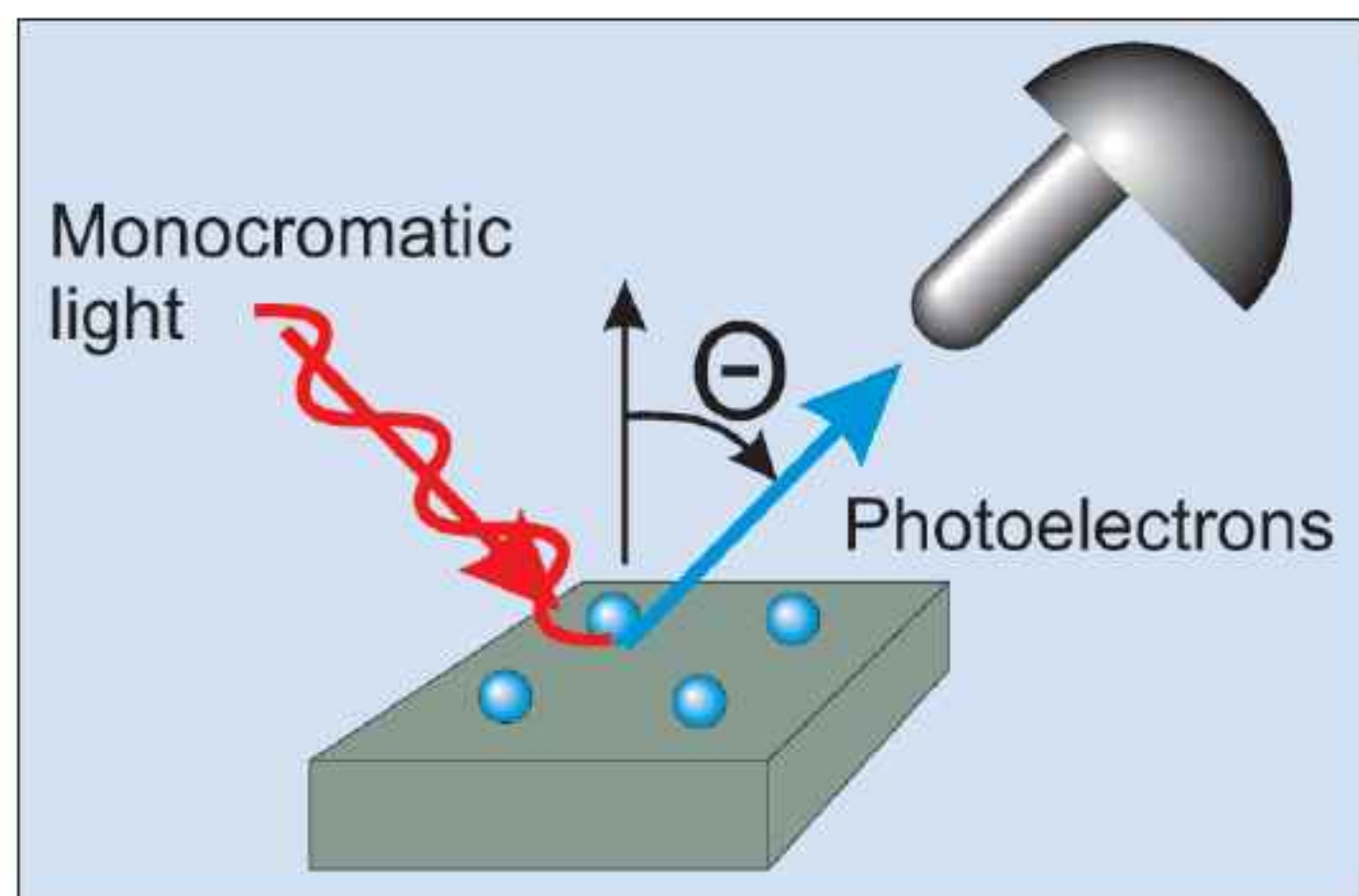


Figure 3. Schematic of angle-resolved photoemission spectroscopy (ARPES).

involved complex sculpting of nanostructures (dots, ribbons, combinations of monolayer and bilayer regions, etc.).

Scientists from the University of Manchester (UK) and the Institute for Microelectronics Technology in Chernogolovka (Russia) first isolated and studied graphene sheets of carbon by drawing graphite across a surface and searching among the fragments on a silicon dioxide coated wafer with an optical microscope [1, 3]. A silicon dioxide layer of around 300nm gives the best contrast to search for graphene fragments. A 5% difference in the layer thickness significantly reduces the contrast. However, such manual search techniques are best suited to the patient researcher; industrialists will want repeatable, mass production.

Since the first studies on graphene, it has since been produced on silicon carbide, non-crystal substrates, in liquid suspension and as suspended membranes. Also, other 'two-dimensional' (2D) materials have also been found constructed of boron nitride and of a half-layer of the high-temperature superconductor, bismuth strontium calcium copper oxide (BSCCO).

Thermal decomposition of hexagonal (6H) SiC crystals is the main alternative to the 'exfoliation' of the Manchester group. Dr Claire Berger, a researcher into graphene on SiC based both at Institut Néel of the Centre National de la Recherche Scientifique (CNRS) in France and Georgia Tech in the USA, comments: "In our process by thermal decomposition of SiC, graphene covers the entire sample of millimeter size. There is no size limitation in principle. Graphene grows over terraces like a carpet and so extends over very long distances. The terraces we talk about correspond essentially to the SiC substrate local miscut, and are of the order of several hundreds of nanometers. We use commercial SiC from Cree. We start with a 3-inch wafer that we dice into rectangles 3mm x 4mm or so to fit in our measurement and tool setup."

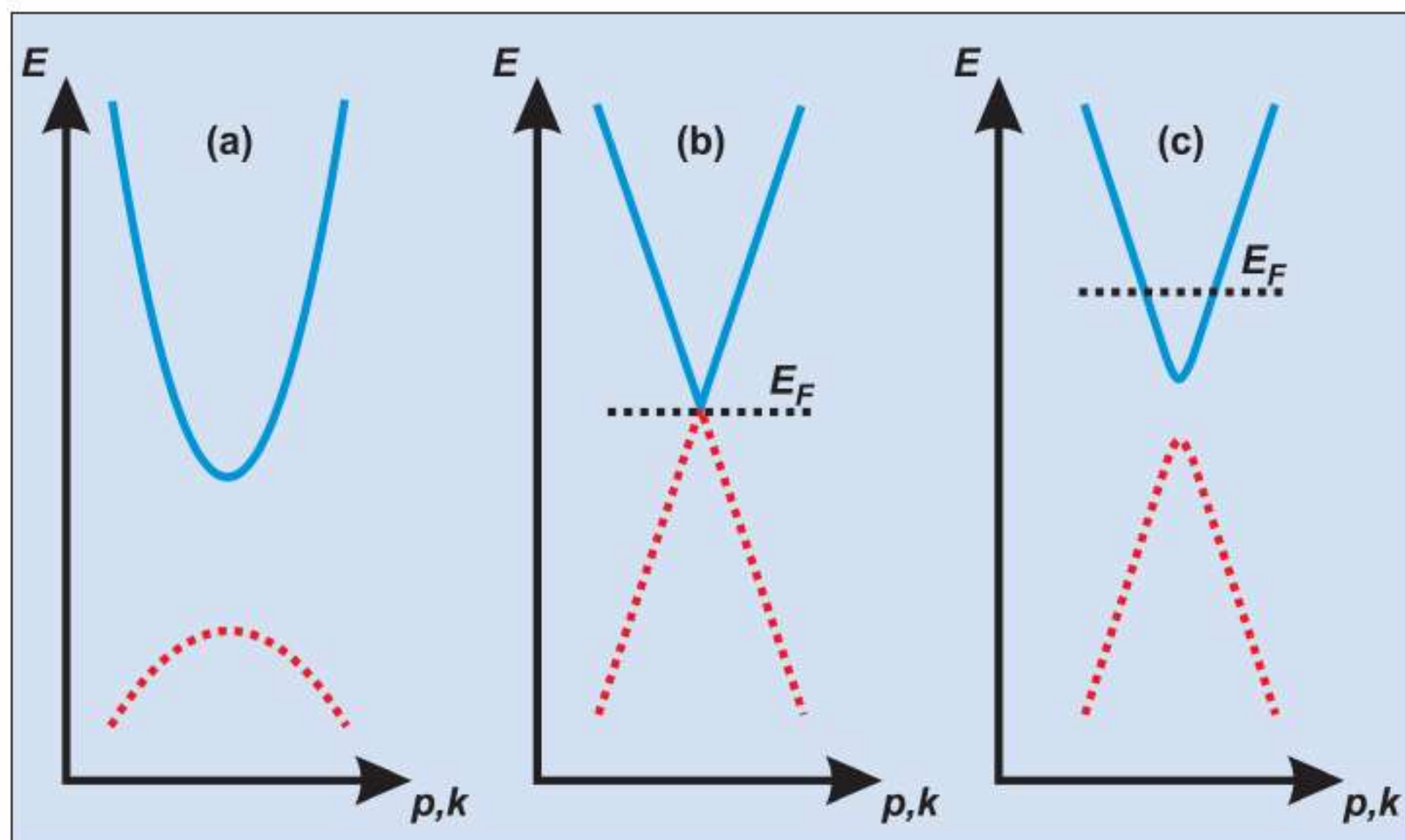


Figure 4. Form of energy-momentum dispersion near a gap in (a) normal semiconductor, (b) single layer graphene, (c) 1–3 layer graphene on SiC. While the Fermi level in graphene is at the cross-over point, on SiC the level is in the conduction band, giving electron conduction in the material.

The first graphene-based transistor was made at the same time as the material's discovery [1], and other groups have since reproduced the result (for example, Georgia Institute of Technology growing the graphene on silicon carbide substrates, [4]). But these graphene

transistors were very 'leaky'. If such high leakage rates continued, this would limit possible applications and rule out use in computer chips and other electronic circuits needing a high density of transistors.

Graphene mobilities of up to $30,000\text{cm}^2/\text{V-s}$ have been measured at 300K ('room temperature'). Silicon mobilities are around $1500\text{cm}^2/\text{V-s}$ and decrease rapidly with the doping levels being used in today's semiconductor devices. Alternative high-mobility channels are being sought for CMOS transistors, and graphene is one possibility. While mass production of controllable graphene layers still seems some way off, results such as producing a positive gap in graphene could draw interest from academic and industrial researchers and accelerate the pace of development. ■

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