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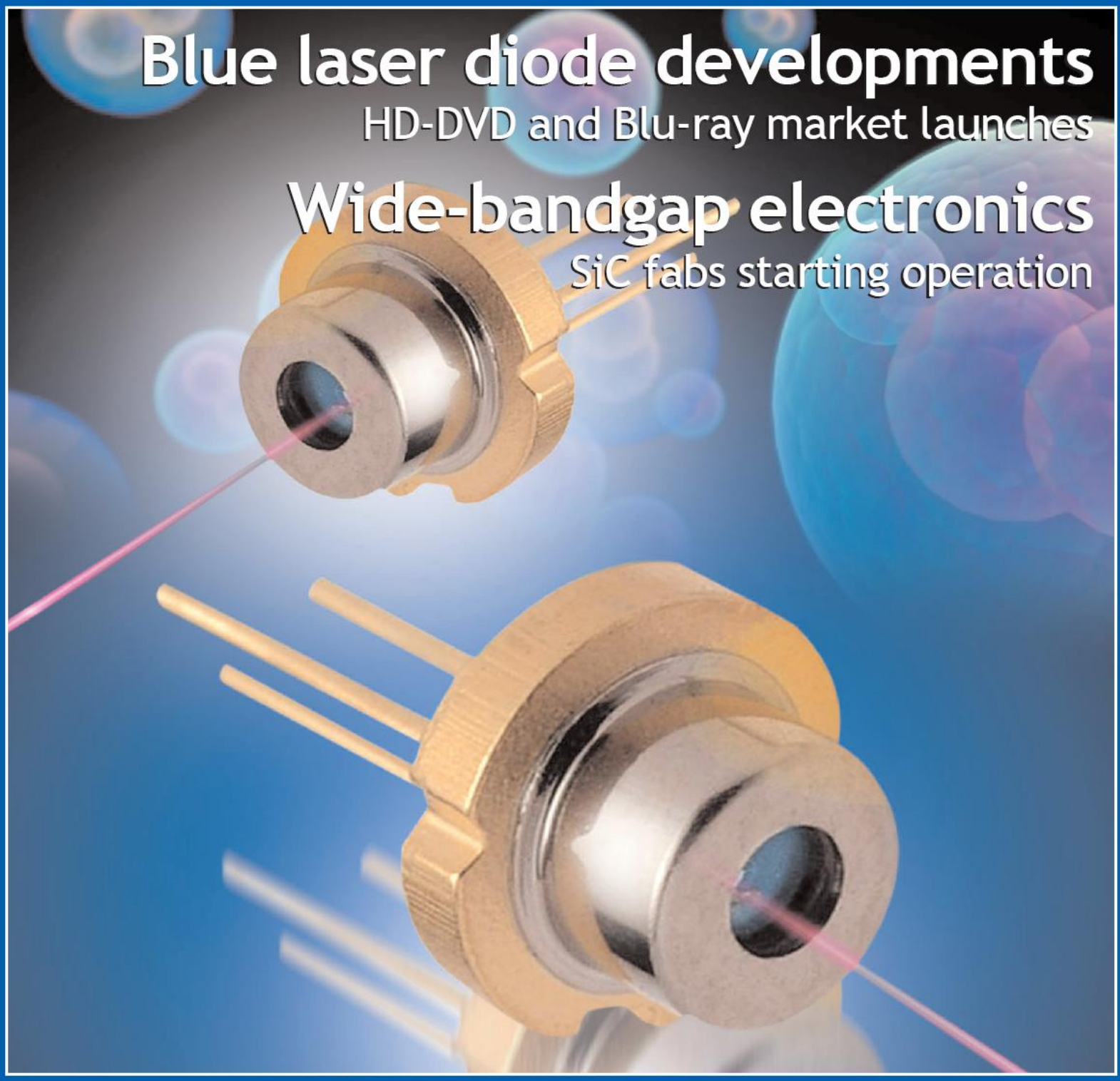

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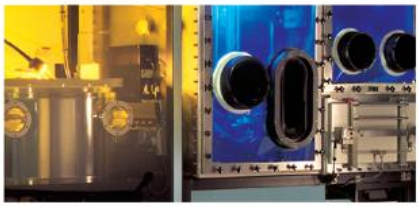

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contents

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COMPOUNDS & ADVANCED SILICON

Vol. 1 • Issue 2 • August 2006

p20 Osram's new CERAMOS LED for cell-phone and camera flashes.

p22 Orion's OS100 visible-blind GaN-based ultraviolet sensor.

p25 An oxidation furnace for 3" SiC in Cree's new SiC/GaN electronics fab.

Cover: The Sanyo DL-5146-152 blue-violet (405nm), 35mW laser, which has an internal monitor photodiode for uses where a stable, accurately controlled output is critical, such as biomedical instrumentation, imaging, fluorescence sensing, and spectroscopy, as well as next-generation DVD. **p32**

editorial

GaAs and GaN gains sustain growth

In last month's launch issue of *Semiconductor Today*, we covered the feature topic of subtrates for nitride-based semiconductors (Issue 1, page 28). Here, in Issue 2, we extend our coverage to include a feature on the optoelectronic applications of nitride-based semiconductor materials, specifically blue-spectrum lasers and their end-uses. In particular, we focus on the ongoing commercial introduction of high-density DVD and Blu-ray players, as well as future non-storage applications such as the drive to shorter visible and UV wavelengths for biomedical applications (see page 30, as well as the Sanyo blue-violet laser on the cover).

Meanwhile, afterthe consolidation among Taiwanese GaN-based blue LED chip makers over the previous year or so, burgeoning orders from Asia for nitride MOCVD reactors for blue high-brightness LED capacity expansions continue apace (see 'Asia tools up for GaN HB-LEDs', Issue 1, page 13, and this issue, page 16), with many orders for new-generation 30x2"- and even 42x2"-wafer reactors (see report on IC-MOVPE, page 29). Not only are the remaining Asia–Pacific LED makers expanding (with last year's merger between Epistar and UEC already forming the world's largest LED chip maker), but Taiwanese DRAM silcion manufacturer ProMOS is even forming a joint venture to make blue LEDs, so that it can enter the sector.

This issue also sees the reporting by most companies of second-quarter 2006 financial results. A highlight is the continuing growth of GaAs RFIC device makers. Suppliers such as RFMD, Triquint and Anadigics are now all in their fifth conescutive quarter of revenue growth, and most are turning around heavy losses of a year ago to healthy profits now (see page 8), driven by the trend for the use of more GaAs chips per phone in multi-band, multi-mode cell phones, as well as growth in cell-phone usage in emerging markets. GaAs RFIC makers are consequently in the midst of expansions, particularly the biggest supplier RFMD, which stands to use its ability to invest heavily in capacity to win market share during this current capacity-constrained period for the GaAs industry.

The knock-on effect up the supply chain is manifested in 40% growth in the usage of semi-insulating GaAs epiwafers in 2005, and a 16% rise in the market for semi-insulating GaAs substrates (see page 12). Here, the less dominant suppliers, such as Asian epiwafer foundries VPEC and MBE Technology and the fast-recovering substrate supplier AXT, stand to make gains, while capacity-constrained incumbent suppliers decide whether to risk investing in expansions.

Regardless of how long demand may last, one thing seems certain: market shares between competitors can change — as can be seen from Motorola's recent rapid gains in market share on Nokia — representing opportunities for those that are able to make change.

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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 RF ICs, lasers and LEDs in wireless and optical communications etc).

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- suppliers' directory.

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news

Auto front-lighting LED market to grow as performance rises

In 2007, GaN-based LEDs will reach a higher luminous efficiency than fluorescents, and solid-state lighting business will really start ramping-up, in particular for automotive applications (both interior and exterior), says Research and Markets in its report 'LED4Auto — LED & HB-LED for Automotive Applications'.

HB-LEDs have strong automotive market opportunities, due to:

- high reliability (with lifetimes much larger than needed);
- usability for both internal and external lighting;
- low consumption and power saving;
- mercury free materials.

Their small size also enables:

- new design possibilities and high-tech appearance; and
- increased integration.

In terms of security, an LED's fast reaction time (lighting up 250ms quicker than bulbs) gives a gain in braking distance of 7m at 100km/h.

Market opportunities for HB-LEDs for front lighting will grow as their performance rises, although fewer chips will be necessary (less than 15 by 2009 for all functions). The cost target for widespread proliferation (10$/klm) will be reached in 2010, but front-lighting HB-LEDs will be implemented earlier on high-end cars (around 2007).

Today's high-end car can have up to 200 LEDs, and this is expected to grow to up to 800 LEDs in 2009. The HB-LED market for front light is just beginning, but the market for automotive external lighting is forecast to be 40% of the total HB-LED automotive market in 2009.

The white LED market will be shared by five major players: Lumileds, Osram, Nichia, Toyoda Gosei and Cree. Also, recent interest in head-up displays (HUDs) in cars should also benefit from HB-LED technology. HB-LEDs are bright enough to be used as a backlight on an FPD instead of bulbs.

www.researchandmarkets.com

Gallium and indium production in CIS to grow

According to a report from Russia's InfoMine Research Group, gallium raw material reserves in the CIS (Commonwealth of Independent States) total over 10 kilotons. The vast majority of affirmed reserves, about 93%, are in Russia, with 6% in Kazakhstan, and the rest (1%) concentrated in Ukraine, Azerbaijan, Uzbekistan, Armenia and Tajikistan. In Russia, the principal share of gallium reserves is found in nepheline rock, apatite and nepheline ore and bauxites.

Indium raw material reserves in the CIS are over 5 kilotons. Russia has a 76% share, Kazakhstan about 12%, Azerbaijan 8%, and other countries about 4%. Indium reserves in Russia are mainly present in copper-zinc-pyrite ores and in tin-ore deposits.

During 2000-2005, 25-43 tons of gallium was produced in the CIS annually. Despite most reserves being in Russia, the principal share of production volume belonged to Kazakhstan and Ukraine. At present, ten enterprises possess capacities for producing metallic gallium in the CIS. The main manufacturers are the joint stock company JSC Aluminy Kazakhstana (Kazakhstan) and JSC Nikolayevsky Glinozemny Zavod (Ukraine), together with JSC Aluminy Kazakhstana (Ukraine) and JSC Achinsky Glinozemny Kombinat, LLC Gally and JSC Pikalevskoye Ob'yedineniye "Glinozem" (all in Russia).

CIS countries produce 6-10 tons of metallic indium annually. Of that, Russia produces over 95%. At present, six enterprises in the CIS possess capacities for producing metallic indium, led by JSC Chelyabinsky Tsinkovy Zavod, together with JSC Elektrotsink, JSC Novosibirsky Olovianny Kombinat (all in Russia), JSC Kaztsink (Kazakhstan), and JSC Chistye Metally (Ukraine).

Russian export volumes of gallium and indium amount to nearly the same as the production volume, because there is practically no home consumption of these metals. Consumption of gallium in Russia is estimated to be no more than 100–150kg; consumption of indium does not exceed 20–30 kg. Enterprises in Russia export gallium mainly to the Netherlands, Slovakia, the USA, Germany, Japan and the UK; indium is exported to Japan, the Netherlands, the USA, the UK and Belgium.

InfoMine forecasts that annual production of gallium in the CIS could rise from 43 tons in 2005 to about 47 tons by 2010, and that annual production of indium in Russia could increase to 10 tons in the period up to 2010, while production volumes in Kazakhstan and Ukraine will be maintained at the present level.

www.infomine.ru

8Gb/s FC to hit same problems as 10GbE?

Most Fibre Channel (FC) switch and Host Bus Adapter sales will remain at 4Gb/s speeds beyond 2010, predicts Dell'Oro Group's 5-Year Forecast Report. Sales of 1Gb/s Fibre Channel dominated the market for about five years and 2Gb/s for four years, but 4Gb/s will dominate beyond five years, it reckons.

"But we don't see 8Gb/s FC being able to offer a price advantage [per gigabit of bandwidth] over 4Gbit/s speeds in the next few years," said Tam Dell'Oro, principal storage-area network analyst. "Also, we expect 8Gb/s FC will hit the same 15m distance limitation and laser jitter problems that Ethernet has at 10Gb/s. Until 8Gb/s FC or 10Gb/s Ethernet (10GbE) can offer a price advantage, 4Gb/s is the logical choice".

● Nevertheless, following lacklustre results the prior quarter, the 10 Gigabit Ethernet Switch market grew substantially to $302m in Q2/2006, says Dell'Oro in its Ethernet Switch Quarterly Report.

"Not only did 10 Gigabit Ethernet port shipments increase dramatically during the quarter, but average selling prices also rose, resulting in extra strong revenue growth," said Seamus Crehan, senior director of Ethernet Switch Research.

"Although prices did increase during the quarter, we expect the general trend of steep declines to resume as vendors introduce higher port density line cards and fixed configuration products," Crehan added.

www.DellOro.com

IN BRIEF

RF power market to near $1bn in 2011

The market for RF power semiconductors operating at 3.8 GHz and below with outputs above 5W will near $1bn by 2011, says ABI Research. (A later study will target those operating at higher frequencies.)

"This market has been overshadowed for many years by the wireless infrastructure sector," says Wilson. "Now that new 3G/cellular wireless infrastructure deployments are declining, there is a paucity of information about how the rest of the industry is faring. This study puts wireless infrastructure — which is well understood — into the context of the rest of these markets [military, broadcasting, commercial avionics, non-cellular communications and industrial/scientific/medical]."

www.abiresearch.com

IN BRIEF

Triple-band UMTS handsets drive RFICs

The need for handsets that can operate in UMTS and legacy GSM modes across multiple regions will drive shipments of handsets with as many as seven or more bands, says the report 'Popular UMTS Multi-Band Combinations: Implications for Radio Components' from Strategy Analytics' RF & Wireless Components Service. Operator decisions on which bands to support in these handsets have already started to set the product development course for suppliers of radio components.

Based on regional spectrum allocations and the plans of leading wireless operators, the report assesses which combinations of frequency bands will emerge as most significant as UMTS matures. With this knowledge, and careful design, suppliers of radio components can minimize the number of transceivers and front-end modules that they will have to develop to address the future handset market.

"By focusing on the most popular bands, radio component designers can target the needs of high-volume markets or select niches best suited to their company's capabilities," notes Stephen Entwistle, VP of Strategy Analytics' Strategic Technologies Practice.

"The leading suppliers do not have the luxury of developing unique transceivers and front-end modules for each and every possible combination of bands," adds Chris Taylor, director of the RF & Wireless Components Service. "Instead, they are attempting to develop a small suite of products that can address as many combinations of bands as possible, particularly the ones that they believe will emerge in high volume."

www.strategyanalytics.com

Over 235m handsets

Cell-phone shipments were a record 235m units in Q2/2006, a year-on-year growth of 25% (down slightly from Q1's 30%), according to Strategy Analytics' 'Q2 2006 Global Handset Market Share Update'.

All of the top-five OEMs except Samsung grew annual shipments faster than the market average, led by Nokia (29%) and Motorola (53%), which had a record 55% combined market share (33% and 22%, respectively). Nokia continued to "blitz the competition in WCDMA". Motorola, due to continued strength of its RAZR, hit record highs in profits, revenues, and shipments, and jumped to second position in CDMA, as it boomed in North America. Its gap to Samsung (11%) was the widest since 1999, as Samsung misses out on the boom in emerging GSM markets.

Sony Ericsson (6.7%) returned to fourth position for the first time in 2 years, with "both balanced product design and brand relevance with its Walkman products", maintaining its upward trend in GSM and yielding record shipments, revenues and profits, adds Chris Ambrosio, director of the Wireless Device Strategies (WDS) service.

For OEMs showing improvements in volumes and profits (Nokia and Motorola), the ability to get new products rapidly into the pipeline played a critical role, with "notable improvements" for Sony Ericsson: "the Walkman and Cybershot brands have legs to provide strong growth well into first-half 2007." Tier-2 vendors, such as TCL, remain under intense competitive pressure.

No vendors reported noticeable inventory build-up or slackening of demand in a broad number of markets, so Strategy Analytics retains its forecast of 22% growth from 2005's 817m units to 1bn in 2006.

In 2007 shipment growth will slow to 15% and margin and pricing pressure intensify for most OEMs as shipments continue to diverge between entry-tier and 3G products (in Q2/2006, five of the top six brands saw average selling prices drop). Given the strength of their core designs, Motorola could overtake Nokia in first-half 2007, says Neil Mawston, WDS Service associate director. "Nokia should feel pressure to more rapidly improve both entry- and mid-tier products in terms of designs and numbers."

www.strategyanalytics.com

Handsets shipped (millions) and market share (Strategy Analytics)

Shipments	Q2/05	Q3/05	Q4/05	2005	Q1/06	Q2/06
Nokia	60.8	66.6	83.7	264.9	75.1	78.4
Motorola	33.9	38.7	44.7	146.0	46.1	51.9
Samsung	24.4	26.8	27.2	102.9	29.0	26.3
Sony Ericsson	11.8	13.8	16.1	51.1	13.3	15.7
LG Electronics	12.1	15.5	16.2	54.9	15.6	15.3
Others	44.2	48.8	57.6	197.2	46.6	47.7
Total	**187.2**	**210.2**	**245.5**	**817.0**	**225.7**	**235.3**
Share (%)	**Q2/05**	**Q3/05**	**Q4/05**	**2005**	**Q1/06**	**Q2/06**
Nokia	32.5%	31.7%	34.1%	32.4%	33.3%	33.3%
Motorola	18.1%	18.4%	18.2%	17.9%	20.4%	22.1%
Samsung	13.0%	12.8%	11.1%	12.6%	12.8%	11.2%
Sony Ericsson	6.3%	6.6%	6.6%	6.3%	5.9%	6.7%
LG Electronics	6.5%	7.4%	6.6%	6.7%	6.9%	6.5%
Others	23.6%	23.2%	23.5%	24.1%	20.6%	20.3%
Growth YoY	**17.6%**	**25.5%**	**24.9%**	**20.1%**	**29.6%**	**25.7%**

shipped in Q2/2006

According to IDC's Worldwide Mobile Phone Tracker, shipments were a near-record 237.8m units in Q2/2006, up 2.1% on Q1 and 22.5% on a year ago. First-half 2006 shipments were 470.7m, promising close to 1bn for full year.

"IDC does not see this milestone [1bn] being surpassed this year," said research analyst Ryan Reith. "Although demand for handsets in emerging markets continues to soar, the market's surging growth rate has been balanced by slowing demand in select mature markets."

Most shipments were entry-level devices, but Q2 also saw strong growth in handsets capable of using bulked-up, 3G network infrastructure. With EV-DO and UMTS now common in many regions, 3G networks and services are becoming increasingly significant. The presence of established high-speed networks has resulted in the launch of new handsets capable of video conferencing, internet access at broadband speeds, and real-time content sharing, which all boosted demand.

"With a number of carriers marketing subscription services that take advantage of 3G's advanced capabilities, all major vendors are now offering 3G-compatible devices across multiple regions," said Reith. "There has been much talk about 3G being a standard, but that could only become a reality when carriers were able to market services that were appealing to consumers. With competitive services in place to drive usage on mobile phones for applications beyond voice, handset vendors are putting an increasing amount of resources into 3G handsets. But lower-end devices still make up most of the market."

- Nokia's shipments grew 4.3% on Q1 and 28.9% on a year ago to 78.4m units, boosted by both the E-series and N-series device lines.
- Motorola shipped 51.9m units (its fifth consecutive record quarter), up 12.5% on Q1 and 53.1% on a year ago, due to the popularity of the RAZR,and driven by new product releases such as iDEN.
- Samsung's shipments were up 8.2% on a year ago but down 9.4% on Q1, due to 3G UMTS handset launches going through consumer adoption, mostly due to the EMEA region (though shipments grew to Asia/Pacific and the Americas).
- Sony Ericsson's shipments grew 33.1% year-on-year, passing LG to become number 4 vendor. It built on its Walkman-branded phones by launching new devices, including the first UMTS Walkman phone (the W900) and the UMTS-capable W850.
- LG Electronics' shipments were up 26.4% year-on-year but down 1.7% on Q1, mainly in CDMA shipments, dropping from 6.5m to 4.3m units in North America. WCDMA handset shipments rose 170%, with HSDPA handset shipments into Europe, coupled with plans to ship into the US, accounting for growth.

www.idc.com

Shipments (in millions) and share (IDC).

Shipments	Q2/05	Q2/06	Growth
Nokia	60.8	78.4	28.9%
Motorola	33.9	51.9	53.1%
Samsung	24.3	26.3	8.2%
Sony Ericsson	11.8	15.7	33.1%
LG Electronics	12.1	15.3	26.4%
Others	51.2	50.2	-2.1%
Total	**194.1**	**237.8**	**22.5%**
Share (%)	**Q2/05**	**Q2/06**	
Nokia	31.3%	33.0%	
Motorola	17.5%	21.8%	
Samsung	12.5%	11.1%	
Sony Ericsson	6.1%	6.6%	
LG Electronics	6.2%	6.4%	
Others	26.4%	21.1%	

IN BRIEF

EDGE shipments 148m in 2006

EDGE-enabled handset shipments will reach 148m in 2006, 14% of the total, forecasts ABI Research.

"EDGE is downplayed in the market because it cannot really provide a mobile broadband experience and is therefore not seen as being at the cutting edge of cellular handset evolution," says principal analyst Stuart Carlaw. "It is viewed purely as an evolutionary step on the GSM ladder, and industry attention is very much focused on the newer technologies such as W-CDMA and HSDPA. That view is further compounded by the fact that operators do not actively report EDGE numbers in the public domain."

"However, this lack of general market attention belies the real importance of the role EDGE plays in delivering mobile services today and will play in the effective delivery of content in the network of tomorrow," adds research director Jake Saunders.

Apart from the sheer volume of EDGE handsets, ABI believes that the industry as a whole should pay more attention to this market, because EDGE is the only choice for some carriers today to support any type of near-acceptable mobile broadband experience, especially those with no 3G licenses or those waiting for 4G. Carlaw adds, "When the prospects for EDGE are viewed in the context of next-generation networks, its true value comes to light. The technology still represents the only viable choice for supporting seamless service delivery on a very wide-area basis. Neither WiMAX nor LTE nor HSUPA will be rolled out with enough geographic coverage to guarantee minimum service requirements on a wide scale."

www.abiresearch.com

RFIC makers record growth

For the June quarter (Q2/2006), number-one RFIC maker **RF Micro Devices** of Greensboro, NC, USA, which supplies to the six largest handset makers, reported its fifth consecutive quarter of sales growth, up 5.5% sequentially and 50% year-on-year to a record $238.3m. After a loss of $1.7m in Q1, operating income was $13.9m (despite $6m in charges), driven by strength at the leading handset makers, market share gains in RFICs, and increased demand for cellular transceivers and transmit modules.

In Cellular, RFMD extended its market share lead in power amplifiers and GPRS/EDGE transceivers. Polaris Total Radio sales rose to 28% of revenue (the eighth consecutive quarter of growth in transceivers). In Wireless Connectivity, sales of WLAN components rose. In Infrastructure, RFMD started sampling 50W GaN power amplifiers for wideband-CDMA base-stations.

"The handset industry will experience healthy growth this year of at least 15% and we're positioned to grow well in excess of the overall market," said CFO Dean Priddy. "Demand for our GaAs technology has increased rapidly with transmit modules, WCDMA and WLAN in handsets, as well as complete front-end GaAs solutions for the emerging 802.11n PC market."

For Q3, RFMD expects market share gains in RFICs, led by cellular transceivers and transmit modules, and is booked for growth with the four largest handset makers, which are increasing their collective market share. Sales should be $240–250m (up 1–5% on Q2 and 35–41% year-on-year). Expecting the usual strong year-end, RFMD's goal of annual revenue of $1bn is "on track".

To alleviate GaAs HBT capacity constraints and transfer pHEMT production from foundry to in-house, by Q4 RFMD should complete a $80m 40% expansion in 6" fab capacity, as well as a doubling in internal assembly capacity in Beijing. This should give "substantial cost and cycle time advantages," RFMD says. It will also "capitalize on the rapid increase in worldwide demand for GaAs technology," said president and CEO Bob Bruggeworth.

RFMD has also added $25m in five-year asset-based financing. "It gives us the flexibility to continue making the investments we feel are necessary to drive revenue and earning growth while maintaining a healthy cash balance," says Priddy.

Number 2 GaAs device maker **Skyworks Solutions** of Woburn, MA, USA reported sales of $197.1m, up 6% on Q1's $185.2m and 3% on $191.5m a year ago. But, excluding baseband products and legacy assembly and test services, revenue was up 14% year-on-year. Excluding charges of $4.2m, net income was $8.0m (up from $4.6m in Q1).

This reflects the ramp of several next-generation products supporting tier-one handset OEMs, says president and CEO David J. Aldrich. "Our Intera front-end modules and Helios radios are increasingly powering some of the world's most popular EDGE, WEDGE and WCDMA handsets... This differentiated offering, coupled with the introduction of a new wave of higher-margin linear products, is positioning us for substantial growth over the long term."

"Our RF solutions continue to gain momentum among leading handset OEMs, highlighted by ramps of Helios EDGE radios across nearly 20 new models at Samsung, CDMA RF subsystems at LG, WEDGE front-end modules at Sony Ericsson, and several new platforms at Motorola" says CFO Allan M. Kline. "Our linear products portfolio is at record backlog, with design wins transitioning into production," he adds.

"However, while handset demand remains robust, we experienced isolated forecast changes that reduced our demand signal," said Aldrich. Q3 sales should be $197–200m.

Number 3 GaAs device maker **TriQuint Semiconductor Inc** has recorded its fifth consecutive quarter of revenue and gross margin growth, and its largest operating income since March 2001. Revenue was $96.3m, up 10% on Q1 and 42% on a year ago.

Transmit module orders rose 48% on Q1 due to extending the form factor into CDMA and 3G markets.

Gross margin has risen from Q4/2005's 28.7% through Q1's 31.1% to 32.9%, due mainly to improved product mix and yield and capacity utilization. Net income was $5.6m, up from Q1's $2.2m, compared with a loss of $7.7m in Q1/2005. After Q4/2005, Triquint had said it expected quarterly profit to reach $5–10m by end-2006.

For Q3, TriQuint expects revenue up 4–8% on Q2.

Anadigics of Warren, NJ, USA reported its fifth consecutive quarter of sales growth: $40.2m (versus guidance of $39.3m), up 12.6% on Q1's $35.7m and 68% on $23.9m a year ago. Net loss was cut from $9.1m a year ago and $4.6m in Q1 to $2.8m.

"We expect revenue momentum and operating leverage to continue as a result of our strong positioning in existing growth markets, including 3G cell phones, Wi-Fi, and tuner ICs", said Bami Bastani, president & CEO. For Q3, Anadigics expects sales up 7–9% on Q2 and 50% year-on-year.

Hittite Microwave reported sales of $32.4m, up 71.2% on a year ago and 16.2% on Q1, due to 'greater international sales [57% non-US] and a favorable product mix'. Net income has risen from $4.2m in Q2/2005 and $9m in Q1 to $10.2m. Gross margin is up from 66.4% a year ago to 73.5%.

"We launched three new product lines, increasing our total to 13," said chairman & CEO Stephen Daly.

For Q3/2006, Hittite expects increased revenue of $33.5–34.5m and net income of $10.2–10.6m.

Hittite, Mitsubishi, Toshiba make gains

In its reports 'GaAs Device Vendor Market Share 2005: North America' and 'GaAs Device Vendor Market Share 2005: Asia Pacific and Europe', Strategy Analytics gives its annual rankings for 2005.

Seven of the top ten are based in North America. RF Micro Devices, Skyworks and TriQuint remain leaders, with 52% of the merchant market. But these have been joined by fabless company Hittite Microwave after strong growth.

Of Japanese GaAs device makers, Eudyna Devices (the former Fujitsu Quantum Devices and Sumitomo Electric Industries' electronic devices divisions, merged in 2004), Sony and NEC slipped from the top ten, while Mitsubishi Electric and Toshiba gained market share. Mitsubishi Electric was the Japanese market leader and saw significant growth for its MMIC business as it led supply of GaAs power amplifiers for Japanese 3G cellular handsets.

"2006 will bring some changes as well. None of the European GaAs device manufacturers held a top-ten position in 2005, yet we expect Filtronic [of the UK] to climb into this top-ten GaAs device manufacturer ranking in 2006," says Asif Anwar, director of Strategy Analytics' GaAs and Compound Semiconductor Technologies service. "Asia–Pacific foundries will also maintain growth in 2006 and 2007. Demand for foundry services in some cases is actually coming from the traditional GaAs device companies themselves, many of whom are choosing to outsource excess GaAs device production rather than investing in upgrading existing facilities."

"Despite these movements, we believe that North American players will continue to cement their dominance of the GaAs device market in 2006, since they supply the majority of GaAs devices to the strategically important handset market," maintains Stephen Entwistle, VP of Strategy Analytics' Strategic Technologies Practice.

www.strategyanalytics.com

RFMD and Skyworks included in NASDAQ's New Global Select Market

RFMD and Skyworks Solutions have been included in NASDAQ's Global Select Market, a new premier listing tier for companies that satisfy the highest financial and liquidity qualifications. RFMD was previously listed on NASDAQ's National Market (now the NASDAQ Global Market).

Firms must meet NASDAQ's existing corporate governance standards, have a majority independent board and an independent audit committee, and independent directors that participate in determining executive officer compensation and the nominees to serve on the board.

www.nasdaq.com/GlobalSelect

Anadigics joined Russell Investment Group's Russell 3000 Index family of US equity indexes at the end of June. Membership, which is determined mainly by market capitalization rankings and style attributes, remains in place for one year.

"It will broaden investor awareness of Anadigics," said Tom Shields, executive VP and CFO. "It demonstrates the significant momentum that we have achieved."

The indexes are used by investment managers and institutional investors for index funds and as benchmarks for investment strategies.

www.russell.com

IN BRIEF

Samsung gets EDGE from Skyworks

In its move to EDGE-enabled cell phones, Samsung has incorporated Skyworks Solutions' Helios EDGE radio subsystem into its new lineup of nearly 20 models.

Helios integrates an RF transceiver, PA and PA controller, halving RF board space and enabling inclusion of multimedia features. It also eliminates additional factory calibration, enabling simpler testing and easing high-volume manufacturing.

"Our solution delivers superior RF functionality and an unprecedented level of radio integration, allowing for compact designs and robust performance even under extreme conditions," claims Kevin D. Barber, senior VP and general manager of Mobile Platforms.

www.skyworksinc.com

RFMD ships linear EDGE PA to Samsung

RFMD is now shipping its RF3159 linear EDGE PA to Samsung for at least 15 EDGE-enabled handsets. "We anticipate ongoing collaboration across multiple platforms," said Components Business Unit general manager Konrad Alvarino.

The high-linearity quad-band GSM/GPRS/EDGE PA supports multiple EDGE transceiver platforms and is optimized for either direct I&Q or small-signal polar modulation. The module is fully matched for easy implementation and has a 6mmx6mm package (industry-leading for linear EDGE PAs). The gain and linearity line-ups enable optimization of the transmit chain for varying linearity, efficiency and output power needs. The module is designed to be the final amplification stage in a dual-mode GSM/GPRS/EDGE mobile transmit line-up operating at 824–915 and 1710–1910MHz.

www.rfmd.com

Filtronic's foundry breaks even

For its fiscal 2006 (to end-May), Filtronic plc of Shipley, UK, reported revenue from continuing operations of £221.0m (up 3.8% from 2005's £212.9m). This was split between Wireless Infrastructure 78%, Defence Electronics 14%, and Compound Semiconductors 8% (more than doubling to £20.8m).

But the Wireless Infrastructure division's operating profit fell from fiscal 2005's £17.5m to £5.5m, giving an overall fall from a £5.6m profit to a £4.2m loss. In contrast, the Compound Semiconductors division in second-half fiscal 2006 cut its operating loss (to £5.1m) compared with first-half fiscal 2006.

In fiscal Q4/2006, the Compound Semiconductors division grew sales 45% and met its target of run-rate break-even. Filtronic says it was the market leader for 4-way and above pHEMT cell-phone switches, supplying 20% of the handset market.

In June Filtronic agreed to sell its Wireless Infrastructure division's filter-based transmit receive module and power amplifier businesses by end-September to wireless network supplier Powerwave Technologies Inc of Santa Ana, CA, USA, for $336m ($150m plus 20.7m shares, about 13% of Powerwave's stock).

Apart from repaying outstanding bank debt, to "meet demand forecasts from a number of established handset module suppliers" proceeds will be used to spend £45m ($83m) over the following 12 months to expand its Compound Semiconductors division's 6" GaAs fab in Newton Aycliffe, UK, which has already ramped up capacity for pHEMT switches (for handset transmit modules). Main customer RF Micro Devices is expanding its own in-house manufacturing capacity for pHEMTs, but may still need Filtronic's capacity to satisfy demand. Filtronic is now also supplying a second customer with pHEMT die.

Filtronic's 6" GaAs foundry in Newton Aycliffe, UK.

Filtronic aims to grow its compound business by up to threefold in the next two years, driven by "strong long-term market growth" as handsets adopt switches based on pHEMTs, with the expectation that they will be used in around 80% of handsets produced by 2008.

"We have considerable opportunity to grow our presence in the supply of switch components for mobile handsets", says founder David Rhodes. "The aim is to enhance our position as the number-one supplier of switches for handsets with a substantial market share in a market of over one billion units a year."

To help finance expansion, Filtronic has a further bank facility of £15m, available until end-November, bringing total facilities to £35m.

Since announcing the expansion in June, at the end of July Filtronic said that the financing plan for Compound Semiconductors needs less than £15m of additional cash this fiscal year (to end-May 2007). After that, the division is targeted to be self-financing for further investment. "The company constantly reassesses the market forecasts and business cases on which investment plans are made and believes that, in the current financial year, the level of investment is appropriate to the company's current planned market position," a spokseman told *Semiconductor Today*.

www.filtronic.co.uk

John Poulter joined Filtronic plc in mid-July as non-executive chairman. Former senior non-executive director Rhys Williams has retired as chairman, but remains a board member until he retires at the annual general meeting on 29 September. Also at the AGM, professor David Rhodes, Filtronic's founder, will retire as group chief executive and board member.

Williams became chairman temporarily at the end of January when professor John Roulston (CEO from September 2004) was ousted by non-executive directors after complaints about the slow pace of change. This followed a pre-tax loss of £5.6m on revenue from continuing operations of £110.8m in the first half of its fiscal 2006 (to end-November), compared with a profit of £3.5m on revenue of £103.2m a year previously. Roulston was replaced by the then-chairman Rhodes to "stabilize the company's operational position". Rhodes now considers that this will have been fully achieved by the AGM. However, Rhodes will continue to support the group with advice and guidance in the future, Filtronic says.

...engineered

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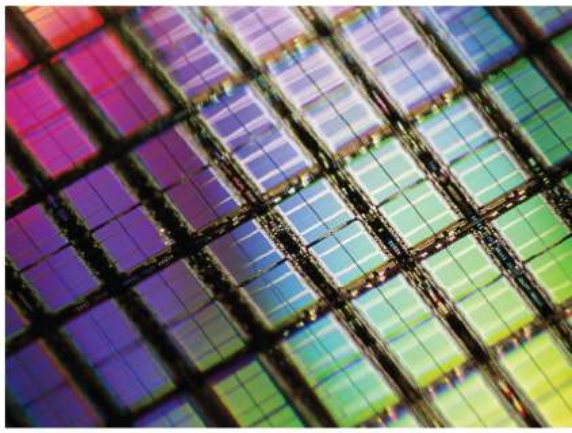

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AXT recovery drives extra 6" expansion

AXT Inc has once again exceeded sales and earnings expectations. Q2/2006 sales were up 22% on Q1 to $10.4m (versus the forecast $8.6–8.9m): GaAs wafers $8.1m (up 20.3%); InP wafers $613,000; Ge wafers $169,000; and raw materials $1.4m.

"Much of this strength came from growing demand for 2-4" semiconducting GaAs substrates used in LEDs and for 6" semi-insulating GaAs substrates used in wireless handsets, and the overall constrained capacity in the industry," says CEO Phil Yin.

Gross margin rose from 8.4% in Q4/2005 to 17.8% in Q1/2006, to 26.6% of revenue, driven by growing volume, favorable product mix and cost-cutting innovations, including improved slicing, lapping and polishing processes.

Operating loss has been cut from $3.4m in Q4/2005 and $2.3m in Q1/2006 to $1.7m, despite expenses rising from $3.8m to $4.4m (mainly due to increased sales commissions and expenses to close US property). Net loss has been cut from $2.7m in Q4/2005 and $2.2m in Q1/2006 to $876,000 (outperforming the forecast $1.4–1.8m).

"Over the past year, we have focused tremendous energy into restoring and growing our customer base," adds Yin. "We are actively engaged in a number of new and returning customer qualifications."

"Our China production facility allows us to produce substrates in a low-cost environment and reach economies of scale at lower-volume production," says Yin. AXT recently increased 6" capacity by 50%. But due to order visibility from its returning customer base, AXT plans to add an extra 40% by end-Q1/2007. For Q3/2006, AXT expects revenue to rise to $10.5-11.0m.

www.axt.com

GaAs wafer growth

In 'Markets for Semi-Insulating GaAs Substrates 2005-2010', Strategy Analytics estimates that demand rose 16% year-on-year to $129m in 2005. But with 2006 representing the starting point for trends towards multi-mode and multi-band cellular handsets that use increasingly complex multi-functional front-end modules, there will be significant demand over 2006-2008, and the market will grow to $247m by 2010.

In 2005, merchant supply still came mainly from Freiberger Compound Materials, Sumitomo Electric Industries and Hitachi Cable. AXT of Freemont, CA, USA, which has operations in China and large available capacity, continued its efforts to re-establish itself with users as a primary supplier of GaAs bulk wafers. Its market share grew 2%.

But despite healthy growth, "GaAs bulk substrate suppliers are facing tough decisions," says Asif Anwar, director of Strategy Analytics' GaAs and Compound Semiconductor Technologies service. "On the one hand, there is pressure to increase capacity to meet burgeoning demand over the next 18 months. On the other side of the equation is the danger that suppliers will put too much capacity in place now, which increases the risk of commoditizing the market in future."

"It wouldn't surprise me if smaller volume customers are being turned away right now so that the market leaders can concentrate on the major consumers," observes Stephen Entwistle, VP of Strategy Analytics' Strategic Technologies Practice. "We may see a significant change in market share in 2006, with AXT best positioned at this time to mop up excess demand."

GaAs epi market grew 40% in 2005; Asia-Pac suppliers 145% to 15% share

The semi-insulating (SI) GaAs epitaxial substrate market (merchant plus captive) rose by 40% in 2005, from 8511ksi (thousand square inches) in 2004 to 11932ksi, says Strategy Analytics' in its study 'Markets for SI GaAs Epitaxial Substrates 2005–2010'. Merchant demand jumped 44% in 2005, with Kopin, Hitachi Cable and IQE the top three suppliers. Healthy demand, coupled with tight supply, will translate to increased revenues for merchant suppliers.

While the market share at the top has largely remained unchanged over the past few years, Asia–Pacific vendors established themselves as viable alternatives to North American and Japanese suppliers in 2005 and will continue to threaten the dominant suppliers. Year-on-year, the combined output at VPEC and MBE Technology increased 145% in 2005, accounting for 15% of merchant supply, "We expect to see continued growth across the whole industry, and the Asia–Pacific suppliers will want to be at the forefront of this growth in 2006," said Strategy Analytics' Asif Anwar.

"We will see some significant shifts in market share in 2006. In particular, IQE's acquisition of the Emcore GaAs epi business will challenge market leaders Kopin and Hitachi Cable," adds Strategy Analytics' Stephen Entwistle. "VPEC and MBE Technology are well positioned to take advantage of ramps at GaAs device foundries in their region, which could see them gain market share in 2006."

In terms of value, the SI GaAs epi market should grow at a compound average annual growth rate of 16% to $487m in 2010, the study says.

www.strategyanalytics.com

Kopin expanding

Kopin Corp of Taunton, MA, USA has reported Q2/2006 epi sales up 34% on a year ago to $12.1m, though down slightly on $12.8m last quarter. HBT products were strong due to an "increase in wireless handset sales and, more importantly, a higher percentage of HBT content per handset to accommodate the increased functionality of new models," said president and CEO John C.C. Fan.

"With a global handset market projected to produce over 950m units in 2006, Kopin has begun a major capacity expansion to accommodate increased demand for our HBT transistors," Fan said. "Our capacity expansion is taking a two-pronged approach: the installation of additional III-V equipment in our domestic facilities and the qualification of our licensed HBT OEM partner in Taiwan, KTC. We anticipate getting initial production from both locations by year end as we work toward our goal of a 50% capacity increase in the next 12 months." In April, Kopin signed a multi-year supply agreement with Aixtron for MOCVD reactors. The first two (the latest 12x4" and 7x6" 'Integrated Concept Platform' reactors) were due to be installed in Taunton, MA, for commercial runs this year. Kopin is also ramping up its utilization of existing systems in both Taunton and at KTC.

"We anticipate continued strength in our III-V business," says Fan, "driven by demand for advanced wireless handsets equipped with our transistors, including our newest transistor solution, the GAIN-HBT," which began initial volume production in Q1/2006, and provides reduced operating voltage, increased RF performance and greater temperature stability.

www.kopin.com

IN BRIEF

WiMAX mass market five years away

Certified WiMAX equipment for fixed wireless has finally reached the market, coverage areas have begun to expand beyond basic trials, and a push by supporters to accelerate mobile WiMAX could lead to certified mobile devices by the end of 2006, says Strategy Analytics in its report "Capitalizing on WiMAX: The Market for WiMAX Radio Chips". Equipment suppliers and chip makers face a less uncertain future. However, "equipment shipments will not reach tens of millions of units per year until after 2010. This will make recovery of product development costs problematic for many in the already large base of component suppliers," says Chris Taylor, director of the RF & Wireless Components Service.

www.strategyanalytics.com

IQE closes acquisition of EMD, funded by £12m share issue

Epiwafer foundry IQE of Cardiff, UK, which also has manufacturing plants in Milton Keynes, UK and Bethlehem, PA, USA, has completed its acquisition of component and subsystem maker Emcore Corporation Inc's Electronic Materials Division (EMD), one of the top five third-party epiwafer foundries, for $16m. This comprises an initial cash payment of $13m, plus $3m in financing (at 7.5% annual interest) in four equal quarterly payments. For its fiscal year to end-September 2005, EMD's revenue was $12.2m and its asset value was $9m. The business has continued to grow strongly in the current financial year.

To finance the acquisition and working capital, at an extraordinary general meeting on 15 August shareholders approved the issue of 87.5m new shares (at 13.75p per share) in a placement on the London Stock Exchange's AIM market to raise about £12m ($22.7m). This is equivalent to 21.6% of IQE's enlarged ordinary share capital.

IQE says that EMD has pursued a similar strategy to that of IQE, in building a strong outsource foundry model for the supply of epiwafers. EMD uses 10 TurboDisc MOCVD reactors to provide foundry production of electronic epitaxial materials, with a focus on the wireless markets, and has concentrated on GaAs HBT-based technologies, as well as integrated GaAs BiFET and GaN structures, for use in power amplifiers and switches in GSM, CDMA multiband wireless handsets, Wi-MAX, Wi-Fi, cellular handsets, and in wireless LAN applications. Consequently, it supplies a range of highly complementary products to a range of customers different to that of IQE's own customer base.

IQE claims that the acquisition has created "the leading global outsource supplier of current and next-generation epiwafers into the wireless marketplace, including pHEMT, HBT, integrated BiFET and advanced GaN technologies". It also provides "significant opportunities to accelerate sales into existing and new customers".

The acquisition represents a key step forward in IQE's development as the leading outsource wafer supplier worldwide, says Dr Drew Nelson, IQE plc's president and CEO. "The joining of the two companies allows IQE to offer a truly one-stop wafer outsource service," he adds.

IQE's directors believe this will create significant opportunity to grow revenues within existing IQE and EMD customers by offering all major technology platforms to the enlarged customer base, from the "largest, state-of-the-art production capacity in the industry".

All of EMD's 50 or so staff, including its management team, have been offered employment with IQE. The IQE board intends that EMD will continue to be run as a standalone entity in Somerset, NJ, USA.

"This transaction assures EMD's current customers that, as part of a larger wafer outsource group, all the necessary resources are in place to fully support the joint customer base as their wafer demands continue to grow," adds Nelson.

According to Strategy Analytics, IQE's acquisition will increase its share of the commercial epitaxial substrate market, allowing it to generate net profits by end 2007.

Strategy Analytics forecasts that overall demand for epiwafers will grow 40% year-on-year in 2006 and 30% year-on-year in 2007. However, commercial demand for MBE substrates is restricted by captive capabilities and regional preferences for MOCVD. By acquiring EMD, IQE can offer GaAs device manufacturers a one-stop shop for both MOCVD and MBE material.

"We believe this is a positive move for IQE that will enable the company to increase its share of the commercial SI GaAs epitaxial substrate market and move into profitability," says Asif Anwar, director of the GaAs and Compound Semiconductor Technologies service. However, Stephen Entwistle, VP of the Strategic Technologies Practice, adds that "IQE will still need to overcome several commercial challenges to achieve its target of becoming the world's leading commercial supplier of SI GaAs epitaxial substrates."

www.iqep.com

IQE has provided a trading update ahead of its formal preliminary first-half results on 30 August.

"Trading has continued in line with our pre-Annual General Meeting Trading Update released on 30 May," said Drew Nelson, president and CEO. "During Q2, the overall business continued to grow strongly."

Detailed half-year results are still to be finalised, but directors expect H1/2006 revenues of about £14.5m, up 30% on H2/2005 and up 50% on H1/2005.

All four business units have grown, particularly the wireless division, IQE Inc in the USA and IQE Silicon in the UK. Both the optical and substrate businesses have also grown significantly, says IQE, and are set to grow even more strongly in H2/2006.

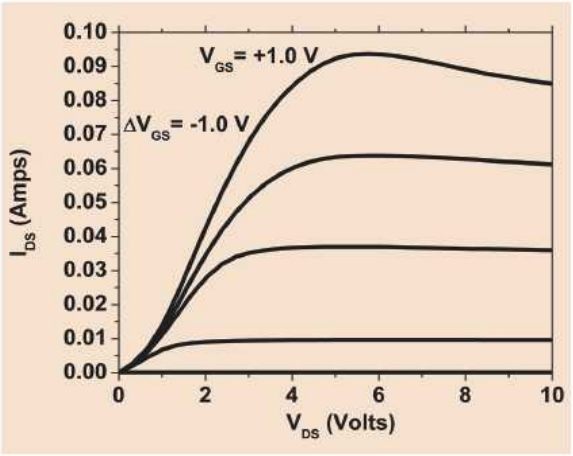
However, IQE Group's breakeven revenue point for EBITDA (earnings before interest, taxes, depreciation and amortization) remains about £30m.

First GaN-on-diamond HEMT

A team including component and subsystem manufacturer Emcore Corp of Somerset, NJ, USA, Group4 Labs LLC of Menlo Park, CA, USA and engineers at the US Air Force Research Labs (AFRL) has demonstrated what is claimed to be the first successful fabrication of an operational GaN-on-diamond HEMT device.

AlGaN/GaN epitaxial transistor layers were grown by MOCVD at Emcore and atomically attached to CVD diamond substrate by Group4 Labs, which was founded in April 2003. The AFRL team fabricated the transistors. Emcore says that the achievement highlights the feasibility of producing GaN-based RF devices closely thermally coupled to diamond substrates to maximize heat extraction from these devices.

The team expects the technology to improve power density and efficiency of devices operating at high frequencies due to higher packing density and better heat dissipation in the immediate vicinity of the active device area.



I–V curves for early device mounted on sub-optimized heatsink (with some heating effect due to test configuration).

The novel process has a wide range of possible applications, including high-performance GaN-based RF devices, high-brightness LEDs and laser diodes.

"We are excited by the promise of this technology combining the most robust semiconductor material with the best heat spreader," says Dr Ivan Eliashevich, director of R&D at Emcore's EMD epiwafer foundry division (now acquired by epi foundry IQE — see page opposite). "Epitaxial wafers based on a GaN-on-diamond platform should enable device makers to push the limits of high-power performance and reliability across a wide range of applications," he adds.

● The work was supported in part by a DARPA-funded Cooperative Agreement between Emcore and AFRL.

www.emcore.com
www.Group4Labs.com
www.afrl.af.mil

Aixtron loss narrows despite lower sales; orders rise 74%

For Q2/2006, Aixtron's sales fell from €44.4m a year ago to €35.7m. However, gross profit rose from €11.5m to €13.3m and margin from 26% to 37%, while net loss was cut from €2.6m to €1.2m.

"At the end of the [previous] quarter, we said the cautious growth in industry confidence first witnessed in the latter half of 2005 had continued into Q1/2006," said CEO Paul Hyland. "This improvement in sentiment has continued, and perhaps even strengthened in Q2."

Orders were €49.5m, 74% up on a year ago and the most for five years. Backlog was up 52.5% to €81.2m, the most since Q3/2004. This includes a good performance from the silicon division (24% of orders in first-half 2006, largely due to Genus, acquired in March 2005) and first-half 2006 MOCVD orders for compounds up 62% year-on-year, driven by demand for LCD backlights featuring LEDs.

"Our customers have shown more confidence and exhibited less demand volatility than before, the latter being particularly true in the silicon space, where we had seen considerable turbulence in the first quarter of 2006," said Hyland.

"Gross margin continues to move towards the targeted 40%," said Hyland. "Nevertheless, for the remainder of the year, we will continue to focus on resource efficiency improvements and cost reduction."

For full-year 2006, Aixtron has reiterated its guidance of net breakeven on €150m in sales, supported by ongoing cost reductions from gains in operational efficiency.

- The latest step in the four-year Philips Lumileds–Aixtron epitaxial deposition system supply contract has seen an order for a 30x2"-wafer Thomas Swan CRIUS MOCVD system, to be installed at its facility in San Jose, CA, USA for GaN-based LED manufacturing.
- EpiValley Co Ltd is installing a 30x2"-wafer CRIUS system (ordered in Q1/2006) at its headquarters in Gwangju City, South Korea for the mass production of GaN-based high-brightness LEDs.

Founded in December 1999, EpiValley also has a second plant (opened in April 2005) in Seongnam City and has 170 staff. EpiValley supplies epiwafers for blue, green, and UV LEDs and LED chips. In 2004, it raised $17m in two rounds from The Carlyle Group of the US, Investor AB of Sweden, and IMM, and in November 2005 it gained technology by acquiring KT Mark, launched in 1993 by Korea's Ministry of Science and Technology.

"Having already expanded capacity for LEDs and related products, the market demand now requires us to add further capacity," said EpiValley. The CRIUS system forms a "vital part of our ongoing expansion".

www.aixtron.com

SMI doubles size of its facility

Following "another year of continuous growth", Structured Materials Industries Inc (SMI), which supplies MOCVD systems and components, has doubled the size of its headquarters in Piscataway, NJ, USA, allowing it to fully separate manufacturing facilities from its Customer Service Application Laboratory. The latter houses over 10 systems and is capable of producing a range of oxides, nitrides, carbides, chalcogenides and a range of other materials.

Currently under construction are a clean manufacturing area and the integration of clean areas in the applications laboratory.

www.structuredmaterials.com

Army SBIR grant to develop Mg_2Si as alternative HgCdTe substrate

Structured Materials Industries Inc has received a US Army Phase I Small Business Innovative Research (SBIR) grant to investigate and develop an alternative substrate material for HgCdTe (mercury cadmium telluride, or MCT), using MOCVD to grow Mg_2Si on silicon.

As a strategically important infrared detector material, MCT is used in military as well as civilian applications where the highest IR sensitivities are required. However, MCT has no readily available economical large-area substrate. Mg_2Si has potential as an MCT substrate, since it can be grown epitaxially on silicon and has a low lattice mismatch with MCT.

The ability to produce a workable substrate layer on a low-cost large-area substrate material like silicon could greatly improve material cost and availability and improve system capabilities with larger sensing areas. MOCVD is advantageous for this material system, as it can accommodate substrates through 12" diameters, has high throughput, is economical and can produce high-quality materials.

- SMI has appointed Jung Won Corp as its representative in Korea for selling MOCVD, PECVD, ALD and related equipment.

www.structuredmaterials.com
www.jwc.co.kr

Self-calibrating evaporation source

RJM Semiconductor of Berkeley Heights, NJ, USA, which specializes in MBE growth of custom epiwafers and contract R&D, has launched its first product, the InfinitiCell 2000. The first self-calibrating metal evaporation source for MBE, it combines "the flux stability of a virtual infinite source with the thermal agility of a small-capacity source".

A large-capacity pump feeds liquid metal into the thermal evaporator, where a level sensor probe controls its height. The metal beam flux can be reproducibly controlled to ±0.1%. Also, the evaporator's low thermal mass allows rapid modulation, with ramp rates up to ±20C/min.

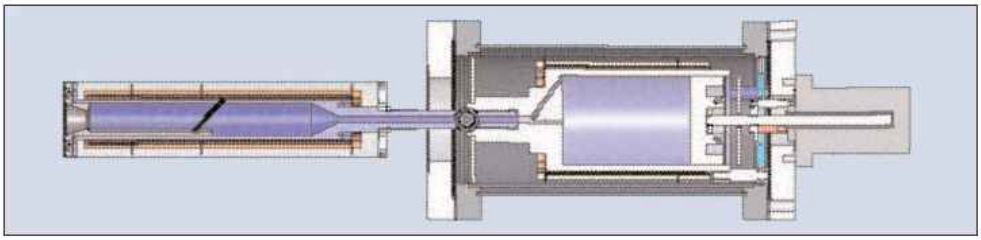
"The stability of the metal beam fluxes is very important, since they directly control the growth rates and alloy compositions," says founder and president Dr Roger Malik. Other thermal metal evaporators exhibit decreasing evaporation rates at fixed temperature due to source depletion effects, requiring frequent recalibration of the evaporator temperature to maintain constant flux.

Rapid thermal response allows precision alloy grading and can be used to idle the metal sources at lower temperatures while not growing to conserve source material.

The cell is made from pyrolytic graphite-coated graphite. Metals that do not react with or wet graphite can be evaporated (Ga, In, Cu, Ge, Sb, Hg, Ag, Au, and Pt). A design for Al is in development. Metal pump loading capacities are 1–10kg (spanning R&D and production systems). The metal level can be adjusted within 1 minute for flux calibration to ±0.1%. An optional EpiLock Control Unit combined with a stepper motor drive on the pump piston can automatically maintain a constant flux.

- RJM has made ARS Associates its exclusive North America agent.

www.rjmsemi.com



RJM Semiconductor's InfinitiCell self-calibrating metal evaporation source.

Ion-free oxygen atom beam source

Developed in collaboration with Dr K.G. Tschersich at Julich's Institute of Bio- and Nanosystems Research Centre, MBE Komponenten of Weil der Stadt, Germany has launched its new Oxygen Atom Beam Source (OBS), an oxygen-resistant thermal gas cracker that produces an ion-free oxygen gas beam for UHV, MBE, and ALD applications.

Based on thermal dissociation within a DC-heated cracking tube, the OBS provides a narrow angle-distributed atomic oxygen beam. Efficient cracking of O_2 with a degree of dissociation of more than 80% is achievable, so O_2 background pressure in the chamber is very low compared to other sources.

The new Oxygen Atom Beam Source.

The OBS can obtain a high oxygen flux of up to 10^{16} atoms/s.

www.mbe-components.com

IN BRIEF

Research MBE sales

Riber has received two orders from unnamed research clients: one for a Compact21T system; one for its new Compact21TM research tool, a modified version of the Compact21T. The Compact21TM's reactor can replace the reactor of existing MBE32 research machines (allowing updating). About 260 MBE32s have been sold in the last 20 years.

www.riber.com

Cluster tool sales

Veeco Instruments Inc has received two orders for its 4x4"-wafer GEN200 MBE cluster tool:

- Fiber laser and amplifier maker IPG Photonics of Oxford, MA, USA is to increase production of 980nm GaAs-based lasers, for which it is building extra fab capacity.
- A "multi-billion dollar electronics manufacturer" will collaborate at Veeco's MBE Process Integration Center in St Paul, MN, USA on developing deposition of oxide films on silicon, followed by delivery of an identical system to the customer.

www.veeco.com

Veeco COO joins FEI

Don R Kania, president and chief operating officer of Veeco Instruments, has left the company to become president, CEO and board member of metrology equipment supplier FEI Company in Portland, OR, USA. "At present, Veeco will not replace the president/COO position," said its chairman and CEO Edward H. Braun.

Kania has held technical and general management positions at both Lawrence Livermore and Los Alamos National Laboratories, and joined Veeco in 1998. He replaces president, CEO and chairman Vahe A Sarkissian. FEI has not yet chosen a new chairman.

www.fei.com

IN BRIEF

Bridging lab to fab

Suss MicroTec AG of Munich, Germany has introduced its latest BlueRay probe system, for discrete devices, MEMS, RF and opto devices. It is capable of testing up to 70,000 die per hour, and is the only prober that can be upgraded from semi-automated to fully automated in the field, it is claimed.

A wafer-handling robot can be quickly docked onto the system, and undocked as needed. The test platform can now remain constant from ramp-up to production, minimizing change-over costs and capital investments.

"Essentially, it's the bridge from lab to fab," says Stojan Kanev, international product manager for Test Systems.

www.suss.com

Freiberger's MD becomes CEO

Freiberger Compound Materials GmbH of Freiberg, Germany, which claims about a 30% share of the GaAs wafer market, has made Dr Hermann Schenk CEO.

He replaces Dr Klaus Romanek, who has decided to pursue new professional interests. Schenk joined Freiberger in June as managing director, after founding Covion Organic Semiconductors GmbH and serving six years as its CEO. Schenk has a Ph.D. in Physics from the University of Bonn.

www.fcm-GaAs.com

AXT CEO Phil Yin rings the changes

On 9 August, to mark the 20-year corporate anniversary of substrate maker AXT Inc of Fremont, CA, USA and its eighth anniversary as a public company, CEO Phil Yin presided over the NASDAQ stock market closing bell.

www.axt.com

Aviza and Tegal post continued growth

California-based plasma etch and deposition system makers Tegal of San Jose and Aviza Technology of Scotts Valley have both reported sales growth for the June quarter.

For its fiscal Q1/2007, Tegal had revenues of $6.6m, up 9% on the previous quarter and 116% on a year ago. Shipments included several 901ACS etch tools to "a leading US-based wireless component supplier undergoing a significant capacity expansion".

Net loss was cut from $2.5m a year ago and $2.3m last quarter to $1.8m. Gross margin rose from 22% and then 20% to 38%.

"Gross margin resulted principally from product mix, and we are clearly making progress towards our goal of achieving sustainable 40% plus margins," said Thomas Mika, president and CEO.

For its fiscal Q3/2006, Aviza's revenues were $43.7m, flat on a year ago but up 20.5% on the previous quarter, due mainly to Asia-Pacific increased sales. Gross margin was 24.6%, up from 15.6% a year ago.

Aviza shipped its Celsior next-generation single-wafer ALD system to manufacturing sites in Taiwan, China and Europe, including China's leading IC foundry, Taiwan's Inotera Memories Inc (for 90nm and below DRAM production), and "one of the world's largest DRAM suppliers" for 90nm production.

For fiscal Q3/2006, net loss was cut from $6.0m a year ago and $5.3m last quarter to $4.0m, Also, April's private placement of shares with Caisse de depot et placement du Quebec (CDPQ) for $15m boosted cash reserves from $3.9m at end-March to $17.9m at end-June.

Aviza expects revenues of $45-50m for the September quarter, and an operating profit in the December quarter.

www.tegal.com
www.avizatechnology.com

STS appoints interim COO

Plasma etch and deposition tool maker Surface Technology Systems plc of Newport, UK has appointed Dr Robin Johnson as its interim chief operating officer.

Since returning from being president of a component-making company in North America in 2000, Johnson has overseen change management within businesses seeking rapid deployment of their technology to market.

"The time between research and volume production is getting shorter and shorter," says Johnson. "Through capitalizing on the opportunities new technologies offer, I intend to bring strong competitive advantage to STS that will benefit our customers globally."

Johnson has a PhD in Solid State Physics and an MBA in International Business and Management of Innovation.

Johnson has delivered innovative products to companies such as Intel, Dell and IBM, says STS. "His impressive track record at creating productive, efficient companies makes him a strong addition to our team...as we continue to take new products from R&D through to production and capitalize on the strong momentum we have gained," said CEO John Saunders.

www.stsystems.com

Synova raises $8m for apps centers

Synova of Lausanne, Switzerland, which supplies Laser MicroJet systems for wafer dicing based on a water-jet-guided laser beam, has raised CHF10m ($8.1m) in financing (mainly from Swiss banks).

The funds will be used to develop micromachining centers (MMCs) in key regions worldwide. With over 50 full-production systems at 30 user sites, the MMCs will provide local support and application labs offering on-site product demonstrations.

Synova's technology is already qualified in the electronics market. At July's Semicon West event, it said that its first MMC will open in Silicon Valley in January, headed by Joseph Battaglia (former field sales and marketing development manager for North America at EFD/Nordson Corp) and containing the most recent Laser MicroJet tools (an LDS 300 A and an LCS 300). Future MMCs will open in 2007 and 2008.

Synova believes the local MMCs will help it to further penetrate not only the wafer-dicing market but also burgeoning, precision-centric sectors such as inkjet print-head MEMS, hard disk drives and organic LEDs. According to IDC, the OLED market is forecast to grow at a compound annual rate of 74% by next year alone.

● At April's Semicon Europa event, Synova announced its first executive management team: Martin Achtenhagen (VP R&D, a former long-wavelength VCSEL researcher at the Swiss Federal Institute of Technology, and leader of optical amplifier development at JDSU); Phil Durrant (VP, sales and marketing, formerly marketing director at SAW Components Dresden, Germany); Frank Meier (VP operations, formerly of HP); and Quoc Phong Dang (chief financial officer).

www.synova.ch

Ruggedized high-speed wafer scribing

New Wave Research of Fremont, CA, USA has launched the AccuScribe AS2000FX, the next generation of its diode-pumped, solid-state (DPSS) wafer-scribing systems. Throughput of up to 10 wafer per hour reduces operating costs in LED wafer-scribing applications. Also, the rugged and customizable platform is optimized for reliable, 24/7 operation in demanding environments.

High-speed performance is achieved via high-efficiency, high-stability, UV DPSS laser technology and advanced optical and image-processing technologies. Its industrial platform provides 4" wafer support capability and is easily customized, as well as advanced features to enhance work efficiency, including a highly accurate, repeatable and reliable X-Y stage, user-selectable energy output with stability feedback loop, advanced debris removal system and many other options to increase ease of use and productivity.

Other performance-enhancing features include a wafer-edge detection system that enables scribing of partial or broken wafers, increasing yields. Also, unique backside alignment capability enables scribing from the backside of wafers when opaque wafer materials make topside alignment and scribing impossible.

A single operator can perform all scribing operations via an intuitive and easy-to-use LCD-screen GUI, adjustable LCD panel and an industrial-grade computer system.

www.new-wave.com

IN BRIEF

GaN FET R&D

Kyma Technologies of Raleigh, NC, USA has signed a cooperative R&D agreement (CRADA) with the US Air Force Research Laboratory to understand how low-defect-density native GaN substrates might positively impact GaN FET device performance and reliability.

The aim is to characterize native GaN materials and FETs for RF applications. In late March, Kyma signed a similar CRADA with the Naval Research Laboratory on low-defect-density GaN substrates for high-power RF GaN FETs.

Since native GaN substrates are just becoming available, efforts to develop high-performance GaN FETs have relied on SiC substrates, says Kyma. While SiC has yielded excellent device performance demonstrations by several groups, persistent problems with device reliability must be solved before GaN FETs can be inserted into military systems. Such device reliability problems are considered to have roots in poor device layer materials characteristics that arise when a non-native substrate such as SiC is used.

"Native GaN substrates are a potential enabling technology for realization of ultra-high performance and reliability high-power high-frequency transistors needed for next-generation DoD and commercial RF applications. However, much work in materials and device characterization is needed," said co-founder and CTO Drew Hanser, technical lead for Kyma on both CRADAs. AFRL program manager for the CRADA is John Blevins.

"The improved understanding we hope to reach has the potential not only to positively impact RF FET applications but also can be leveraged across a broad range of other device applications of import to both the military and commercial sectors," added Keith Evans, president and CEO.

www.kymatech.com

IN BRIEF

Chairman drops COO and marketing roles

Laser diode maker Modulight of Tampere, Finland has announced the re-election of co-founder Seppo Orsila as chairman and his withdrawal from his operational role as chief operational officer and VP of marketing. As re-elected chairman, he continues to contribute to the strategic planning of the company.

"My decision stems from personal career aspirations and opportunity to experience different type of responsibility, business and organization to further develop myself," said Orsila. "The change will provide more room for our new emerging talent to rise and blossom as they take increasing amount of responsibility in the current climate of high growth and the constantly diversifying product range," he adds.

www.modulight.com

Opto center names associate director

Professor Eric G. Johnson, director of the Micro-Photonics Lab in the College of Optics & Photonics/CREOL, University of Central Florida and a fellow of SPIE, has been named as the new associate director of the Center for Optoelectronics and Optical Communications at the University of North Carolina at Charlotte (UNCC).

In May, the center moved into a new $24m, 90,000ft^2 facility (to be dedicated in September) that will house 25 optics faculty and several user facilities, including a cleanroom for photonic device fabrication. The center is also promoting industry partnerships and has lab space for commercial use.

Before joining CREOL in 2000, Johnson was VP of R&D at UNCC spin-off Digital Optics Corp in Charlotte.

http://opticscenter.uncc.edu

Flash LEDs for cell phones and cameras

Osram Opto Semiconductors has developed two 'super-bright' LEDs especially for flash lights.

The compact OSLUX, with its aspherical lens and luminous efficacy of 48lm/W, has beam characteristics suited for photo formats and provides homogeneous light right into the margins at a distance of 1–3m, says Osram. Illumination is optimized for rectangular photos. In the 1.15mx0.87m direct target area, it achieves more than 50lx. Good thermal properties, combined with short switching times, allow rapid flash frequencies and high output with 1500mA peak current. The LED and lens can handle SMT solder processes at up to 260°C.

CERAMOS can be combined with proprietary and customer-specific lenses, and has the versatility for applications in which space is at a premium (e.g. mobile phones) but high luminous intensity is still needed, says Osram. Lumen values correspond to those of OSLUX; lux values depend on the lens used. With low thermal resistance and short switching times, it can handle higher than normal currents and flash rapidly in succession.

Osram's CERAMOS LED for flashes.

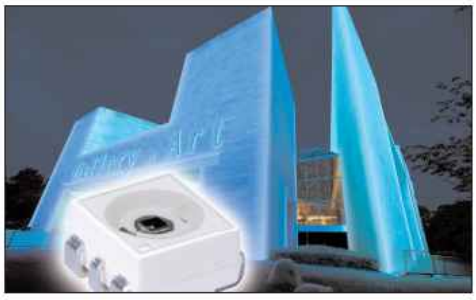
The LEDs are based on a 1mm^2 ThinGaN chip and can be operated either in pulse mode or with a constant current. They provide high levels of brightness for low power consumption. Rapid flash frequencies make even small mobile terminals fit for short flash sequences or complete series of pictures.

www.osram-os.com

Power TopLEDs boosted by thin film

Due to using thin-film chip technology, Osram Opto Semiconductors says its new Advanced Power TopLED is 50% brighter than its predecessor, and ranks between its standard Power TopLED and the high-power Golden Dragon LEDs.

At 140mA, the Advanced Power TopLED has an output of 19lm in green and amber, 15lm in white and red, 14lm in yellow and 5lm in blue. The high output makes blue, green and red LEDs fit for illuminated advertising and effect lighting, the company claims, and opening up new areas of application for all colours, particularly for blue and green LEDs which, like the other colour variants, can be used for area and effect lighting.



Osram's Advanced Power TopLED.

Existing LED lighting solutions can provide the same light with fewer sources, or the same number of sources can give more light, saving energy and reducing costs for the entire system. The SMT package ensures that the LEDs are compatible with standard solder processes.

www.osram-os.com

Taiwan DRAM firm sets up LED JV

A new blue LED chip making joint venture called EpiLED, with initial capitalization of $16.8m, is being established in Tainan Science Park by Taiwanese silicon DRAM memory manufacturer ProMOS Technologies (with a 29% stake) and process equipment maker Hermes-Epitek (with a 14.5% stake). ProMos chairman ML Chen will be chairman of the joint venture.

Trial manufacturing will start in Q2/2007, according to the Economic Daily News. Chen said that ProMos will supply semiconductor technologies, including MOCVD techniques.

The JV comes after much consolidation between Taiwanese LED chip makers in the last few years, including the merger of UEC and Epistar. But Chen says that, although LED product prices plummeted last year, this has stimulated demand. Indeed, this year has seen much investment by Taiwanese blue LED chip makers in new MOCVD capacity (see Issue 1, page 13).

● In October 2003, another Taiwanese DRAM maker, Powerchip Semiconductor Corp, established blue, green, and UV LED chip-maker Luxxon Technology Corp with $14.7m in capital. Luxxon plans to merge with fellow Taiwanese LED maker Arima Optoelectronics, according to the latter's president, PJ Wang, reported in DigiTimes at the end of July.

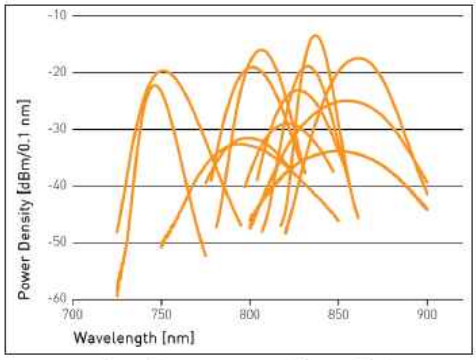
www.promos.com.tw

SLEDs for biomedical applications

Switzerland's EXALOS AG has added a 750nm product line to its family of superluminescent LEDs (which combine the spatial coherence of a laser diode with the temporal incoherence of an LED).

Like its 850 and 1300nm SLEDs (launched in January), due to their high output power and large bandwidth, as well as high suppression of second coherence peaks, the 750nm SLEDs are suited for optical coherence tomography and biomedical applications, resulting in high resolution and fast scan times. Spectra show a clean Gaussian shape with very low ripple values.

The EXS7505-1411 gives 3mW optical output power in a single-mode fiber and 21nm 3dB spectral bandwidth, and the EXS7510-1411 5mW and 14nm, respectively. The standard product is in a 14-pin DIL housing with built-in thermo electric cooler and monitor diode. Uncooled devices in TOSA housings are also available.



Power density vs wavelength for EXALOS' short-wavelength SLEDs.

● EXALOS AG has moved its corporate headquarters to a new facility with double the available space in Schlieren, in the Greater Zurich Area, Switzerland. EXALOS was spun off from Opto Speed (Zurich) AG in June 2003.

"We have already achieved double the total revenues of the last financial year after only six months of operations" said CEO Dr Christian Vélez.

www.exalos.com

IN BRIEF

Infinera gets CFO

InP-based photonic integrated circuit and digital optical network system maker Infinera of Sunnyvale, CA, USA has recruited Duston Williams as chief financial officer as it moves into its next phase of growth and expansion.

Williams will lead the finance and IT functions as Infinera continues to scale up its infrastructure, production, and staff. In June, Infinera won a contract with network operator Global Crossing and aims to increase staffing by 120.

Williams was executive VP and CFO at disk-drive maker Maxtor Corp, where he played a key role in reducing losses and restructuring the balance sheet, product lines, and manufacturing strategy, leading to acquisition by Seagate in May for $2.5bn.

www.infinera.com

Sales and Marketing VP becomes CEO

VERTILAS GmbH of Garching, Germany, which develops long-wavelength (1.3-2µm) InP-based VCSELs for communications, sensing and spectroscopy, has promoted Christian Neumeyr, VP Sales and Product Marketing, to CEO, as it enters a new phase of rolling out its product portfolio. In March, third-round venture funding, led by previous investor High-Tech Equity GmbH and new investor KfW Mittelstandsbank, raised Euro3.6m ($4.4m), enabling mass production.

In over 16 years, Neumeyr has held executive positions at companies such as Infineon, Multilink Technology and Broadcom. Accomplishments include establishing and managing fast-growing and profitable business lines, expanding businesses into new markets, and being a key team member of a NASDAQ IPO.

www.vertilas.com

Green LEDs get $1.8m SSL boost

Under the US Department of Energy's Solid State Lighting Core Technologies Program, $1.8m has been awarded to a team led by professors Christian Wetzel and E. Fred Schubert of Rensselaer Polytechnic Institute's Future Chips Constellation for the three-year project "High Performance Green LEDs by Homoepitaxial MOVPE" (one of 16 chosen for funding in March's Funding Opportunity Announcement, but starting in August).

The team aims to develop improved III-nitride materials and processes to boost green LEDs efficiencies by a factor of 2-3, to fill the 'green gap' in white solid-state lighting sources combining red, green and blue LEDs. Subcontract partners are Kyma Technologies Inc of Raleigh, NC, USA, which makes bulk GaN-based substrates and epiwafers (with Dr Drew Hanser, co-founder and CTO, as principal investigator) and Crystal IS Inc, which makes bulk AlN substrates.

Kyma says that key materials improvements are expected to arise from use of its low-defect-density native GaN substrates. Such materials and process improvements must be realized to fully capitalize on solid-state lighting, generally considered to be the largest nitride device market opportunity. According to Strategies Unlimited, the commercial market for nitride devices should grow from $3.2bn in 2004 to $7.2bn in 2009. The SSL program targets the development, by 2025, of solid-state lighting technology that, compared to conventional lighting, is much more energy efficient, longer lasting, and cost competitive, aiming for a product system efficiency of 50% with lighting that accurately reproduces sunlight spectrum.

Under the program, Kyma will continue to develop their native crystalline GaN materials technology and will also provide both polar and non-polar native GaN substrates to the researchers for epitaxial growth, device fabrication and performance testing. The addition of native non-polar GaN substrates to Kyma's product line was announced earlier this year and is the highest-quality non-polar GaN commercially available, claims Kyma.

Kyma says that nitride materials and devices experts, including University of Cailfornia Santa Barbara professor Shuji Nakamura, have touted the potential of non-polar GaN to enable LED performance improvements, but the efficiency of initial devices made from non-polar GaN-based materials has been limited by defects resulting from a non-native fabrication approach. Use of Kyma's native GaN substrates should enable reduction of such defects by a factor of over 10,000, claims Kyma.

"While much progress has been made in developing blue and green LEDs on sapphire and SiC substrates, much more progress is required, especially in the green, before nitride LEDs can begin to realize their full commercialization potential," says Hanser. "We believe that Kyma's native GaN substrates have the potential to enable the development of green LEDs with the kind of price point and operating characteristics that fulfill the promise of solid-state lighting for general illumination."

www.rpi.edu
www.netl.doe.gov/ssl/

Visible-blind GaN-based UV sensor ships from Orion

After releasing first samples in June, Hong Kong's Orion Semiconductor, which started designing and manufacturing GaN-based UV sensors in Q4/2005, has begun volume shipment of the OS100. Fabricated using a proprietary n-GaN Schottky process on sapphire at a foundry in Asia and assembled and tested in house in Guangzhou, China, the device is sensitive to UV-A, B and C radiation but completely blind to the visible spectrum.

While typical UV sensors generate a wide output range for a given UV index, the OS100 can be supplied to a +/-3% tolerance, enabling it to be used without in-circuit trimming. Alternatively it can be supplied in module form, producing a known amplified output for a given UV intensity. This minimizes design effort and increases ease of manufacture, it is claimed.

Typical applications include personal UV index measurement systems, pedometers with UV detection, watches, weather stations, fire detection systems, UV sterilization systems, climate control and medical equipment.

Orion's OS100 GaN-based UV sensor.

The device is available in a miniature surface-mount package or through-hole TO18 package suitable for harsh environments. Both are Pb free and RoHS compliant.

www.orion-semi.com

New III-V on CMOS silicon center

At July's Semicon West trade show, the university-research consortium Semiconductor Research Corp (SRC) of Research Triangle Park, NC, USA took the opportunity to announce its Non-Classical CMOS Research Center.

Five universities — led by University of California Santa Barbara (UCSB) together with Stanford University, University of California San Diego, University of Massachusetts-Amherst and the University of Minnesota — will collaborate to "stretch CMOS to its ultimate performance" by introducing III-Vs as alternatives to current silicon technologies.

Funds of up to $7m will be provided by SRC's member companies plus matching funds from the universities over an initial three-year program. Two more years of funding will be possible as options.

"We plan to ensure that Moore's Law will be alive and well for several more generations," said Dr Jim Hutchby, director of Device Sciences for the Global Research Collaboration, a unit of SRC responsible for narrowing the options for carrying CMOS to its ultimate limit. "And when the day comes that Moore's Law for classical silicon CMOS is no longer a viable solution, we'll have developed a new set of materials and devices for improvements to the speed and power of the historically successful CMOS technology."

Results from the research are projected to enhance speed for CMOS gates and lower power dissipation in circuits. Significant impact on chip manufacturing is expected as early as 2012–2014. In comparison, the International Technology Roadmap for Semiconductors (ITRS) calls for alternative materials to be available to address production at the 22nm level around 2016–2019.

"We expect that a new class of compound semiconductors can provide better peak velocities and lower voltages and allow the industry to supplement silicon's critical paths for speed and power," said Center director and UCSB professor Mark Rodwell. "This new research effort proposes to benefit a long line of applications and users."

Benefits will serve chipmakers and end-users for communications, computing, gaming, automotive and consumer electronics, and a wide range of other applications dependent on silicon's performance.

As an example of the potential for technology and footprint improvements provided by compound semiconductors, Rodwell cites the incorporation of InGaAs to the preamps in satellite dishes, providing shrinkage of the dish from 5 feet to 1.5 feet wide in less than 10 years while doubling reception quality.

Dr Jim Hutchby, director of Device Sciences for SRC's Global Research Collaboration unit, talked to *Semiconductor Today*.

Will research focus exclusively on III-V semiconductors, or first enhance silicon CMOS then introduce III-V CMOS?
The Device Science's area of SRC has been and is currently funding research on specific approaches and related topics for enhancing silicon CMOS (e.g. we have supported research to explore various approaches to high-k, metal gate stacks, to understand and apply biaxial and uniaxial strain to Si MOSFETs, and to exploit multiple-gate FET structures). The Non-classical CMOS Research Center will focus on forming both n- and p-channel MOSFETs in III-V materials embedded in an otherwise silicon technology (in terms of isolation, interconnect, etc) to form III-V CMOS transistors integrated on silicon.

Which materials will be investigated?
Compound semiconductors addressed by the Center will include InGaAs, InP, and GaSb, among others.

What is the schedule for achieving the objectives?
Our objective is to demonstrate III-V n- and p-channel enhancement-mode MOSFETs with high drive currents, low intrinsic transistor delays, and very low leakage currents, and to fabricate and demonstrate state-of-the-art, highly scaled, III-V MOSFETs integrated with silicon by the completion of the Center.

Will the Center collaborate with other research organizations?
We do not have any such collaboration with any other organizatons underway in III-V MOSFETs at present. However, we remain open to collaborations with other organizations. For example, we currently collaborate with the US National Science Foundation in a related topical area.

- SRC facilitates semiconductor research among its community of 23 companies and partners and 100 universities worldwide.

Established in 1982, SRC drives long-term semiconductor research contracts on behalf of its participating members: Advanced Micro Devices, Applied Materials, Axcelis Technologies, Cadence Design Systems, Freescale Semiconductor, Hewlett-Packard, IBM, Intel, LSI Logic, Mentor Graphics, The Mitre Corp, Novellus Systems, Rohm and Haas Electronic Materials, and Texas Instruments. SRC also seeks to leverage funding from global government agencies.

www.src.org

SemiSouth, II-VI open SiC fab

More than 150 people attended the opening of SemiSouth Laboratories' new high-volume SiC epiwafer and device fabrication facility in Starkville, MS, USA; the 'first major semiconductor manufacturing operations in Mississippi'. At the same ceremony, II-VI Inc also announced the opening of their SiC wafer processing facility in the same complex. SemiSouth has strategic supply relationships with II-VI and SiCrystal AG, and has a supply arrangement with Cree.

The milestone is the result of "significant private investment and the strong support received from local, state and national government and leaders", says SemiSouth. Speakers included II-VI Inc CEO Dr Carl Johnson, Congressmen Chip Pickering and Roger Wicker, as well as Mississippi State University (MSU) president Dr Robert Foglesong.

SemiSouth was spun out of MSU in 2000 by two MSU professors: president and CEO Dr Jeff Casady and CTO Dr Mike Mazzola. Though now privately held, it still has a strategic alliance with MSU and its ongoing SiC R&D programs.

In September 2005, SemiSouth was chosen by Venturewire/Dow Jones as one of the top 50 emerging technology companies in the USA, prior to their inaugural Emerging Ventures conference in Boston, MA, and in March was named by delegates at Semiconductor Venture Fair in Millbrae, CA as one of the 'Top Five most promising emerging semiconductor companies'. Also in March, SemiSouth closed an $8m credit facility with Ritchie Technology and Life Science Finance, to "fund growth and finance capital equipment requirements". This enables it to "leverage our SiC technology and our new SiC manufacturing cleanroom, to seek a larger presence in the overall power electronics market," says Casady.

SemiSouth Laboratories' new high-volume SiC epiwafer and device fab.

The cleanroom is now operational, and SemiSouth is currently transferring existing equipment and staff from its pilot line at MSU. Additional capital equipment has been delivered. The facility should be fully operational by the end of Q3/2006. SemiSouth says it has secured contracts with both governmental and commercial customers. The first major customer-proprietary product will ramp into production in Q4, based on SemiSouth's patented SiC JFET technology.

SemiSouth has already doubled staffing in the last 12-18 months, but in May said it plans a five-fold rise in staffing from 45 to up to 250 within the next five years. It is currently seeking device and application engineers. The fab is expected to produce more than 50m components and generate annual revenue approaching $100m.

Keith Nootbaar, VP of sales and marketing, says that initial capacity at full operation (four-shift, 24/7) will be more than 1500 3" or 4" wafers per month, i.e. an equivalent of 7500 6" silicon wafers per month, given that SiC devices are generally 10 times smaller than equivalent silicon devices (allowing 10 times more die per wafer). As demand increases, capacity will be ramped with further equipment and operators, says Nootbaar. Fully equipped, the capacity will be up to three times the current equipment set.

Following June 2005's series A round of financing, SemiSouth expects to close a further investment of about $5m by early September. Funds will be used for new product development and to expand its commercial production ramp.

www.SemiSouth.com

II-VI reports record revenues, plus $1m 3" SiC order

In July, the Wide Bandgap Materials Group of II-VI Inc's Compound Semiconductor Group, which is based in Pine Brook, NJ, USA (and has a second SiC wafer production facility in Saxonburg, PA), received an order worth $1m for 3" SiC substrates from a "large domestic customer". The substrates will be delivered over the next 12-15 months, and will support the commercialization of GaN-based RF power technology for wireless base-station applications.

"This validates our view that the market for this leading-edge technology is moving forward rapidly", said Dr Thomas Anderson, the general manager of the Wide Bandgap Materials Group.

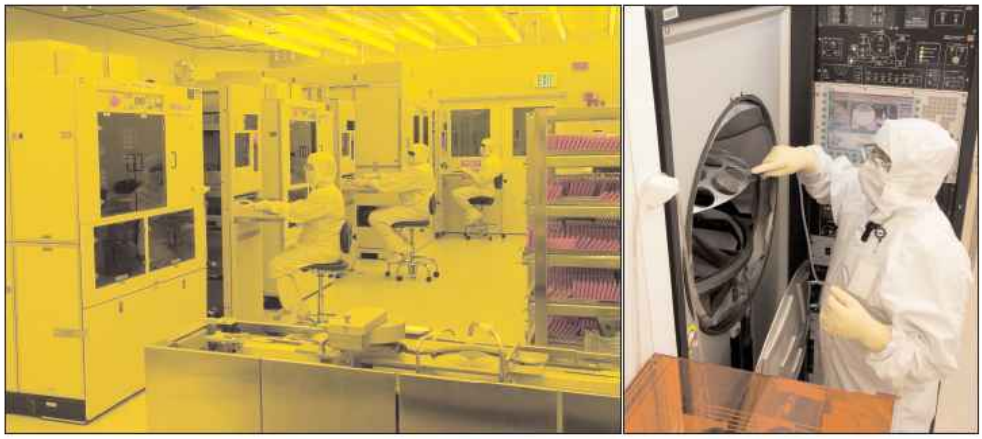
- II-VI had record sales of $64.9m for fiscal Q4 (to end June), up 14% on a year ago, and $232.5m for fiscal 2006 (up 20% on 2005). Compound Semiconductor Group sales were $13.8m for Q4 (up 22%) and $48.8m for 2006 (up 55%). The Group also had its third consecutive quarter of positive earnings.

www.iiviwbg.com

Cree's SiC and GaN electronics facility starts operation

Cree Inc of Durham, NC, USA has started operation of its 230,000ft^2 engineering and production facility in Research Triangle Park for making SiC- and GaN-based electronic devices. "The advanced power components being developed and produced here are important elements of our business strategy," said CEO Chuck Swoboda at the opening.

The site is one of the first commercial SiC and GaN production facilities devoted to serving the power and wireless infrastructure markets, says John Palmour, executive VP for Advanced Devices. "SiC and GaN technologies enhance the performance of traditional power-supply, motor-drive and wireless-communications systems by enabling the design of devices with significantly higher efficiencies than are available with similar silicon devices."



Cree's Advanced Device Clean Room: (left) step-and-repeat lithography tools; (right) 3" SiC wafers being loaded into a high-temperature oxidation furnace.

Devices produced at the site include high-efficiency SiC power components for power supplies and motor drives. Cree is also developing SiC and GaN RF devices for Department of Defense and WiMAX applications, and will provide SiC and GaN MMIC foundry services for defense and general-purpose applications. The initial staffing level is 150, and this is expected to grow with the power and wireless components businesses.

www.cree.com

Profits fall during investment in higher-value products

After its preliminary results in July, Cree has confirmed record sales of $423m for fiscal 2006 (to 25 June), up 10% on fiscal 2005's $384.5m. This is despite Q4 being down 1% on the previous quarter's record of $107.7m to $106.7m, at the low end of its $106–110m target.

CEO and chairman Chuck Swoboda had warned in April that unexpectedly high demand from mobile applications meant that LED chip output was capacity-limited while it transitioned from 2" to 3" wafers, from Durham to its new Research Triangle Park fab, and to producing high-power products.

Net income fell from $91.1m in fiscal 2005 to $76.7m in fiscal 2006. Fiscal Q4 income fell from $21m a year ago and $24m last quarter to $13.2m, below the target $17–19m.

Cree also confirmed July's warning of a quarterly drop in gross profit margin from 48% to 42% (below the target 46–47%) due to "lower LED revenue as a proportion of total sales [$84.5m, down 2% sequentially, due to greater competition and a fall in average selling price for chips in cell-phone keypads and display backlights, despite increased volumes], a less favorable mix within the LED product line, and incrementally higher production costs associated with new products".

"We can expand our business by leveraging our strengths in LED chip and SiC materials technology to broaden our product line with higher-value, component-level products for the emerging markets in LED lighting and power," said Swoboda. "These markets are projected to grow rapidly in the coming years as the global need for more energy-efficient and environmentally sound technology increases" — fiscal Q4 revenue for high-power electronic products was up 29% sequentially, to $5m.

R&D costs rose from fiscal 2005's $40m to $50.8m in fiscal 2006. The strategy may limit operating results in the near term. However, it is "critical to put Cree in position to increase shareholder value over the next several years". Swoboda expects a 60–70% boost in revenue over the next three years.

Cree said in July that, for fiscal Q1/2007, it expects LED chip sales down slightly due to a recent slowing in demand for mobile products. However, this should be mostly offset by increased sales of its Schottky diodes and XLamp LED lighting products (after initial problems scaling up production). Cree now targets sales of $102–106m.

www.cree.com

Microsemi buys back into silicon carbide

We profile Microsemi, a supplier of analog/mixed-signal ICs and high-reliability semiconductors that has acquired APT, a supplier of power semiconductors for RF, microwave, linear, and switchmode applications that has SiC fabrication and product development technology freshly licensed from Northrop Grumman.

Microsemi Corp of Irvine, CA, USA is a maker of silicon analog and mixed-signal ICs and high-reliability semiconductors for applications such as managing and controling/regulating power, protecting against transient voltage spikes and transmitting, receiving and amplifying signals. Markets include medical devices (e.g. implantable defibrillators and MRI systems), defense avionics and satellites, notebook computers, monitors and LCD TVs, and automotive and mobile connectivity applications. In Q1/2006, sales were $84.9m (up 16% on a year ago).

But last November Microsemi announced the $169m acquisition (finalized in late April) of Advanced Power Technology Inc (APT), a supplier of power semiconductors focusing on the high-power, high-speed markets for RF, microwave, linear, and switchmode applications, with 2005 sales of $64m. APT had 220 staff across SiC fabrication and product development in Boulder, CO, and a silicon RF line at its base in Bend, OR, USA (where in April it inaugurated construction of a new 3" SiC fab), as well as operations in Santa Clara, CA and Montgomeryville, PA, USA, and Bordeaux, France.

Microsemi highlights the combination of two high-performance analog companies offering both differentiated RF products and high-reliability products. "APT is a recognized leader in RF products, offering high-frequency products for the analog market as well as being a technology leader with its high-power switching products," claims James J. Peterson, Microsemi's president and CEO. Following "several years of consolidation", Microsemi is "moving forward in this next stage of our life cycle" he adds. "APT is the first step toward a focus on growing organically and through acquisition."

Microsemi says that SiC-based power semiconductors are strategically important to a wide array of next-generation high-reliability and commercial applications. The company offered SiC Schottky diodes starting in 2002 through a partnership but, due to a lack of demand and the high cost of the die itself, chose not to continue the product line.

Batches of wafers being loaded into a horizontal furnace in Microsemi's internal fab facility.

Interest in SiC stems from high-reliability customers (e.g. for military/radar applications etc). Microsemi therefore aims, in "a relatively short period of time", to offer its defense and avionics customers a much wider range of high-reliability product to address critical applications. However, it also sees "enormous potential" in APT's SiC technology for not just its defense customer base but also commercial applications. For example, it aims to rapidly expand its new product offerings to the medical market. More recent interest stems from applications like electric-powered cars.

Microsemi has been looking for a while how to get back into the SiC market

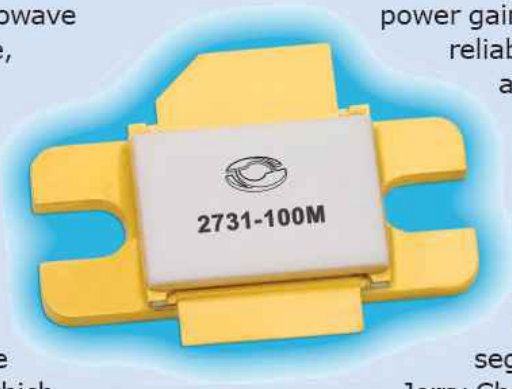
"Microsemi has been looking for a while how to get back into the SiC market", adds Steve Litchfield, vice president of Business Development. "But, because there are a lot of established players, we didn't want to start from scratch." In addition, there are 'revenue synergies', since APT was in the defense/aerospace and medical markets.

"APT's SiC strategy and capabilities were an important element in our decision to acquire the company," says

Power transistors at MTT-S

At the IEEE MTT-S International Microwave Symposium in San Francisco in June, Microsemi demonstrated its next-generation SiC RF power transistors line for pulsed applications from its new RF Power Products division (formerly a division of Advanced Power Technology).

As well as the SiC demonstration, Microsemi launched its 2731-100M high-power, high-gain medium pulse silicon transistor for S-band radar, which has a common base, class C, output stage offering 100W of peak power, 40% collector efficiency, 8.0dB power gain, and a hermetically sealed high-reliability package for Air Traffic Control and Military Radar applications.



A new chip design and processing enhancements offer high power and high gain at 2.7–3.1GHz, with a 250μs pulse width and 10% duty cycle. "This is a leading-edge S-band product designed to strengthen our position in that segment of the radar market," said Jerry Chang, director of Radar and RF Module Business. "This is a significant step for our overall product development and marketing strategy."

Litchfield, together with "knowledge of a pending licensing agreement". In January 2005, APT bought small, specialist SiC chip design company PowerSiCel of Boulder, CO, USA, which is now an integral part of the company and its SiC effort. Then, this February, APT licensed certain SiC technology from US defense contractor Northrop Grumman's Electronics Systems (NGES) division. This includes patents and manufacturing methods allowing it to manufacture proprietary high-performance microelectronic devices exclusively for Northrop Grumman (forming an exclusive foundry supplier relationship).

NGES has spent "millions" on SiC research, says Litchfield, and has several contracts to expand its expertise with several device types. However, Litchfield says that Northrop Grumman "no longer wanted to be involved in captive manufacturing of components", preferring instead for costs to be driven down, especially because of the proliferation of merchant SiC manufacturing.

In addition, says Litchfield, Microsemi may work with Northrop Grumman on product extensions ("since Northrop Grumman has other products, it makes sense to license those", he says) as well as products for sale in non-defense sectors.

However, the license also allows Microsemi to develop (with partners such as existing customers) other SiC devices of its own for commercial purposes. "Development of SiC products for both switch-mode and RF power conversion applications has been, and continues to be, a key strategic initiative," says the new VP and GM of the Power Products Division, Russell Crecraft. Of APT's transistor products, 50% are for RF and 50% are for power switching applications.

"We are impressed by APT's existing efforts in SiC and, with the combination of Northrop Grumman's extensive know-how in SiC technology, we expect to accelerate APT's progress towards becoming the leading supplier of SiC power semiconductor products," says Peterson.

Litchfield adds that Microsemi's plan is to take APT's products and 'militarize' them, as well as developing more switching devices for medical applications.

For the next couple of years Microsemi will focus on transistors for RF applications, Litchfield says, but switching will gradually become an increase in focus.

Litchfield adds that the short-term SiC focus will be on radar applications. Longer-term applications include switching bipolar junction transistors for avionics (i.e. electric aircraft) and hybrid vehicles (to reduce weight and noise), and commercial applications.

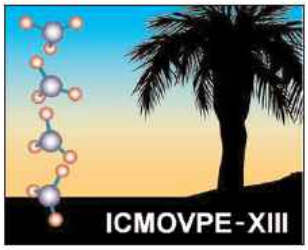
SiC-based power semiconductors are strategically important to a wide array of next-generation high-reliability and commercial applications

Microsemi plans to concentrate SiC fabrication in Bend. New equipment will be installed in early 2007, for first SiC wafer runs scheduled for mid-2007, according to Marc Vandenberg, director, Silicon Operations for the Power Products Division. Dedicated SiC development, design and prototyping capabilities will remain in Boulder. Although other changes were not identified, "where capabilities are duplicated, manufacturing efficiencies will be made", said Litchfield.

"There are significant efficiency gains to be realized on the operational level as well as the business opportunity level," concludes Peterson. "We can continue to drive revenue growth with the acceptance of our new products." For Q2/2006 (including the APT acquisition), Microsemi expected sales up 15-19% sequentially.

www.microsemi.com

Nitrides hogging the (UV) limelight



This year's International Conference on Metal Organic Vapor Phase Epitaxy in Miyazaki, Japan drew a healthy attendance of about 500 delegates, with a focus on developments in nitrides, including progress on deep ultraviolet emission.

As usual, the IC-MOVPE conference covered research on equipment, GaAs and related materials (including dilute nitrides) and other materials such as 'MOVPE of antimonide/phosphide heterostructures' by S. Watkins of Canada's Simon Fraser University and 'ZnO nanorod heterostructures and nanodevices based on catalyst-free MOVPE' by G.-C. Yi of Korea's Pohang University of Science and Technology. However, in tune with both research and industry trends, most presentations this year focused on GaN-related topics. This included, for example, a session on growth of BGaN, in which NTT reported a dislocation density in GaN of 2 x $10^8 cm^{-2}$ using BGaN micro-islands as buffer layers on sapphire.

UV emitters

In the first plenary session, in 'MOVPE of nitride UV emitters and detectors' professor M. Asif Khan, director of the Photonics and Microelectronics Laboratory at the University of South Carolina (USC), gave an update on his group's work towards efficient AlGaN-based UV emitters and detectors. Khan discussed using patterned sapphire substrates and pulsed MOCVD to achieve high-quality epitaxial lateral overgrowth of aluminium nitride.

Previously, in 2002, to reduce the defect density in AlN and to minimize the effect of lateral current crowding in devices on insulating sapphire substrates, Khan's group had developed AlN/AlGaN short-period superlattices to manage strain and enable the growth of thick crack-free n+-AlGaN buffer layers. The group also used a p-AlGaN/p+-GaN heterostructure to boost hole injection due to a polarization-field-induced hole accumulation at the heterointerface.

Khan's group had previously been first to report quaternary-based deep UV LEDs (emitting at 305nm) in 2001, and was then first to report sub-280nm LEDs in 2002, and first to 250nm in 2004, when the group also reported the first continuous wave 280nm deep UV LEDs with output powers of over a milliwatt. This was followed in 2005 by demonstrating the first deep UV LED-based white light source.

USC's Khan collaborates with Sensor Electronic Technology Inc (SET), which was spun off in 1999 from Rensselaer Polytechnic Institute by Remis Gaska (president and chief executive officer) and Michael Shur, but moved to Columbia, SC (home to USC) in 2001. In January 2005, SET became the first commercial supplier of DUV LEDs when it began shipping 265–365nm 'UVTOP' DUV LEDs. SET now offers 247–365nm UVTOP DUV LED die, for applications including biomedical equipment, water/air/surface purification/sterilization, biological agent detection, analytical laboratory systems and sensors, and industrial UV curing. This July SET agreed a strategic partnership with high-volume LED packaging house Seoul Optodevice Company to "accelerate low-cost, high-quality products to market".

Khan's group has now achieved 245nm LEDs in research. For milliwatt output powers, 250nm LEDs should be achievable, adds Khan.

Shortest-ever wavelength LEDs

Yoshitaka Taniyasu of Japan's NTT Basic Research Laboratories discussed the development of an LED with the record short emission wavelength of 210nm, using an AlN-based LED grown by MOCVD on a SiC substrate (published in May in *Nature*. vol. 441 no.7091, p325).

Although AlN's wide direct 6eV bandgap enables the emission of very short-wavelength deep UV radiation, it makes it difficult to dope AlN to produce a diode. Taniyasu *et al* raised the growth temperature to 1100°C and increased the flow of the $Al(CH_3)_3$ and NH_3 source gases, reducing defect density and impurity concentration by an order of magnitude. This enabled them to precisely control both n- and p-type doping of AlN layers with either silicon and magnesium, respectively, allowing fabrication of an LED comprising an AlN PIN homojunction between p- and n-type AlN/AlGaN superlattices, overlaid by a Pd/Au semitransparent p-type electrode and a Ti/Al/Ti/Au n-type electrode.

Taniyasu attributes emission to an exciton transition. He says that the development represents an important step towards achieving exciton-related LEDs.

But to increase the external quantum efficiency (from 10–6%, millions of times less efficient than visible LEDs) and to decrease the operating voltage (from the current 25V), the conductivity of the AlN layers must be raised, perhaps by developing more efficient p-doping methods. Taniyasu is therefore exploring alternatives to magnesium such as carbon, beryllium, zinc or cadmium.

The limiting factor is the defect density. The lattice mismatch between AlN and the SiC substrate produces dislocation densities as high as $10^9 cm^{-2}$. However, this could be reduced by instead using a native AlN substrate (which have become available at diameters of 2" only this year from Crystal IS and The Fox Group).

Backing up the invited presentations on UV emitters in the conference, one of two rump sessions concerned 'Ultraviolet emitters and epitaxial growth; exploration toward even shorter wavelength region', co-organized by USC's Asif Khan, Y. Ohba of Toshiba Corp's Corporate Research and Development Center (who also gave a presentation 'Low Threshold Current Density of GaN-Based Blue-Violet Laser Diodes Fabricated on Sapphire Substrate Using High-Temperature-Grown Single-Crystal AlN Buffer Layer') and H. Kawanishi of Kogakuin University (who also gave a presentation on 'Anisotropic polarization characteristics of lasing and spontaneous surface and edge emissions from deep-ultra violet ($\lambda \approx 240$ nm) AlGaN multiple-quantum-well lasers').

The other rump session, 'MOVPE modeling and simulation; are they real or imaginary?', discussed how far the understanding of MOVPE mechanisms has progressed, and to what extent the simulation based on that knowledge can predict the reality. This session was co-organized by M. Sugiyama of the University of Tokyo, K. Matsumoto of Taiyo Nippon Sanso, and J. Randall Creighton of Sandia National Laboratories, who also gave a presentation on 'Fundamental chemistry and modeling of group-III nitride MOVPE' in the conference.

GaN-on-silicon

The growth of GaN-on-silicon was reported by a few groups. In 'Strain gradients and strain engineering in thick GaN and GaN LED structures on Si substrates', Armin Dadgar of Germany's AZZURRO AG reported growth of crack-free InGaN/GaN MQW LEDs on a 6" silicon wafer on a production-line TSSEL 1x6"-wafer reactor using low-temperature AlN interlayers. Also, in 'GaN growth on 150mm-diameter (111) Si substrates', A. Ubukata *et al* of Japan's Nagoya Institute of Technology and Taiyo Nippon Sanso Corp demonstrated smooth Mg-doped (1-101) GaN on 7°-miscut silicon (100).

● The proceedings of the ICMOVPE conference will be published this December as a special issue of the *Journal of Crystal Growth*.

Recent developments in commercial MOCVD systems include larger capacity reactors. These include Aixtron's AIX 2800G4HT 42x2"-wafer Planetary Reactor (left), developed for high-brightness LED production and featuring optimized thermal conditions and an improved gas inlet (boosting yield and uniformity), and its Thomas Swan CRIUS 30x2"-wafer reactor (right), both based on Aixtron's new 'Integrated Concept'. The re-design of many system components, including the reactor cell, optimizes uptime and cuts cost. Features include compact footprint, improved maintenance, easier operation and handling, and improved reliability and reproducibility compared to previous reactors.

The wide blue yonder

Dr Mike Cooke looks at blue laser developments in the light of the recent market introduction of HD-DVD and Blu-ray optical storage disks, and surveys future applications and prospects for improvements in the technology.

With blue-light high density optical storage entering the market earlier this year, more than 10 years of development towards a commercial GaN-based laser diode (LD) seems to have achieved a successful outcome. Many difficulties have been met, but there is still immense room for improvement. Also, having focused on creating one market for the product, it is now time to look for further applications and variations.

High-density pressure

Much of the pressure for high -density storage systems such as HD-DVD and Blu-ray, which are currently being introduced, comes from high-definition (HD) TV systems that increase both image resolution and frame rates. Current DVD and digital TV image resolutions are typically 720x480 pixels (NTSC, National Television System(s) Committee) or 720x576 pixels (PAL, phase-alternating line) with frame rates of less than 30 per second (fps). Proposed HD formats are 1280x720 pixels or even 1920x1080 pixels at up to 60fps. Also the maximum number of color levels per channel is increasing from 8-bit (256) to 10-bit (1024). Naturally, the bit rate for HD video is much increased. Naively, one could end up increasing data rates by a factor of almost (1920/720)x(1080/480)x(60/24)x(10/8), i.e. a factor of about 19x. However, the higher picture resolutions are generally used with lower frame rates and vice versa, so, with the usual compression techniques, a full 19-fold increase is not intended. While single-layer DVD disks have a capacity of just under 5 Gigabytes (GB), HD-DVD offers 15GB and Blu-ray 25GB. Double-layer disks offer twice the capacity.

Blu-ray and HD-DVD are essentially developments of compact disk and DVD technology. Data is encoded either as a series of pits (read-only) or crystalline/amorphous (read-write) regions, typically on 120mm diameter disks. Laser light is used for its coherence benefits in terms of focusing and interference. Data is written or erased by the laser melting the phase-change medium, which is cooled either 'slowly' to achieve crystallization or quickly to produce amorphous material, affecting the reflectivity of the surface. For greater storage density, the laser light has to be focused to a smaller spot, which means reducing the wavelength to about the same size.

The Blu-ray laser has a 405nm (blue-violet) wavelength, compared with 635nm or 650nm (red) for standard DVDs and 780nm (infrared) for CDs. HD-DVD also uses the 405nm wavelength, but differences in disk structure (such as a thicker protection layer) and other system features mean that the spot is less tightly

HD-DVD and Blu-ray formats see first commercial launches

The high-density DVD (HD-DVD) format is supported by the DVD Forum, while Blu-ray is an independent format that some see as analogous to the difference between the DVD Forum's 'dash' rewritable format (DVD-RW) and the 'plus' of the DVD+RW Alliance.

The DVD+RW Alliance split away from the DVD Forum "to develop and promote a universally compatible, rewritable DVD format to enable true convergence between personal computing and consumer electronics products" (for further information, see www.dvdrw.com/alliance/history.htm).

Toshiba released the first HD-DVD player in Japan on 31 March 2006, and a number of players debuted in the USA in April (e.g. the RCA HDV5000; below, left). The US release for Blu-ray was first set for 23 May, but was delayed to 25 June, when Samsung launched its BD-P1000 player (below, right). Another round of Blu-ray players is due for launch in third-quarter 2006. Sony's Playstation 3 will use Blu-ray, at an increased price, and is due for release in November (already represents a postponement for this application). www.blu-ray.com/players

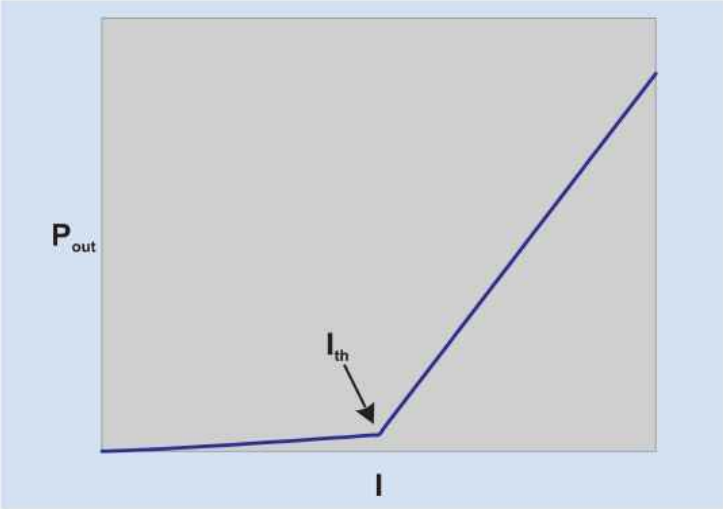


Figure 1: Light output power characteristics of a laser diode. The slope efficiency of laser power above the threshold current is given by dP_{out}/dI.

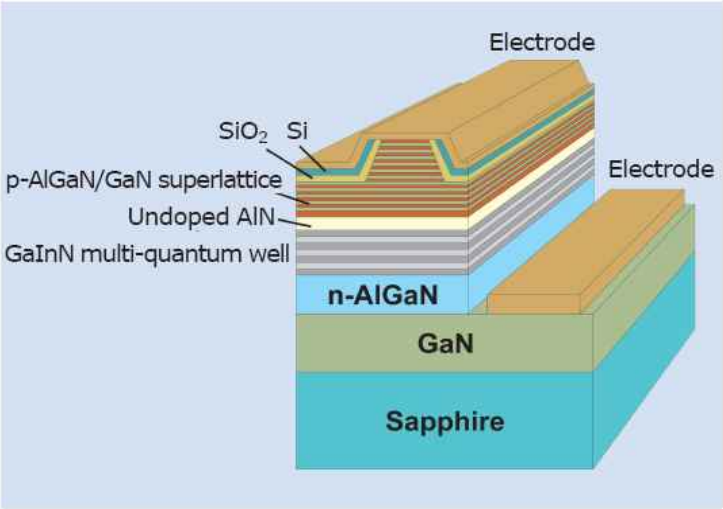


Figure 2: Laser structure on sapphire substrate. Since the substrate is insulating, electrical contact has to be made on one-side of the chip surface.

focused, leading to lower storage density. HD-DVD systems tend to be lower cost (~$500) compared with Blu-ray (~$1000).

As with DVDs, one demand is that the HD-DVD and Blu-ray optical disk systems also handle the previous formats (DVD/CD). This requires three-laser systems, preferably in a module. For DVD, the laser is typically built using the AlGaInP quaternary system, while the requirements of CD storage are met by AlGaAs.

The 405nm laser is based on wide-bandgap AlGaInN nitrides. While AlGaAs and AlGaInP can be grown on a single GaAs substrate, it is difficult to achieve monolithic three-laser systems. Instead, GaAs-based DVD/CD laser chips are mounted on the GaN substrate alongside the blue laser chip. In terms of thermal performance, GaN has comparable thermal conductivity (200W/m/K) to those of the usual two-laser mounting materials (Si, 130W/m/K; AlN, 285W/m/K).

Blue lasers

For DVD use, lasers must have high output power and reliability. A typical definition for the mean time to failure (MTTF) reliability measure involves a certain percentage increase in current that is required to maintain light output power at a given temperature. The device "fails" when the operating current has increased to this level (e.g. a 20% current increase for 50mW output power at 70°C). High operating temperatures are used to accelerate degradation and to perform burn-in testing for weeding out early failure modes.

In a laser diode, the light emission is non-lasing (and incoherent) until the threshold current is reached (see Figure 1). This threshold represents the point at which the gain from stimulated emission equals the absorption in the active layer. This requires a large amount of carriers (electrons/holes) and light in one place. Since the production of non-lasing light is inefficient, it is necessary to reduce the threshold current as much as possible. A high threshold current indicates that most of the energy going into the device is being wasted and this raises operating temperatures, increasing the likelihood of failure. Also, once reached, one requires as much of the extra current above the threshold to be converted into laser light as possible (slope efficiency = dP_{out}/dI).

Since one is also trying to control the laser for the purpose of reading or writing data, low-noise operation is also vital. This is enabled through control of the horizontal and vertical transverse properties of the light wave in the active layer of the laser device. One wants a single wavelength mode to emerge from the waveguide structure formed from the active and associated barrier and cladding layers. Fortunately, the correlation between bandgap energy and refractive index in a semiconductor laser diode structure generally allows one to confine carriers and light together.

The transverse modes are also important for controlling the nature of the output light such as its far-field properties. 'Astigmatism' results when the light appears to diverge from different points relative to the horizontal and vertical transverse directions. Such astigmatic light is difficult to focus, which is a key requirement for reading off and writing on small areas. To stabilize the transverse modes, a very narrow 2μm-wide dielectric ridge is currently used, but this results in the p-type electrode having a very small surface area, which increases the contact resistance to tens of ohms, pushing up the operating voltage of blue-violet lasers and creating heat.

The most reliable blue-violet nitride semiconductor lasers so far have been based on a GaInN active layer. The first reports of GaN-based pulsed blue-violet laser operation appeared in 1995 (Nakamura *et al* (1996) *Jpn J. Appl. Phys.* **35**, L74; Akasaki *et al* (1996) *Elec. Lett.* **32**, p1105). Stimulated emission can be

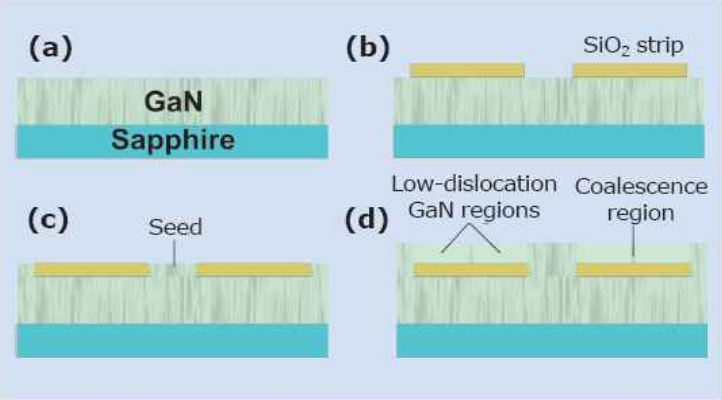


Figure 3: Epitaxial lateral overgrowth: (a) GaN layer on sapphire (or SiC) substrate; (b) silicon dioxide mask; (c) epitaxial growth in window; and (d) lateral growth over mask creates areas with reduced dislocations.

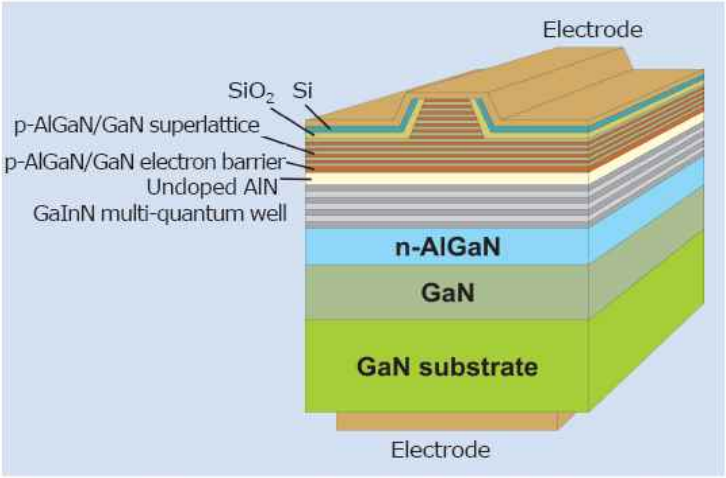


Figure 4: With a conducting GaN substrate, electrical connections can be made to the top and bottom of the device, simplifying the manufacturing process.

achieved from transitions between the base of the conduction band to a state in the heavy-hole band (the recombination of an electron and a hole). The layer absorbs radiation (negative gain) when the excited carrier density is below $10^{19}/cm^3$, a level that is an order of magnitude greater than in GaAs-based lasers. The result is that the threshold current in GaN-based lasers is large.

The 'traditional' substrate material (since the early 1990s) for GaN devices has been sapphire, based on the independent work of the groups led by Akasaki and Nakamura. However, sapphire is insulating and requires the etching of elaborate step 'mesa' structures to make electrical contact with the n-type nitride layers (see Figure 2). Further, since there is a large mismatch between the GaN and sapphire crystal structures, it is necessary to use dislocation-reducing techniques such as epitaxial lateral overgrowth (ELO) to create lasers with a reasonable lifetime (see Figure 3). Typical lifetimes for lasers on sapphire without dislocation-reduction techniques are a paltry 40 minutes of continuous-wave 1 mW output power. Nakamura *et al* (1997 *Appl. Phys. Lett.* **70**, 868) describe this as a 'long lifetime' for room-temperature continuous-wave operation of InGaN multi-quantum-well laser diodes.

Dislocations are observed as dark spots in photoluminescence measurements excited, for example, by a 325nm He-Cd laser, with a detection wavelength of 363nm. Where the regions of ELO meet (coalescence), dislocations are also observed (Figure 3(d)). ELO laser structures have to be grown over the regions between the growth seed windows and coalescence. While sapphire substrates have dislocation densities of more than 10^8–$10^{10}/cm^2$, using ELO allows this to be reduced to 10^5–$10^6/cm^2$ away from the coalescence and seed regions. Other heteroepitaxial substrates, such as silicon carbide and spinel ($MgAl_2O_4$), have been used to try to improve matters, but with only limited success.

Despite the expense, for laser diode production it has been found that pure GaN substrates have many attractions, such as much reduced dislocation levels. Further advantages of pure GaN are its conducting nature, so that lasers with more traditional top and bottom electrodes can be created, easing the manufacturing process (see Figure 4), and better cleavage properties for producing the mirror facets of the active region. Thermal conductivity also favors pure GaN (200W/m/K) over sapphire (40W/m/K), since thermal control is more critical for laser diode systems compared to conventional light-emitting diodes.

The first lasers on free-standing GaN (Nakamura *et al* (1998) *Jpn J. Appl. Phys.* **37**, L309) used resistive substrates, so mesa structures were needed, as for sapphire-based devices. The first attempt at using conducting substrates (Kuramoto *et al* (1999) *Jpn J. Appl. Phys.* **38**, L184) was hampered by high dislocation densities ($2–4x10^7/cm^2$). By 2001, low-defect-density GaN substrates ($\sim10^5/cm^2$) were available (Motoki *et al* (2001) *Jpn J. Appl. Phys.* **40** (part 2), L140), enabling high-performance laser diodes to be produced with a much simplified manufacturing process. The width of the low-dislocation-density regions is expanded from ~6 μm for ELO/sapphire to ~150μm for low-defect-density GaN substrates.

Some of the developments leading to better devices include the use of low-temperature buffer layers, the formation of low-resistance p-type layers using Mg doping and electron radiation anneals, and improved growth of GaInN crystal layers.

A large number of structures have been tried, particularly for the GaInN active layer. Here, multi-quantum wells are common, but early attempts using up to 26 layers have been scaled back to around three. One reason for reducing the number of wells is to reduce threshold currents, as happens with conventional semiconductor lasers. In nitride lasers, in particular,

when there are too many wells, non-uniform hole injection results in a large overflow current (which overshoots the intended recombination region and hence does not produce laser light). In general, non-uniform hole injection hits both the threshold current and the slope efficiency.

P-type conduction is often difficult to achieve, and hole masses tend to be large in nitride semiconductors. To reduce operating voltages, a superlattice p-type clad layer is used (e.g. p-GaN/AlGaN) — see S. Nakamura *et al* (1997) *Jpn. J. Appl. Phys*. **36**, L1568. To keep the electrons in the active layer and to stop them overshooting into the p-type layers, an electron barrier (p-AlGaN) is often used. Also, the p-type layers are commonly produced by Mg doping. It has been found that Mg-doped layers tend to absorb light, which is counter-productive in a light emitting device. One response has been to shift the light towards the less absorbing n-type region (M. Kuramoto *et al* (2002) *Phys. Stat. Sol*. (a) **192,** 329). Another approach is to use an 'intermediate' layer (GaInN and AlGaN) to separate the Mg-doped regions from the active layer (M. Takeya *et al* (2002) *Phys. Stat. Sol.* (a) **192**, 269). Using an intermediate layer can cut absorption losses from up to 43/cm down to ~5/cm, which is a figure comparable with conventional lasers. If the distance between the active layer and the Mg-doped layer is kept to less than or around 100nm, then the internal quantum efficiency of the laser can be maintained. Reduced carrier overshoot also results in better temperature performance. The lower threshold resulting from the intermediate layers also suppresses noise. However, blue–violet laser diodes still have a larger relative noise intensity figure during high-frequency modulation and a larger temperature dependence of the threshold voltage compared with red lasers.

Breaking out of storage

GaInN active layers are not restricted to the narrow needs of optical storage devices. The possible GaInN wavelength range (482–365nm) covers blue–green to near-ultraviolet opportunities in medicine, biotech analysis, and full-color displays (see Figure 5). Increasing the indium content in the active layer increases the wavelength. However, for laser operation, the threshold current increases dramatically beyond 475nm, due to spatial fluctuations in the active layer's composition. Even at 482nm, thresholds are larger than for 400nm devices. So, for 'long'-wavelength nitride-based lasers, one not only needs improved substrates but also more uniform levels of In concentration in the active layer. Full-color displays need blue lasers emitting at 440–460 nm wavelengths at high power.

Shorter-wavelengths (UV) have biological applications such as medical sterilization, food processing and treatment of skin conditions such as psoriasis (for

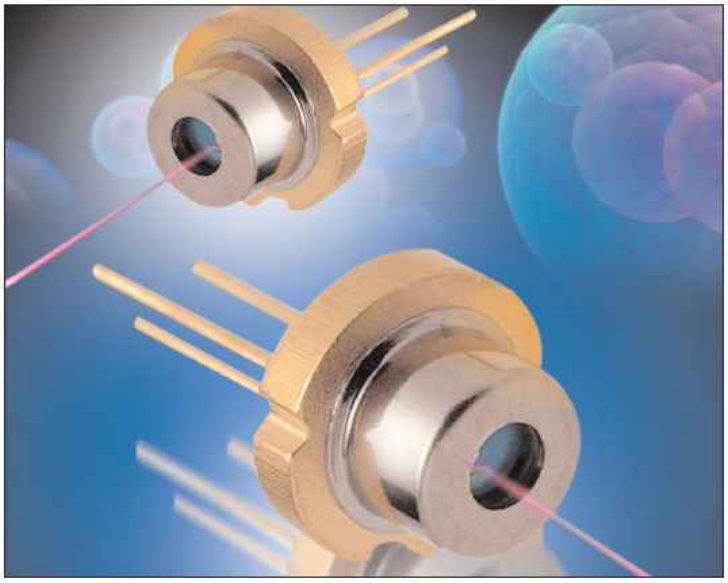


Figure 5: Sanyo's DL-5146-152 blue-violet (405nm), 35mW laser, for DVD and biomedical applications.

which the optimum wavelength is 311 nm). Application as an exposure source for leading-edge microlithography (193nm) would seem to be out of the range of semiconductor laser systems for now, although some of the older microlithographies based on bulky, high-voltage, incoherent mercury lamps, such as i- and g-line (365nm and 436nm, respectively), are in range.

An alternative in the short-wavelength sphere is the use of non-linear optics to up-convert longer wavelengths to short wavelengths. For example, infrared lasers combined with KTP ($KTiOPO_4$, potassium titanyl phosphate) and other related photonic crystals (e.g. niobium oxide, tantalum oxide lithium) can be used to produce blue or green light. The same principle has been attempted using blue GaN-based laser diodes with BBO (beta-barium borate) crystals to produce laser emission of tens of microwatts output at 210nm, which is not far from the required 193nm. Improvements in 'second harmonic generation' (SHG) crystals can be expected to reduce this to 200nm. However, the SHG crystal route is complicated and expensive. If possible, the direct production of UV laser light from a semiconductor laser diode would be preferred.

AlGaN laser structures on SiC substrates have managed pulsed operation at 343nm (Edmond *et al* (2004) *J. Crystal Growth* **272**, 242), and the recent production of AlN LEDs at 210nm (Taniyasu *et al*, *Nature*, p325, 18 May 2006) gives hope for further reductions. AlGaN double heterostructures have produced optically excited gain at 241nm (Takano *et al* (2004) *Appl. Phys. Lett.* **84**, 3567). Development requires improved internal quantum efficiency (the reduction of non-radiative recombination), increases in electron and hole density in the cladding layers, and improved carrier confinement. Also improved doping is needed to allow carriers to be transported more easily into the active region.

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