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## II-VI gains extra \$410m funding from Apple



Raytheon & GF partner on GaN-on-Si • Navitas to go public  
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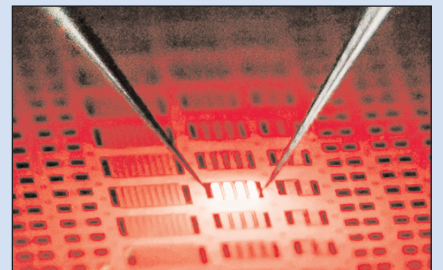
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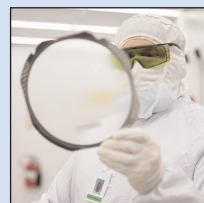
**p26** Raytheon and GlobalFoundries are collaborating to develop and commercialize GaN-on-Si for 5G & 6G mobile and wireless infrastructure.



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**p52** KAUST has reported InGaN-based red micro-LEDs that they plan to integrate with green and blue micro-LEDs to create full-color micro-displays.



Cover: Apple has announced a further \$410m award from its Advanced Manufacturing Fund for II-VI to expand capacity and accelerate the delivery of future components for iPhones, creating 700 new jobs in Sherman, Texas; Warren, New Jersey; Easton, Pennsylvania; and Champaign, Illinois.. **p60**

## GaN making gains in high power

Despite the shortage of semiconductors impacting automotive and consumer electronics production due to disruption from the COVID-19 pandemic, first-quarter 2021 shipments of smartphones were up 28% year-on-year, according to Omdia, as the delayed iPhone 12 roll-out saw Apple leapfrog Chinese brands Oppo, vivo and Xiaomi. Q1's growth was despite Huawei being squeezed out of the top 5 (see page 7). For 5G in particular, shipments have grown more than five-fold, with Apple gaining a leading 30% market share, displacing Samsung (see page 6).

Components hence in greater demand include the lasers for 3D sensing applications such as facial recognition, comprising one reason why Apple is investing an extra \$410m to expand manufacturing capacity at II-VI Inc (page 60). This includes the former Finisar VCSEL fab in Sherman, Texas, in which Apple invested \$390m in late 2017 (before II-VI acquired Finisar).

A consequence of the adoption of 5G (due to the need for backward compatibility with 4G/3G) is the increased RF IC content in handsets, by \$5–7 per smartphone reckons Qorvo. This has helped to drive year-on-year revenue growth in Q1 of 45% for Qorvo's Mobile Products Group (page 12) and 47% for Skyworks' Mobile business sector (see page 14).

Also, revenue growth of 14% for Qorvo's Infrastructure & Defense Products Group and 67% for Skyworks' Broad Markets sector is attributed mainly to the adoption of Wi-Fi 6. Skyworks also cites 5G infrastructure as a driver.

The need for greater data rates/bandwidth, range and power efficiency in wireless infrastructure is driving the replacement of incumbent semiconductor materials such as gallium arsenide with the wide-bandgap material gallium nitride. Qorvo, for example, cites its expanding shipments of GaN power amplifiers to major US MSOs for DOCSIS 3.1 broadband applications.

After initially being developed for defense applications, GaN transistor technology has since been applied to commercial sectors, especially as it is made compatible with silicon-based production processes. The latest example is Raytheon licensing its GaN-on-Si for GlobalFoundries to commercialize it in 5G & 6G mobile and wireless infrastructure applications (see page 26).

As well as RF, GaN has also been penetrating the power device sector, initially for low-power consumer electronics. For example, Transphorm has shipped its millionth GaN power device, addressing applications ranging from 45W fast-chargers through 1–4kW power supplies and automotive inverters up to 10kW. With its shipments doubling in each of the last two quarters, the firm is upgrading its stock listing from the OTCQB to the OTCQX market, while it targets the Nasdaq Capital Market (see page 30). Similarly, Navitas (which has shipped over 18 million GaNFast power ICs) is aiming to raise \$400m by going public, targeting expansion into higher-power applications (page 28). Meanwhile, Nexperia has launched second-generation 650V power GaN FETs targeting 2–10kW (page 27), ST has launched STI2GaN 100–650V integrated devices for automotive applications (page 24), and GaN Systems has added a 60A bottom-side-cooled transistor to its 650V range, targeting high-power EV applications (page 33).

GaN- and SiC-based power electronics accounted for 29% of the Q1 revenue of MOCVD system maker Aixtron (page 42), which has also demonstrated epitaxial growth of GaN layers qualified for 1200V applications on 200mm substrates, paving the way for GaN-on-Si as a less costly option to SiC for high voltages. See pages 78–79 for Yole's roadmap of the penetration of GaN devices into higher-power applications.

*Mark Telford*

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# Global 5G smartphone shipments soar 458% year-on-year to 134 million in first-quarter 2021

## OPPO, Vivo & Xiaomi close on Apple, benefiting from Huawei's collapse

Global 5G smartphone shipments soared 458% year-on-year from 24 million units in Q1/2020 to a record 133.9 million in first-quarter 2021, according to market research firm Strategy Analytics.

China's rapid adoption of 5G technology is powering demand. "Huge demand in China, a strong push from Apple iPhone, and a wave of value-priced Android models fueled a record quarter for 5G smartphone shipments," notes associate director Ville-Petteri Ukonaho.

Apple and China's domestic trio of OPPO, Vivo and Xiaomi benefitted most as demand exploded. OPPO, Vivo and Xiaomi closed on Apple, capturing 16.1%, 14.5% and 12.4% global market share in Q1, respectively.

Apple shipped a record 40.4 million 5G iPhones worldwide in Q1/2021, building on its strong performance

of 52 million shipments globally in Q4/2020. "Apple iPhone is the clear 5G leader, with a 30.2% 5G smartphone market share globally in the quarter," states director Ken Hyers. "Apple iPhone 12 5G is proving wildly popular across China, Europe and the United States, due to its sleek hardware design and surprisingly competitive pricing."

OPPO captured 16.1% global 5G smartphone market share in Q1/2021, more than doubling its share from 7.1% in Q1/2020. "OPPO has leapt ahead of domestic competitors Vivo and Xiaomi, taking advantage of Huawei's collapse in 5G smartphones to capture share," notes senior analyst Yiwen Wu. "OPPO's A55 5G and Reno 5 5G have become hugely popular in China."

Vivo increased its global 5G smartphone share from 10.8% in

Q1/2020 to 14.5% in Q1/2021 (taking third place) as its shipment volumes rose by 646% year-on-year from just 2.6 million to 19.4 million.

Samsung's global 5G smartphones shipments more than doubled from 8.3 million in Q1/2020 to 17 million in Q1/2021. However, its 5G smartphone market share fell from 34.6% in Q1/2020 to 12.7% in Q1/2021.

"The surge in 5G volumes in China, allied with the Apple factor, inevitably had a negative impact on share despite impressive product diversity from Samsung in 5G," comments director Woody Oh.

Rounding out the top five global 5G smartphone vendors on volume, Xiaomi's shipments rose from 2.5 million in Q1/2020 to 16.6 million in Q1/2021, boosting its market share from 10.4% to 12.4%..

[www.strategyanalytics.com](http://www.strategyanalytics.com)

Global 5G Smartphone Shipments (Millions of Units)	1Q 2020	1Q 2021	Growth YoY (%)
Apple	0.0	40.4	100%
OPPO	1.7	21.5	1165%
Vivo	2.6	19.4	646%
Samsung	8.3	17.0	105%
Xiaomi	2.5	16.6	564%
Others	8.9	19.0	114%
<b>Total</b>	<b>24.0</b>	<b>133.9</b>	<b>458%</b>

Global 5G Smartphone Marketshare (% of Total)	1Q 2020	1Q 2021
Apple	0.0%	30.2%
OPPO	7.1%	16.1%
Vivo	10.8%	14.5%
Samsung	34.6%	12.7%
Xiaomi	10.4%	12.4%
Others	37.1%	14.2%
<b>Total</b>	<b>100.0%</b>	<b>100.0%</b>

Global 5G smartphone shipments and marketshare for top five vendors (numbers are rounded).

# Smartphone shipments up 28.1% YoY to 353 million in Q1

## Xiaomi, Oppo and vivo benefit as Huawei falls outside top 5

Global smartphone shipments grew 28.1% year-on-year (YoY) from 275.7 million units in Q1/2020 to 353 million units in Q1/2021, reckons Omdia, demonstrating that the smartphone form factor continues to be a key piece of technology for users worldwide.

While there is significant recovery, 2021 marks a period of much transition, and Huawei's role in the market will continue to change, says the market research firm. LG's announcement that it is exiting the market will impact multiple OEMs competing in the mid-range segment, all in the context of a component shortage.

Samsung took the top spot, shipping 76.1 million units, up 22.8% quarter-on-quarter from 62 million in Q4/2020 and up 29.2% year-on-year from 58.9 million in Q1/2020.

An early update to the Galaxy S line allowed Samsung to take market share from Apple in Q1/2020 and put a focus on its own flagships as well as its latest range of devices in the A series.

Apple continues to benefit from the delayed roll out of its iPhone 12 range. A blockbuster Q4/2020 was followed by the shipment of 56.4 million units in Q1/2021, up 46.5% year-on-year from 38.5 million in Q1/2020, as Apple continues to dominate the premium smartphone market.

Xiaomi reached third place in Q1/21, shipping 49.5 million units — up 78.3% from 27.8 million in Q1/20.

Shipments also grew by 4.9% quarter-on-quarter, from 47.2 million in Q4/2020. Xiaomi is solidifying third position, as Huawei is declining continuously compared with the competition.

Oppo and vivo continue to battle for fourth and fifth

places in the global rankings. In Q1/2021, vivo shipped 38.2 million units (up 10.7% on Q4/2020's 34.5 million and 95.9% on Q1/2020's 19.5 million). This is slightly more than Oppo's 37.8 million units (up 11.11% on Q4/2020's 34 million and 85.3% on Q1/2020's 20.4 million). Both firms are rapidly replacing Huawei in the China local market.

Huawei fell out of the top five global smartphone OEMs in Q1/2021, shipping 14.7 million units, down 55.5% on 33 million in Q4/2020 and 70% on 49 million in Q1/2020. Even after one quarter under a new US administration, there are no signs that Huawei's technology ban on US components and software is ending any time soon, notes Omdia. The global component shortage is adding additional pressure on the firm, as suppliers are looking towards other OEMs for stable business.

The previous Huawei sub-brand Honor shipped 3.6 million units in Q1/2021 — its first as an independent entity.

Motorola increased its shipments to 12.6 million units in Q1/2021, up 28.6% on 9.8 million in Q4/2020 and 128.1% on 5.5 million in Q1/2020. LG's exit from the smartphone business will open up opportunities for Motorola to further increase shipments throughout 2021, as both companies focus on the North America, Latin America and

Caribbean regions, Omdia notes.

Realme grew shipments by 86.9% to 11.4 million units, up from 6.1 million in Q1/2020 — enough for 8th place globally, despite its shipments falling by 20.3% quarter-on-quarter from 14.3 million in Q4/2020.

Transsion holdings brand Tecno shipments were 8.2 million units in Q1/2021, up 6.5% on 7.7 million in Q4/2021 and 133.4% on 3.5 million in Q1/2020. The Transsion family of brands is focused on markets in Africa, where there is still big demand for feature-phone replacement as well as Huawei's vacancy, notes Omdia.

Rounding out the top 10 is LG, which will leave the smartphone market by summer 2021. Its shipments grew by 26.2% year-on-year from 5.4 million units in Q1/2020 to 6.8 million units in Q1/2021, but this is down quarter-over-quarter by 18.9% from 8.4 million in Q4/2020.

"The smartphone market continues to show resiliency in the face of multiple challenges," comments principal analyst Gerrit Schneemann. "Global component supply shortage is looming large over the market. On the other hand, two well-known smartphone brands will disappear from the global smartphone market this year, in Huawei and LG, opening the door for other brands to reach new markets and buyers."

<https://technology.informa.com>

Rank	OEM	1Q21		4Q20		1Q20		QoQ	YoY
		Shipment	M/S	Shipment	M/S	Shipment	M/S		
1	Samsung	76.1	22%	62.0	16%	58.9	21%	22.8%	29.2%
2	Apple	56.4	16%	84.5	22%	38.5	14%	-33.3%	46.5%
3	Xiaomi	49.5	14%	47.2	12%	27.8	10%	4.9%	78.3%
4	vivo	38.2	11%	34.5	9%	19.5	7%	10.7%	95.9%
5	Oppo	37.8	11%	34.0	9%	20.4	7%	11.1%	85.3%
6	Huawei	14.7	4%	33.0	9%	49.0	18%	-55.5%	-70.0%
7	Motorola	12.6	4%	9.8	3%	5.5	2%	28.6%	128.1%
8	Realme	11.4	3%	14.3	4%	6.1	2%	-20.3%	86.9%
9	Tecno	8.2	2%	7.7	2%	3.5	1%	6.5%	133.4%
10	LG	6.8	2%	8.4	2%	5.4	2%	-18.9%	26.2%
	Others	41.3	12%	46.4	12%	41.1	15%	-11.0%	0.6%
	Total	353.0	100%	381.8	100%	275.7	100%	-7.5%	28.1%

Smartphone shipments (in millions) and market shares for the top 10 manufacturers.



# LED market to grow 8.1% to \$16.53bn in 2021

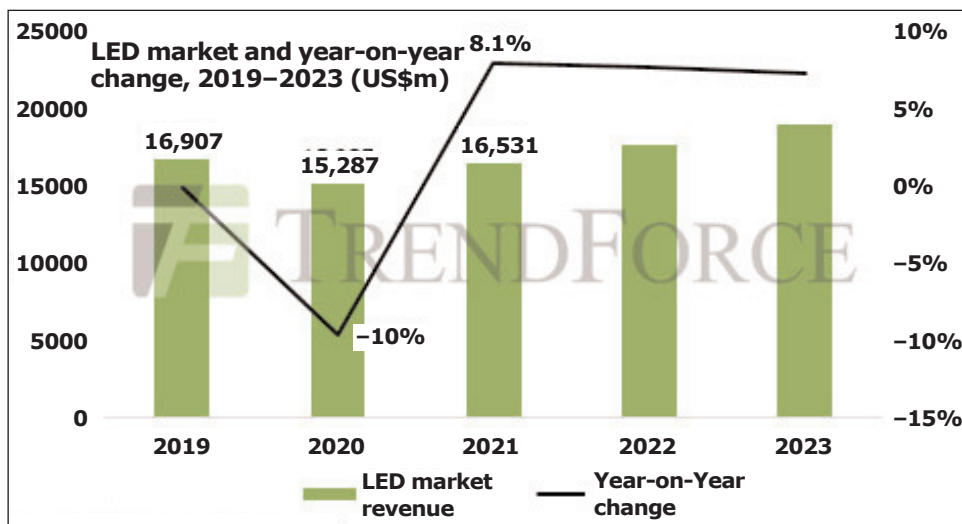
## Automotive/mini-LED applications to drive growth

Due to the impact of the COVID-19 pandemic in 2020, not only did LED revenue experience a downward trajectory but this decline also reached a magnitude rarely seen in recent years, according to market research firm TrendForce. However, as vaccinations begin taking place in first-half 2021, the LED market's long-stifled demand is expected to rebound from rock bottom. Hence, global LED market revenue (i.e. revenue from packaged LEDs, plus revenue from mini/micro-LED chips directly used in backlighting and other self-emitting products) will likely undergo a corresponding recovery this year as well, growing by 8.1% to a forecasted \$16.53bn in 2021. Most of this increase can be attributed to four major categories, including automotive LEDs, mini/micro-LEDs, video wall LEDs, and ultraviolet/infrared (UV/IR) LEDs.

TrendForce expects the soaring growth of NEV (new energy vehicle) sales and the accelerated adoption of LED lighting solutions in new models of conventional fossil-fuel vehicles this year to result in a persistent rise in the penetration rate of automotive LED solutions from 2020. Automotive LED revenue will likely grow by 13.7% to \$2.93bn in 2021, making it the fastest-growing sector among all LED applications.

Demand for emerging mini/micro-LED technologies in display applications, on the other hand, has been skyrocketing this year. In particular, the latest 12.9-inch iPad Pro and Samsung TVs both feature mini-LED backlighting technology, and these products will propel mini/micro-LED revenue up by 265% to \$380m in 2021, in turn giving the mini/micro-LED sector the second-largest growth among the four categories.

Third largest is the video-wall market. Emerging solutions, such as all-in-one LED displays for meetings and conferences, 5G 8K ultra-high-resolution video walls, home theaters and virtual production, have placed

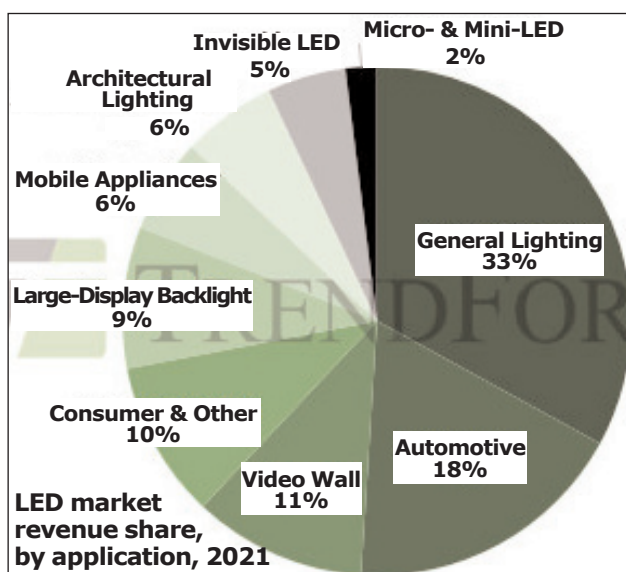


the video-wall market in the spotlight in recent years. Video-wall LED revenue is expected to grow at 12% to \$1.78bn in 2021, making it the third-largest growing sector in the LED industry.

Among all segments of the UV/IR LED market, the UV-C LED segment has garnered significant attention due to the onset of the pandemic. Not only have various brands been gaining major awareness of the importance of disinfection and sterilization but UV-C LED products have also been improving in terms of radiant power (optical power). Notably, home-appliance brand manufacturers from China, Europe, Korea and Japan are all planning to integrate UV-C LED technologies

into their products, and over 35 manufacturers are introducing or planning to introduce UV-C LED in their products. All in all, various applications are expected to drive UV/IR LED revenue up by 27% to \$830m in 2021.

On the whole, the gradual recovery and rebound of demand for traditional LED applications, as well as the upcoming ramp-up of niche LED technologies, will be the main drivers of LED market revenue. At the same time, both demand and revenue in the LED industry are expected to enter an upward trajectory accordingly due to two factors. First, the improvement in supply and demand in the LED industry has allowed prices of most



LED products to stabilize, with some products even seeing a price hike. Second, emerging LED applications command higher average selling prices (ASPs) and gross margins. TrendForce thus believes that LED makers will no longer have to reduce price by increasing order quantity. Companies in the LED industry are therefore expected to post improved earnings as a result.

[www.trendforce.com](http://www.trendforce.com)

## Mini-LED backlight TV shipments to reach 2.6–3 million South Korean brands trailblazed high-end market, while Chinese brands ramping up cost-effective models

For the past two years, brands such as Samsung, LG, TCL and Xiaomi have launched their own mini-LED backlight TVs, which are expected to reach annual shipments of about 2.6–3 million units in 2021 because Korean brands have successfully trailblazed the high-end market, and because Chinese brands have also been ramping up shipments via highly cost-effective models, according to TrendForce.

TrendForce's analysis of the current TV market indicates that organic light-emitting diode (OLED) models have become synonymous with high-end TVs due to the former's high color saturation and high contrast ratios, both of which produce high-quality images favored by consumers. However, LG Display is the sole supplier of OLED TV panels, and retail prices of OLED TV sets have shown no signs of weakening. Hence, TV brands have in turn transitioned their offerings to mini-LED backlight TVs, which likewise boast advantages of high bright-

ness and high contrast ratios. Not only have OLED TVs and mini-LED backlight TVs shaped the current competitive landscape of the high-end TV market, but these two products are also expected to set new standards for high-end TV specs going forward.

### Samsung's new mini-LED offerings to help redefine mid-range and high-end market segments against OLED TVs

Samsung has officially released its latest Neo QLED products in 2021; these TVs sport various features, including mini-LED backlighting, 55-inch to 85-inch display sizes, 4K and 8K resolutions, 8000–30,000 mini-LED chips as a backlight source, 500–2500 backlight zones, a 1,000,000:1 contrast ratio, and quantum dot technology (which delivers high color saturation). These features allow Samsung to compete on an equal footing with OLED TVs in the high-end segment while quickly increasing the viability of mini-LED backlight TVs.

### Chinese brands to be growth drivers as cost-effective products seize market share

Chinese TV brands TCL and Xiaomi have been cultivating their presence in the mini-LED TV market ahead of Samsung by releasing their own offerings before their Korean rivals. In particular, TCL's mid-range 6 series features 3840 mini-LED chips across 240 backlight zones, which allow for greater flexibility in terms of manufacturing costs. For instance, TCL's 75-inch, 4K UHD 6 series TVs retail for about US\$2000 less than equivalent offerings from Samsung, making TCL's products much more attractive for early adopters on a budget. By offering highly cost-effective products, TCL achieved annual shipments of 120,000 mini-LED backlight TV sets in 2020. TrendForce expects cost-effective products such as those from TCL to continue to serve a pivotal role in driving the shipment growth of mini-LED backlight TVs in 2021.

[www.trendforce.com](http://www.trendforce.com)

## Mini-LED display market growing at 91.1% CAGR

The global mini-LED display market was pegged at \$20.19m in 2019 and, from 2020, is estimated to be rising at a compound annual growth rate (CAGR) of 91.1% to \$1.9bn in 2027, according to a report from Allied Market Research.

Growth is being driven by the rise in demand for mini-LED backlights in the electronics industry, the surge in demand for mini-LED displays in the automotive industry, and growth in the adoption of smartphones, notes the report. However, the high cost of mini-LED displays is hindering market growth. In contrast, the surge in investment in mini-LED display technologies in Asia-Pacific should open up lucrative opportunities for the market players in the future, it is reckoned.

### COVID-19 impact

Due to the Covid-19 outbreak and consequent pandemic, mini-LED display production facilities were closed. The slowdown and unavailability of the workforce across the globe further reduced production. The travel bans and facility closures kept workers out of factories, creating a huge gap in demand-supply.

As Asia is the largest producer and exporter of products needed for automotive and electronics, the impact of Covid-19 outbreak in the region hampered the supply chain and production in 2020. However, demand for mini-LED displays is said to have improved post-pandemic.

Based on application, the TV segment comprised the largest share of the market in 2019 (at over a

quarter of the market). However, the automotive display segment is expected to have the highest CAGR (100%) during the forecast period.

Based on end use, the consumer electronics segment dominated the market in terms of revenue in 2019, contributing to more than three-fifths of the market. However, the automotive segment is estimated to register the highest CAGR of 102.7% during the forecast period.

The mini-LED display market in the Asia-Pacific held the largest share in 2019, accounting for nearly two-fifths of the market. However, the market across Europe is expected to register the highest CAGR of 100.2% during the forecast period.

[www.alliedmarketresearch.com/request-for-customization/10925](http://www.alliedmarketresearch.com/request-for-customization/10925)

# GaN & SiC power semiconductor market to exceed \$4.5bn by 2027

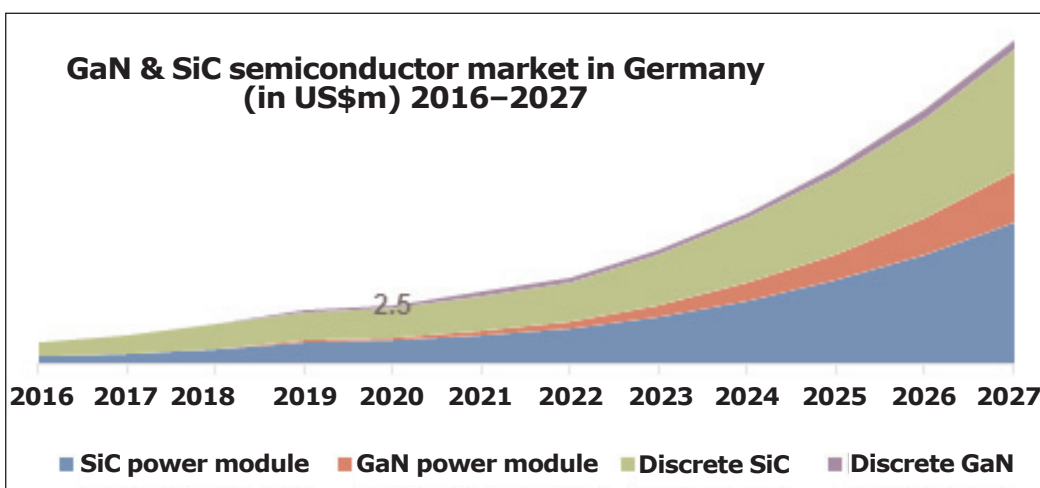
## Adoption of all-electric vehicles to drive growth

The gallium nitride (GaN) and silicon carbide (SiC) power semiconductor market is set to exceed \$4.5bn by 2027, driven by growing adoption in all-electric vehicles (EVs), according to a report by Global Market Insights Inc.

Compared with traditional silicon-based power semiconductors, GaN and SiC power semiconductors offer several benefits, such as high-power efficiency, high thermal conductivity and reduced footprint. These high-end features have increasingly led them to be integrated into on-board chargers, electronic control units (ECUs), DC-DC converters and traction inverters in electric vehicles (EVs).

However, the design complexity associated with manufacturing GaN and SiC power semiconductors is one of the major factors restraining market expansion. Deposition of GaN and SiC layers onto the substrate is difficult and requires high-precision manufacturing equipment such as PVD and CVD tools, which are high cost, further increasing the overall manufacturing cost of GaN and SiC power semiconductors. Furthermore, the low cost and simpler design associated with conventional silicon-based power semiconductors will pose a major challenge to market progression during the forecast timeline.

The SiC power module segment held more than 40% market share in 2020 and will see a 35% growth rate through 2027, driven by several features such as high reliability, greater electrical stability and optimized energy consumption compared with discrete GaN and SiC power semiconductors. SiC-based power modules are integrated with dedicated ICs, which helps the overall module to execute self-protection functions such as



short circuit, supply under voltage, and over-temperature. These features increase their acceptance for high-power electrical systems such as smart grids and smart energy meters. Market players are focusing extensively on increasing the energy efficiency, achieving low-noise operations, and reducing device footprint.

### Increasing usage of industrial motor drives in robotics and automation equipment to propel market

The industrial motor drive segment captured 3% of the market in 2020 and is expected to rise at a compound annual growth rate (CAGR) of 35% through 2027 on account of the increasing adoption of industrial motor drives for robotics and automation equipment in manufacturing and process industries. The manufacturing sector is extensively

**The SiC power module segment held more than 40% market share in 2020 and will see a 35% growth rate through 2027, driven by several features such as high reliability, greater electrical stability and optimized energy consumption**

incorporating industrial robots, automated assembly lines, conveyors, CNC machines etc, which require industrial motor drives. SiC and GaN embedded motor drives deliver high power efficiency and help to drive heavy loads in the starting position in industrial machinery. The proliferation of industrial robots across developed economies will fuel the acceptance of industrial motor drives in the market, it is reckoned.

### Expansion of renewable energy sector in US to foster market revenue

The North America GaN and SiC power semiconductor market is projected to grow at a CAGR of 29% through 2027 due to the proliferation of solar power plants in the USA. According to the Solar Energy Industries Association last December, in third-quarter 2020 US solar energy producers accounted for the installation of 3.8GW of solar PV capacity. The country reached a total installed capacity of 88.9GW in 2020. This will increase demand for GaN and SiC power semiconductors in PV converters, inverters, PV modules, generators, and solar battery systems, it is forecasted.

[www.gminsights.com/industry-analysis/gan-and-sic-power-semiconductor-market](http://www.gminsights.com/industry-analysis/gan-and-sic-power-semiconductor-market)

# Lighting LED price hike in Q2 to drive market to \$6.709bn in 2021

Prices to rise in Q2 by 0.3–2.3% for mid- and low-power, indoor products and 1.3–1.8% for outdoor, high-power products

Product prices across the overall lighting LED market are expected to increase by about 0.3–2.3% quarter-on-quarter in second-quarter 2021, reckons market research firm TrendForce.

This price hike can be attributed primarily to overall demand in the LED lighting market rebounding since Q1/21 and remaining in an uptrend in Q2/21. Furthermore, the industry-wide shortage of LED components in the upstream supply chain, caused by the onset of the COVID-19 pandemic, has yet to be addressed, compelling lighting product manufacturers to ramp up their procurement activities this year in order to avoid a component shortage, which they suffered last year. TrendForce hence expects this bullish trend in the LED supply chain to result in lighting LED market revenue growing 3.43% year-on-year to \$6.709bn for full-year 2021.

TrendForce further indicates that major suppliers of lighting LED packages, including Samsung LED, ams/Osram, Cree LED, Lumileds, Seoul Semiconductor, MLS and Lightning Optoelectronic, have since Q1/21 seen soaring revenues, which are expected to persist through Q2/21 due to a swift rise in demand for human-centric lighting (HCL), smart lighting, horticultural lighting and niche lighting (such as lighting for nuclear power stations, pharmaceutical manufacturing facilities, and metal fabrication plants).

Regarding the specific LED packages that will see a continued price hike, these products include mid- and low-power, indoor lighting LED products with under (not including) 1W in power consumption, such as 2835 LEDs, 3030 LEDs and 5630 LEDs. Prices of these products are expected to increase by 0.3–2.3%

LED Package	1Q21	2Q21(E)	QoQ Change
<b>Mid &amp; Low Power LED</b>			
2835 [0.2W]	5.37	5.49	2.2%
2835 [0.5W]	10.82	11.07	2.3%
5630 [0.2-0.5W]	30.57	30.66	0.3%
5630 [0.3-0.6W]	45.56	45.92	0.8%
3030 [0.5-0.9W]	41.09	41.86	1.9%
<b>High Power LED</b>			
3030 [1-1.3W]	45.04	45.85	1.8%
1-3W-Ceramic [MAX1000mA]	262.37	266.83	1.7%
1-3W-Ceramic [MAX700mA~800mA]	233.36	236.86	1.5%
1-5W-Ceramic [MAX1500mA]	276.74	280.34	1.3%
7070 [5-10W]	674.00	684.38	1.5%

**Forecasted quarter-on-quarter increases in lighting LED products, Q2/2021 (in US\$/1000 LEDs).**

quarter-on-quarter in Q2/21. On the other hand, a 1.3–1.8% quarter-on-quarter increase in prices for the same period can be expected for outdoor, industrial high-power lighting LED products with at least 1W in power consumption, such as LEDs with ceramic substrates and 7070 LEDs.

### Companies releasing products post-pandemic to secure market share ahead of high demand for LED lighting

Regarding the movement of lighting LED product prices from the perspective of the LED supply chain, the pandemic caused a price hike across various materials, such as metals and LED chips required for lighting LED manufacturing last year. Faced with the upward pressure of prices in their upstream supply chains, certain suppliers of lighting LED products

were subsequently forced to maintain their bottom lines by raising prices accordingly on lighting LED products, which had been sold at excessively low retail prices.

On the whole, however, despite the price hike across various upstream components, suppliers of lighting LED products are still actively improving their products' performances, including luminous efficacy and color saturation, and releasing products that fulfill the demand of post-pandemic applications in order to secure their market shares and competitiveness.

Some examples include outdoor atmospheric lighting LED products from Osram and Lumileds, as well as horticultural LED products from Cree LED for indoor horticulture and plant factories.

[www.trendforce.com](http://www.trendforce.com)

Lighting Applications	2020	2021(E)	YoY
General Lighting	5,328	5,428	2%
Architectural & Landscape Lighting	897	941	5%
Horticultural Lighting	261	340	30%
<b>Total</b>	<b>6,486</b>	<b>6,709</b>	<b>3%</b>

**Lighting LED market revenue, 2020–2021 (in US\$ millions).**

# Qorvo's quarterly revenue up 36% year-on-year

## Growth driven by demand for 5G smartphones and Wi-Fi 6

Qorvo Inc of Greensboro, NC, USA has reported full-year revenue growth of 24%, from \$3.239bn for fiscal 2020 to over \$4.015bn for fiscal 2021 (ended 3 April).

"We concluded our fiscal 2021 with an exceptionally strong March quarter," comments president & CEO Bob Bruggeworth. Fiscal fourth-quarter 2021 revenue was \$1072.7m, down just 2% from \$1094.8m last quarter and up 36% on \$787.8m a year ago (and exceeding the \$1025–1055m guidance), driven by demand for 5G smartphone handsets and Wi-Fi 6 and 6E. Demand was broad-based across customers.

### Mobile Products

Mobile Products revenue was \$808m, down slightly from \$826m last quarter but up 45% on \$556m a year ago due to the growth of higher-content 5G smartphones. Strategic highlights are listed as:

- achieving record shipments of low-, mid-high and ultra-high-band main-path solutions and Wi-Fi 6E front-end modules (FEMs) in support of leading Android smartphone OEMs;
- continuing to expand the firm's content opportunity with the leading Android OEMs by securing complete main-path solutions and secondary transmit in the diversity path;
- selection by a leading provider of consumer Internet of Things (IoT) products to integrate ultra-wideband (UWB) into a broad set of connected home devices;
- being honored by Samsung with its 'Best Quality Award' in recognition of Qorvo's innovation and outstanding performance in support of the Galaxy product family.

### Infrastructure and Defense Products

Infrastructure and Defense Products (IDP) revenue was \$265m, down slightly from \$269m last quarter but up 14% on \$232m a year ago.

- Growth was led principally by record Wi-Fi revenue. "The rate of adoption of Wi-Fi 6 is outpacing the

adoption we experienced for Wi-Fi 5, and the rollout is forecasted to span multiple years across enterprise, retail and service providers," notes Bruggeworth. "Qorvo is seeing a strong attach rate, given the performance advantages we enabled related to range, efficiency, signal integrity, and form factor," he adds. To that end, Qorvo secured the entire Wi-Fi 6 radio-frequency front-end (RFFE) bill of materials (BOM) in support of a major US MSO gateway and releasing multiple 5GHz iFEMs delivering improved band isolation and enhanced capacity and range in tri-band Wi-Fi 6 home mesh networks.

- In broadband, MSOs are increasing downstream and upstream data capabilities by upgrading to DOCSIS 3.1 infrastructure. During the quarter, Qorvo expanded shipments of DOCSIS 3.1 gallium nitride (GaN) power amplifiers to major US MSOs, offering greater efficiency, longer range and increased bandwidth to maximize upstream and downstream data connectivity.

- In infrastructure, Qorvo continued to ramp shipments of GaN power amplifiers and small-signal components to a major base-station OEM in support of US C-band massive MIMO deployments. It also captured initial design wins for mMIMO deployments in Canada, Japan and Korea.

- In automotive, Qorvo has for years been successful supporting the increased demand for in-vehicle infotainment. "During that time we've expanded our automotive portfolio and engage with customers to enable the transition to connected car through cellular V2Xm," says Bruggeworth. In the March quarter, these efforts helped to generate the firm's first production orders for our cellular V2X front-end modules and bulk acoustic wave (BAW) coexistence filters to support the leading European automotive OEMs. (Qorvo's high-frequency BAW

coexistence filters also enable the concurrent operation of cellular V2X and Wi-Fi.)

- In programmable power management, customer demand has been strong and supported two trends. First, the transition to solid-state drives is ongoing, primarily in laptops and gaming consoles. During the quarter, Qorvo's programmable power management integrated circuit (PMIC) continues to support this transition with expanded shipments to and new engagements with multiple leading solid-state drive providers. Second, the transition of brushless DC electric motors is accelerating, enhancing efficiency and a broad set of consumer products, including power tools and appliances. Qorvo increased shipments with motor control solutions during the quarter, supporting multiple major consumer brands.

- In defense applications, the shift to higher frequencies, the adoption of phased-array radar and the proliferation of GaN are among the trends supporting demand for Qorvo's products. For radar applications, the firm released a reconfigurable dual-band (S-band and X-band) GaN power amplifier monolithic microwave integrated circuit (MMIC), enabling more compact next-generation radar systems. Also, over 30 million miles away, the successful landing of NASA's JPL Mars Perseverance rover was supported by Qorvo's components integrated into the rover's descent radar.

On a non-GAAP basis, gross margin was 52.6% (the third consecutive quarter over 50%, taking full-year fiscal 2021 gross margin to over 52%). This is down from 54.4% last quarter but up on 49.6% a year ago, and above the 50.5–51% guidance range, as a less favorable mix was more than offset by better-than-expected price, manufacturing costs and inventory charges.

Operating expenditure (OpEx) has risen further, from \$194.2m

(17.7% of revenue) last quarter to \$207.5m (19.3% of revenue), driven by technology and product development expenses, associated with recent acquisitions and other key growth programs.

Net income was \$315.4m (\$2.74 per diluted share, above the \$2.42 guidance), down from \$356.7m (\$3.08 per diluted share) last quarter but up on \$185.3m (\$1.57 per diluted share) a year ago.

Cash flow from operations was \$402.9m (roughly level with last quarter). Capital expenditure (CapEx) more than doubled to \$77.4m (taking full-year CapEx to \$187m, below 5% of sales). Free cash flow was hence \$325m (taking full-year free cash flow to over \$1.1bn, up five-fold over the past four years). Also during the quarter, Qorvo repurchased \$175m of shares.

Cash and cash equivalents hence rose from \$1234m to \$1398m. The debt balance remained unchanged at about \$1.7bn. "Our leverage remains low, our revolver is untapped and we have no near-term maturities," notes chief financial officer Mark Murphy. "In April S&P upgraded our credit rating to investment grade, reflecting the steps we've taken to profitably grow the business and maintain a strong balance sheet."

After quarter-end, Qorvo received an emergency use authorization (EUA) from the US Food & Drug Administration (FDA) for the Omnia COVID-19 rapid antigen test, which uses high-frequency BAW sensors for high sensitivity and specificity. "Qorvo began efforts to use BAW sensors to develop diagnostic test solutions in 2013, in a manner similar to how we leveraged our BAW filters to achieve superior frequency selectivity in RF applications," says Bruggeworth. "With the authorization from the FDA, we are preparing to scale production to help support ongoing public health efforts," he adds. To that end, Qorvo was awarded a contract with the US National Institutes of Health (NIH) through the Rapid Acceleration of Diagnostics (RADx) initiative. With \$24m from the Biological Advanced Research and Development

Authority (BARDA), the award is helping to advance the production and market launch of the Omnia diagnostic test platform.

Also, in early May, Qorvo acquired NextInput Inc of Mountain View, CA, USA, a pioneer in the emerging field of force-sensing human-machine interface (HMI) solutions utilizing micro-electro-mechanical systems (MEMS)-based sensors for mobile, true wireless stereo (TWS), consumer, automotive, IoT, robotics, medical and industrial applications. NextInput will be part of the Mobile Products Group. "They have shipped tens of millions of MEMS-based sensors solutions to leading manufacturers of smartphones, wearables, automobiles, and other applications," says Bruggeworth. "We see multiple opportunities for their solutions to augment or displace capacitive touch and mechanical buttons with smaller, more reliable and air-tight solutions applicable to any surface, including glass, polycarbonate, aluminium and carbon fiber. We are excited to expand our technology portfolio and accelerate the deployment of the technology to our broad customer base and new markets," he adds.

"Our outlook is strong as Qorvo is enabling multi-year upgrade cycles in existing markets and introducing disruptive technologies including ultra-wideband, RF-based biotechnology testing and MEMS-based solutions," summarizes Bruggeworth.

For fiscal first-quarter 2022 (to end-June 2021), Qorvo expects revenue of \$1.065–1.095bn, reflecting sustained and broad-based customer demand driven by multi-year technology upgrade cycles. Mobile Products revenue should grow slightly quarter-on-quarter to \$810m (up 73% on \$468m a year previously), as demand for 5G is adding RF complexity and driving higher content. IDP revenue should grow to \$270m, sustained by Wi-Fi 6 demand and other markets.

Reflecting seasonal patterns and a less favorable mix, gross margin is expected to fall to about 50%, but that is still up on 48.6% a year

previously due to higher volumes, active portfolio management and pricing, and continuous productivity efforts. "We expect our June-quarter gross margin to be the lowest gross margin quarter of the year," notes Murphy.

OpEx should rise to about \$214m, as a result of added labor and other development expenses associated with recent acquisitions and key growth programs.

Net income is expected to fall to \$2.45 per diluted share, but this is still up on \$1.50 per diluted share a year previously.

Capital expenditure will remain around \$70m, as Qorvo works to "intersect projected demand and support long-term supply agreements with multiple customers".

For full-year fiscal 2022, Qorvo forecasts approximately 15% revenue growth, based on an increase in smartphone volumes of 5–10%, a doubling in 5G smartphone handsets (within which RF content is expected to increase \$5–7 per phone compared with 4G, including in the mid-tier), sustained Wi-Fi demand, and growth in other markets including power management and defense. Gross margin is targeted to be about 52%. OpEx is expected to increase sequentially through the year but remain below 20% of sales for the full year. "This level of OpEx is in line with what we laid out years ago and supports Qorvo's ongoing product and technology leadership in existing markets, while funding investment in newer areas such as UWB, biosensors, power management and MEMS," says Murphy. CapEx should be 5% of revenue. Due to slightly higher CapEx and working capital build, free cash flow is expected to grow only modestly year-on-year.

"Based on our strong free cash flow performance in fiscal year 2021 and our fiscal year 2022 outlook, along with our substantial balance sheet capacity and other factors, the board of directors has authorized a \$2bn share repurchase program," announces Murphy.

[www.qorvo.com](http://www.qorvo.com)

# Skyworks reports record March-quarter revenue of \$1.172bn, up 53% year-on-year

## Growth driven by early 5G adoption and strong Broad Market demand

For fiscal second-quarter 2021 (to 2 April), Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) has reported revenue of \$1171.8m (near the top of the \$1125-1175m guidance range), down from last quarter's all-time record of \$1510m (which was boosted by Skyworks' largest customer spiking to 70% of total revenue – before falling back this quarter to about 50%). Despite this, the March quarter is still a fiscal Q2 record, up 53% on \$766.1m a year ago, based on early 5G adoption as well as strong demand for Broad Market solutions.

For the Mobile business sector (Integrated Mobile Systems and Power Amplifiers), revenue was \$787m, down 34% on the exceptional \$1184m last quarter but up 47% on \$536m a year ago, driven largely by widespread content increases as 5G phones are ramping across smartphone OEMs worldwide. In particular, Skyworks expanded the reach of its Sky5 portfolio across premium- and mid-tier 5G smartphone launches at Samsung, Oppo, Vivo, Xiaomi and other leading OEMs.

"Our Broad Markets portfolio continues to gain momentum, with strong sequential and year-over-year growth," notes president & CEO Liam K. Griffin.

For the Broad Markets sector, revenue was a record \$385m, up 18% on \$326m last quarter and 67% on

\$230m a year ago, benefiting from a diverse set of use cases, including the adoption of technologies such as WiFi 6 and 6E, 5G wireless infrastructure, and automotive, along with continued positive momentum in the audio solutions business.

In the Internet of Things (IoT) space, Skyworks secured wins across a diverse set of customers, specifically: partnering with Netgear to deploy WiFi 6 and 6E routers; launching WiFi 6 gateways at Deutsche Telekom, Nokia and Altice; shipping home security solutions to Xfinity; capturing design wins with Google Nest for smart audio devices; and delivering low-latency cognitive audio platforms powering wireless gaming headsets at Microsoft and Sony.

In the industrial space, Skyworks delivered cellular IoT modules to Quectel and Gemalto.

In infrastructure, the firm leveraged its wireless infrastructure portfolio to deploy MIMO base stations with Nokia and Ericsson.

In automotive, Skyworks ramped telematics and driver-assist platforms with Volkswagen, LG and GM OnStar. "Our demonstrated operational expertise allowed us to drive yet another strong quarter of design-win execution," summarizes Griffin.

On a non-GAAP basis, gross margin was 50.8%, down from last quarter's 51.1% but still up on 50.2% a year ago, despite a challenging and tight supply-chain environment.

Operating expenses have risen further, from \$149m last quarter to \$155m (13.2% of revenue), exceeding the expected \$150-152m but demonstrating spending discipline while continuing strategic investments to drive growth.

Net income was \$395.2m (\$2.37 per dilute share, exceeding the \$2.34 guidance), down from last quarter's record \$560m (\$3.36 per diluted share) but up from \$229.5m (\$1.34 per dilute share) a year ago.

Operating cash flow was a record \$615.7m (up from last quarter's \$485.1m). Capital expenditure (CapEx) was \$140.8m. Free cash flow was hence a record \$475m (free cash flow margin of 41%). Skyworks paid \$83m in dividends (the same as last quarter).

Overall, during the quarter, cash, cash equivalents and marketable securities rose from \$1019.3m to \$1423.6m. Skyworks has no debt.

Given the acquisition of the Infrastructure & Automotive business of Silicon Labs (announced on 22 April, and expect to close in the September quarter), Skyworks has temporarily suspended its share repurchase program.

Nevertheless, Skyworks' board of directors has still declared a cash dividend of \$0.50 per share, payable on 8 June, to stockholders of record on 18 May.

"We continue to leverage our expansive technology reach and

## Skyworks prices offering of senior notes to raise \$1.5bn

### Proceeds to fund acquisition of Silicon Laboratories' Infrastructure & Automotive business

Skyworks priced its underwritten public offering of senior notes to raise \$1.5bn, consisting of \$500m of its 0.900% senior notes due 2023, \$500m of its 1.800% senior

notes due 2026 and \$500m of its 3.000% senior notes due 2031.

Skyworks intends to use the net proceeds of the offering, together with other sources of cash, to

finance the cash consideration of \$2.75bn for the acquisition of the Infrastructure & Automotive business of Silicon Laboratories Inc (announced on 22 April).

deep customer engagements, spanning both Mobile and Broad Markets, to capture the exploding demand for connectivity. And with our planned acquisition of the Infrastructure & Automotive business of Silicon Labs, we expect to accelerate that momentum further," says Griffin. "Our core business, combined with our pending acquisition of the Infrastructure and Automotive business of Silicon Labs, position Skyworks to capture an outsized portion of the opportunities that lie ahead," he believes.

"Based on robust demand for connectivity solutions in Mobile and Broad Markets, we expect continued momentum and year-over-year growth into the June quarter," says chief financial officer Kris Sennesael.

For fiscal third-quarter 2021 (the firm's slowest seasonal quarter of the year), Skyworks expects revenue of \$1.075–1.125bn, down 6% sequentially (including Broad Markets flat to slightly down) but up 49–50% year-on-year (with Broad Markets up 50–60%). Gross margin should correspondingly fall slightly sequentially to 50.25–50.75%, while still being up 40 basis points year-on-year. With operating expenses of \$159–161m, diluted earnings per share should be \$2.13 (up 70% year-on-year).

"We do of course expect further gross margin improvement in the second half of the year as we start ramping, as we usually do in the September and the December quarters," notes Griffin.

"Skyworks is on track to deliver record results for fiscal 2021, clearly demonstrating the value of our technologies as we address an increasingly broad landscape of impactful customers and applications," says Griffin. "Further, the pending acquisition of the Infrastructure & Automotive business fits squarely with our strategic priorities to expand our market reach, accelerate revenue diversification, and drive industry-leading profitability and cash flow. In parallel, Skyworks is solidifying its global leadership, technology breadth and vast operational scale powering the connected experience in mobile, industrial, automotive, enterprise and other emerging application."

[www.skyworksinc.com](http://www.skyworksinc.com)

## President & CEO Griffin adds chairman role as Aldrich retires

David J. Aldrich has retired as chairman of Skyworks' board. He is succeeded by Liam K. Griffin, who continues to serve as president & CEO. The board's lead independent director Christine King also continues to serve in her current role.

Aldrich joined the firm in 1995 became CEO and director in 2000. He was made chairman in May 2014 and served as executive chairman

from May 2016 to May 2018.

"On behalf of the entire board, I want to congratulate Dave for his distinguished career and thank him for his steadfast service to Skyworks," says King. "Given Liam's nearly 20-year tenure at the company serving in executive roles, including the last five years as CEO, he possesses both the experience and skills that uniquely

qualify him to lead the Skyworks board," she comments.

"As a result of his strong leadership, Skyworks has established an industry-wide reputation for innovation, creativity and tenacity and built a track record of delivering best-in-class connectivity solutions," says Griffin. "His vision and counsel have been invaluable to the company," he adds.

## Qorvo acquires MEMS-based sensor provider NextInput

Qorvo Inc of Greensboro, NC, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has acquired NextInput Inc of Mountain View, CA, USA, a pioneer of force-sensing solutions for human-machine interface (HMI) applications.

Founded in 2012 and providing micro-electromechanical systems (MEMS)-based sensing solutions for the mobile, true wireless stereo (TWS), consumer, automotive, Internet of Things (IoT), robotics, medical and industrial markets, NextInput has shipped tens of millions of MEMS-based sensors to

leading manufacturers of smartphones, wearables, automobiles and other applications.

The acquisition of NextInput expands Qorvo's technology portfolio and enables Qorvo to accelerate the deployment of force-sensing solutions utilizing MEMS-based sensors. NextInput will be part of Qorvo's Mobile Products Group and will be led by NextInput's CEO & founder Ali Foughi.

"The NextInput team is a great addition to our Mobile Products business, providing MEMS-based sensors in innovative products for customers in existing and new markets," comments Eric Creviston,

president of Qorvo Mobile Products. "NextInput enhances Qorvo's technology and product leadership while opening new opportunities in next-generation human-machine interface solutions," he adds.

"Our team is excited to take this next important step and continue our mission to innovate and revolutionize the touch experience with the world's best sensing solutions," states Foughi. "Qorvo's broad portfolio of complementary technologies and world-class supply-chain capabilities enable us to scale the business rapidly."

[www.nextinput.com](http://www.nextinput.com)

[www.qorvo.com](http://www.qorvo.com)



# Cree's quarterly revenue growth of 21% year-on-year driven by 50% growth for devices

## Factory transitions and new fab expansion hitting profit margins in the short term

For fiscal third-quarter 2021 (ended 28 March), for continuing operations, Cree Inc of Durham, NC, USA has reported revenue of \$137.3m, up 8% on \$127m last quarter and up 21% on \$113.9m a year ago, and above the \$127–133m guidance range.

"We are building solid momentum, and during our fiscal third quarter we continued to execute and drive our strategy, delivering strong top-line performance as customers continue to realize the benefits of silicon carbide," comments CEO Gregg Lowe.

On 1 March, Cree completed the divestiture of its LED Products business (announced in October) to SMART Global Holdings Inc for up to \$300m. This follows Cree's sale in May 2019 of its Lighting Products business unit.

"With the sale of our LED business now complete, we accomplished a critical milestone in our journey to becoming a pure-play semiconductor powerhouse [focused on the silicon carbide (SiC) and gallium nitride (GaN) power & RF solutions of the continuing business Wolfspeed] and have an even greater focus on converting opportunities in our pipeline and expanding our manufacturing capacity," says Lowe.

"In power, we delivered a solid performance driven by continued momentum of our solutions across a number of sectors," says chief financial officer Neill Reynolds. "Looking at RF, we are encouraged to see improving trends driven by increased 5G activity as communications infrastructure providers expand their activities," he adds. "The strong demand across our device portfolio showed a notable year-over-year revenue increase of more than 50%."

On a non-GAAP basis, gross margin has fallen, from 39% a year ago

and 35.4% last quarter to 35% (slightly below the midpoint of the 34.5–36.5% guidance), due to temporarily higher factory costs as Cree ran up capacity in its Durham fab (ramping up new products — including some RF products — in manufacturing space vacated by the now outsourced LED products) as well as ongoing COVID-19 safety measures.

Operating expenses were \$80m, up slightly from \$78m (61.4% of revenue) last quarter. "As we invest in our operations to capitalize on the tremendous growth opportunity ahead, we will remain disciplined in our cost control across the business," notes Reynolds.

Net loss was \$24.7m (\$0.22 per diluted share), up from \$18.4m (\$0.17 per diluted share) a year ago but cut from \$26.6m (\$0.24 per diluted share) last quarter, and towards the positive end of the guidance range of \$23–28m (\$0.21–0.25 per diluted share).

Net cash used in operating activities was \$26.8m (cut from \$29m last quarter). Including patent spending of \$1.7m, capital expenditure (CapEx) was \$138.2m (down slightly from

\$144.7m). Free cash flow was hence -\$165m (cut from -\$173.7m, although still up on -\$93.3m a year ago).

During the quarter, cash, cash equivalents and short-term investments rose from \$969m to

\$1293m. So, Cree has a strong balance sheet, with liquidity to support its growth strategy, zero withdrawn on its line of credit, and convertible debt with a total face value of \$1bn.

"We further bolstered our financial position this quarter with the successful completion of an at-the-market equity offering with gross proceeds of approximately \$500m. This equity offering provides us with additional liquidity as we grow the Wolfspeed business, particularly our capacity expansion efforts," notes Reynolds.

"We are seeing more demand in our core automotive and RF markets, as well as additional interest in new areas across energy, industrials, and aerospace & defense," says Lowe. "Our device pipeline stands at more than \$10bn and our team is identifying more opportunities at a rapid pace. Additionally, our sales team continues to generate new business, securing more than \$580m in design-ins during the quarter. A significant portion of these were for automotive products and the rest were spread across industrial, communications infrastructure, energy, and aerospace and defense," he adds. This represents a total of about \$2.5bn in design-ins secured over the last five quarters, including applications such as air conditioners, compressors, motor drives and a robotic arm.

"A year ago, we launched our portfolio of 650V silicon carbide MOSFET products, exclusively with [distributor] Arrow Electronics," notes Lowe. "We are extremely pleased with the success of this partnership, which has since generated an opportunity pipeline of more than \$800m, with dozens already in the design-in stage and some even transitioning to design win. Our sales team continues to partner closely with Arrow to exe-

**With the sale of our LED business now complete, we accomplished a critical milestone in our journey to becoming a pure-play semiconductor powerhouse and have an even greater focus on converting opportunities**

cute on these opportunities, including the introduction of our 1200V WolfPACK module portfolio. And we remain well positioned to continue to sell our superior solutions to customers across industrials and geographies through this partnership," he reckons.

"At the end of March, we launched four new multi-stage, high-efficiency X-band GaN-on-SiC devices, which are used in a diverse array of applications, including marine, weather surveillance and unmanned aerial system radars," Lowe adds.

"We expect the momentum we're seeing in our Power and RF device product lines to continue as we enter the final quarter of the fiscal year," says Reynolds. "Our [order] backlog underscores the growing opportunity we have as 5G rolls out across the globe," he adds. "Our materials product line is expected to post modest improvements, supported by a better order flow."

For fiscal fourth-quarter 2021 (to end-June), Cree expects revenue to grow to \$142–148m. Nevertheless, gross margin is expected to fall further, by about 200 basis points to 32–34%. About 150 basis points of that drop is from an unfavorable product mix, due to the growth in demand for devices that currently have lower profitability. "We view the gross margin impact as short-term in nature due to the suboptimal [higher-cost] production footprint we have in North Carolina and expect it to modestly improve going forward as we work through factory transitions and eventually shift production to our new Mohawk Valley fab in calendar year 2022," says Reynolds. Also, in the early stages of increasing capacity in the device business, productivity is lower while hiring and training staff (before picking back up to the mid-30s in the second half of the year).

Operating expenses should rise to \$82–83m, fueled by investments in R&D including development projects underway at the Mohawk Valley pilot line in order to support the firm's 200mm SiC wafer launch as well as increased sales & marketing

expense as Cree pursues new business opportunities.

Cree hence expects net loss to rise back up slightly, to \$25–30m (\$0.22–0.26 per diluted share).

"We continue to expect fiscal 2021 to be our peak investment year, with capital expenditures of approximately \$550m to support our capacity expansion plan, including the launch of our Mohawk Valley Fab at 200mm," says Reynolds. "We are making great and steady progress in this development, which will be critical to ensure we are able to support our long-term strategy, particularly given the steepening demand curve for silicon carbide that we are seeing in 2024 and beyond," he adds.

"As we focus on executing across our business, we are pleased to see our strategy is further supported by developments in the broader market," says Lowe. "Just a few months ago, the European Commission unveiled its mobility strategy as part of its \$2 trillion green deal, aiming to have at least 30 million zero-emission cars in operation on European roads by 2030. At the same time, European automakers are pushing for new taxes on gasoline and diesel vehicles to promote the competitiveness and the adoption of electric vehicles. Finally, new European regulations could also lead to the potential phasing out of plug-in hybrid vehicles, further benefiting full-electric vehicles. In the USA, the administration recently unveiled a proposed \$2 trillion infrastructure plan, of which a significant portion has been directed towards electric

**We continue to expect fiscal 2021 to be our peak investment year, with capital expenditures of approximately \$550m to support our capacity expansion plan, including the launch of our Mohawk Valley Fab at 200mm**

vehicles, including sales rebates, tax credits and charging stations. We anticipate this will have a significant impact on the adoption of electric vehicles. We are now seeing US automakers make big commitments to ramp their EV efforts. For instance, General Motors and LG Chem recently announced plans to invest \$2.3bn to build a battery cell plant to support the automaker's efforts to expand its electric vehicle. We've had a number of conversations with our customers regarding these developments. And the enthusiasm reinforces the long-term opportunity here, as well as the necessity of our capacity expansion investments to ensure we can deliver on the increased demand that we are seeing," Lowe adds.

"Additionally, in the USA, the proposed infrastructure plan also includes \$100bn dedicated to increasing broadband access with a special emphasis on 5G infrastructure. This development, combined with strong sales of 5G smartphones during the pandemic, underscores how 5G is continuing to gain momentum and offers a global opportunity in the years ahead."

"We remain well positioned to capitalize on these opportunities," reckons Lowe. "Importantly, we're on track with our investment plans to begin production in Mohawk Valley's 200mm fab in early 2022, which will support increased adoption across a wide range of industry sectors [as well as driving gross margin up to the targeted 50% in the 2024 time frame]. We are very pleased with the strong progress we've made in our R&D projects that are fueling our 200mm development as well," he adds.

"Additionally, with the equity raise we completed earlier in the quarter, we are further bolstering our financial position through this period of increased investment. By making these investments in our operations now, we are securing our long-term leadership position in silicon carbide," Lowe reckons.

[www.cree.com](http://www.cree.com)

## ON Semi launches new-generation 1200V SiC diodes

### Smaller die size and lower capacitance yield a lower forward voltage drop, 4x increase in rated current, and 20% lower thermal resistance

During the 2021 PCIM Europe (Power Conversion and Intelligent Motion) Digital Days event, power semiconductor IC supplier ON Semiconductor of Phoenix, AZ, USA introduced new automotive (AECQ101)- and industrial-grade-qualified next-generation 1200V silicon carbide (SiC) diodes, suitable for high-power applications such as

electric vehicle (EV) charging stations and solar inverters, uninterruptible power supplies (UPS), EV on-board chargers (OBC) and electric vehicle DC-DC converters.

Due to a smaller die size and lower capacitance, the new design improves on the first-generation SiC diodes. The NVDSH20120C,

NDSH20120C, NVDSH50120C and NDSH50120C deliver a lower drop in forward voltage and a 4x increase in rated current, with a higher rate of change (di/dt) of 3500A/ $\mu$ s. The smaller die size also yields a 20% lower thermal resistance in an F2 package.

[www.mesago.de/en/PCIM/main.htm](http://www.mesago.de/en/PCIM/main.htm)  
[www.onsemi.com](http://www.onsemi.com)

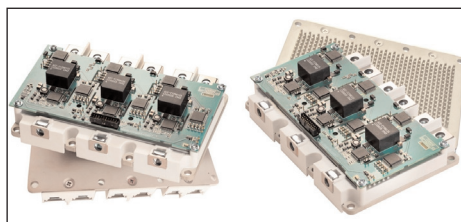
## CISSOID adds new liquid-cooled modules for E-mobility to SiC MOSFET intelligent power module range

### AlSiC flat baseplate variant targets natural cooling in aerospace and industrial applications

CISSOID of Mont-Saint-Guibert, Belgium is adding to its platform of three-phase silicon carbide (SiC) MOSFET intelligent power module (IPM) products by introducing new liquid-cooled modules for E-mobility tailored for lower switching losses or for higher power.

The firm is also introducing a module based on a lightweight AlSiC flat baseplate that meets the demand for natural convection or forced cooling in aerospace and in dedicated industrial applications. These products integrate a three-phase SiC MOSFET module with a powerful gate driver.

Leveraging a technology platform that can be rapidly adapted to new voltage, power and cooling requirements, the new IPMs accelerate the design of SiC-based power converters enabling high efficiency and high power density, says the firm. The embedded gate driver solves multiple challenges related to fast-switching SiC transistors: negative drive and active Miller clamping (AMC) prevent parasitic turn-on; desaturation detection and soft shut down (SSD) react rapidly but safely to short-circuit events; and undervoltage lockout (UVLO) functions on gate driver and DC



bus voltages monitor the proper operation of the system.

Two new liquid-cooled power modules based on a pin fin baseplate are rated for 1200V blocking voltages and for 340A to 550A maximum continuous currents. On-resistance ranges from 2.53m $\Omega$  to 4.19m $\Omega$ , depending on current rating. The total switching energies are as low as 7.48mJ ( $E_{on}$ ) and 7.39mJ ( $E_{off}$ ) at 600V/300A. The co-design of the power module and the gate driver enables optimizing the IPMs for lowest switching energies by tuning dV/dt and controlling voltage overshoots inherent to fast switching. The reverse-bias safe operating area (RBSOA) authorizes peak currents up to 600A with DC bus voltages up to 880V making the power modules safe for 800V battery applications.

The new air-cooled module is designed for applications where liquid cooling is not an option, like aerospace electro-mechanical actuators and power converters, for

example. This module is rated for a blocking voltage of 1200V and a maximum continuous current of 340A. The on-resistance is equal to 3.25m $\Omega$ . Turn-on and turn-off switching energies are, respectively, 8.42mJ and 7.05mJ at 600V and 300A. The power module is cooled down through an AlSiC flat baseplate. Thermally robust, the module is rated for 175°C junction temperature and the gate driver for 125°C ambient temperature.

"We initially developed this IPM platform to accelerate SiC-based motor drive development for E-mobility and we are also very pleased to see demand from aerospace customers," says CEO Dave Hutton. "We are delighted to deliver this new SiC intelligent power module designed for natural convection or forced cooling in compact and lightweight power converters addressing these new demanding markets."

Part numbers for the new products are CXT-PLA3SA12340AA (1200V/340A/pin fin baseplate), CXT-PLA3SA12550AA (1200V/550A/pin fin baseplate) and CMT-PLA3SB12340AA (1200V/340A/flat baseplate).

[www.cissoid.com/sic-power-modules](http://www.cissoid.com/sic-power-modules)

# JEDEC publishes document for bias temperature instability of SiC MOS devices

## JEP184 follows January's JEP183 guidelines for measuring $V_T$ of SiC MOSFETs

The JEDEC Solid State Technology Association (which develops standards for the microelectronics industry) has published 'JEP184: Guideline for Evaluating Bias Temperature Instability of Silicon Carbide Metal-Oxide-Semiconductor (MOS) Devices for Power Electronic Conversion'. Developed by JEDEC's JC-70.2 Silicon Carbide Subcommittee, JEP184 is available for free download from the JEDEC website.

JEP184 provides definitions and procedures for characterizing the threshold voltage instability of SiC-based power electronic conversion devices having a gate dielectric region biased to turn devices on and off.

Bias temperature instabilities (BTI) involve variations in threshold voltage ( $V_T$ ) and other device parameters such as resistance in the on-state and leakage current in the off-state as a function of the stress time, stress voltage and stress temperature. The assessment of BTI in SiC MOSFETs is particularly challenging since the measured threshold shift can be composed of different components such as long-term  $V_T$  drift, transient  $V_T$  changes and hysteresis behavior or changes in hysteresis. The new publication provides guidelines for stress procedures being able to distinguish between different shift components and allowing measurement of their stability over time, as affected by gate bias and temperature.

JEP184 also follows JEDEC's publication in January of 'JEP183: Guidelines for Measuring the Threshold Voltage ( $V_T$ ) of SiC MOSFETs'. Together, these two closely related publications provide the industry with guidance on assessing and evaluating BTI variations of  $V_T$ , as well as accurately measuring the  $V_T$  of SiC MOSFETs.

"BTI is a frequently requested topic of interest from the automotive and industrial markets adopting SiC power MOSFETs," notes JC-70.2 subcommittee chair Dr Jeffrey Casady, Wolfspeed Power Die product marketing engineering manager at Cree. "Adding JEP184 to address BTI fills a critical need in this space, and we are grateful to have active participation in JC-70.2 on BTI," he adds.

"JEDEC's JC-70 committee is pleased to add JEP184 to its expanding ecosystem of publications," says JC-70.2 subcommittee vice-chair Dr Peter Friedrichs, vice president SiC at Infineon Technologies. "After releasing the first guideline for SiC specific test procedures ( $V_T$ ) in January (JEP183) we are excited to now start the series of reliability related documents."

Formed in October 2017 with 23 member companies, JC-70 now has over 60 member companies, underscoring industry commitment to the development of universal standards to help advance the adoption of wide-bandgap (WBG) power technologies. Global multinational corporations and technology startups from the USA, Europe, Middle East and Asia are working together to bring to the industry a set of standards for reliability, testing and parametrics of WBG power semiconductors. Committee members include industry leaders in power GaN and SiC semiconductors, plus users of wide-bandgap power devices, and test & measurement equipment suppliers. Technical experts from universities and national labs also provide input.

JEDEC says interested companies worldwide are welcome to join it in the standardization effort.

[www.jedec.org/standards-documents/docs/jep184](http://www.jedec.org/standards-documents/docs/jep184)

### IN BRIEF

## Infineon showcasing power management solutions at APEC 2021 Silicon carbide and gallium nitride devices highlighted

During the IEEE's APEC 2021 Applied Power Electronics Virtual Conference & Exposition (14-17 June), Infineon Technologies AG of Munich, Germany is highlighting its range of power management solutions, which spans silicon and wide-bandgap (WBG) devices.

The firm's virtual exhibit is organized around application and product groups, including: computing/data center/telecom; wide-bandgap devices, including silicon carbide (SiC) and gallium nitride (GaN) power supply designs; USB-C power delivery; specialty power (renewable energy and e-mobility solutions, ultra-low-profile supplies for consumer electronics and automotive charging systems, and energy-efficient lighting); industrial power and motor control (discretes, modules, drivers and controllers); and IR HiRel (qualified for aerospace applications).

During the event, several new products are being shown for the first time, including innovative packaging to extend MOSFET performance and application-optimized gate driver devices. In addition to its APEC exhibits, Infineon is again playing a large role as a contributor to the conference program.

[www.apec-conf.org](http://www.apec-conf.org)

[www.infineon.com/apec](http://www.infineon.com/apec)

# Infineon launches EasyPACK CoolSiC MOSFET module supporting 1500V DC-link solar applications

## Power module suitable for fast-switching applications such as energy storage systems

Infineon Technologies AG of Munich, Germany has launched a new EasyPACK 2B module in the firm's family of 1200V devices. The module comes in 3-level active NPC (ANPC) topology and integrates CoolSiC MOSFETs, TRENCHSTOP IGBT7 devices and an NTC temperature sensor along with PressFIT contact technology pins. The power module is suitable for fast-switching applications such as energy storage systems (ESS). The module also increases the power rating and efficiency of solar systems and supports the growing demand for 1500V DC-link solar applications.

Using the latest CoolSiC MOSFET and TRENCHSTOP IGBT7 technology combined with an increased diode rating, the EasyPACK module F3L11MR12W2M1\_B74 (available now) is designed to operate over the entire power factor ( $\cos \phi$ ) range. A single module per phase is capable of supplying a power level of up to 75kW in energy-storage applications. For solar applications a power level of up to 150kW can be reached by operating two modules in parallel per phase.

With its improved pin positioning, the module also ensures short and clean commutation loops with

reduced stray module inductances. Its optimized layout enables what is claimed to be excellent thermal conduction of the CoolSiC MOSFET chips within the EasyPACK 2B package. In addition, the power module supports easy design-in and provides a high degree of freedom for inverter design.

The new product was showcased at Infineon's Virtual Power Conference (available live, 4–6 May), which complemented the PCIM Europe (Power Conversion and Intelligent Motion) Digital Days event.

[www.infineon.com/easy](http://www.infineon.com/easy)  
[www.infineon.com/coolpic](http://www.infineon.com/coolpic)

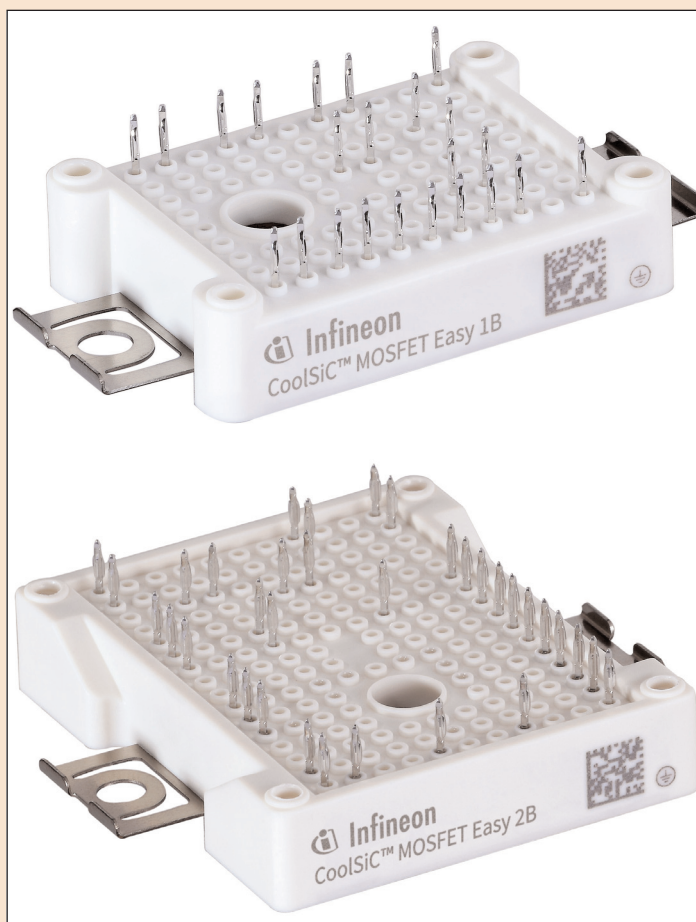
# EasyDUAL CoolSiC MOSFET power modules upgraded

## Al ceramic enables increased power density & more compact designs

Infineon has upgraded its EasyDUAL CoolSiC MOSFET modules with aluminium nitride (AlN) ceramic. The devices come in half-bridge configuration with an on-state resistance ( $R_{DS(on)}$ ) of 11m $\Omega$  in an EasyDUAL 1B package and 6m $\Omega$  in an EasyDUAL 2B package.

With high-performance ceramic, the 1200V devices are suitable for high-power-density applications including solar systems, uninterruptible power supplies (UPS), auxiliary inverters, energy storage systems and electric vehicle (EV) chargers.

Available now, the EasyDUAL CoolSiC MOSFET modules FF11MR12W1M1\_B70 and FF6MR12W2M1\_B70 are equipped with the latest CoolSiC MOSFET technology that features superior gate-oxide reliability. With the improved thermal conductivity of the DCB (direct copper bonded) material, the thermal resistance to the heat sink ( $R_{th(j-h)}$ ) can be lowered by up to 40%. Combined with



**EasyDUAL 1B (top) and 2B (bottom) packages.**

the CoolSiC Easy modules, the new AlN ceramic enables an increase in the output power or a reduction in the junction temperatures. This can lead to an improved lifespan of the system.

The EasyDUAL was showcased at Infineon's Virtual Power Conference (4–6 May), which complemented the PCIM Europe (Power Conversion and Intelligent Motion) Digital Days event.

# Infineon agrees SiC material supply and development contract with SDK

## Infineon increases SiC supply security by expanding supplier base

Semiconductor manufacturer Infineon Technologies AG of Munich, Germany has concluded a supply contract with the Tokyo-based wafer manufacturer Showa Denko K.K. (SDK) for an extensive range of silicon carbide (SiC) material, including epitaxy, thus securing more base material to meet the growing demand for SiC-based products.

SiC enables highly efficient and robust power semiconductors that are used in particular in the fields of photovoltaic, industrial power supply, and charging infrastructure for electric vehicles (EVs).

Infineon claims to have the industry's largest portfolio of

SiC semiconductors for industrial applications. "Our broad and fast-growing portfolio demonstrates Infineon's leading role in supporting and shaping the market for SiC-based semiconductors, which is expected to grow 30–40% annually over the next five years [according to Yole's April report 'Compound Semiconductor Market Monitor — Module 1 Q1 2021']," says Peter Wawer, president of the Industrial Power Control Division at Infineon. "The expansion of our supplier base with Showa Denko for wafers in this growth market marks an important step in our multi-sourcing strategy. It will support us to reliably meet the

growing demand mid to long term. Furthermore, we plan to collaborate with Showa Denko on the strategic development of the material to improve the quality while cutting costs at the same time," he adds.

"Our aim is to continuously improve our SiC material and develop the next technology," says Jiro Ishikawa, senior managing corporate officer at Showa Denko. "We value Infineon as an excellent partner in this regard."

The contract between Infineon and SDK has a two-year term with an extension option.

[www.sdk.co.jp](http://www.sdk.co.jp)

[www.infineon.com/coolisic](http://www.infineon.com/coolisic)

## Infineon launches CoolGaN IPS family for the 30–500W power range

### 600V CoolGaN half-bridge IPS IGI60F1414A1L suits compact and lightweight designs in low- to medium-power range

Infineon Technologies has added to its portfolio of wide-bandgap (WBG) power devices by launching the CoolGaN IPS family of integrated power stage (IPS) products.

The initial IPS portfolio consists of half-bridge and single-channel products, targeting low- to medium-power applications, including chargers and adapters and SMPS (switched-mode power supplies).

The 600V CoolGaN half-bridge IPS IGI60F1414A1L is suitable for compact and lightweight designs in the low- to medium-power range. Coming in a thermally enhanced 8x8 QFN-28 package, it enables systems with very high power density. The product combines two 140mΩ/600V CoolGaN e-mode HEMT switches with dedicated galvanically isolated high- and low-side gate drivers out of Infineon's EiceDRIVER family.

The IGI60F1414A1L is easy to

control due to the isolated gate driver with two digital PWM inputs. The integrated isolation function, the clean separation of digital and power ground and the reduced complexity of the PCB layout are crucial in achieving shorter development time, lower system bill-of-material and lower total cost. The gate driver's input-to-output isolation is based on Infineon's proven on-chip coreless transformer (CT) technology. The firm says that this guarantees high speed and excellent robustness even for extremely fast switching transients with voltage slopes exceeding 150V/ns.

The IGI60F1414A1L's switching behavior can be easily adapted to the needs of different applications by means of a few passive gate path components. This allows optimization of slew rate, for example, to reduce EMI efforts, steady-state gate current setting, and negative

gate drive for robust operation in hard-switched applications.

Furthermore, due to the system-in-package integration and the highly accurate and stable propagation delay of the gate drivers, the IGI60F1414A1L enables the lowest possible system dead-times. This helps to maximize system efficiency, leading to the next level of power density up to 35W/in<sup>3</sup> for charger and adapter solutions. Flexible, easy and fast designs are also enabled for uses including LLC resonant topology and motor drives.

Showcased at Infineon's Virtual Power Conference (4–6 May), which complemented the PCIM Europe (Power Conversion and Intelligent Motion) Digital Days event, the IGI60F1414A1L is available now in a thermally enhanced 8x8 QFN-28 package.

[www.infineon.com/coolgan-ips](http://www.infineon.com/coolgan-ips)

# Infineon launches first automotive-qualified SiC six-pack power module for EV traction inverters

## HybridPACK Drive power upscaled from silicon to CoolSiC technology

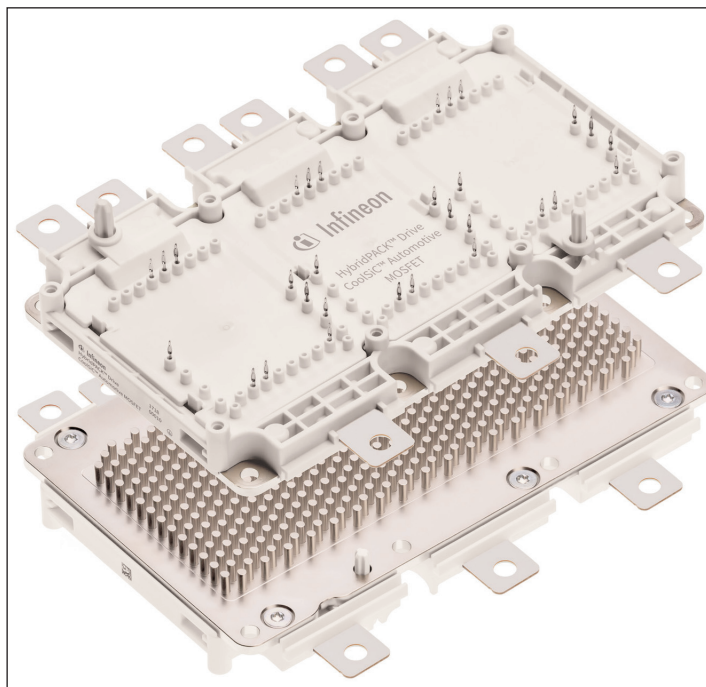
At the virtual PCIM Europe (Power Conversion and Intelligent Motion) Digital Days trade show, Infineon Technologies AG of Munich, Germany is introducing a new power module based on automotive CoolSiC trench MOSFET technology for high-power density and high-performance applications.

In production now and available from June, the HybridPACK Drive CoolSiC is a full-bridge module with 1200V blocking voltage optimized for traction inverters in electric vehicles (EV). This offers higher efficiency in inverters with longer ranges and lower battery costs, particularly for vehicles with 800V battery systems and larger battery capacity.

"The 800V system of the Electric Global Modular Platform (E-GMP) represents the technological basis for the next generation of electric vehicles with reduced charging time," notes Dr Jin-Hwan Jung, head of the Electrification Development Team at Hyundai Motor Group. "By using traction inverters based on Infineon's CoolSiC power module, we were able to increase the range of the vehicle by more than 5% because of efficiency gains resulting from the lower losses of this SiC solution compared to silicon-based solutions," he adds.

"The automotive e-mobility market has become highly dynamic, paving the ground for ideas and innovation," says Mark Münzer, head of Innovation and Emerging Technology at Infineon. "As the price of SiC devices significantly decreases, the commercialization of SiC solutions will accelerate, resulting in more cost-efficient platforms adopting SiC technology to improve the range of electric vehicles," he believes.

The HybridPACK Drive was first introduced in 2017 using Infineon's silicon EDT2 technology, specifically optimized to deliver the best efficiency on a real-world driving cycle.



It offers a scalable power range of 100–180kW in the 750V and 1200V class. This product is Infineon's market-leading power module, with a track record of more than 1 million units shipped for more than 20 electric vehicle platforms. The new CoolSiC version is based on Infineon's SiC trench MOSFET structure. Compared with planar structures, the trench structure enables a higher cell density, resulting in what is claimed to be the best-in-class figure of merit. Trench MOSFETs can therefore be operated at lower gate-oxide field strengths, resulting in increased reliability.

The power module offers an easy upscale path from silicon to silicon carbide with the same footprint. This allows the inverter design to achieve higher power of up to 250kW in the 1200V class, greater driving range, smaller battery size and optimized system size and cost. To offer an optimal

**The automotive e-mobility market has become highly dynamic, paving the ground for ideas and innovation**

**The HybridPACK Drive CoolSiC module, which offers an upscale path from silicon to SiC with the same footprint.**

cost-performance ratio for different power levels, the new product is available in two versions with different chip counts, resulting in either a 400A or 200A DC rating version in the 1200V class.

**CoolSiC auto-**

**motive MOSFET technology**

The first generation of CoolSiC automotive MOSFET technology is optimized for use in traction inverters, with a focus on achieving the lowest conduction losses, especially under partial load conditions. Combined with the low switching losses of SiC MOSFETs, this enables an efficiency gain in inverter operation compared with silicon IGBTs.

Infineon says that, in addition to optimizing performance, it puts great emphasis on reliability. Automotive CoolSiC MOSFETs are designed and tested to achieve short-circuit robustness and a high degree of cosmic-ray and gate-oxide robustness (key for designing efficient and reliable automotive traction inverters and other high-voltage applications). The HybridPACK Drive CoolSiC power module is fully qualified to the AQG324 norm for automotive power modules.

The HybridPACK Drive CoolSiC power module was showcased at Infineon's Virtual Power Conference (4–6 May), which complements the PCIM Europe Digital Days event.

[www.infineon.com/coolpic](http://www.infineon.com/coolpic)

[www.infineon.com/sicatv](http://www.infineon.com/sicatv)

# Fuji Electric Lambda Series Safety, Compact, Powerful



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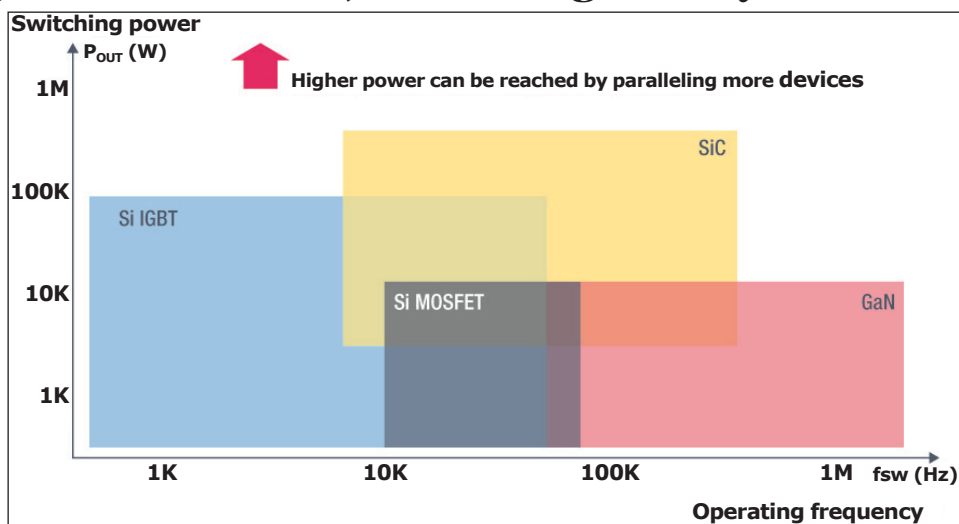


# STi<sup>2</sup>GaN product family launched for automotive use

## Power GaN plus intelligence for smaller, more integrated systems

STMicroelectronics of Geneva, Switzerland has launched a family of ST intelligent and integrated gallium nitride (GaN) solutions. STi<sup>2</sup>GaN combines power and intelligence in compact, high-performance solutions required by the automotive industry as it shifts to electrified platforms.

Building on ST's automotive experience, innovations in smart power technology, wide-bandgap semiconductor materials and packaging expertise, the STi<sup>2</sup>GaN family combines a monolithic power stage along with drivers and protections in GaN technology as well as system-in-package (SiP) solutions for application-specific ICs with additional processing and control circuitry. The STi<sup>2</sup>GaN solutions use ST's novel bond-wire-free packaging technology to provide what is claimed to be high robustness, reliability and performance.



"Initial offering of STi<sup>2</sup>GaN solutions suit on-board chargers, LiDAR [light detection & ranging] for autonomous driving, bidirectional DC-DC converters, Class-D amplifiers and power conversion systems," says Alfio Russo, group VP & general manager Low Voltage and STi<sup>2</sup>GaN Solutions Macro Division,

at STMicroelectronics. "The new product family aims to leverage the high power density and efficiency of GaN to offer an industry-unique range of devices in 100V and 650V clusters that ensure scalability, compactness, and outstanding performance."

[www.st.com/sti2gan](http://www.st.com/sti2gan)

## First reference design for ST's MasterGaN power packages demonstrates heatsink-free 250W resonant converter

ST has released the first reference design for its MasterGaN power packages, demonstrating how the new highly integrated devices increase power density, boost energy efficiency, simplify design, and accelerate time to market.

The EVLMG1-250WLLC reference design is a 250W resonant converter with a 100mm x 60mm board outline and 35mm maximum component height. It features the MasterGaN1, which contains one half-bridge STDRIVE gate driver optimally connected to two 650V normally-off GaN transistors with matched timing parameters, 150mΩ on-resistance ( $R_{ds(on)}$ ), and 10A maximum current rating. The logic inputs are compatible with signals from 3.3V to 15V.

MasterGaN1 is suitable for high-efficiency soft-switching topologies including resonant converters,

active clamp flyback or forward converters and bridgeless totem-pole PFC (power-factor correction) in AC/DC power supplies, DC/DC converters, and DC/AC inverters up to 400W.

The primary side runs heatsink-free, leveraging the high efficiency of the GaN power transistors. In addition, GaN's superior switching performance allows a higher operating frequency than ordinary silicon MOSFETs, permitting smaller magnetic components and capacitors for greater power density and reduced bill of materials.

Designed for a nominal 400V supply, the EVLMG1-250WLLC provides a 24V/10A output and achieves maximum efficiency above 94%. Benefiting from MasterGaN's integrated safety features, the converter output is protected against short circuit and

overcurrent. There is also brown-out protection and an input-voltage monitor that permits sequencing within an array of DC/DC converters and prevents a motor from starting under low-voltage conditions.

ST's MasterGaN family comprises pin-compatible integrated half-bridge products including symmetrical and asymmetrical configurations, housed in a 9mm x 9mm low-profile GQFN package. Containing circuitry rated up to 650V, the packages have over 2mm creepage distance between high-voltage and low-voltage pads. MasterGaN modules are available in various power ratings, allowing engineers to scale their designs with minimal hardware changes.

The EVLMG1-250WLLC is available from ST and distributors for \$230.

[www.st.com/en/evaluation-tools/evlmg1-250wllc.html](http://www.st.com/en/evaluation-tools/evlmg1-250wllc.html)



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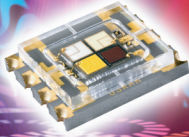


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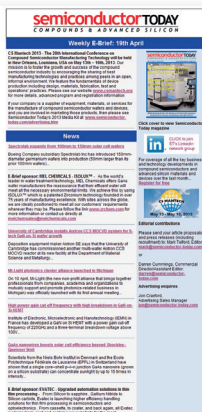


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# Raytheon and GlobalFoundries partner to develop and commercialize GaN-on-Si for 5G and 6G mobile and wireless infrastructure

## Raytheon licensing GaN-on-Si technology to GF for Fab 9 in Burlington

Aerospace & defense technology firm Raytheon Technologies Corp of Waltham, MA, USA and GlobalFoundries (which has operations in Singapore, Germany and the USA) are collaborating to develop and commercialize gallium nitride on silicon (GaN-on-Si) technology for 5G and 6G mobile and wireless infrastructure, which requires higher radio-frequency performance than legacy wireless systems (for which gallium nitride can handle the significantly heat and power levels).

Raytheon will license its proprietary GaN-on-Si technology and technical expertise to GlobalFoundries, which will develop it at its Fab 9 facility in Burlington, Vermont (where it has nearly 2000 staff, out of more than 7000 across the USA).

The collaboration with Raytheon Technologies is the latest of several strategic partnerships for GlobalFoundries. Over the past 10 years GlobalFoundries has invested \$15bn in US semiconductor development and is doubling its planned investment in 2021 to expand global capacity and support growing demand from the US government and industry customers for secure processing and connectivity applications.

"Raytheon Technologies was one of the pioneers advancing RF gallium arsenide technology which has been broadly used in mobile and wireless markets, and we have similarly been at the forefront of advancing gallium nitride technology for use in advanced military systems," says the firm's chief technology officer Mark Russell. "Our agreement with GlobalFoundries not only demonstrates our common goal to make high-performance communications technologies available at an affordable cost to our customers, it continues



**GlobalFoundries Fab 9 in Burlington, VT.**

to prove how investments in advanced defense technologies can improve lives, as well as defend them," he adds.

"GlobalFoundries' fab in Essex is leading the way in domestic production of this important 5G-enabling technology and beyond," comments Senator Patrick Leahy, chairman of the Senate Appropriations Committee. "This collaboration between a world-class manufacturer, GlobalFoundries, and Raytheon Technologies, a leader in technological innovation, is good news for the nation's semiconductor supply chain and competitiveness," he adds.

"GlobalFoundries'

**Raytheon will license its proprietary GaN-on-Si technology and technical expertise to GlobalFoundries, which will develop it at its Fab 9 facility in Burlington**

innovations have helped drive the evolution of four generations of wireless communications that connect over 4 billion people. Our collaboration with Raytheon Technologies is an important step to ensuring the development and manufacturing capability of solutions for critical future 5G applications," says GlobalFoundries' CEO Tom Caulfield. "This partnership will enable everything from AI-supported phones and driverless cars to the smart grid, as well as governments' access to data and networks which are essential to national security."

Combined with GlobalFoundries' manufacturing and services in RF, testing and packaging, Raytheon's GaN technology will increase RF performance while maintaining production and operational costs, enabling higher levels of power and power-added efficiency to meet evolving 5G and 6G RF millimeter-wave operating frequency standards.

[www.globalfoundries.com](http://www.globalfoundries.com)

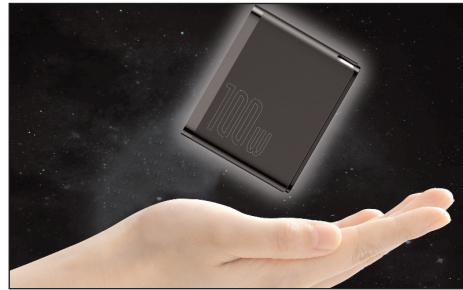
# Nexperia makes available second-generation 650V power GaN FET device family

## Reduced component count, form factor and system costs for 2–10kW 80 PLUS Titanium-class power supplies

Nexperia BV of Nijmegen, Netherlands (which makes discrete and MOSFET components and analog & logic ICs) has announced volume availability of its second-generation 650V power GaN FET device family (GAN041-650WSB), offering significant performance advantages over previous technologies.

With on-resistance ( $R_{DS(on)}$ ) performance down to  $35m\Omega$  (typical), the power GaN FETs target single-phase AC/DC and DC/DC industrial switched-mode power supplies (SMPS) ranging from 2kW to 10kW, especially server and telecoms supplies that must meet 80 PLUS Titanium efficiency regulations. The devices also suit solar inverters and servo drives in the same power range.

Available in TO-247 packaging,




the new 650V H2 power GaN FETs deliver a 36% shrinkage in die size for a given  $R_{DS(on)}$  value, for better stability and efficiency. The cascode configuration eliminates the need for complicated drivers, speeding time to market. The devices are said to deliver outstanding performance in both hard-switching and soft-switching configurations, offering designers maximum flexibility.

"Titanium is the most demanding

of the 80 PLUS specifications, requiring >91% efficiency under full load conditions (>96% at 50% load)," notes GaN strategic marketing director Dilder Chowdhury. "Achieving this level of performance in server power applications operating at 2kW and above, using conventional silicon components, is complex and challenging," he adds. "Nexperia's new power GaN FETs are ideally suited to an elegant, bridgeless totem pole configuration that uses fewer components and reduces both physical size and costs."

Designers were able to see Nexperia GaN FETs in action at the firm's booth at the PCIM (Power Conversion and Intelligent Motion) Digital Days event (3–7 May).

[www.nexperia.com](http://www.nexperia.com)






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# Navitas to go public via Live Oak II SPAC business combination

## Expected proceeds of \$400m to be used for accelerated product development and expansion into power semi markets

Navitas Semiconductor Inc of El Segundo, CA, USA and Dublin, Ireland has entered into a definitive agreement to combine with Live Oak Acquisition Corp II (Live Oak II), a publicly traded special-purpose acquisition company (SPAC). The transaction, which values the combined entity at a pro forma equity value of \$1.4bn, will result in Navitas becoming a publicly traded company on a national exchange under a new ticker symbol.

GaN is reckoned to run up to 20x faster than silicon, and enables up to 3x more power or 3x faster charging in half the size and weight. Founded in 2014, Navitas introduced what it claimed to be the first commercial GaN power ICs, which monolithically integrate GaN power field-effect transistors (FETs) with drive, control and protection circuits, enabling faster charging, higher power density and greater energy savings.

Driven by increasing demand for connectivity, electrification away from fossil fuels, and efficient sustainable energy sources, Navitas predicts that GaN ICs can address markets that are estimated to grow to over \$13bn in 2026. Markets include mobile, consumer, enterprise (data center, 5G), renewables (solar, energy storage) and electric vehicles (EVs)/eMobility.

Navitas is in mass production and ramping shipments to many major OEMs and after-market suppliers, including Dell, Lenovo, LG, Xiaomi, OPPO, Amazon, Belkin and dozens of others. Over 18 million GaNFast power ICs have been shipped, with zero reported field failures.

With a proprietary process design kit (PDK) and over 120 patents granted or pending, Navitas reckons that it has an early-mover advantage in the GaN market. A robust

roadmap for new GaN generations and continued cost reductions is helping to accelerate the transformation away from CO<sub>2</sub>-burdened fossil fuels. Navitas estimates that GaN can impact up to 2.6Gtons of CO<sub>2</sub> reduction annually by 2050.

"Navitas was formed with the vision to revolutionize the world of power electronics while addressing significant sustainability challenges for our planet," says Navitas' co-founder & CEO Gene Sheridan. "Not only has Navitas' world-class team invented and patented revolutionary new technology, but we have also overcome all the key hurdles associated with successfully bringing it to market. We are proud to enter the public capital markets with strong operating momentum and investor partners who share our enthusiasm for our long-term mission," he adds.

"This is the most compelling opportunity we have seen in the semiconductor industry, and we are delighted that Navitas' solutions contribute meaningfully to reduced carbon emissions through more efficient power delivery," comments Live Oak's CEO Rick Hendrix.

"The capital raised through this transaction will allow Navitas to accelerate that vision as they expand from mobile and consumer markets into even more power-intensive applications like data centers, solar energy and electric

vehicles — all while delivering a significant CO<sub>2</sub> reduction as part of their Net Zero initiative."

Navitas was originally funded by the company's management team, along with venture capitalists with long-term track records, focused on disruptive businesses in the clean-tech and electronics industries. Capricorn Investment Group, Atlantic Bridge and seed investor Malibu IQ, along with all current investors, are rolling 100% of their equity in this transaction. "With a doubling of electrical energy demand driving the global energy transition, Navitas' GaN power ICs are already having a powerful, positive energy-efficiency impact, benefiting all of us globally," says Malibu IQ founder David Moxam.

### Overview of transaction

The transaction is expected to deliver up to \$398m of gross proceeds to the combined company, assuming minimal redemptions by Live Oak II's public stockholders. This includes an oversubscribed and upsized \$145m private placement of Class A common stock in Live Oak II at \$10 per share (the 'PIPE' private investment in public equity), from a diversified group of institutional investors.

Proceeds of the transaction will be used to fund Navitas' future growth initiatives. Existing Navitas shareholders will roll 100% of their equity into the combined company. The transaction, which has been unanimously approved by the boards of Live Oak II and Navitas, is expected to close in third-quarter 2021, subject to approval by Navitas' shareholders, which has been secured through support agreements, Live Oak II's shareholders and other customary closing conditions, including any applicable regulatory approvals.

[www.navitassemi.com](http://www.navitassemi.com)

**The capital raised through this transaction will allow Navitas to... expand from mobile and consumer markets into even more power-intensive applications like data centers, solar energy and electric vehicles**

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## Transphorm's revenue grows 20% in Q1 to record \$2.4m, driven by increased GaN adoption

### Millionth GaN power device shipped, as unit volume doubles

In preliminary results for first-quarter 2021, Transphorm Inc of Goleta, near Santa Barbara, CA, USA — which designs and manufactures JEDEC- and AEC-Q101-qualified 650V and 900V gallium nitride (GaN) field-effect transistors (FETs) for high-voltage power conversion applications — expects revenue of about \$2.4m (up 20% on Q4/2020's \$2m), driven by increased adoption of the firm's GaN power device products in applications ranging from 45W fast chargers/adapters to 1–4kW crypto-mining power supplies,

gaming and data-center servers, and higher-power industrial, UPS (uninterruptible power supply) and automotive converter/inverter applications.

"We also achieved a key milestone of shipping more than 1 million GaN devices that address power ranges from 45W to 10kW, which is an industry first," says president & co-founder Primit Parikh. "The doubling of our volume shipments from the third quarter to the fourth quarter of 2020, and then doubling shipments again sequentially in the first quarter of 2021 demonstrates

customers' growing recognition of the differentiating performance and reliability of Transphorm's GaN power devices as well as our robust supply-chain capabilities."

Also, Transphorm expects GAAP operating expenses to rise by about 10% in Q1/2021, from Q4/2020's \$4.5m.

● After approval by its board of directors, Transphorm completed the change of its fiscal year-end from 31 December to 31 March as part of preparations for a planned uplist to the Nasdaq Capital Market.

[www.transphormusa.com](http://www.transphormusa.com)

## Transphorm to begin trading on OTCQX Best Market Firm upgraded from OTCQB Venture Market

After trading on the OTCQB Venture Market since last August, Transphorm's common stock has been approved for upgrade to the OTCQX Best Market, "a designation that aligns with Transphorm's commitment to meet the highest financial standards for compliance, disclosure and corporate governance," says chief financial officer Cameron McAulay.

"Further, trading our stock on OTCQX expands our reach to a

broader set of prospective investors, while also providing shareholders with increased liquidity and accessibility," adds McAulay. "This achievement is another important milestone in our growth and development toward our ultimate goal of trading on a national exchange."

The OTCQX Market provides investors with a premium US public market to research and trade the shares of investor-focused

companies. Graduating to the OTCQX Market marks an important milestone for companies, enabling them to demonstrate their qualifications and build visibility among US investors. To qualify for OTCQX, companies must meet high financial standards, follow best-practice corporate governance, and demonstrate compliance with applicable securities laws, notes Transphorm.

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# GaN Systems releases highest-power-density 3kW LLC reference design for power applications

## Full-bridge resonant converter design integrates 650V E-mode transistors

GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) has introduced a new reference design for a high-density, high-efficiency GaN-based 3kW LLC resonant converter (GS-EVB-LLC-3KW-GS) aimed to reduce design cycles, costs and time to market for companies developing data-center, telecom, and industrial switched-mode power supply (SMPS) applications.

The full-bridge LLC resonant converter design, integrating GaN Systems' 650V E-mode transistors, exceeds the 80 PLUS Titanium standard for power supply units, achieving high power density

(AC/DC PSU) above 100W/inch<sup>3</sup> and high efficiency of more than 96%.

Key benefits and features of the 3kW LLC include:

- high density: up to 146W/inch<sup>3</sup> (including air-forced cooling);
- high efficiency: peak efficiency >98%;
- small size: <30mm height and meets low-profile 1U data-center form factor;
- high switching frequency, with maximum up to 450kHz; and
- current, short-circuit and over-voltage system protections.

In the data center, power density and efficiency metrics are becoming more significant with demands to deliver more power in a smaller footprint and new regulatory policies,

including the European Union's 'Lot 9' 2023, which focuses on data-center infrastructure as related to power-supply and energy-efficiency requirements.

The industry has also been shifting from a 'dollar per Watt' to 'dollar per density' value, where density is a measure of size and power of the power supply. Smaller power supplies using GaN allow for more storage and memory to be added into the same rack space, allowing for data-center capacity growth without having to build more data centers.

The new reference design is now available for purchase through GaN Systems' distributors.

[www.gansystems.com/evaluation-boards/gs-evb-llc-3kw-gs](http://www.gansystems.com/evaluation-boards/gs-evb-llc-3kw-gs)

## GaN Systems Cup 2021 China Power Supply Society design competition underway

### Finalists announced on 25 August; award ceremony in November

GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) says that the seventh annual 'GaN Systems Cup' China Power Supply Society (CPSS) design competition is now in progress. Engineering teams from China's top universities are in the preliminary stages of the competition, with the goal to develop the best design for a high-efficiency, high-power-density wide-output power supply design using GaN Systems' GS-065-011-1-L transistors.

"The GaN Systems Cup is a great way for lots of young engineers to design with our GaN as it becomes the power electronics industry's fundamental building block," says CEO Jim Witham.



University teams are tasked to develop a GaN-based power supply design that meets several technical requirements, including:

- 90–265V<sub>ACrms</sub> input voltage;
- 5V–15V output voltage (test two working conditions of 15V/5A and 5V/5A);
- greater than 90% efficiency at 15V/5A output;
- not less than 10W/in<sup>3</sup> power density;
- run continuously for 30 minutes.

Finalists will be announced on 25 August and the on-site finals and award ceremony will be held

in November during the CPSS Annual Conference. Designs will be judged on meeting design criteria, functionality during test day, ingenuity, and quality of presentation.

The CPSS design competition focuses on innovation in energy conservation, emission reduction, and new energy utilization and encourages students to pursue careers in the power electronics industry.

The GaN Systems Cup is organized by Chongqing University and is sponsored by GaN Systems, CPSS and the organization's Science Popularization Working Committee, and Ningbo Xici Electronic Technology Co Ltd. Itech Electronics Co Ltd is the supplier of the test equipment.

[www.cpss.org.cn](http://www.cpss.org.cn)  
[www.gansystems.com/gan-transistors/gs-065-011-1-l](http://www.gansystems.com/gan-transistors/gs-065-011-1-l)

## GaN Systems showcases GaN transistors & applications

At the PCIM (Power Conversion and Intelligent Motion) Europe 2021 Digital Days event (3–7 May), GaN Systems' CEO Jim Witham joined other GaN experts in a panel session 'WBG GaN: Serving Low to Line Voltage' moderated by Bodo's Power Systems to illustrate how GaN power semiconductors have become the fundamental building block in power electronics.

Sessions and company innovations point to the advances and explosive increase in demand for GaN power semiconductors and adoption. This is demonstrated by GaN Systems' announcements that its high-volume GaN transistors have fallen below US\$1, shipment of its 20 millionth GaN transistor, and a 40x capacity expansion to be completed in 2021.

In the last year, GaN Systems has seen significant customer growth and innovative power system design applications, including:

- the debut of new 650V, 60A transistors for the automotive market designed to exceed automotive reliability standards including AEC-Q101 qualification and GaN Systems' AutoQual+ testing and qualification;
- the industry's smallest 100W

dual USB-C intelligent PD GaN charger from GaN Systems, which achieves what is claimed to be outstanding efficiency, power density and circuit intelligence;

- a reference design for the highest-power-density, high-efficiency GaN-based 65W ACF (active clamp flyback) chargers in collaboration with Silanna Semiconductor; and
- a new 3kW full-bridge LLC resonant converter design to pair with its 3kW bridgeless totem-pole PFC reference design for data-center applications that exceeds the 80 PLUS Titanium standard for power supply units.

Attention has focused on data-center, automotive and industrial applications, including the following:

- *Data centers:* GaN power transistors, which have made their way into data-center power supplies, can reduce energy costs by more than \$100m annually and reduce CO<sub>2</sub> emissions by nearly 1 million metric tons for a large data-center operator, it is reckoned. In addition to data-center power supplies, significant savings are also attained in 5G power applications and crypto-mining power supplies.

- *Automotive:* GaN is being designed in a wide range of automotive applications including onboard battery chargers (OBC), DC/DC converters and traction inverters. GaN can save electric vehicle auto manufacturers \$1.1bn in lower materials and battery costs and increase driving range (km) by 6%, it is reckoned, reducing driver range anxiety. BrightLoop incorporates GaN Systems' transistors in its family of DC/DC converters (which is half the size and weight of its first-generation product family) designed for the demanding environment of e-motorsport racing.

- *Industrial:* GaN is making waves in areas such as wireless charging of robots and drones, industrial power supplies, and motor drives. An example of how some of the world's largest companies are innovating with GaN is Siemens, which released a GaN-based motor drive as part of its Simatic Micro-Drive product line, offering increased efficiency and faster motor response time, noting that GaN has brought about a breakthrough in drive technology. The mini drive is only 2cm wide and requires no active cooling.

## GaN Systems expands automotive product line 60A bottom-side-cooled transistor targeted at high-power electric vehicle applications

GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) has expanded its family of automotive-grade 650V transistors by launching the GS-065-060-5-B-A, a 60A bottom-side-cooled transistor for demanding high-power electric vehicle (EV) applications such as on-board chargers, traction inverters, and DC-DC converters.

The high-frequency properties of

GaN combined with GaN Systems' proprietary Island Technology layout, and GaNPX packaging provides the high-power, low-loss performance required in today's power electronics. Power engineers take advantage of GaN power transistor features to make their products 50% smaller and lighter and reduce system costs. The new product is AEC-Q101- and AutoQual+-qualified; has a low R<sub>DS(on)</sub> (25mΩ) and ultra-low-loss figure of merit (FOM); a 60A I<sub>DS</sub> rating; and a small, 11mm x 9mm

PCB footprint with dual gate pads for optimal board layout.

"We're setting high benchmarks with our new automotive products and qualification testing that exceed industry standards," says CEO Jim Witham. "Automotive is a key market for GaN Systems, where reducing battery size, extending driving range, and keeping the power electronics systems small and lightweight are all imperative to current and future EV design."

[www.gansystems.com/](http://www.gansystems.com/)

# Cambridge GaN Devices appoints Alain Charles as non-executive board member

## Appointment follows \$9.5m Series A funding round as part of scale-up

Fabless semiconductor company Cambridge GaN Devices (CGD) has appointed industry veteran Dr Alain Charles as a non-executive board member. Charles has more than 30 years in the semiconductor industry and has joined to accelerate CGD's mission to shape a sustainable future for power electronics.

CGD was spun out of the University of Cambridge Department of Engineering's Electrical Power and Energy Conversion group in 2016 by chief executive officer Dr Giorgia Longobardi and chief technology officer professor Florin Udrea in order to develop power semiconductors using gallium nitride (GaN)-on-silicon substrates. The company's core business is to design, develop and commercialize power transistors and integrated circuits.

CGD is developing a range of GaN transistors that are customised for key applications in market segments such as consumer and industrial switch-mode power supply (SMPS), lighting, data centers and automotive hybrid electric vehicles (HEV/EV). The firm says that its proprietary ICeGaN technology will allow it to replace silicon in those key applications, while enabling more compact power systems and better use of energy resources.

Following a Ph.D. in 1989 from the Institut National des Sciences Appliquées (INSA) de Toulouse (France) for his work on optical lithography for microelectronics,

during 30 years in the semiconductor industry Charles has been involved in most of the key technology changes, ranging from sub-wavelength pattern printing through larger-wafer (300mm) technology development to power efficiency and the introduction of wide-bandgap semiconductors.

His international career began with driving optical lithography efforts at the Motorola Mesa site in Arizona and later the ST-Microelectronics factory in Carrollton, TX, USA. He later joined the Motorola-Siemens joint venture in Dresden, Germany (pioneering 300mm silicon manufacturing) and was part of the team that produced the first 64Mbit DRAM on 300mm wafers in 1998. He then managed Fab5 and Fab3 engineering teams at silicon foundry Chartered Semiconductor (now Global Foundries) in Singapore. In 2003 he joined International Rectifier's power device technology development team in Newport, Wales, UK, then headed its silicon technology development team for all discrete power devices from company headquarters in El Segundo, CA, USA. After International Rectifier's acquisition by Infineon Technologies, he assumed worldwide responsibility for the GaN technology development initiative within the company. In 2021 he created his own power semiconductor-focused consulting company.

Charles will give CGD an independent view on the GaN ecosys-

tem while serving as a strategic advisor on energy-related initiatives, influencing and steering the board direction. He will also support CGD through strategic introductions to influential R&D institutions, partners, industry bodies and policy makers. These connections are expected to help to support CGD's efforts towards delivering green electronics and reshaping the industry towards more sustainable practices.

"His profound knowledge of the semiconductor industry and renowned expertise will be instrumental in helping CGD in its mission to create green electronics and deliver a more sustainable future in some of the most power-intensive industries," believes Longobardi.

"The development in the industry that CGD is working on will help to emphasise the key role of GaN-based power electronic to build a more energy efficient world," comments Charles.

Since CGD's \$9.5m Series A fundraising, Charles is the fourth addition to its board, following Tim Rae, Ed Stacey and Nick Mettyear - partners of venture capital backers BGF, IQ Capital and Foresight Williams - bringing with them deep industrial expertise and their network.

In addition to the multi-million seed fund and Series A private investments, CGD has also secured four projects funded by iUK, BEIS and EU (Penta).

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# Keysight adds customized GaN test board for PD1500A dynamic power device analyzer/double-pulse tester

## Repeatable, reliable characterization to reduce prototype cycles and speed introduction of new products

Keysight Technologies Inc of Santa Rosa, CA, USA has announced a customized gallium nitride (GaN) test board for its dynamic power device analyzer/double-pulse tester (PD1500A), enabling tier-one and OEM power converter designers to reduce prototype cycles and speed the introduction of new products.

Power converters are a key component for enabling the electrification of the transportation, renewable energy and industrial markets. For e-Mobility, the main application of the power converter (i.e. traction inverter) is to efficiently convert the power stored in the high-voltage battery pack of an electronic vehicle (EV) to drive the AC motor. There are many other applications for the power con-

verter in EVs, including the on-board charger, which is the key link for vehicle-to-grid applications.

To facilitate advances in power converter design, new wide-bandgap (WBG) semiconductor technologies are being commercialized, providing improvements in speed, voltage and thermal operation. This, in turn, improves efficiency, while decreasing size and reducing cost. However, the resulting high-performance power converters are proving difficult to design.

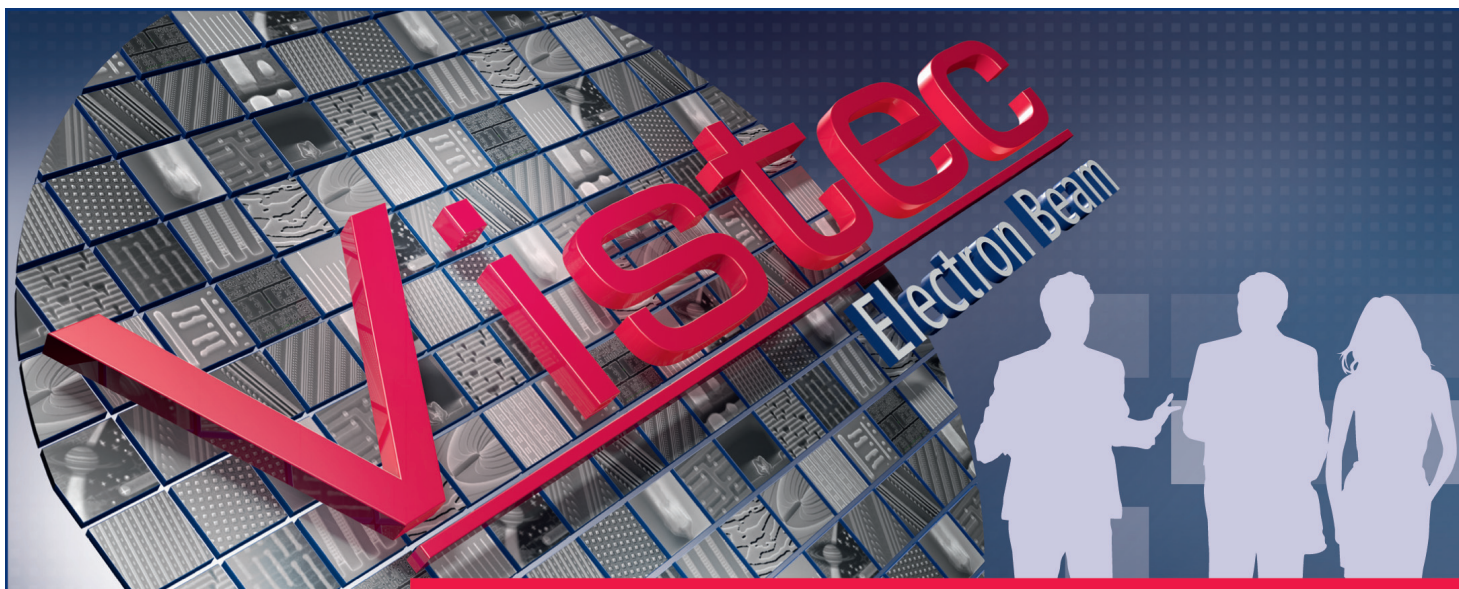
To deliver consistent, reliable characterization of WBG semiconductors, Keysight developed the PD1500A dynamic power device analyzer platform. The PD1500A is modular, allowing discrete silicon and silicon carbide (SiC)-based

power devices to be characterized. Now, with a customized GaN test board, the PD1500A delivers repeatable and reliable characterization for faster switching devices.

GaN is currently only targeting on-board chargers and DC-DC converters in EVs. However, with the advent of vertical GaN, expectations are that operating voltages will catch up with SiC (1.2kV and higher), making GaN an option for higher-power applications in e-Mobility.

Keysight's measurement science enables a commercially available solution for repeatable and reliable characterization of GaN power devices, accelerating the ability of OEM and tier-1 providers to introduce competitive EV technology to market.

[www.keysight.com](http://www.keysight.com)



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# AXT's revenue surpasses \$30m per quarter in Q1

## Growth driven by rising raw materials pricing and InP demand for 5G

For first-quarter 2021, AXT Inc of Fremont, CA, USA — which makes gallium arsenide (GaAs), indium phosphide (InP) and germanium (Ge) substrates and raw materials — has reported revenue of \$31.4m, up 16% on \$27m last quarter and 51% on \$20.7m a year ago.

"We expected that the convergence of expanding markets such as 5G, moving past the relocation program, and overall growth in indium phosphide would push us past the \$30m mark, but we could not predict the exact quarter for this event," notes chief financial officer Gary Fischer.

"Our performance surpassed our expectations, with growth in nearly all of our strategic products," says CEO Morris Young.

Revenue from AXT's two consolidated raw materials joint ventures — BoYu (which makes high-temperature pyrolytic boron nitride crucibles and pBN-based tools for organic light-emitting diodes) and JinMei (a diversified industrial high-purity material supplier) — has grown further, from \$3.8m a year ago and \$5.5m last quarter to \$8m (up 45% sequentially), as the market for raw materials has tightened up and pricing has hence increased. "In 2020, both companies relocated to our campus in Kazuo, enabling them to expand capacity in response to strong market demand," says Young. "This, coupled with a recovery in pricing of raw materials such as raw gallium [which more than doubled from about \$150 per kg last year to \$350–400 per kg], has allowed both companies to grow meaningfully in recent quarters."

Substrate revenue was \$23.4m, up 8.8% on \$21.5m last quarter and 38.5% on \$16.9m a year ago.

Of this, germanium revenue fell modestly in Q1, following a very strong Q4/2020.

GaAs revenue was the highest since Q1/2018, growing in both wireless and LED applications,

driven by high-end applications including automotive, lighting and display and Internet of Things (IoT).

InP revenue was the second largest ever (after only Q2/2019, which included a very large order from a single customer buying for future demand). Sales were driven by a number of customers across a diversified set of applications, indicating that demand is broad based and building momentum. "Ten years ago, InP revenue was barely \$1m and was the lowest revenue generator out of all product lines, lower even than germanium or raw materials. It was classically a product waiting for the market to arrive," notes Young. "Today, we have demand from a number of different applications, and we are seeing additional applications on the horizon. In particular, we saw continued strength from 5G and its related technologies."

"In data-center connectivity, demand remains steady and at a positive level," says Young. "During Q1, we were pleased to become fully qualified at our tier-1 customer. This was a multi-quarter process that touched nearly every aspect of our business and elevated our operations for our benefit of all our customers."

Of total revenue in Q1/2021, the proportion from the Asia-Pacific region rose further, from 71% last quarter to 73%, and Europe rebounded slightly from 16% to 17%. North America fell from 13% to 10%.

No customers reached 10% of revenue, and the top five generated just 26% (compared with 37% last quarter). "Usually, we do have at least one 10% customer. And usually the top five customers contribute approximately 35–40% of total revenue," notes Fischer. "This quarter, when we achieved over \$31m in revenue, it was not because of one big order from one big customer. Further, on this point, the top five customers made up a smaller percentage of our total revenue than normal. Together, these

factors vividly portray an increasingly broad-based, diversified set of customers and applications. From a business perspective, it is significant in demonstrating the growing adoption of the materials we manufacture, as well as the repeatability of this quarter's success," he adds.

"We drove significant improvement in our gross margin and achieved strong growth in profitability," notes Young. Gross margin rose further, from 26.6% a year ago and 33.9% last quarter to 36.8%, driven primarily by product mix and increasing revenue volume, and some tailwind from one of the consolidated raw material companies.

Operating expenses have risen further, from \$6.2m a year ago and \$7.2m last quarter to \$8m (25.4% of revenue, lower than the 2020 quarterly average of 27.6%), with 55% of the year-on-year increase due to R&D expenses, including development costs for GaAs wafers.

Operating income was \$3.6m, almost doubling from \$1.9m last quarter and an improvement from an operating loss of \$0.63m a year ago.

After turning profitable the quarter before last, unconsolidated partially owned joint ventures in AXT's supply chain grew their net profit further, to \$1.1m (due to a 214% rise in revenue in Q1, driven by the improvement in commodity pricing).

However, these gains were offset by a foreign exchange loss of \$173,000 and a tax provision of \$746,000. Q1 results also included about \$275,000 in tariffs as a result of the 25% tariff charge on importing wafers into the USA from China.

Despite this, net income was \$3.4m (\$0.08 per share), up from \$2.1m (\$0.05 per share) last quarter and a net loss of \$0.18m (\$0.01 per share) a year ago.

Q1/2021 saw a slight rise in both depreciation & amortization to \$1.6m and capital expenditure (CapEx) to \$5.6m.

During the quarter, cash, cash equivalents and investments fell

from \$78.6m to \$66.9m, due mainly to an increase in working capital for accounts receivable (which rose by \$3.9m), for inventory and prepaids of \$9.8m, modestly offset by an increase in accounts payable of \$730,000 plus CapEx payments.

During Q1/2021, AXT's net inventory rose by \$3.2m to \$54.7m, consisting of 46% in raw materials, 48% for work in progress (WiP) and 6% in finished goods.

Inventory rose for two reasons:

(1) the order rate is strong, so AXT needs more inventory; and (2) raw material prices are rising, so AXT is buying a little bit ahead of the market to keep COGS (cost of goods sold) low.

"The early months of Q1 had the Chinese New Year — a week-long break — and, as a result, our shipments were back-end loaded for the quarter," notes Fischer.

"Collections from these shipments will move into Q2, benefiting cash this quarter."

"The demand environment remains healthy in Q2/2021," says Fischer.

"Indium phosphide coming off a very strong quarter, we believe we will see continued growth. We also expect growth in gallium arsenide revenues for LED and a modest increase in germanium [driven by the satellite solar cell market]," he adds. "We expect a pullback in

GaAs for wireless, and flat to slightly down [from the strong Q1 level] for raw materials."

For second-quarter 2021, AXT therefore expects revenue of \$30.5–31.5m. Gross margin will probably be at or above 35%, believes Fischer. Net profit should be \$0.06–0.08 per share.

In late April, AXT said that it had developed and shipped its first 8" diameter GaAs substrates (silicon-doped n-type) to a major customer.

"We are currently in development of 6" indium phosphide wafers. This is another R&D project that is expected to position us to participate in some exciting new applications for indium phosphide," says Fischer.

"We continue to see a convergence of major technology trends across our portfolio, and these are beginning to have a meaningful impact on the demand for our products.

These include applications in 5G telecommunications and its related technologies, data-center connectivities, LED-based sensing and display, healthcare monitoring (also referred to as biometrics), consumer devices and others," says Young. "With our new facilities ramping and our successful development of 8" GaAs substrates, we believe we are in a strong position to enable some of the most exciting new and emerging applications for specialty materials today."

### Update on STAR Market listing

On 16 November, AXT announced a strategic plan to access China's capital markets and progress to an initial public offering by its wafer manufacturing firm Beijing Tongmei Xtal Technology Co Ltd on the Shanghai Stock Exchange's Sci-Tech innovAtion board (the STAR Market). The first major step in this process is engaging reputable private equity firms in China to invest in Tongmei.

Going public on the STAR Market includes several periods of review. "The process is more complicated than an IPO in the USA and it takes longer to accomplish," notes Fischer. "A prospective IPO company in China is required to have mandatory training in what it actually means to be a public company, what are the requirements and expectations placed upon a public company."

In January, a number of private equity firms invested about \$49m in exchange for an approximately 7.28% minority stake in Tongmei. "The rest of Q1 efforts included aligning our hidden assets in China beneath our main company in Beijing in Tongmei," says Fischer. "Tongmei is also undergoing an audit conducted by Ernst & Young China. We're hoping to submit our SEC application around 30 June or in Q3." Tongmei expects to achieve listing in mid-2022.

[www.axt.com](http://www.axt.com)

## AXT supplies first 8-inch GaAs wafers

AXT has developed and shipped its first 8" diameter GaAs substrates to a major customer. The silicon-doped n-type substrates demonstrate low etch pit densities (EPD) and low levels of slip lines.

"Every step up in diameter size comes with a major increase in the technical challenge of producing it," says CEO Morris Young. "The material quality of our first wafers demonstrates our commitment to excellence and the differentiation of our VGF [vertical gradient freeze] crystal growth process," he adds. "We are pleased to be able to offer

our customers meaningful advances in scalability, low stress and low defect rates."

AXT says it has received significant interest from several customers due to the market development of high-volume applications, including vertical-cavity surface-emitting lasers (VCSELs) for 3D sensors and light detection & ranging (LiDAR), as well as micro-LEDs for displays. AXT predicts a broader scaling of demand for 8" GaAs wafers when these applications are adopted.

"Although we still have development work to undertake on this project,

our new world-class manufacturing facilities in Dingxing and Kazuo can enable commercial viability of 8" GaAs," Young says. "Both of AXT's new facilities have been purposefully designed and built for high-volume manufacturing of compound semiconductor substrate wafers, utilizing advanced equipment and improved automation. Further, manufacturing volume expansion was taken into account when designing the new facilities, and we believe we have a short path to develop and launch a high-volume manufacturing line for 8" GaAs."

# Riber grows margin and makes profit in 2020 despite 10% drop in revenue

## Deferments and export license refusals mitigated by 25% growth in Services & Accessories revenue

For full-year 2020, Riber S.A. of Bezons, France — which manufactures molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells — has reported revenue of €30.2m, with a limited contraction of just 10% from 2019's €33.5m.

The firm says that the Covid-19 pandemic and the lockdown measures introduced by governments in most countries have deeply affected business and limited travel to visit Asian clients to finalize their machine installations, resulting in revenues being deferred.

Despite these operational difficulties, Riber was able to respect its production plan, due to its adapted organization, and deliver to its clients within the timeframes set.

MBE system sales showed a good level of resilience, with 10 machines delivered, versus 12 in 2019, yielding Systems revenue of €18.2m (down 21% from €23m).

Due to the current lack of investment in the organic light-emitting diode (OLED) screen industry, the evaporator market remained sluggish, with Evaporators revenue falling further, from 2019's €1.1m to just €0.3m in 2020.

In line with the strategy rolled out by the firm, sales of Services & Accessories further strengthened their organic growth, rising by 25% from 2019's €9.4m to a record €11.7m in 2020, despite the export licenses rejected in December for €1.7m.

Due in particular to a favorable change in the product mix and

better productivity, gross margin was 30.1%, slightly higher than 2019's 29.6%.

Operating expenditure fell from €9m in 2019 to €8.4m in 2020, primarily factoring an 18% drop in sales & marketing costs. Administrative costs rose by 6%. Gross R&D investments were increased by 16%, from €2.4m to €2.8m (9.4% of revenue).

Operating income was €0.7m, down from €0.9m in 2019 (falling from 2.7% to 2.3% of revenue). Likewise, net income fell from €1.1m (3.4% of revenue) in 2019 to just €0.3m (0.9% of revenue) for 2020, although this includes -€0.4m of financial income and expenses (linked primarily to a provision for the exchange rate risk on receivables denominated in US dollars).

The cash position rose by €2.1m during 2020 to €8m, reflecting the impact of an increase in working capital requirements, positive cash flow from operations, and two government-backed loans (€8m) that were taken out and will be repayable from 2022.

Shareholders' equity is down by €0.2m to €19m, linked to earnings for the year and the distribution of amounts drawn against the issue premium for 2019 to shareholders.

Riber notes that in 2020 it faced a significant slowdown in its commercial activity. On the one hand, a number of clients deferred their investment decisions due to the lack of visibility in the context of the health crisis. On the other

hand, the French authorities refused to issue several export licenses to the firm for a total of €13m for the year.

As a result, the order book has contracted significantly during 2020, from €28.7m to €14.4m. System orders of €5.7m include two research machines. Orders for Services & Accessories have risen by 26% to €8.7m.

### Outlook for 2021

Driven by information technology innovations, the MBE market is still fundamentally buoyant, reckons Riber. The firm expects to consolidate its order book in 2021, as illustrated by the additional orders for one research machine and two production machines, announced in January, March and April, respectively.

Riber also expects to benefit from investments being made in the semiconductor industry as part of stimulus plans. Meanwhile, the Services & Accessories business is expected to continue to make progress.

Building on a sound financial structure, the firm aims to continue improving its profitability compared with 2020.

Illustrating its confidence in the company's future, the Executive Board is submitting a proposal to shareholders at the General Meeting on 25 June to approve a cash payout based on reimbursing part of the issue premium for €0.03 per share (to be released for payment on 7 July).

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# Veeco's Q1 revenue up 27.9% year-on-year to \$133.7m

## Growth driven by Semiconductor and Data Storage segments

For first-quarter 2021, epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA has reported revenue of \$133.7m, down 3.7% on \$138.9m last quarter but up 27.9% on \$104.5m a year ago (and near the top end of the \$115–135m guidance range), driven by the Semiconductor and Data Storage segments. Of Veeco's end-2020 order backlog of \$366m (which was \$100m up on end-2019), most was in the Data Storage segment, followed by Semiconductor, then Compound Semiconductor, and lastly Scientific & Other.

Data Storage hence contributed \$41m (31% of total revenue) in Q1/2021, up from just \$19.2m (14% of revenue) last quarter.

Semiconductor (Front-End and Back-End, as well as EUV Mask Blank systems and Advanced Packaging) contributed \$51.6m (39% of total revenue), up on \$37.4m a year ago, driven by laser annealing and lithography products.

Compound Semiconductor (Power Electronics, RF Filter & Device applications, and Photonics including specialty, mini- and micro-LEDs, VCSELs, laser diodes) contributed \$24.8m (18% of total revenue), up on \$18.4m a year ago, driven by wet-processing systems sold for RF applications.

The Scientific & Other segment contributed \$16.4m (12% of total revenue), roughly level with \$17.1m (12% of revenue) last quarter but up on just \$9.8m a year ago.

By region, the Asia Pacific (excluding China) comprised 41% of total revenue (down from 48%), the USA 34% (up from 26%), China 15% (up slightly from 14%, after declining since Veeco exited the commodity LED MOCVD business at the end of 2018), Europe, Middle-East & Africa (EMEA) 10% (down from 12%), and the rest of the world (RoW) again less than 1%.

"We improved revenue and

profitability year-on-year as we continued to invest for growth," says CEO William J. Miller Ph.D.

On a non-GAAP basis, gross margin was 41.5%, down on 44.9% a year ago but up slightly from 41.3% last quarter, and toward the top end of the 40–42% guidance range.

Operating expenses were \$39.3m (29% of revenue), up from \$34.2m a year ago but cut slightly from \$39.7m last quarter.

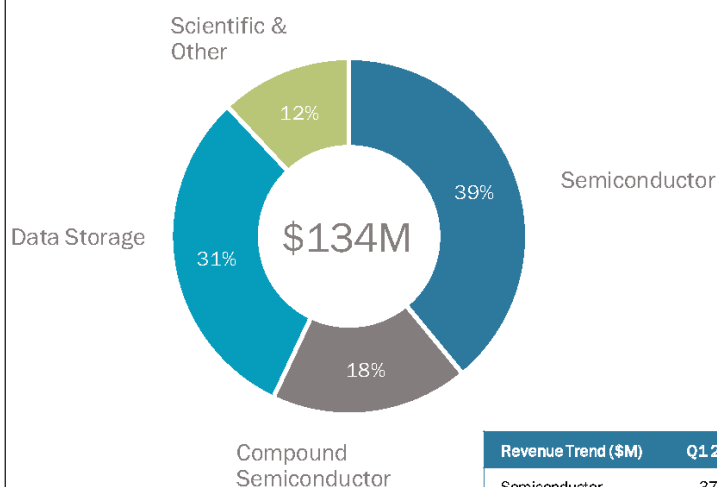
Net income was \$12.6m (\$0.25 per diluted share), down from \$15m (\$0.30 per diluted share) last quarter but still up on \$10.9m (\$0.22 per diluted share) a year ago.

Cash flow from operations was \$10m. Capital expenditure (CapEx) was \$2m. During the quarter, cash and short-term investments hence rose by \$8m, from \$320m to \$328m. Long-term debt rose slightly from \$321m to \$325m, representing the carrying value of \$389m in convertible notes.

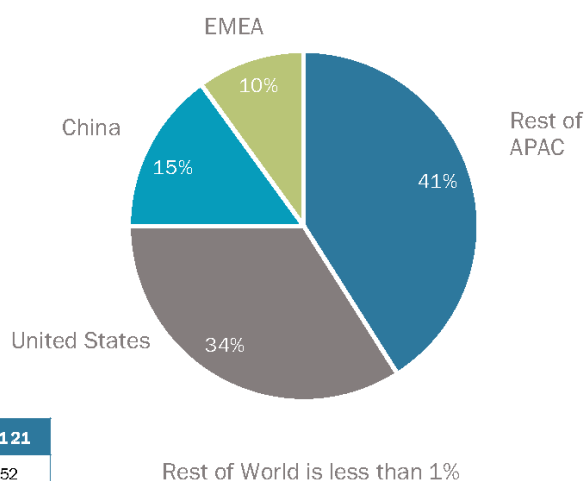
From a working capital perspec-

## Q1 2021 Revenue by Market & Region

### Revenue by Market



### Revenue by Region



Revenue Trend (\$M)	Q1 20	Q4 20	Q1 21
Semiconductor	37	57	52
Compound Semi	18	45	25
Data Storage	39	19	41
Scientific & Other	10	17	16
<b>Total</b>	<b>105</b>	<b>139</b>	<b>134</b>

tive, accounts receivable rose from \$80m to \$87m, driving days sales outstanding (DSOs) back up from 52 days to 59 days. Accounts payable rose from \$34m to \$43m, with days payable outstanding (DPOs) increasing from 37 days to 49 days.

For second-quarter 2021, Veeco expects revenue to be roughly level at \$125-145m, with increased Data Storage revenue (since most of the increased Data Storage order backlog of end-2020 should be delivered in Q2-Q3/2021.) but no significant LED-related sales in the Compound Semiconductor sector. Gross margin should be 40-42%. With operating expenses of \$38-40m, net income is expected to be \$9-18m (\$0.17-0.35 per diluted share).

With revenue growth expected in second-half 2021 in not only the Data Storage segment but now also the Semiconductor segment (particularly laser annealing, as well as advanced packaging), Veeco has now raised its guidance for full-year 2021 revenue growth from 17% to 21% (to \$540-560m). Gross margin is expected to also grow, while net income should be \$1.10-1.30 per diluted share (up 40% year-on-year, rather than 28%).

To support the planned increase in volume in second-half 2021 and investments in evaluation systems, inventory has been raised further, from \$146m to \$156m, with days of inventory (DOI) rising from 159 days to 173 days.

"We are making progress toward

our long-term growth by actively engaging with customers in the Semiconductor and Compound Semiconductor markets," says Miller. "We shipped multiple evaluation systems to leading device manufacturers as part of our strategy to penetrate targeted high-growth markets. Additionally, construction is well underway at our new San Jose manufacturing facility to better meet the demands of our Semiconductor customers," he adds.

"We are planning to have 10 evaluation systems in the field throughout 2021. Today, we have six in the field and four are planned to ship the rest of this year. We are making large investments in 24x7-service support," says Miller. "Of those 10 tools, five are laser annealing [for logic and memory]; two are MOCVD [one for 8-inch power electronics and one for micro-LED applications]; and two are in advanced packaging [one of which is a core Veeco technology being developed for the Semiconductor market, for shipping later this year]."

"In Compound Semiconductors, we have two product lines. One is wet processing, where we are seeing significant demand from customers for RF filters and RF power amplifiers, really driven by 5G adoption in handsets," says Miller. "In the MOCVD space, our business is at low levels, after exiting the commodity LED business. We've obviously restructured that business. We go to market with two products. One is gallium nitride. We have a

single-wafer reactor. That is really tuned for the power electronics, RF and innovative silicon-based micro-LED applications. What we are seeing now is growth in GaN power applications, particularly at 8-inch... customers are moving from 6-inch to 8-inch format. Those customers that are doing that are choosing Veeco. So that's a driver of growth this year into next year. Longer-term opportunities like micro-LEDs... that is still further out on the horizon, like 2-3-plus years," he adds. "[For arsenide-phosphide (As/P) MOCVD] we go-to-market with Lumina batch tools. That's tuned for applications in photonics, such as indium phosphide lasers, VCSELs, as well as red micro-LEDs. We just recently shipped an evaluation system for micro-LEDs with this product. It's still further out, but that's certainly an opportunity for the company."

"We are encouraged by customer feedback and demo results from our gallium nitride and arsenide-phosphide MOCVD platforms. These products enable fast charging and other power management solutions, 5G RF devices and micro-LEDs," continues Miller. "Recent early-stage wins and an evaluation shipment position Veeco to grow with these emerging markets as they gain traction," he adds. "Most of these evals are lasting one year post-installation. So there may be a few that will be signed off late this year... mostly we'll be seeing those in the first half of 2022."

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# Aixtron's Q1 revenue up 21% year-on-year, driven by optoelectronics

## Order growth driven by GaN power electronics and 5G wireless

For first-quarter 2021, deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has reported revenue of €49.5m, down 54% from €108.1m last quarter (due to many customer requests for shipments to be pulled forward into Q4/2020) but up 21% on €41m a year ago.

In particular, equipment revenue grew by 28% year-on-year from €29.9m to €38.2m (rebounding from 73% to 77% of total revenue), while after-sales spares & services revenue rose by only 4% from €11m to €11.4m (falling from 21% to 23% of total revenue).

Growth was driven mainly by systems for producing optoelectronics devices (particularly lasers for optical data communications, 5G applications and 3D sensing), rising to 56% of total revenue

(up from just 38% a year previously).

Another key driver, at 29% of total revenue, was systems for manufacturing energy-efficient power electronics based on gallium nitride (GaN) and silicon carbide (SiC), e.g. for fast charging of batteries in mobile devices such as smartphones and in the powertrain of electric vehicles (EVs).

Equipment for LED production comprised 14% of revenue (up on 9% a year ago).

On a geographic basis, Asia contributed 62% of revenue, Europe 30% (up from 17% a year ago) and the Americas just 7% (falling from 18%).

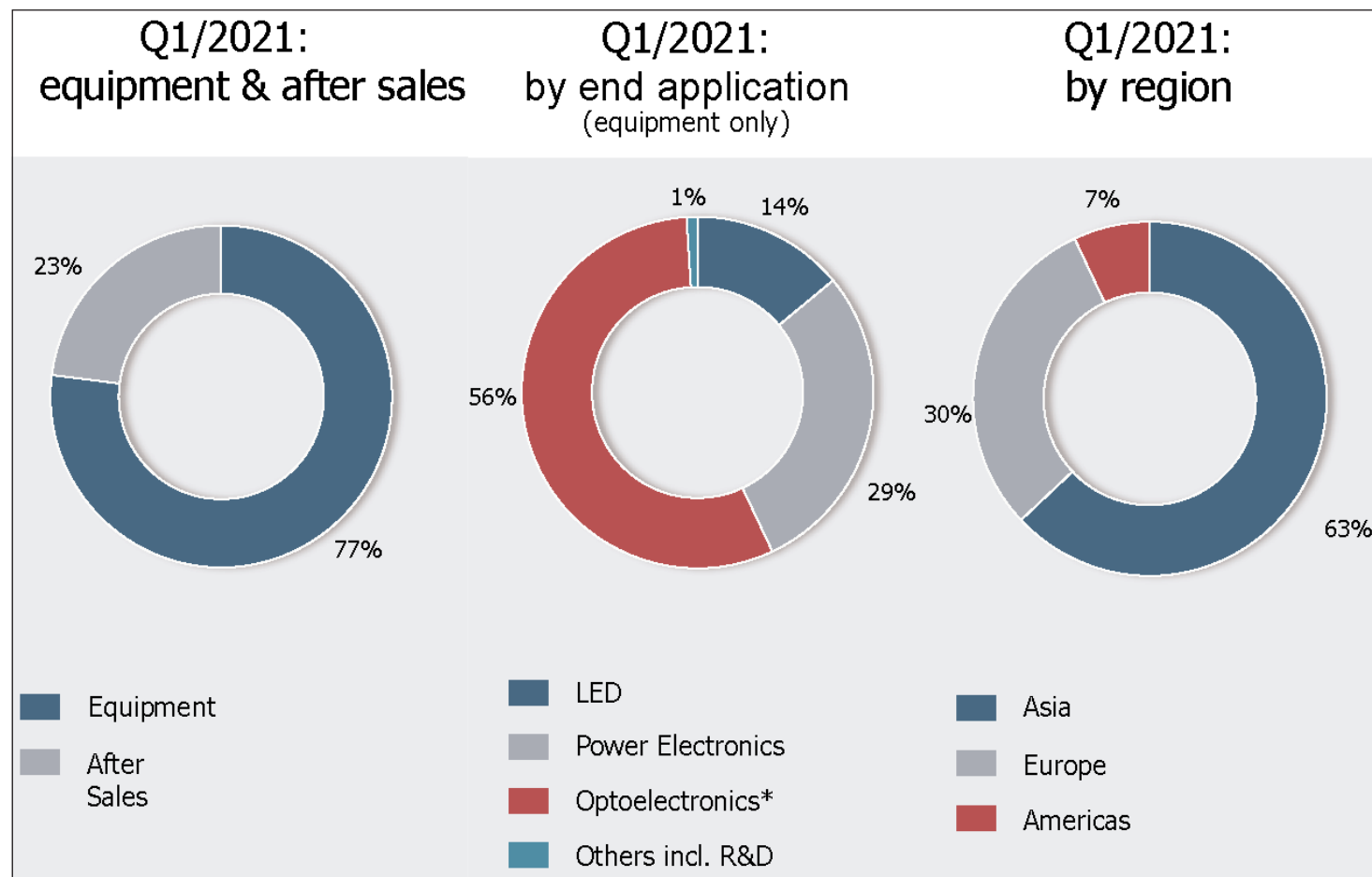
Gross margin was 35%, down from 42% last quarter but roughly level with 36% a year ago. Higher sales volume effects year-on-year were partially offset by the impact

of the weaker US dollar. Furthermore, additional expenses were incurred for preparing production capacities for the increased output planned for second-half 2021.

Operating expenses of €18m were up on €15.7m a year ago but cut from 20.5m last quarter. To bring next-generation MOCVD systems for various applications to market maturity, Aixtron spent €11.9m on R&D. This includes lower ongoing costs for organic light-emitting diode (OLED) technology.

Operating result (earnings before interest and taxes) was -€0.7m (EBIT margin of -1% of revenue), improving from -€1.1m (-3% EBIT margin) a year ago, mainly due to revenue growth.

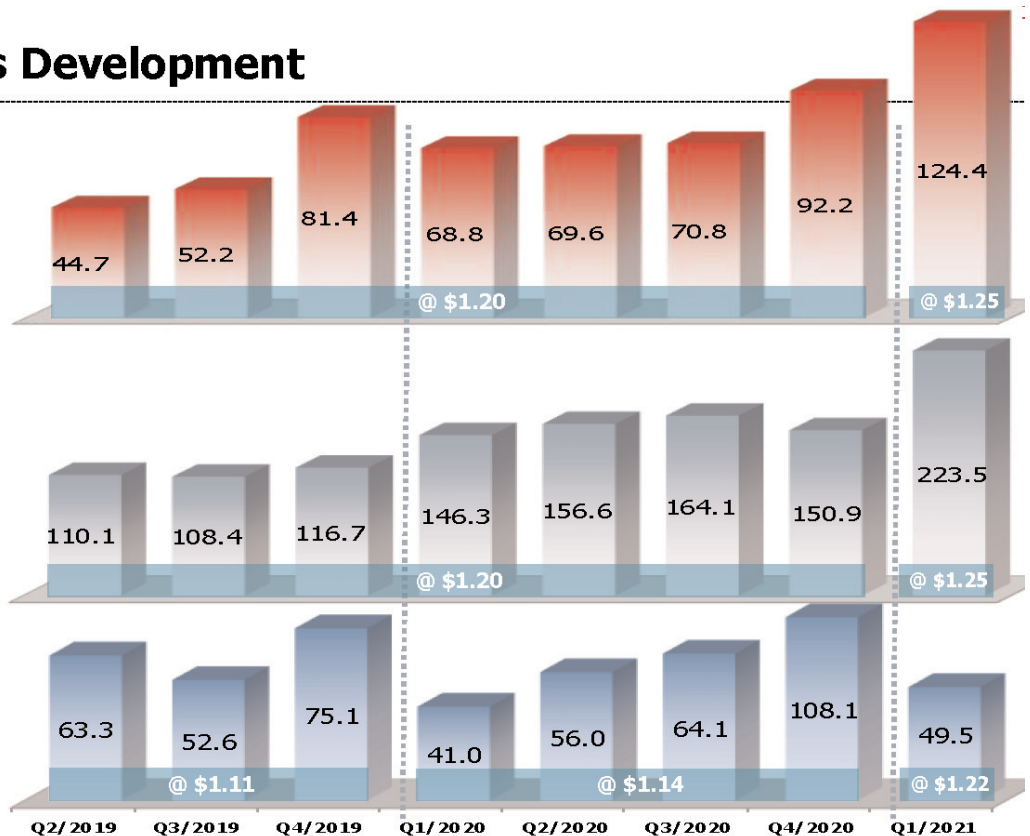
Net income of €3.8m was an improvement on a net loss of -€0.8m a year ago, due primarily



## 24 - Month Business Development

(€ million)

**Order Intake**  
(incl. Equipment & After Sales)



**Order Backlog**  
(Equipment only)

**Revenues**  
(incl. Equipment & After Sales)

to further recognition of deferred tax assets.

Operating cash flow was €31.8m. Capital expenditure (CapEx) was €3.7m. Free cash flow was hence €28.1m, significantly higher than €3m a year ago and €17.3m last quarter.

During the quarter, cash and cash equivalents rose from €309.7m to €341m, due mainly to an increase in customer deposits and despite the scheduled increase in inventories (by 23%, from €79.1m to €97.3m) in preparation for increased future shipments.

### GaN power electronics driving order growth

Order intake has grown further, to €124.4m, up 35% on last quarter's record €92.2m and up 81% on €68.8m a year ago, driven largely by GaN power electronics and 5G wireless telecoms. "Demand for our systems is pleasingly high — across all three application areas of power electronics, optoelectronics and LEDs," comments CEO Dr Felix Grawert.

Equipment order backlog at the end of March was €223.5m, up 48% on €150.9m last quarter and up 53% on €146.3m on a year ago.

### Accelerated growth in 2021

For full-year 2021, Aixtron continues to expect a strong upturn in business. Based on Q1/2021 and the internal assessment of the demand development, Aixtron now expects order intake to come out at the upper end of its €340–380m guidance range.

Based on the equipment order backlog (convertible into 2021 revenue) of €180m as of 31 March joined by an expected €90m of order intake that should be convertible into revenue during 2021 plus €40m of after-sales spares & services revenue, together with the €49.5m of revenue from Q1/2021, for full-year 2021 Aixtron now expects revenue at the upper end of the €320–360m guidance range. Gross margin guidance remains about 40%. But, due to the improved revenue expectations, the Executive Board is now raising its expectation for EBIT margin from 16% to about 18%. This also takes into account the impact of the COVID-19 pandemic, which at this stage is not considered to be significant for Aixtron's business.

Aixtron says that, as customer discussions initiated with the previous Asian customer after qualification

of the Gen2 deposition system did not lead to the envisaged result, its South Korea-based OLED-focused subsidiary APEVA is now addressing opportunities in China for the production of OLEDs using its technology. Together with the joint venture partner IRUJA Co Ltd, commercialization of the organic vapor phase deposition (OVPD) core technology is to be driven forward there. APEVA will hence focus on the supply of key components. The successful conclusion of talks with potential customers in China is not expected before 2022.

"With our focused investment program to further develop our leading-edge technologies and product portfolio, we have set the course at an early stage to be able to continue to satisfy our customers' demand for innovative equipment in the years to come in the best possible way," believes Grawert.

At the end of March, Dr Bernd Schulte left the Executive Board (at the end of his contract) and retired, and Felix Grawert was appointed chairman. On 1 May, Dr Christian Danninger joined the Executive Board as the new chief financial officer.

[www.aixtron.com](http://www.aixtron.com)

# Imec and Aixtron demo 200mm GaN epi on AIX G5+ C for 1200V applications with breakdown over 1800V

## Result paves way for GaN to enter SiC high-voltage domain

Nanoelectronics research centre imec of Leuven, Belgium and deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany have demonstrated epitaxial growth of gallium nitride (GaN) buffer layers qualified for 1200V applications on 200mm QST substrates, with a hard breakdown exceeding 1800V. The manufacturability of 1200V-qualified buffer layers is reckoned to open doors to the highest-voltage GaN-based power applications such as electric vehicles (EV), previously only with feasible silicon carbide (SiC)-based technology.

The result comes after qualification of Aixtron's G5+ C fully automated metal-organic chemical vapor deposition (MOCVD) reactor at imec for integrating the optimized material epi-stack.

Wide-bandgap materials GaN and SiC have proved their value as next-generation semiconductors for power-demanding applications where silicon falls short. SiC-based technology is the most mature, but it is also more expensive.

Over the years great progress has been made with GaN-based technology grown on 200mm silicon wafers, for example. At imec, qualified enhancement-mode high-electron-mobility transistors (HEMTs) and Schottky diode power devices have been demonstrated for 100V, 200V and 650V operating voltage ranges, paving the way for high-volume manufacturing applications.

However, achieving operating voltages higher than 650V has been challenged by the difficulty of growing thick-enough

GaN buffer layers on 200mm wafers. Therefore, SiC so far remains the semiconductor of choice for 650–1200V applications — including electric vehicles and renewable energy, for example.

For the first time, imec and Aixtron have demonstrated epitaxial growth of GaN buffer layers qualified for 1200V applications on 200mm QST (in SEMI standard thickness) substrates at 25°C and 150°C, with a hard breakdown exceeding 1800V.

"GaN can now become the technology of choice for a whole range of operating voltages from 20V to 1200V," says Denis Marcon, senior business development manager at imec. "Being processable on larger wafers in high-throughput CMOS fabs, power technology based on GaN offers a significant cost advantage compared to the intrinsically expensive SiC-based technology."

Key to achieving the high breakdown voltage is the careful engineering of the complex epitaxial material stack in combination with the use of 200mm QST substrates, executed in scope of the Imec Industry Affiliation Program (IIAP). CMOS-fab friendly QST substrates from Qromis Inc of Santa Clara, CA, USA have a thermal expansion

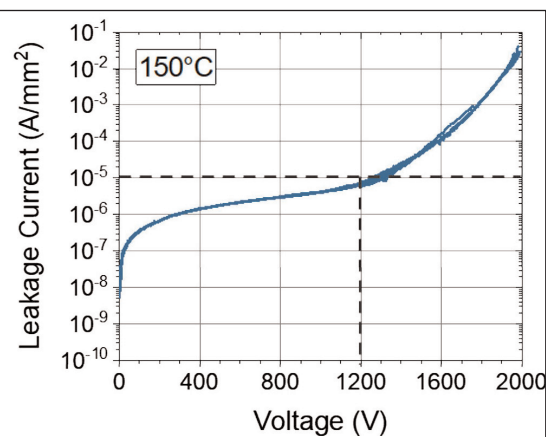
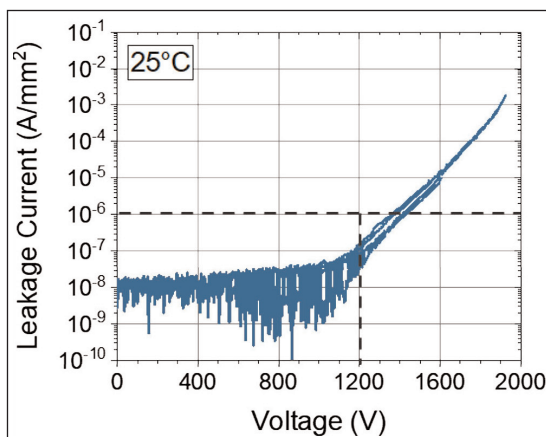
that closely matches the thermal expansion of the GaN/AlGaN epitaxial layers, paving the way for thicker buffer layers — and hence higher-voltage operation.

"The successful development of imec's 1200V GaN-on-QST epi technology into Aixtron's MOCVD reactor is a next step in our collaboration with imec," says Aixtron's CEO & president Dr Felix Grawert. "Earlier, after having installed Aixtron G5+ C at imec's facilities, imec's proprietary 200mm GaN-on-Si materials technology was qualified on our G5+ C high-volume manufacturing platform, targeting for example high-voltage power switching and RF applications and enabling our customer to achieve a rapid production ramp-up by pre-validated available epi recipes," he adds. "With this new achievement, we will be able to jointly tap into new markets."

Lateral e-mode devices are being processed to prove device performance at 1200V, and effort is ongoing to extend the technology towards even higher-voltage applications. imec is also exploring 8-inch GaN-on-QST vertical GaN devices to further extend the voltage and current range of GaN-based technology.

[www.aixtron.com](http://www.aixtron.com)

[www.imec.be](http://www.imec.be)



**Vertical forward buffer leakage current measured on 1200V GaN-on-QST at two different temperatures: (left) 25°C and (right) 150°C. Imec's 1200V buffer shows vertical leakage current below 1µA/mm² at 25°C and below 10µA/mm² at 150°C up to 1200V with a breakdown in excess of 1800V both at 25°C and 150°C, making it suitable for processing of 1200V devices.**

# imec and Soitec CEOs appointed chair and vice-chair of SEMI Europe Advisory Board

## Former chair Kevin Crofton continues as member of board

SEMI (the industry association representing the global electronics manufacturing and design supply chain) has appointed Luc Van den hove, president & CEO of nanoelectronics research centre imec of Leuven, Belgium, as chair and Paul Boudre, CEO of engineered substrate manufacturer Soitec of Bernin, near Grenoble, France, as vice-chair of SEMI Europe's Advisory Board.

SEMI Europe Advisory Board members provide strategic guidance and represent the collective interests of all SEMI members to help foster the growth and profitability of the European microelectronics industry.

"We are honored to collaborate with a diverse group of executive leaders that epitomize both the technological and competitive advantages of Europe's microelectronics industry," comments Laith Altimime, president of SEMI Europe. "Together, we will work to advance the European microelec-



**imec's president & CEO Luc Van den hove (left), and Soitec's CEO Paul Boudre (right).**

tronics ecosystem to drive future growth and promote European strategic initiatives and partnerships."

"We thank Kevin Crofton, CEO of Comet, for his strategic leadership and valuable support to SEMI Europe as a chair over the past years and continued member of the board," he adds.

"I am extremely honored to be appointed chair of the SEMI Europe board and consider this a recognition of the key position that imec has

established over the years being one of the leading R&D centers in Europe," says Van den hove. "I am looking forward to taking up my role and leverage my expertise and knowledge to further strengthen SEMI Europe's efforts in connecting and supporting its members and drive innovation and growth in Europe by protecting its core competencies while

strengthening global supply chains," he adds.

"Our world and societies are facing major changes and disruptions. This creates significant opportunities for the semiconductor industry and for Europe as a whole," believes Boudre. "SEMI is a key motor of this transformation, because it drives the development of our ecosystem, up and downstream, and helps us to bolster Europe's leadership and sovereignty."

## Epiluvac appoints VP sales & marketing CVD system maker sees growing demand for both silicon carbide and gallium nitride applications

Epiluvac AB of Lund, Sweden — which was founded in 2013 and makes chemical vapor deposition (CVD) equipment for wide-bandgap semiconductors — says that Dr Michael MacMillan has joined the firm as VP of sales & marketing, based at its new office in Orange County, CA, USA.

"We see a growing demand for the next-generation CVD equipment, not only for silicon carbide (SiC) but also for gallium nitride (GaN)," notes Bo Hammarlund, board director, business development. "Mike's expertise in SiC epitaxy, together with his long experience from both research and manufacturing companies, will certainly

bring exciting benefits to our products and also our customers," he believes.

MacMillan was recently chief epitaxial scientist at SemiQ (formerly Global Power Technologies Group) of Lake Forest, CA, USA, and his career spans from early SiC research at Linköping University, Sweden in the 1990s to many years as leader and SiC scientist in major US companies such as Northrop Grumman and Dow Corning. He holds a PhD in Physics from University of Pittsburgh.

"This is a great opportunity and privilege to be part of this highly skilled team with their new, exciting CVD platform for wide-bandgap

semiconductors," comments MacMillan.

Epiluvac recently introduced a new product generation, primarily intended for SiC and GaN epitaxy. The new WBG-Multi-Reactor-CVD systems are based on hot-wall CVD and single-wafer processing of up to 200mm (8")-diameter wafers, with an option to connect multiple chambers and wafer handling robots together in a cluster tool configuration to meet each customer's requirement for higher output, flexibility or stepwise wafer processing through multiple chambers. Epiluvac's products are sold worldwide, either directly or through local partners.

[www.epiluvac.com](http://www.epiluvac.com)

# OIPT breaks ground on new manufacturing facility

## Lab, office and manufacturing space to comprise 107,660ft<sup>2</sup>

Plasma etch and deposition processing system maker Oxford Instruments Plasma Technology (OIPT) of Yatton, near Bristol, UK has broken ground at the site of its new manufacturing facility in Bristol.

The relocation is driven by the growing demand from customers (which include leading semiconductor device makers and materials research institutions, the firm says).

“Our new building will comprise both a state-of-the-art manufacturing facility as well as advanced research laboratories which will support our leading-edge developments and enable the future innovations of our customers,” says managing director Matt Kelly.

Strong growth in the last four years has seen the company grow to more than 400 employees worldwide, with over 300 of these working across the laboratory, office and manufacturing space at the existing Plasma Technology UK headquarters in Yatton.



“The building will comprise 107,660ft<sup>2</sup> with an extensive additional fit-out,” says Mark Wright, partner at Trebor Developments, who is managing the project.

For many years, OIPT has focused its expertise on compound semiconductors and optimized its hardware, making it suitable for operation in the fab, delivering critical device performance, yield and cost of ownership. The markets for compound semiconductor appli-

cations, such as gallium nitride (GaN) fast chargers and silicon carbide (SiC) power devices, are growing notably, driving the need for expansion. The evolution of Plasma Technology into the semiconductor production space, combined with the increased demand for its systems, not only calls for additional space but also requires a facility to further enhance capabilities as a production supplier, the firm says.

<https://plasma.oxinst.com>

## OIPT's ALE technology chosen by tier-1 automotive supplier for GaN power electronic program

### PlasmaPro100 Cobra system to be used for gallium nitride power device development

OIPT says that a “leading German semiconductor manufacturer to the automotive industry” has selected its PlasmaPro100 Cobra system for the development of gallium nitride (GaN) power electronic devices.

The PlasmaPro100 Cobra system is designed for superior uniformity, high-precision and low-damage process solutions, says OIPT. The production-proven system allows for rapid change between wafer sizes up to 200mm, and cost of ownership is one of the lowest in the market, it claims.

The PlasmaPro100 Cobra system will be incorporated into the

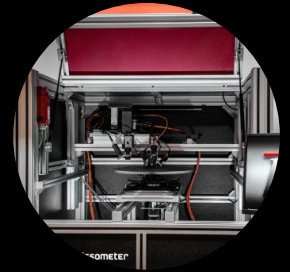
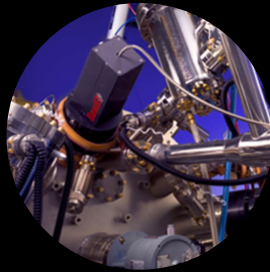
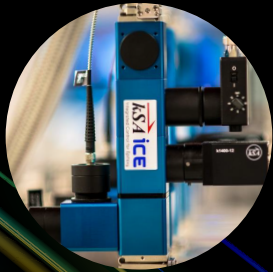
semiconductor manufacturer's R&D section and will be used for the development of GaN power devices, which are gaining market share in fast-charger applications and offer benefits in electric vehicle (EV) power management systems.

“We continue to see very encouraging signals in the form of increasingly proactive customer engagement and clear market preparation and positioning activities from significant industry players for the emerging wide-bandgap power electronic market,” says OIPT.

“Our atomic-scale processing

etch solution being selected by this world-leading manufacturer for their GaN power electronics program is an important strategic win for Oxford Instruments Plasma Technology,” comments Klaas Wisniewski, Plasma Technology's strategic business development director. “The GaN-based power electronic market is very dynamic, with improvements to both performance and cost expected at each design iteration,” he adds. “This reiterates the importance of our strategy to focus on atomic-scale processing solutions such as atomic layer deposition (ALD) and atomic layer etching (ALE).”

# When Accurate Real-Time Measurement Matters



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# Axis improves process performance for single-wafer silicon carbide CMP

Focus on thin/fragile wafer handling reliability, sub-micron TTV, sub-Angstrom surface finish, and reduced cost of ownership

Axis Technology of Chandler, AZ, USA — a provider of chemical-mechanical polishing/planarization (CMP), wafer thinning and surface-processing solutions) — has been working to develop and improve CMP process performance and hardware capability for single-wafer silicon carbide (SiC) CMP applications. The primary focus of these efforts is: (1) thin/fragile wafer handling reliability, (2) premium substrate flatness (total thickness variation, or TTV), (3) substrate surface quality, and (4) reduced cost of ownership (CoO).

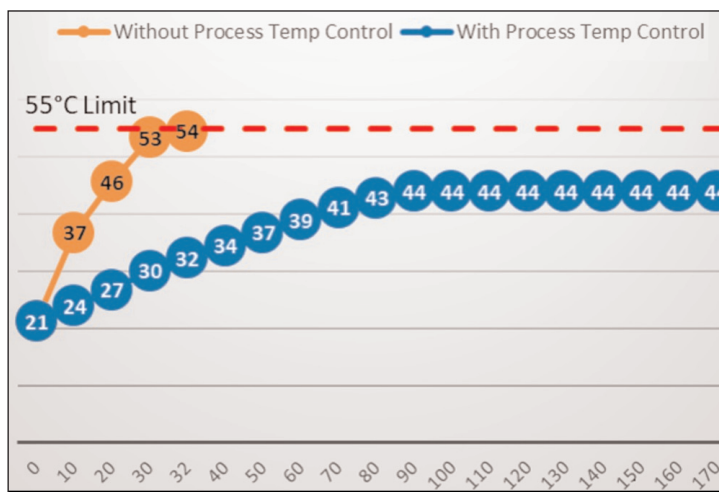
Based on the architecture of the Capstone CMP system, coupled with the firm's Crystal carrier specifically designed for fragile wafer handling and advanced profile control, Axis has demonstrated process performance that has so far met or exceeded all customer specifications.

Axis has successfully handled and processed 150mm diameter SiC substrates from SEMI-standard thickness of 350µm down to 175µm, without the need for temporary bonding or handle wafers to support these substrates.

In addition to fragile wafer handling capability, Crystal carriers also provide the ability to accurately control the material removal profile during CMP, allowing customers to reduce pre-CMP TTV and produce premium-quality, sub-micron TTV substrates. The market demand for such substrates will continue to drive the high end of SiC wafer pricing and supplier profit margins, says Axis.

In other cases, Axis has demonstrated the ability to reduce substrate TTV by several microns during full CMP processing (Si-face and C-face) during customer process demonstrations.

For surface quality optimization, Axis works closely on both CMP



**The difference in process temperature with and without process cooling technology developed by Axis (based on pad surface temperature measured by pyrometer), at 5psi wafer pressure.**

consumables development and process optimization on Capstone. These efforts have resulted in the ability to generate sub-Angstrom (Ra) surface finish with a single-step process.

Capstone is said to be the only advanced CMP tool on the market that supports both single-wafer and dual-wafer processing. Dual-wafer processing has been demonstrated to reduce CMP consumables CoO by as much as 50% compared with existing processes of record used on more mature CMP tools.

Since reducing SiC CMP CoO requires faster removal rates and corresponding process throughput, SiC CMP processes typically run at higher wafer pressures and rotation speeds — also known as PV value (pressure x velocity) — compared with other, more mature CMP applications such as silicon. Process temperature becomes a limiting factor as the PV value increases.

Axis has developed a proprietary process cooling system that enables high-PV-value CMP processes that substantially increase the material removal rate

without exceeding the maximum temperature limits of other components of the CMP process, particular the polishing pad (see Figure).

Process temperature control further enables dual-wafer processing for managing the process temperature in both single-wafer and dual-wafer process scenarios.

Based on the Capstone architecture, both platens can perform dual-wafer processing simultaneously, resulting in parallel processing of four wafers concurrently. Capstone is claimed to be the only advanced CMP tool on the market that can process this many wafers in parallel, further improving its throughput advantage.

Recent process improvements have yielded a material removal rate above 10µm per hour on the silicon face. As a breakthrough for single-wafer silicon carbide CMP, Axis is providing SiC wafer suppliers with what is claimed to be the most advanced CMP system on the market and unmatched performance benefits. The Capstone CMP system, coupled with the firm's Crystal carrier (specifically designed for fragile wafer handling and advanced profile control), delivers premium-quality SiC substrates with sub-micron TTV and sub-Angstrom surface finish. The net result for Capstone users is higher throughput while significantly reducing consumables usage and cost of ownership (CoO).

[www.axustech.com](http://www.axustech.com)

# k-Space launches spectral reflectance metrology tool for complex thin-film structures

k-Space Associates Inc of Dexter, MI, USA – which produces thin-film metrology instrumentation and software for research and manufacturing of microelectronic, optoelectronic and photovoltaic devices – has announced the release of kSA SpectR, a complete non-contact metrology solution for measuring absolute spectral reflectance,  $L^*a^*b^*$  color parameters, and growth rate.

The tool has many applications for in-situ monitoring and process control, including vertical-cavity surface-emitting lasers (VCSELs), distributed Bragg reflectors (DBRs), and other complex device structures. Thin-film production and research facilities can use it in sputtering, molecular beam epitaxy (MBE) and

metal-organic chemical vapor deposition (MOCVD) growth methods.

The kSA SpectR optics are configured in a specular reflectance geometry. k-Space utilizes a method that was developed at Sandia National Laboratory and is licensed to k-Space. In this approach, the fitting routine restarts with each new layer, treating the underlying film stack as a 'virtual' substrate. The kSA SpectR can perform measurements simultaneously at multiple wavelengths, each of which offers potential advantages. The tool easily measures custom spectral features such as reflectance minima, maxima, inflection points, or baseline scatter level, over a user-defined wavelength range of interest.

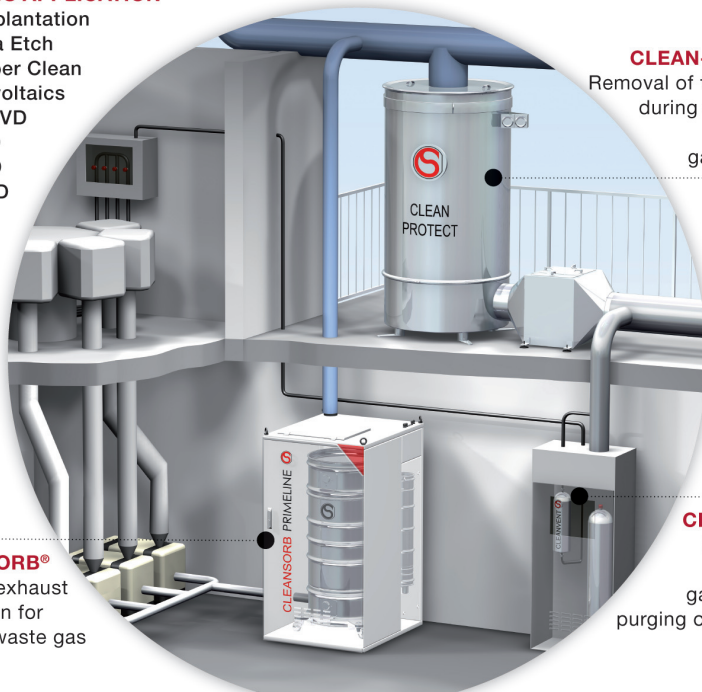
"This tool, like many of our tools, is the direct result of a specific customer need," says CEO Darryl Barlett. "When the customer came to us, we listened to their measurement requirements and then designed a system, incorporating Sandia National Laboratory's technology, that worked for their application," he adds. "As the complexity of thin-film layers advances, so does the need for metrology that measures the right parameters for yield and performance. This system has the capability to work on complex thin-film structures, including applications such as precisely determining the Fabry-Perot dip during DBR growth."

[www.k-space.com/product/ksa-spectr](http://www.k-space.com/product/ksa-spectr)



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# Innovate UK grant for LUSS consortium to develop LED-based UV exposure for safe surfaces

## MicroLink, Wideblue and CSA Catapult target COVID-19 autonomous surface disinfection system for hospitals

MicroLink Devices UK Ltd says that the consortium for the project LUSS (LED based Ultra-Violet exposure for Safe Surfaces) has been awarded a grant by UK Government agency Innovate UK (which provides funding and support for business innovation as part of UK Research and Innovation) to develop an economical solution to combat COVID-19 infection in public spaces, with the added ability to also disinfect surfaces of other viruses and bacteria.

With support from product design specialist WideBlue Ltd (in Glasgow's West of Scotland Science

Park) and the UK's Compound Semiconductor Applications (CSA) Catapult (based in South Wales), lead industrial partner MicroLink Devices will develop an automatically self-cleaning door panel, exploiting specific UV light, that will kill viruses/bacteria and prevent the spread of infection. The door panel will be disinfected automatically between uses, reducing the need for frequent manual cleaning and reducing the transmission of viruses/bacteria.

"As a not-for-profit RTO [research and technology organization], the CSA Catapult's mission is to accel-

erate the development and commercialization of novel applications using compound semiconductors," notes CSA Catapult's chief commercial officer Amar Abid-Ali.

"The consortium is excited to develop a novel COVID-19 system which will aid in the reduction of transmission in public spaces through this innovative technology," says MicroLink's director Steve Whitby. "The consortium is well placed to develop and rapidly take the technology towards commercial exploitation and deployment," he concludes.

[www.mldevices.co.uk/project-luss](http://www.mldevices.co.uk/project-luss)

# Nanosys acquires micro-LED firm glō

## Quantum dot firm adds micro-LED technology for displays

Silicon Valley-based Nanosys Inc, which develops and supplies heavy-metal-free quantum dot light-emitting materials and technology for the display industry, has acquired glō, which commercializes micro-LEDs products through OEM and manufacturing partners. Nanosys says that the transaction expands its capabilities and technology offerings, accelerating its development and progress toward the widespread adoption of micro-LED and nano-LED display technology.

Founded in 2003 by professor Lars Samuelson at the Nanometer Structure Consortium of Sweden's Lund University, glō AB established an R&D and product development pilot line in Sunnyvale in 2010. glō has developed highly efficient xGaIn micro-LEDs based on unique methods and processes, including proprietary defect-free gallium nitride (GaN) nanowire technology.

Founded in 2001 and operating what is said to be the largest quantum dot nanomaterials fab, Nanosys says that consumer elec-

tronics brands have shipped more than 35 million devices from tablets to monitors and TVs based on its proprietary quantum dot technology. But the firm says that the acquisition of glō fills a key role in its technology roadmap, which spans all technologies from mini-LED to OLED and micro-LED to nano-LED. Prior to the acquisition, glō had invested over \$200m in its technology, which funded development of micro-LED epitaxy, device and transfer technology. With its patented room-temperature wafer transfer technology, millions of RGB micro-LEDs can be transferred with high yields, bonded to active backplanes made out of silicon, glass or flexible substrate materials.

The acquisition positions Nanosys with a unique and broad technology portfolio to address all future display applications, comments Eric Virey of market analyst firm Yole Développement. "Micro-LED is one of the greatest potential display technologies but there is one problem: cost. To deliver on this poten-

tial, micro-LED pixels must be ultra-small, bright and cost effective. The market currently lacks a cost-effective micro-LED solution with ultra-small and bright pixels. Bringing micro-LED together with quantum dot is an exciting opportunity to unlock the growth potential in this market," he reckons.

"Nanosys created a vibrant, growing marketplace for our proprietary quantum dot technology over the past two decades," says the firm's president & CEO Jason Hartlove.

"Combining the best quantum dot and micro-LED technologies allows Nanosys to unlock the disruptive potential of micro-LED by lowering production cost and maximizing performance. Together, we can create the smallest, brightest, lowest-cost pixels that will enable micro-LED to penetrate the mainstream TV market and open the doors for new applications in augmented reality (AR), automotive and beyond," he reckons.

[www.glo.se](http://www.glo.se)

[www.nanosysinc.com](http://www.nanosysinc.com)

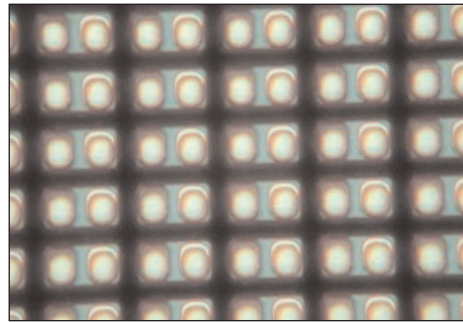
# Nitride Semiconductors develops 12 $\mu\text{m}$ x 24 $\mu\text{m}$ micro UV-LED chips for displays

## Number of chips per wafer quadrupled versus 16 $\mu\text{m}$ x 48 $\mu\text{m}$ chips

Nitride Semiconductors Co Ltd of Tokushima, Japan says that it has succeeded in miniaturizing micro UV-LED chips for micro-LED displays — which are expected to be used for next-generation augmented reality (AR) glasses and smart glasses — as well as developing mass-production technology.

For the next generation of liquid-crystal and organic LED displays, micro-LED displays are being developed by Apple in the USA as well as other companies in various countries. Red, blue and green micro-LED chips are being developed but, with existing methods, it is difficult to miniaturize the red LED chip to 50 $\mu\text{m}$  or less, so development has been encumbered.

Nitride Semiconductors says that it is progressing with the development of displays by using micro-UV (ultraviolet) LEDs to excite red, blue and green phosphors. Also, by



**Chip size: 12 $\mu\text{m}$  x 24 $\mu\text{m}$ ;  
chip spacing 5 $\mu\text{m}$ .**

putting them into practical use, the cost of micro UV-LED chips can be reduced, the firm adds.

Specifically, the firm has been working on developing micro UV-LED chips with a wavelength of 385nm, ahead of other companies, it is claimed.

In the case of a conventional micro UV-LED, the chip size is 16 $\mu\text{m}$  x 48 $\mu\text{m}$ , the chip spacing is as wide as 10 $\mu\text{m}$  in the horizontal

direction and 30 $\mu\text{m}$  in the vertical direction, and about 3.4 million chips can be obtained from a 4-inch wafer. When making a 25mm-square-size display, 300,000 micro-LED chips are required, so 11 micro-LED displays can be made from one wafer. By comparison, the newly developed micro UV-LED chip has a chip size of 12 $\mu\text{m}$  x 24 $\mu\text{m}$ , the chip spacing is 5 $\mu\text{m}$  in both the vertical and horizontal directions, and a 4-inch wafer can accommodate about 14 million chips (four times as many). Also, the cost per chip is a quarter of the conventional chip's cost.

Nitride Semiconductors says that it has confirmed good electrical characteristics of the micro UV-LEDs and has made great strides toward practical application in the near future.

[www.nitride.co.jp](http://www.nitride.co.jp)

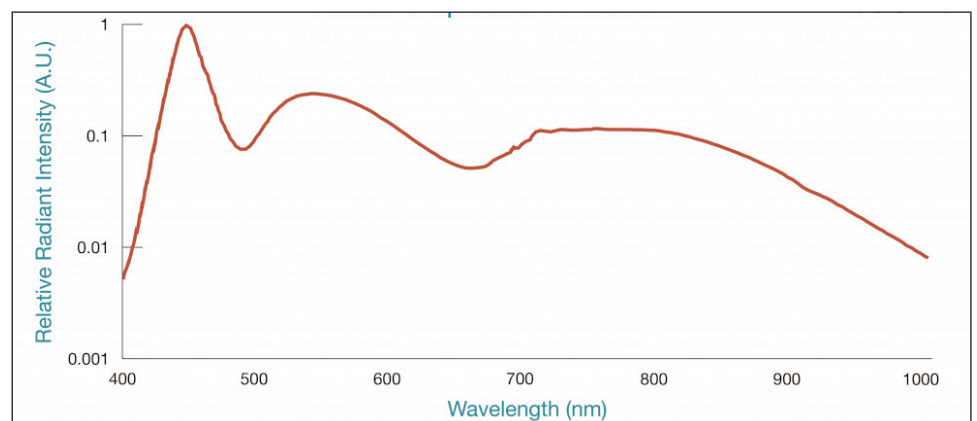
# Ushio's improved Spectro raises broadband LED output power record from 160mW to 180mW

## Visible and NIR spectrum spans 400–1000nm

After launching the Spectro series in 2019 (setting a broadband LED optical output power record of 160mW, Japan's Ushio has now unveiled an improved Spectro LED with an updated indium gallium nitride (InGaN) chip (in the existing package) that has raised the record by a further 20mW to 180mW (at 500–1000nm).

One compact SMBB footprint simultaneously emits a broadband visible and near-infrared (NIR) spectrum, spanning from 400nm to 1000nm. Ushio says that the SMBB package possesses excellent heat dissipation abilities and a choice of lens options (allowing various viewing angles).

The firm says that Spectro LEDs



work best in collaboration with photodetector sensors and spectral imaging cameras. Capturing the spectral absorption properties of common materials allows automated systems perform categorization, quality assurance, and other

sorting tasks. Potential applications include detecting moisture content within an object, such as in optical food sorting applications, or monitoring the fill level of a medicine bottle.

[www.ushio.eu/product/spectro](http://www.ushio.eu/product/spectro)

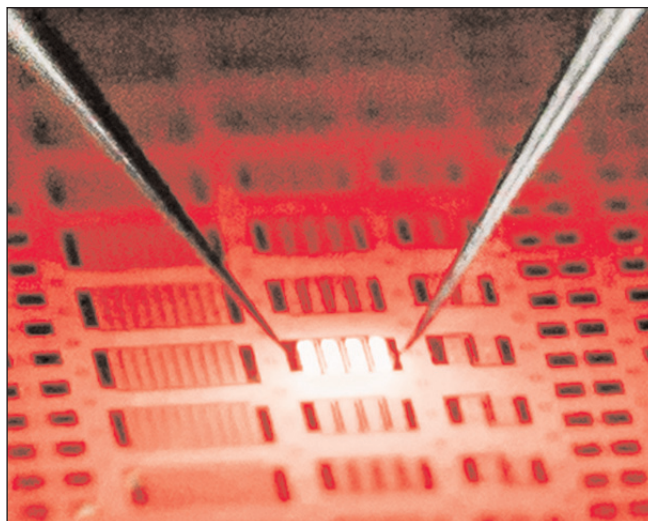
# KAUST fabricates red InGaN-based micro-LEDs

## Higher efficiency and smaller chip size targeted, for integrated RGB nitride-based micro-displays

Saudi Arabia's King Abdullah University of Science and Technology (KAUST) has reported indium gallium nitride (InGaN)-based red micro-LEDs that they plan to integrate with green and blue micro-LEDs to create full-color micro-displays (Zhuang Z, Iida D and Ohkawa K, 'Investigation of InGaN-based red/green micro-light-emitting diodes', Optics Letters 46, 1912–1915 (2021)).

Nitride semiconductors can be used to make blue and green micro-LEDs, whereas phosphide semiconductors are currently used for red light. But combining different semiconductors in this way makes construction of RGB micro-LEDs more difficult and expensive. Also, the efficiency of phosphide micro-LEDs falls significantly with shrinking chip size.

Red-light-emitting InGaN can be created by increasing the materials' indium content. But this tends to lower the efficiency of the resulting LED because there is a mismatch between the separation of atoms in the GaN and InGaN crystal lattices,



**The 47 $\mu$ m-long red-emitting nitride-based micro-LEDs fabricated by KAUST. © 2021 KAUST; Anastasia Serin.**

which causes atomic-level imperfections. Moreover, damage to the sidewalls of an InGaN micro-LED induced during the fabrication process makes the new device less efficient. "But we have a chemical treatment to remove the damage and retain the high crystal quality of the InGaN and GaN sidewall interface," says Zhuang.

Zhang's team created and characterized a series of square devices with a side length of 98 $\mu$ m or 47 $\mu$ m. Their 47 $\mu$ m-long devices emitting light at a peak wavelength of 626nm were shown to have an external quantum efficiency (the number of photons emitted from the LED per electron injected into the device) of up to 0.87%. Also, the color purity of the red micro-LED is optimum because it is very close to the primary red

color defined by the industrial standard known as Rec. 2020.

"The next step is to increase the efficiency of the red micro-LED with even smaller chip sizes, maybe below 20 $\mu$ m," says Zhuang. "Then we hope to integrate RGB nitride-based LEDs for full-color displays."

<https://doi.org/10.1364/OL.422579>  
[www.kaust.edu.sa](http://www.kaust.edu.sa)

# Luminus adds RGBW modules to dynamic tunable chip-on-board portfolio

## Phosphor-converted red, green and white LEDs use the same InGaN blue die

Luminus Devices Inc of Sunnyvale, CA, USA — which designs and makes LEDs and solid-state technology (SST) light sources for illumination markets — has expanded its portfolio of dynamic chip-on-board (COB) modules with the addition of RGBW tunable LED spot modules. The CTM-9 & 14 RGBW modules feature four-channel red, green, blue and warm-white MP-1616 XNOVA Cube LEDs on metal PC boards.

With all four channels using the same indium gallium nitride (InGaN) blue die inside, the phosphor-

converted red, green and white LEDs create consistent InGaN performance and uniformity over wide temperature, current and time ranges, creating smooth spectrums and uniform luminaries with predictable output, Luminus says. The high lumen density produced by the 9mm and 14mm light-emitting surface (LES)-diameter modules is suitable for a variety of directional lighting applications including outdoor landscape, indoor decorative, architectural, and 'architainment'.

"Lighting designers and their end

users are increasingly wanting to create colorful scenes and dramatic accents which can change to match events, preferences or seasons," says Tom Jory, VP of Illumination marketing. "Our RGBW modules produce not only tunable whites but also rich colors, and with phosphor conversion they deliver smooth, predictable spectrums without the need for expensive detectors or feedback circuits."

The new product line is available via Luminus' authorized distributors.

[www.luminus.com](http://www.luminus.com)

# Sundiode develops stacked RGB micro-LED pixel devices on a single wafer

## Firm to demonstrate micro-display on silicon CMOS backplane

Sundiode Inc of Campbell, CA, USA, a Silicon Valley-based company developing micro-LED technologies for display applications including augmented reality (AR) and mixed reality (MR), says that it has achieved fully stacked three-color (RGB) micro-LED pixel devices on a single wafer.

In the stacked-RGB pixel technology patented by Sundiode and developed in collaboration with KOPTI (Korea Photonics Technology Institute), a single pixel features three independently controlled micro-LED subpixels that are stacked vertically to allow full-color emission from essentially the entire area of the pixel. This pixel technology results in a very compact pixel structure and a substantial reduction in the pixel-transfer processing requirement for micro-LED display fabrication, says Sundiode. In addition, the operation of a full-color micro-display consisting of a pixel-array typically sized smaller than a penny is significantly enhanced due to increased utilization of the extremely small pixel area, adds the firm.

The stacked-RGB pixel technology is said to overcome a particularly difficult obstacle to the mass commercialization of micro-LED displays, i.e. a need for laborious pixel-

transfer processing. Whereas fabricating a micro-LED display using conventional planar-RGB technologies typically requires transferring discrete R, G and B subpixels using a pick-and-place process, the stacked-RGB pixel technology substantially or even entirely removes such a requirement.

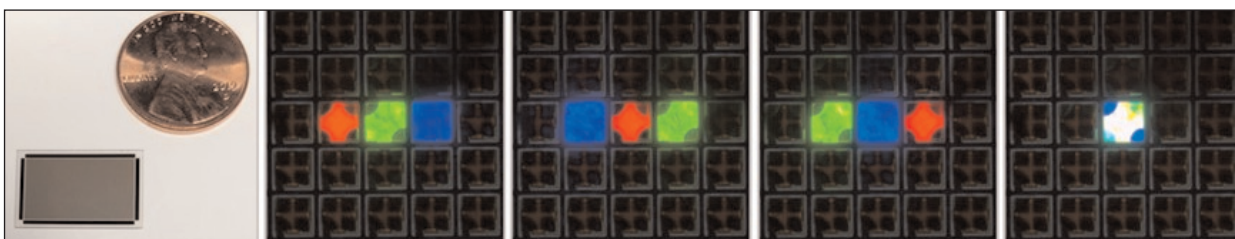
Additionally, flexible in size, Sundiode's stacked-RGB pixels are suitable for a wide variety of applications ranging from TVs to automobiles to micro-displays. They are especially well suited for applications such as AR and MR requiring high pixel density and precision miniaturization of displays, because an entire array of the devices can be fabricated on a single chip, notes Sundiode. This means that, for micro-displays, an array of the pixels is ready for direct and immediate integration

onto a display backplane and, notably, no pixel-transfer processes are required with the stacked-RGB pixel technology.

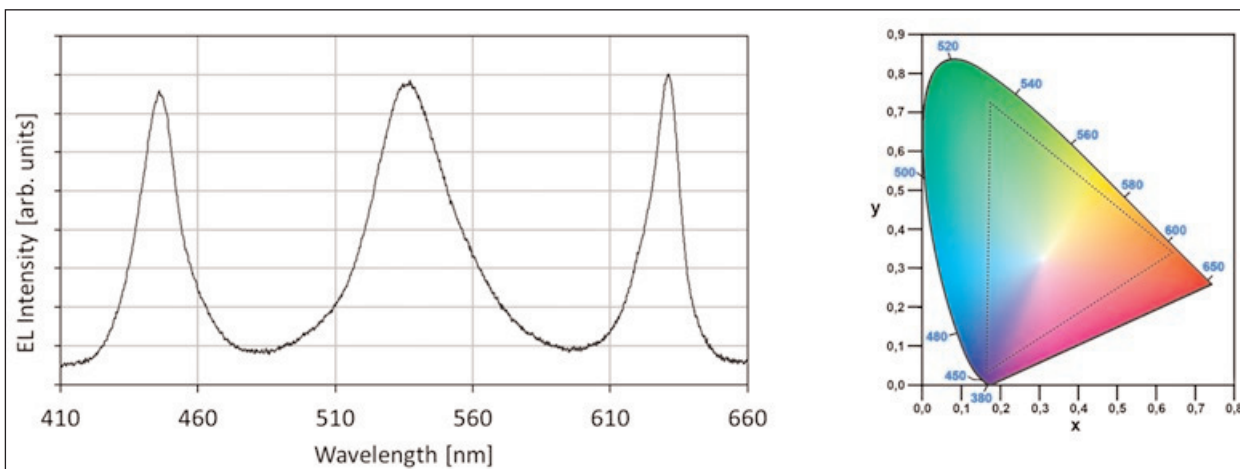
To achieve the stacked-RGB pixel device, epitaxial and fabrication technologies were developed on sapphire substrates that allow the stacking of multiple LED junctions where each LED is independently controlled. This multi-junction-LED technology is pivotal in enabling full-color generation, says Sundiode. The well-defined spectral peaks of the three colors lend themselves to excellent color-saturation characteristics and thus a very large color space, the firm adds.

Sundiode plans further development to soon demonstrate a micro-display using the stacked-RGB pixel technology on a silicon CMOS backplane.

[www.sundiode.com](http://www.sundiode.com)



**A diced array of stacked-RGB pixels (left most). R, G and B subpixels of three adjacent pixels of an array with each subpixel lit up separately (round-robin colors, middle three), and the subpixels of the center pixel lit up simultaneously to 5400K white (right most).**



**Measured spectrum of a single pixel with all R, G and B subpixels lit up simultaneously to yield nearly the same peak intensity and color space rendered by a single pixel.**

# Lumileds issues 2020 Sustainability Report

## All manufacturing sites migrated from OHSAS 18001 to ISO 45001

Lumileds LLC of San Jose, CA, USA has released its 2020 Sustainability Report, which details its progress in supporting the transition to a low-carbon and sustainable economy. In the report, Lumileds highlights how its lighting solutions contribute to positive changes in energy usage, safety, and health and well-being. In 2020, Lumileds averted 6.42 million metric tons of use-phase CO<sub>2</sub> through its LED products. The firm follows a formalized sustainability agenda that identifies specific priorities and tracks progress.

Lumileds has aligned its sustainability efforts with external frameworks such as the United Nations Sustainable Development Goals (SDGs) and identified four SDGs where the most significant contribution can be made: Good Health and Well-Being, Affordable and Clean Energy, Responsible Consumption and Production, and Climate Action. Lumileds says that its Climate Action and envi-

ronmental results in 2020 were significant, with reductions in Greenhouse-Gas Emissions, Energy Consumed, Waste Produced, and Water Used.

"Despite the challenges of a global pandemic and its impact on the end markets we serve, Lumileds remained committed and on track toward reaching our sustainability goals," says CEO Matt Roney. "Our scientists and engineers continued to increase product performance while achieving significant reductions in energy use, carbon emissions, waste generated, and water consumption."

Lumileds says that an intrinsic part of its mission is its commitment to a safe workplace with diversity and inclusion as core values. Employee Health and Safety remains the highest priority.

In 2020 all Lumileds' manufacturing sites were migrated and certified from OHSAS 18001 to ISO 45001 as the basis for its Occupational Health and Safety Management System.

Lumileds recently reviewed its environmental, social and governance issues that have the greatest impact on its business and the highest importance to its stakeholders. From that effort, nine priority issues form the focus of its sustainability efforts (see graphic). The priority issues have been used as the foundation for the firm's 2025 commitments, which include reducing its environmental footprint by more than 15% on energy, emissions, water and waste as well as achieving Supplier Sustainability Performance at 95%.

[www.lumileds.com/sustainability](http://www.lumileds.com/sustainability)

<b>Employee Health &amp; Safety</b>	<b>Product Energy Efficiency</b>	<b>Circular Economy</b>
<b>Business Ethics</b>	<b>Responsible Supply Chain</b>	<b>Hazardous Substances</b>
<b>Employee Engagement Workforce Diversity</b>	<b>Improving Vehicle and Road Safety</b>	<b>Climate Change and Carbon Footprint</b>

## Lumileds boosts LUXEON 5050 Round LED performance

### New, advanced options offered for horticulture applications

Lumileds has again improved the performance of its LUXEON 5050 Round and is characterizing the LED for use in the horticulture industry. For illumination applications, 70-CRI lumen performance increases by as much as 5lm. In the case of a minimum 15,000 lumen streetlight, this equates to a 10% reduction in LEDs and significant cost savings.

"High efficacy, high light output and corrosion resistance that outperforms others are key," says product & marketing manager Mei

Yi. "We've continued to invest in this LED platform and, as a result, our customers can continue to optimize their solutions and support sustainability while improving lighting."

The use of white light in horticulture applications continues to increase. The combination of efficacy, light output and corrosion robustness makes LUXEON 5050 a suitable fit in this segment, reckons Lumileds. The LEDs now deliver what is claimed to be top-rated  $\mu\text{mol/J}$  and PPF ( $\mu\text{mol/s}$ ) performance

and long lifetime with correlated color temperatures (CCTs) ranging from 2200K to 6500K and color rendering indexes (CRI) of 70, 80 and 90 to better support the horticulture industry. Further, the LUXEON 5050 Round offers hot-color targeting to ensure that the LEDs are within color target at application conditions of 85°C.

All LUXEON 5050 products are available now through Lumileds' distribution network.

[www.lumileds.com/products/high-power-leds/luxeon-5050](http://www.lumileds.com/products/high-power-leds/luxeon-5050)

# LAYERS



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Giving our customers the lead through mass production of high performance TCOs, metals and DBRs with the best cost of ownership is our daily business. However, leveraging our know how to help customers develop new more demanding processes or ramp up production of next generation Optoelectronic devices like Micro LED or OLED on CMOS is where we add value too, and in this edition of LAYERS you can also read about solutions we can offer for exactly that.

**Stefan Seifried, Head of BU Optoelectronics**



# Seoul Semiconductor's Q1 net income quadruples

## Revenue to grow 19–29% year-on-year in Q2/2021

South Korea-based LED maker Seoul Semiconductor Co Ltd has reported consolidated revenue of KRW310.4bn for first-quarter 2021 (its third consecutive quarter over KRW300bn), up 27.6% year-on-year.

As a beneficiary of the growing non-contact economy in the pandemic era, strong growth in the IT division led to outstanding performance in Q1. The automotive and lighting divisions also recorded stable growth.

Also, the manufacturing site transition to Vietnam (begun in 2017) has stabilized and contributed to improved profitability.

Operating income is up 243% year-on-year to KRW20.5bn (operating margin of 6.6%). Net income has more than quadrupled year-on-year to KRW24.5bn, which is equivalent to 85% of its full-year net income in 2020.

Seoul hence recorded historically high first-quarter revenue and net profit.

In April, Seoul noted that its LED package business ranked third globally in 2020, surpassing US-based LED maker Lumileds, according to market research firm Omdia. Seoul expects to continue double-digit growth in 2021.

For second-quarter 2021, Seoul Semiconductor forecasts revenue growth of 19-29% year-on-year to KRW320-340bn, indicating strong expectations for the full year.

"We have higher expectations for the second half as mass production of mini-LEDs will lead to better results," says Seoul. "We have been investing to capture new growth opportunities." Seoul's mini-LED products use package-less WICOP (wafer-level integrated chip on PCB) technology (claimed to be the first technology directly mounting LED chips onto a substrate).

[www.SeoulSemicon.com](http://www.SeoulSemicon.com)

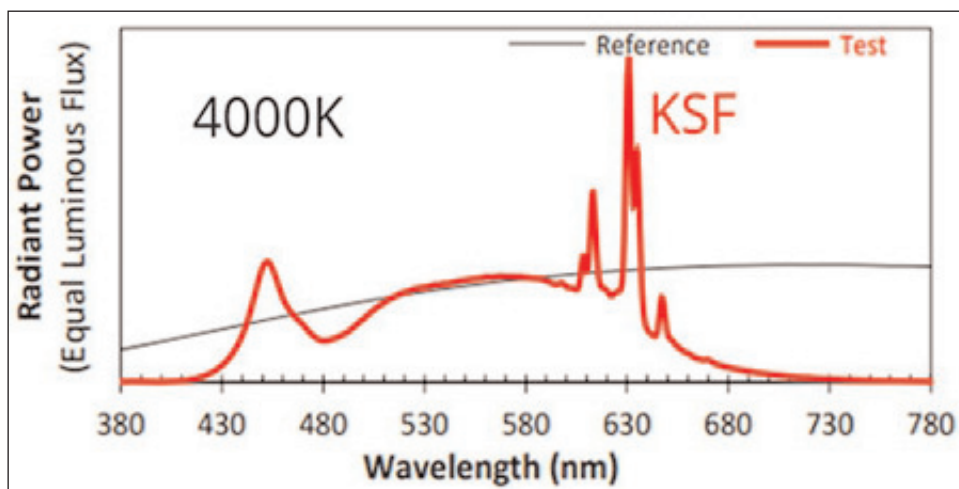
# Bridgelux launches F90 Series for commercial lighting

## New CRI90 LEDs achieve same efficacy as existing CRI80 LEDs

Bridgelux Inc of Fremont, CA, USA (a vertically integrated manufacturer of solid-state light sources for lighting applications) has announced the commercial release of its F90 Series LED products for commercial lighting, which deliver a minimum color rendering index (CRI) of 90 combined with what is claimed to be industry-leading efficacy. F90 LED products use potassium fluorosilicate (PFS) phosphor technology licensed from Current Lighting Solutions LLC for commercial lighting applications.

For traditional LED technology, higher CRI results in a lower efficacy. By replacing broadband red nitride phosphor with narrowband red PFS phosphor, the F90 LED products can achieve today's CRI80 LED efficacy with a CRI of 90, says Bridgelux. Lighting customers can simply replace their existing LEDs in their lighting products with the new F90 LEDs for CRI90 conversion.

The new family of F90 Series LEDs delivers a CRI of at least 90 and R9 of at least 50. The F90 2835 0.2W LED has a lumen efficacy ranging



from 170lm/W to 210lm/W to meet the DLC (Design Lights Consortium) V5.1 Standard for different lighting products including T8 lamps, troffers, high-bay, linear ambient, and case lighting. The F90 2835 1W LED has a lumen efficacy ranging from 139lm/W to 160lm/W for indoor directional lamps and downlights for commercial lighting. F90 LED products also meet the DLC Premium Lumen maintenance technical requirements of  $L90 \geq 36,000$  hours.

Bridgelux says that F90 Series LEDs can be incorporated in virtually

any luminaire (such as linear lamps, downlights, spotlights, high-bay) and can increase the vividness of strong red colors, which is particularly desirable in retail applications.

"By incorporating PFS phosphor to optimize emission spectrum in conjunction with our proprietary packaging technology, the F90 Series of LEDs is able to deliver both industry-leading efficacy and high CRI," says CEO Tim Lester. "F90 product performance is the same or better than today's CRI 80 packages," he claims.

[www.bridgelux.com/products/f90](http://www.bridgelux.com/products/f90)

# Epitaxial nanotechnology

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# Nuburu bolsters 3D printing intellectual property

## Patent encompasses combining methods for blue laser diodes to make a high-power, high-brightness system

Nuburu Inc of Centennial, CO, USA (which was founded in 2015) has been awarded US patent no. 10,971,896 by the US Patent Office. The new patent covers spatial, polarization and wavelength combination of blue laser diodes to make a high-power, high-brightness blue laser diode system, which enables significant gains in speed and quality for metal processing.

In 2021 so far, the firm has added nine patents across 3D printing and material processing. Nuburu's foundational patent ('3D printing Devices & Methods', PCT/US14/35928) was awarded in 16 countries, with several other applications and con-

tinuations pending around the world, including with the US Patent Office (2016/0067780).

"Our new patent encompasses all methods of combining blue laser diodes for developing high-power, high-brightness blue lasers," says founder & chairman Dr Mark Zediker. "Winning this landmark patent is another strong testament to our technological leadership across 3D printing and material processing and the innovations we are bringing to the industry."

Nuburu says that its blue laser is suitable for materials processing applications across e-mobility and automotive, energy storage, aero-

space and additive manufacturing. In many industrial applications, critical materials such as copper, stainless steel and aluminium do not absorb much of the infrared wavelengths transmitted by traditional industrial lasers, which leads to lower quality joints. Nuburu says that its industrial blue lasers leverage a fundamental physical advantage to produce defect-free welds up to ten times faster than the traditional approaches — all with the flexibility inherent to laser processing. Nuburu's blue lasers can also address complex situations such as the joining of dissimilar metals.

<https://nuburu.net/patents>

## Nuburu co-founder Pelaprat joins BluGlass' board

BluGlass Ltd of Silverwater, Australia — which develops remote-plasma chemical vapor deposition (RPCVD) technology for the manufacture of high-performance semiconductor devices — says that laser diode executive Jean-Michel Pelaprat has joined its board as a non-executive director.

Pelaprat has over 30 years' experience establishing, commercializing and scaling laser and semiconductor businesses, including as a director & co-founder (in 2015) of US-based Nuburu Inc — a pioneer in blue gallium nitride (GaN) lasers for industrial, medical, display and 3D applications.

"Jean-Michel joins the BluGlass board at an important time as we launch our laser diode product portfolio and commence customer acquisition," says BluGlass' chair James Walker. "Attracting someone of Jean-Michel's calibre to BluGlass is a major step-forward for the business and a recognition of the potential growth opportunities available," he adds. "Jean-Michel brings a depth of both technical and commercial knowledge in the

laser diode market that will prove invaluable."

Before founding Nuburu, Pelaprat held leadership positions in high-growth photonics businesses, including president & CEO of Vytran, a fiber-optics capital equipment company supplying optical communications, fiber lasers, medical devices, sensing and aerospace applications. He led the business to growth and profitability during the 2009-2010 recession and served on the board of Vytran's parent company NKT Photonics.

Other senior roles include chair & CEO of Novalux Inc, a start-up developing red-green-blue (RGB) semiconductor laser sources for the projection display industry, and director of Nuvonyx, a pioneer in infrared high-powered semiconductor lasers. He is also the founder of A2E, a consulting and advisory firm in Silicon Valley, assisting photonics, semiconductor and deep tech businesses with strategic restructures, merger and acquisition management, and revenue transformation.

"BluGlass' unique technology approach for high-powered GaN

lasers has great potential to disrupt this high-demand market, with significant untapped opportunities and very few competitors," comments Pelaprat. "After spending time with the BluGlass leadership team and understanding the technology as well as the company's future plans, I can see many parallels with my previous successful experiences with emerging technology companies," he adds. "I look forward to utilising my skills, knowledge and experience navigating the market and applications as the business launches its first commercial lasers to market and enters its production ramp-up and revenue growth phases."

Pelaprat has a degree in Physics from the University of Montpellier, France (USTL) and has undertaken Sales Management and Finance education at the Wharton School of Business and studied Strategic Marketing for the High-Tech Industry at Stanford University. He previously served as chair of the Corporate Associates committee for several years and a director of the Optical Society of America.

[www.bluglass.com.au](http://www.bluglass.com.au)

# BluGlass to begin reliability testing of packaged lasers in next two months

## Packaging/integration expert joins US operation as senior laser scientist

BluGlass Ltd of Silverwater, Australia — which develops low-temperature, low-hydrogen remote-plasma chemical vapor deposition (RPCVD) technology for manufacturing devices such as laser diodes, next-generation LEDs and micro-LEDs — has provided an update for March-quarter 2021 on its laser product development.

### Laser diode development progress

BluGlass continues to advance commercialization of its laser diode product suite, with multiple products (405nm, 420nm, 450nm and others) progressing through the final stages in the manufacturing supply chain.

The first products for launch have completed multiple design iterations and processing steps ahead of packaging. These products continue to demonstrate good performance and meet internal specifications as unpackaged devices, says the firm.

Once complete, packaged devices will commence accelerated reliability testing at BluGlass' US facility ahead of product launches. The firm expects these tests to be underway within the next two months.

BluGlass is refining multiple packaging solutions, both internally at its US facility and supported by the firm's recent appointment of specialist laser packaging and integration expert Dr Arkadi Goulakov, and with several expert packaging

vendors at their facilities.

BluGlass expects to deliver packaged products to its customers in the coming months. Following the launch of initial products, BluGlass and its suppliers will qualify the manufacturing process for commercial production and the delivery of further product designs and applications later in the year.

### Laser industry veteran joins US operations

In March, BluGlass appointed laser diode expert Dr Arkadi Goulakov as a senior laser scientist in its US operations. He brings deep fabrication, packaging and product integration expertise to the development and operations team and is currently assisting in the final steps of the pre-launch and delivery of BluGlass' proprietary GaN-based laser technology for the industrial, automotive, lighting and biotech markets.

Goulakov has more than 30 years' experience developing and commercializing optoelectronics, including over 17 years managing dynamic laser innovation projects. He has held technical leadership positions at leading US laser organizations including II-VI Optoelectronic Devices, Western Digital and Seagate Technologies, and has held technical roles at Microsemi, Alfa-Light Inc and Corning Applied Technology.

BluGlass says that the appointment provides enhanced depth to its laser diode business development, bringing extensive fabrication and back-end processing expertise to complement the firm's existing design and epitaxial capabilities.

Goulakov completed his PhD in Physics at the Ioffe Institute in Saint Petersburg, one of Russia's largest research centres specializing in physics and technology. He is the principal inventor of four issued US patents, the author of multiple trade secrets, and a recipient of numerous patent and invention disclosure awards, says BluGlass.

### Product development and paper presented at Photonics West

During first-quarter 2021, BluGlass showcased its laser diode product development at SPIE Photonics West. At the conference it also presented a paper outlining recent developments utilizing hybrid MOCVD and RPCVD techniques ('InAlGaN-based ridge-guide laser diodes using remote-plasma chemical vapour deposition for enhanced performance'). The paper highlighted the latest results and confirmation of the benefits of low-temperature RPCVD for the manufacture of both traditional and novel laser diode structures.

[www.bluglass.com.au/laser-diodes](http://www.bluglass.com.au/laser-diodes)

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# II-VI gains extra \$410m from Apple's Advanced Manufacturing Fund

## Laser capacity expansion to create 700 jobs

Building on an initial \$390m awarded in 2017, Apple has announced a further \$410m award from its Advanced Manufacturing Fund for optoelectronic component maker II-VI Inc of Saxonburg, PA, USA. The expansion of Apple's long-standing relationship with II-VI will create additional capacity and accelerate the delivery of future components for iPhones, with 700 jobs in Sherman, Texas; Warren, New Jersey; Easton, Pennsylvania; and Champaign, Illinois.

II-VI manufactures vertical-cavity surface-emitting lasers (VCSELs) that help to power Face ID, Memoji, Animoji and Portrait-mode selfies. Apple also works with II-VI to manufacture lasers used in the LiDAR (light detection & ranging) scanner — technology that helps to deliver faster, more realistic augmented reality (AR) experiences and improves autofocus in low-light scenes in photos and videos.

Apple began working with II-VI in Sherman, Texas, in 2017 as part of its Advanced Manufacturing Fund, which helped to transform a long-shuttered 700,000ft<sup>2</sup> building into a high-tech manufacturing facility and created hundreds of local jobs. Through close collaboration with Apple engineering and operations teams, II-VI has rapidly increased production in the past year to enable record shipments from the Sherman facility.

"We established Apple's Advanced Manufacturing Fund to support American businesses creating next-generation technology and the jobs of tomorrow," says Apple's chief operating officer Jeff Williams.

"The partnership between Apple and II-VI sets the stage for a new wave of breakthrough technologies that we believe will enable a wide range of applications that will benefit our world for decades to come," believes II-VI's CEO Dr Vincent



Apple has been working with II-VI's facility in Sherman, Texas, since 2017 to produce laser technology used in iPhones.

Mattera Jr. "We are incredibly grateful for Apple's support, which has allowed us to expand our manufacturing capacity and scale our operations across the US." II-VI is a part of Apple's Clean Energy Program, which was designed to advance the use of renewable energy across the company's supply chain, and is

**Apple began working with II-VI in Sherman, Texas, in 2017. The expansion of Apple's long-standing relationship with II-VI will create additional capacity and accelerate the delivery of future components for iPhones, with 700 jobs in Sherman, Texas; Warren, New Jersey; Easton, Pennsylvania; and Champaign, Illinois**

already using 100% renewable energy across all of its Apple manufacturing in the USA.

Apple's expanded partnership with II-VI is part of the firm's plans to invest \$430bn and add 20,000 new jobs across the US over the next five years. Apple's contributions include working with more than 9000 suppliers across the country who are supporting American job creation across dozens of sectors, including silicon engineering, 5G and manufacturing.

To support innovation and high-skilled manufacturing jobs across the USA, Apple established its Advanced Manufacturing Fund in 2017. The \$5bn fund has supported a number of projects to date, including \$450m in awards to Corning Inc in Harrodsburg, Kentucky, which led to the creation of Ceramic Shield, a new material that's tougher than any other smartphone glass.

[www.ii-vi-photonics.com](http://www.ii-vi-photonics.com)  
[www.apple.com](http://www.apple.com)

## II-VI and Coherent schedule shareholder votes on merger Expiration of HSR waiting period keeps deal on track for end 2021

Engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA and Coherent Inc of Santa Clara, CA (which provides lasers and laser-based technology for scientific, commercial and industrial applications) have provided an update on their merger, announced in late March.

The registration statement on Form S-4, filed on 4 May by II-VI and Coherent in connection with the proposed combination, was

declared effective by the US Securities and Exchange Commission (SEC) on 6 May. Accordingly, at special meetings on 24 June, II-VI shareholders and Coherent stockholders of record (as of 17 May) can vote on the related proposals to approve II-VI's acquisition of Coherent.

II-VI and Coherent have also confirmed the expiration of the waiting period under the Hart-Scott-Rodino Antitrust Improvements Act of

1976 (as amended), which is one of the key regulatory conditions necessary for completion of this transaction.

The transaction remains on track to close by year-end 2021, subject to customary closing conditions, including receipt of the required regulatory approvals and approval of II-VI's shareholders and Coherent's stockholders.

[www.Coherent.com](http://www.Coherent.com)

[www.ii-vi.com](http://www.ii-vi.com)

## IQE expands its VCSEL portfolio with turnkey IQVCSEL product line Reference 850nm- and 940nm-wavelength VCSEL epiwafers for communication and sensing markets

Epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK has launched its IQVCSEL product line of reference vertical-cavity surface-emitting laser (VCSEL) epiwafers for the communication and sensing markets.

IQE says that, by partnering with an external, independent third-party designer, its turnkey solution removes the device design burden for customers who do not possess in-house design expertise, thereby facilitating access to leading VCSEL product solutions. The new IQVCSEL solution also ensures that all existing customer designs and IP are fully protected (a core and fundamental principle of IQE's operating model, the firm says).

As the key component for high-speed communications and advanced sensing applications, in

recent years the adoption of VCSELs in volume consumer applications for 3D sensing has accelerated technology development and has driven the adoption of VCSELs on larger-diameter (6") substrates. Claiming to be the market leader for 6" VCSEL epiwafers, IQE now has a viable solution for customers who lack device design capability to enter the market through a ready to use 'drop-in' solution.

IQVCSEL products have high efficiencies (power and slope), low thresholds, and what is said to be excellent temperature performance. The firm offers the following reference solutions:

- IQVCSEL 850-25 for 850nm, 25G communication applications including 5G infrastructure;
- IQVCSEL 850-HP for 850nm, high-power applications; and

- IQVCSEL 940-HP for 940nm, high-power (3D sensing) applications including facial recognition in mobile devices.

"To allow our customers to respond to the opportunities enabled by VCSEL technology, IQE has evolved and expanded its VCSEL portfolio and we have begun sampling our IQVCSEL product," notes chief technology officer Dr Rodney Pelzel. "These solutions are a value-add product and a portion of a wider portfolio enabling such applications as 3D sensing, advanced healthcare, and light detection & ranging (LiDAR)," he adds. "It is the breadth and depth of our portfolio which enables our customers to rapidly respond to the market requirements of today and of the future."

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# NeoPhotonics starts pilot shipments of Class 60 CDM and Micro-ICR for 800G-and-above coherent transmission

## Class 60 coherent components provide complete optical solutions for 96Gbaud-and-above symbol rate applications in combination with Nano ultra-narrow-linewidth tunable laser

NeoPhotonics Corp of San Jose, CA, USA — a vertically integrated designer and manufacturer of silicon photonics and hybrid photonic integrated circuit (PIC) lasers, modules and subsystems for high-speed communications — has announced limited availability of Class 60 versions of its coherent driver-modulator (CDM) and intradyne coherent receiver (Micro-ICR). Unveiled last December, these components are now shipping in initial quantities to multiple customers and address the next generation of 96GBaud-and-above systems.

The Class 60 CDM and Micro-ICR are mechanically compatible with the firm's Class 40 counterparts and provide a natural upgrade path to higher baud rates supporting data rates that include 800G applications. Optical system performance improvements enabled by operation at these increased baud rates enable NeoPhotonics customers to pack more data over longer distances for better economics, lower cost per bit, lower operating expenses and lower power consumption, all under the same hardware envelope as NeoPhotonics' Class 40 components.

Higher symbol rates increase data capacity while maintaining superior

optical signal-to-noise ratio (OSNR) and reach performance, enabling the highest speed-over-distance use. The new components are available in compact form factor packages suitable for use in pluggable modules and compact daughter cards. The Class 60 coherent components extend the highest speed-over-distance performance of NeoPhotonics' existing Class 40 products by increasing the 3dB bandwidth from 40GHz to 60GHz. These NeoPhotonics components work together to enable customers to implement single-wavelength data transmission near 1 Terabit per second over data-center interconnect (DCI) distances, as well as 400~500Gbps transmission over long-haul distances.

NeoPhotonics' Class 60 polarization-multiplexed CDM features a co-packaged indium phosphide (InP) modulator with four linear, high-bandwidth differential drivers, and is designed for low modulation voltage (V-Pi), low insertion loss and a high extinction ratio. The compact package is compliant with the form factor of the OIF Implementation Agreement #OIF-HB-CDM-01.0.

NeoPhotonics' Class 60 high-bandwidth micro-intradyne coherent receiver (Micro-ICR) is designed for 96GBaud symbol

rates, essentially tripling the rate of standard 100G ICRs. The compact package is compliant with the OIF Implementation Agreement OIF-DPC-MRX-02.0.

The components are designed to work together with NeoPhotonics' 'Nano' ultra-narrow-linewidth external-cavity tunable laser, which approximately halves the size compared with existing Micro-ITLAs (integrated tunable laser assemblies), while featuring what is claimed to be industry-leading linewidth, low phase noise and low electrical power consumption.

"We are pleased to be shipping initial quantities of our Class 60 coherent modulators and receivers which, along with our ultra-narrow-linewidth external-cavity 'Nano' tunable laser, provide a complete suite of components enabling customers to efficiently implement 800Gbps-per-wavelength coherent communications systems," says chairman & CEO Tim Jenks.

"We are further extending the bandwidth of our indium phosphide coherent integration platform by developing Class 80 components for 130Gbaud operation as we continue to serve the highest-speed-over-distance applications."

[www.neophotonics.com/developing-coherent-600g](http://www.neophotonics.com/developing-coherent-600g)

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# NeoPhotonics ships 2 millionth ultra-narrow-linewidth laser for coherent transmission systems

## Ultra-pure-light tunable lasers power highest speed-over-distance coherent systems

NeoPhotonics Corp of San Jose, CA, USA — a vertically integrated designer and manufacturer of silicon photonics and hybrid photonic integrated circuit (PIC) lasers, modules and subsystems for high-speed communications — says that it has now shipped a cumulative total of more than 2 million of its ultra-narrow-linewidth tunable lasers since initiating shipments in 2011.

Narrow-linewidth tunable lasers are key elements of coherent data transmission systems used in telecommunications and in data-center interconnects for the cloud. They provide both the light that carries the transmitted data and a reference laser that is used to decode the data. As data rates increase to 400Gbps, 600Gbps and 800Gbps through the use of higher symbol rates and higher modulation orders, it becomes increasingly essential to have the purest possible laser light source that exhibits the lowest possible noise. NeoPhotonics says that its ultra-pure-light tunable lasers meet this essential requirement by having the narrowest linewidth in the industry (the purest color, without noise or other distortion).

To maximize the data-carrying capacity of optical fibers, NeoPhotonics provides these ultra-pure-light tunable lasers with wider tuning ranges, supporting more channels and ultimately increasing total fiber capacity. For high-baud-rate, high-capacity-per-wavelength systems, NeoPhotonics' ultra-narrow-linewidth tunable lasers are also available in a C++ LASER configuration, which has a tuning range of 6THz and covers the full 'Super C-band'. This is 50% more spectrum than a standard laser and supports 80 channels with 75GHz-per-channel spacing, achieving a total fiber capacity of 32 Terabits per second using 400Gbps transceivers in each channel. NeoPhotonics' ultra-pure-light tunable lasers are also available in versions that cover the L-band, essentially doubling fiber capacity.

NeoPhotonics began shipping narrow-linewidth tunable lasers in 2011 in the Optical Internetworking Forum (OIF) standard ITLA form factor, which was about 3-inches long and 1-inch wide. The firm introduced its Micro-ITLA in 2014, which reduced the size by half. In 2019 it introduced the Nano-ITLA, again reducing the size approxi-

mately by half. In addition to what is claimed to be best-in-class low phase noise, the Nano-ITLA has low electrical power consumption, making it suitable for small-form-factor pluggable coherent modules. The Nano-ITLA is now featured in the NeoPhotonics 400ZR QSFP-DD module, which is a complete coherent transceiver capable of sending 400Gbps of data up to 1000km, in a package size that is not very different from the original ITLA laser alone.

"We are pleased to have provided our customers over the last decade with both industry-leading performance and industry-leading volume, reaching 1 million cumulative shipments in 2019 and now 2 million shipments just two years later," says chairman & CEO Tim Jenks. "As industry data rates have increased from 100Gbps to now 800Gbps, the low noise and low power consumption of our lasers have become increasingly important, and their unique qualities have opened up completely new application areas such as satellite communications, remote sensing, automotive LiDAR and medical diagnostics," he adds.

[www.neophotonics.com](http://www.neophotonics.com)

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# QSFP-DD MSA announces Hardware Spec 6.0, CMIS revision 5.0 and thermal design whitepaper

## Seventh public release adds QSFP-DD800 and QSFP112

The Quad Small Form Factor Pluggable Double Density (QSFP-DD) Multi Source Agreement (MSA) group has released a hardware specification revision 6.0 updating QSFP-DD, introducing both QSFP-DD800 and QSFP112.

QSFP-DD is the premier 8-lane data-center pluggable module form factor. Systems designed for QSFP-DD modules can be backward compatible with existing QSFP form factors and provide maximum flexibility for end users, network platform designers, and integrators. With the inclusion of support for 100Gb/s electrical host interfaces, this seventh public release adds QSFP-DD800 and QSFP112 Mechanical and Board Definitions. It also adds QSFP112 electrical and management timing. Revision 6.0 includes updated power supply test methods and support for an increased module power rating to 25W. The module power contact rating is increased from 1A to 1.5A. An appendix with normative connector performance data has also been added.

The group has also announced the release of an updated Common Management Interface Specification

(CMIS) revision 5.0 for QSFP-DD, QSFP-DD800 and QSFP112. The CMIS defines the host-to-module interactions needed to ensure that modules will initialize and operate consistently. This revision provides several extensions and a comprehensive technical and editorial consolidation. It is harmonized with timing parameters defined in QSFP-DD MSA HW Spec revision 5.1 previously published and in this revision 6.0. CMIS is broadly implemented across the industry, beyond just the QSFP/QSFP-DD family of module types. The feedback from many implementers has also been consolidated to improve and extend the specification.

"It is exciting to see how the 63 companies involved came together to harmonize these important QSFP/QSFP-DD form factors and software to future-proof data centers while maintaining backward compatibility," says Scott Sommers, MSA co-chair & founding member.

The MSA group has also announced the release of a new thermal management whitepaper. High-performance network environments need efficient cooling of pluggable optical modules. This is

particularly true for the new high-power 25W modules for QSFP-DD800 systems, which must dissipate heat effectively to ensure operational performance. Careful thermal design of module, cage, heatsink and the overall system for QSFP-DD modules is required for efficient heat dissipation. The new whitepaper explains techniques that can be used to achieve this goal in QSFP-DD/QSFP-DD800 module design and QSFP-DD/QSFP-DD800 system design. It includes both experimental and simulation studies to demonstrate the efficacy of these techniques.

"The performance and power demands for high-speed network solutions are constantly increasing," says Mark Nowell, MSA co-chair & founding member. "This whitepaper captures the design experience garnered over the recent years from many companies and was written to help design engineers understand how they can achieve the thermal characteristics their system requires, even when using new 25W modules, thus ensuring the reliable operation of their products."

[www.qsfp-dd.com](http://www.qsfp-dd.com)

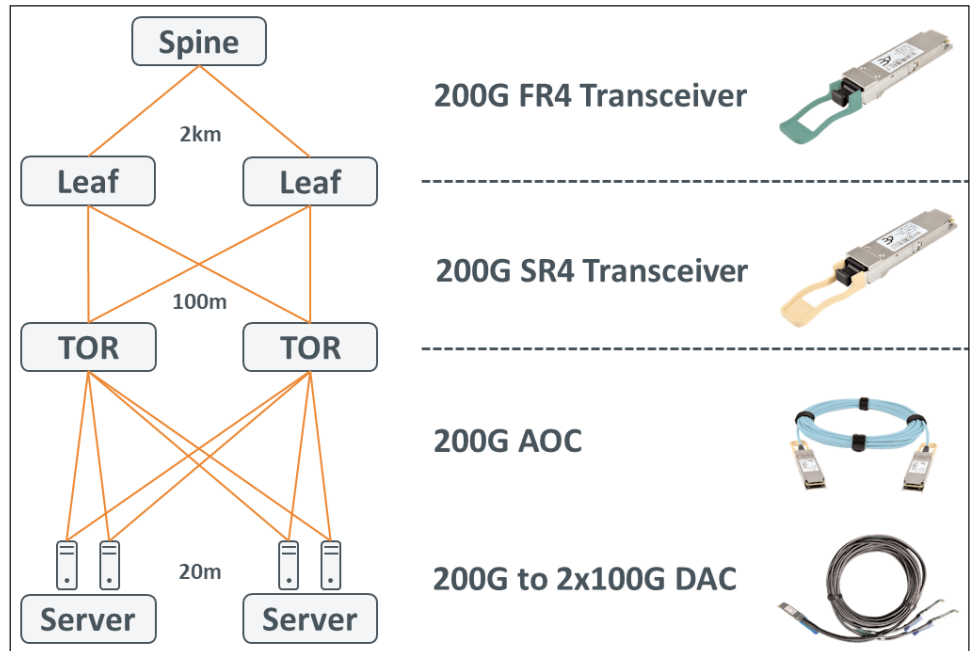
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# Broadex launches 200G modules for intra-data-center interconnects

## AOC, SR4 and FR4 products adopt 4x50G PAM4 signal transmission

Optoelectronic component maker Broadex Technologies Co Ltd of Jiaxing City, Zhejiang, China (which has R&D and production facilities in Shanghai and Chengdu as well as in Edinburgh, UK) has launched a full suite of 200G modules for intra-data-center applications (available now), including 200G copper cables, optical cables and optical transceiver modules (enabling Broadex to provide a one-stop solution for all 200G application scenarios in hyperscale data centers).

"We expect that 200G products will become a popular choice for data-center operators in the next few years as they seek to achieve higher-speed connections at decreased costs," says CEO Dr Wei Zhu. "As an intermediary data rate between 100G and 400G, 200G strikes an effective balance between cost and performance, helping data-center operators to achieve a smooth bandwidth upgrade in a cost-effective way. 200G provides a flexible path through which to scale the internal data-center structure and the



underlying interconnections at a low economic cost," he adds.

Broadex's 200G series transceivers utilize a QSFP56 package, while the 200G direct attach cable (DAC), active copper cable (ACC) and active optical cable (AOC) support a wide variety of 'break-out' options. The AOC, SR4 and FR4 products adopt 4x50G PAM4 signal

transmission and the core optical and electrical chips, such as lasers, drivers and digital signal processor (DSP), are mostly off-the-shelf standard components. This enables full flexibility to adapt to a wide variety of application scenarios and ensure continuity of supply at a manageable cost.

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# First Solar joins Responsible Business Alliance

## Membership gives First Solar access to due-diligence tools and programs

As part of its efforts to drive industry best practices and strengthen its responsible sourcing program, cadmium telluride (CdTe) thin-film photovoltaic (PV) module maker First Solar Inc of Tempe, AZ, USA has joined the Responsible Business Alliance (RBA), the world's largest industry coalition dedicated to supporting the rights and well-being of workers and communities in the global supply chain. First Solar reckons that it is the first of the world's 10 largest photovoltaic (PV) solar manufacturers to join the RBA.

As a regular member of the RBA, First Solar has aligned itself with the organization's vision of creating a coalition of companies driving sustainable value for workers, the environment and business throughout the global supply chain. It has also pledged to support the RBA's mission to collaborate with other members, its suppliers and stakeholders to improve working and environmental conditions and busi-

ness performance through leading standards and practices. First Solar's membership also gives it access to the RBA's due-diligence tools and programs, and the firm will leverage RBA's Validated Assessment Program (VAP), which is a standard for onsite compliance verification and effective, shareable audits.

"Our decision to join the RBA is underpinned by our commitment Responsible Solar. It represents our efforts to build on our track record of responsible sourcing by leveraging the RBA's tools and comprehensive Validated Assessment Program, which conducts third-party audits of potential high-risk suppliers," says First Solar's chief manufacturing operations officer Mike Koralewski. "As the solar industry struggles to address issues like forced labor in the absence of credible audit programs, the VAP illustrates the fact that there is no need to reinvent the wheel in the search for a robust and reputable

assessment framework."

First Solar says that it already has a longstanding zero-tolerance policy towards forced labor, requiring its suppliers to abide by its standards and policies, regardless of geographical location. As an RBA member it is committed to complying with the RBA's Code of Conduct in its global operations and progressively implementing the RBA approach and tools in the spirit of the coalition's common goals. The Code of Conduct, which references international human rights declarations and due-diligence guidelines, addresses the areas of environmental, health and safety, ethics, labor and human rights. First Solar says that it is also committed to progressively applying the RBA Code of Conduct to its suppliers, monitoring its application using RBA practices and tools, and encouraging its suppliers to do the same.

[www.responsiblebusiness.org/vap/about-vap](http://www.responsiblebusiness.org/vap/about-vap)

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# Solliance partners achieve record tandem solar cell efficiencies

## Four-terminal tandems yield 28.7% for perovskite/c-Si and 27.0% perovskite/CIGS

Solliance — a cross-border (Dutch–Flemish–German) public–private thin-film photovoltaic (TFPV) solar energy R&D consortium in the ELAT (Eindhoven–Leuven–Aachen) region — says that partners TNO, imec/EnergyVille and the Eindhoven University of Technology have realized a 18.6%-efficient highly near-infrared-transparent perovskite solar cell. When combined in a four-terminal tandem configuration with an efficient Panasonic crystalline silicon (c-Si) cell or with a Miasolé flexible copper indium gallium diselenide (CIGS) cell, it delivers record power conversion efficiencies of 28.7% and 27.0%, respectively.

Tandem technology offers a viable route to increase the efficiency of commercial solar cells and modules. Four-terminal tandems allows Solliance to build on experience and practices already available in the industry. In addition, four-terminal perovskite/c-Si tandems can be applied broadly and are, for example, very beneficial in combination with bifacial c-Si solar cells which, depending on the actual albedo, can readily achieve a total power generation density as high as 320W/m<sup>2</sup>.

For this breakthrough, the expertise in perovskite solar cell processing and performance optimization of Solliance partners TNO, imec/EnergyVille and TU/e combined to develop an efficient and highly near-infrared-transparent perovskite solar cell with an efficiency of 18.6%.

Demonstrating the wide applicability of the four-terminal tandem approach, this perovskite solar cell was combined with different architectures of bottom solar cells and even with different cell technologies. Specifically:



Dr Mehrdad Najafi holding two samples. (photo: Niels van Loon).

- with a prototype c-Si interdigitated back contact (IBC) silicon hetero-junction (SHJ) cell from Panasonic, a record tandem efficiency of 28.7% was obtained;
- with a commercial c-Si metal wrap-through (MWT) SHJ cell from Choshu Industry and Co, developed by TNO, a tandem efficiency of 28.2% was obtained;
- with a commercial c-Si passivated emitter and rear contact (PERC) cell from Solarlab Aiko Europe GmbH, a tandem efficiency of 27.7% was achieved;
- with a bandgap-optimized flexible CIGS cell from MiaSolé, a record tandem efficiency of 27.0% was realized.

All of these results are more than 1.5% absolute efficiency improvements on earlier records obtained within the Solliance collaboration.

The lab-scale perovskite solar cell has a size of 9mm<sup>2</sup>. The performance measurement of the four-terminal tandem was carried out according to a generally accepted procedure

(J. Werner et al, ACS Energy Letters, vol.1, p474, 2016).

"This performance was achieved by tuning the opto-electrical properties of the perovskite solar cell to better match the optical properties of the bottom cell," says Dr Dong Zhang of TNO/Solliance. "Next, we determined the loss factors in the four-terminal configuration and minimized these step by step," Zhang continues. "Finally, we optimized the light management of the complete tandem device, in other words we maximized light absorption in the tandem solar cell," he adds.

"These excellent results form the basis for the next phase in the development, which includes upscaling of the area and the processes," says Dr Mehrdad Najafi of TNO/Solliance. "Currently, low-cost upscaling processes for large-area modules and maintaining the same performance are being developed by the Solliance partners TNO and imec/EnergyVille."

[www.solliance.eu](http://www.solliance.eu)

# Edge-emitting laser market growing at 15% to \$6.6bn in 2026, driven by historical applications

**Optical communications remains the main driver, while emerging applications are outpacing material processing, says Yole Développement.**

**T**he edge-emitting laser (EEL) market is rising at a compound annual growth rate (CAGR) of 15% from \$2.9bn in 2020 to \$6.6bn by 2026, driven by optical communications, while emerging applications (such as display, sensing, medical and lighting, which are also growing at 15%) are now outpacing traditional material processing, forecasts Yole Développement in its report 'Edge Emitting Lasers — Technology and Market Trends 2021'.

"Since the development of lasers in the 1960s, they have been increasingly used in a large number of applications," says Martin Vallo PhD, technology &

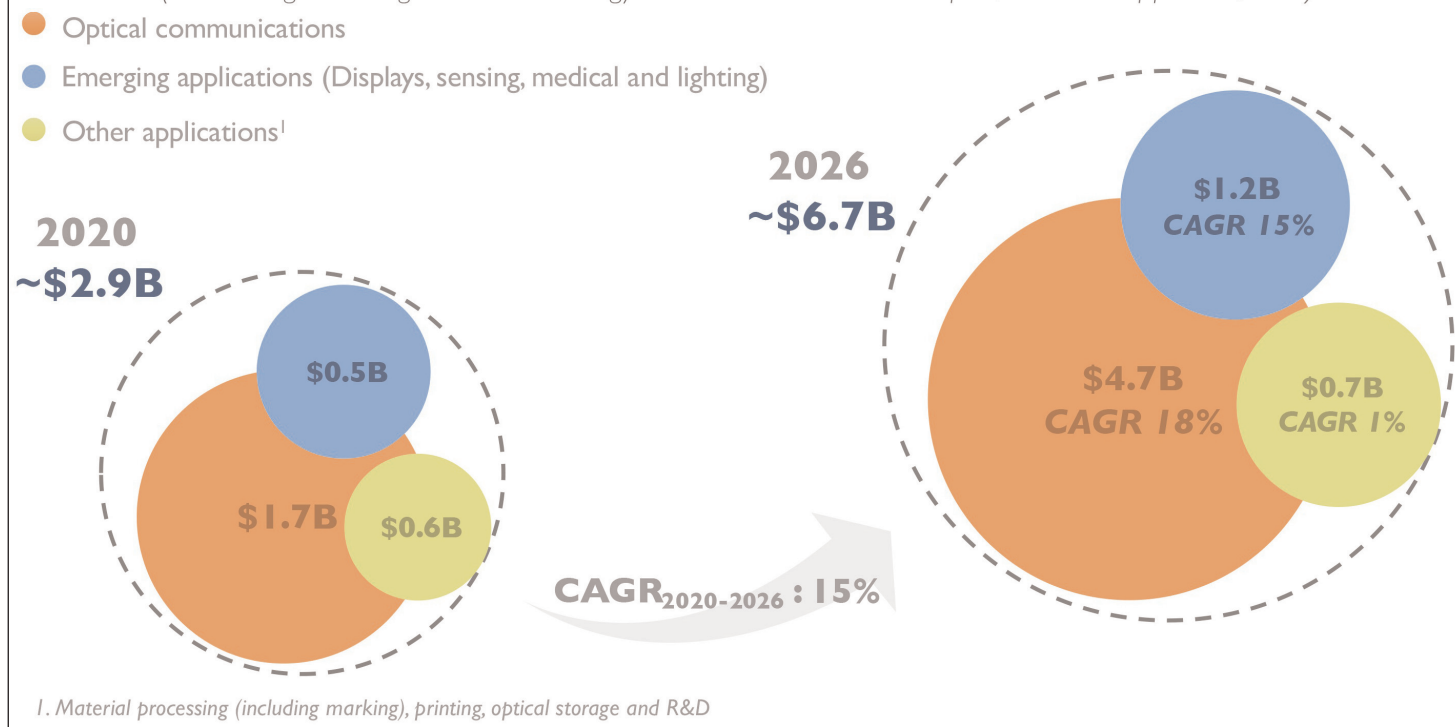
market analyst, solid-state lighting technologies, in the Photonics, Sensing & Display division. "The unique properties of coherent light have helped replace conventional manufacturing methods and have advanced fiber-optic communication. This has propelled the laser market to a trillion-dollar business since the 1990s."

Contributing \$2.2bn of revenue in 2020 (more than 75% of the edge-emitting laser market), material processing and optical communication applications collectively continue to be the main driver.

Laser technologies are also ubiquitous in many emerging applications, mostly spanning semiconductor

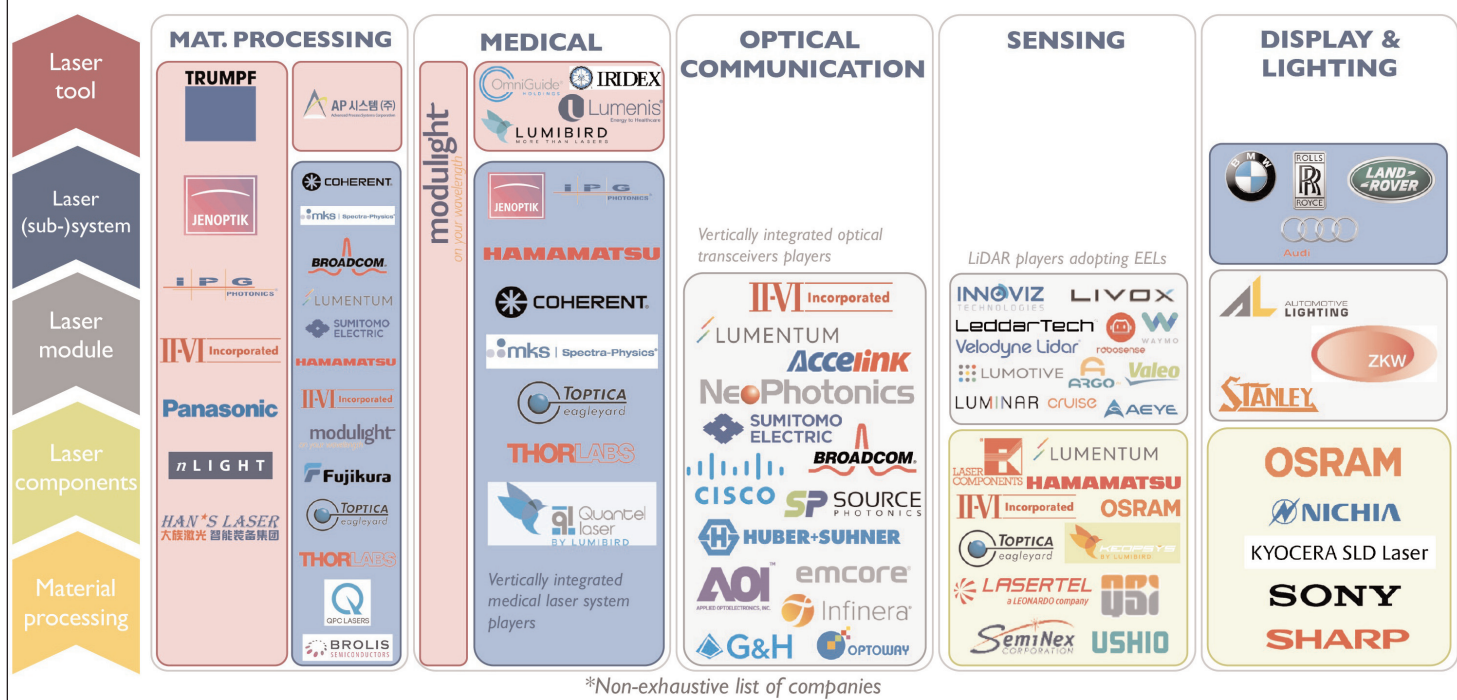
## 2020-2026 Edge-emitting lasers market revenue forecast by segment (\$B)

(Source: Edge Emitting Lasers - Technology and Market Trends 2021 report, Yole Développement, 2021)



# Laser players' positioning by market segments\*

(Source: Edge Emitting Lasers - Technology and Market Trends 2021 report, Yole Développement, 2021)



\*Non-exhaustive list of companies

manufacturing, 3D sensing, spectroscopy, medical, display and lighting applications.

"Edge-emitting lasers can be used as 'direct' lasers but also coupled with optical fibers or crystals to make fiber lasers or diode-pumped solid-state lasers (DPSSLs)," notes Pars Mukish, business unit manager, Solid-State Lighting & Display. "The advanced laser technologies then provide advantages such as better beam quality, improved stability in terms of laser noise, and increased power output," he adds.

Optical sensing, mainly light detection & ranging (LiDAR), will play an increasingly important role in the evolving automotive landscape, notes Yole.

Material processing, which is currently the second largest market for edge-emitting lasers, will remain an attractive business in terms of value but growth will be limited to a CAGR of only 3% over 2020–2026, particularly due to the US-China trade war and COVID-19 pandemic, reckons Yole. On the other hand, some traditional applications such as printing and optical storage will continue to decline rapidly due to trends in digitization and cloud storage.

## Diverse market segments and supply chains

Each market segment addresses its own value chain due to their highly specific demands on laser technology. Most edge-emitting laser manufacturers are therefore vertically integrated, doing in-house epitaxy and front-end-of-line (FEOL) processing.

Such diversified laser technologies, coupled with the wide spectrum of laser applications, create different

leaders for each market segment of the highly fragmented edge-emitting laser industry, Yole notes. The firm's market research has identified more than 100 edge-emitting laser manufacturers, but key semiconductor laser players in the material processing, medical, optical communication, sensing, and display and lighting market segments are as follows:

- Material processing: Trumpf, IPG Photonics, Coherent, Han's Laser, Raycus;
- Medical: Modulight, Coherent, Jenoptik, MKS, Hamamatsu;
- Optical communications: II-VI, Lumentum, Broadcom, NeoPhotonics, Cisco;
- Sensing (LiDAR): Lumentum, II-VI, Osram, Hamamatsu, Laser Components;
- Display and Lighting: Osram, Nichia, Sony, Sharp, Kyocera SLD Laser.

There is hence no overall leader in the laser industry. The vast majority of laser suppliers come from the USA, Japan, Germany and Canada. Chinese laser suppliers focus on assembly laser machines such as automated cutting/welding tools, optical transceivers, LiDAR etc. However, the Chinese government is investing significantly in core laser technologies, notes Yole. As tension between the USA and China escalates, China wants to maintain its economic growth by ensuring a secure and controllable technology supply chain as well as building domestic technology sectors in order to be independent of US parts impacted by tariffs, the market research firm concludes. ■

[www.i-micronews.com/products/edge-emitting-lasers-technology-and-market-trends-2021](http://www.i-micronews.com/products/edge-emitting-lasers-technology-and-market-trends-2021)

# Monolithic ultraviolet LED/photodetector on silicon

**First demonstration of system with a visible-blind, on-chip optical interconnect and compact opto-isolator opportunities.**

**H**ong Kong University of Science and Technology (HKUST) in China has claimed the first demonstration of monolithically integrated ultraviolet (UV) light-emitting diodes (LEDs) and visible-blind UV photodetectors (PDs) based on the same III-nitride wide-bandgap epitaxial structures grown on silicon [Qifeng Lyu, Huaxing Jiang, and Kei May Lau, *Optics Express*, vol29, p8358, 2021]

The researchers see opportunities for on-chip optical interconnect and compact opto-isolator applications, along with visible-blind light communication, biochemical detection and environment monitoring.

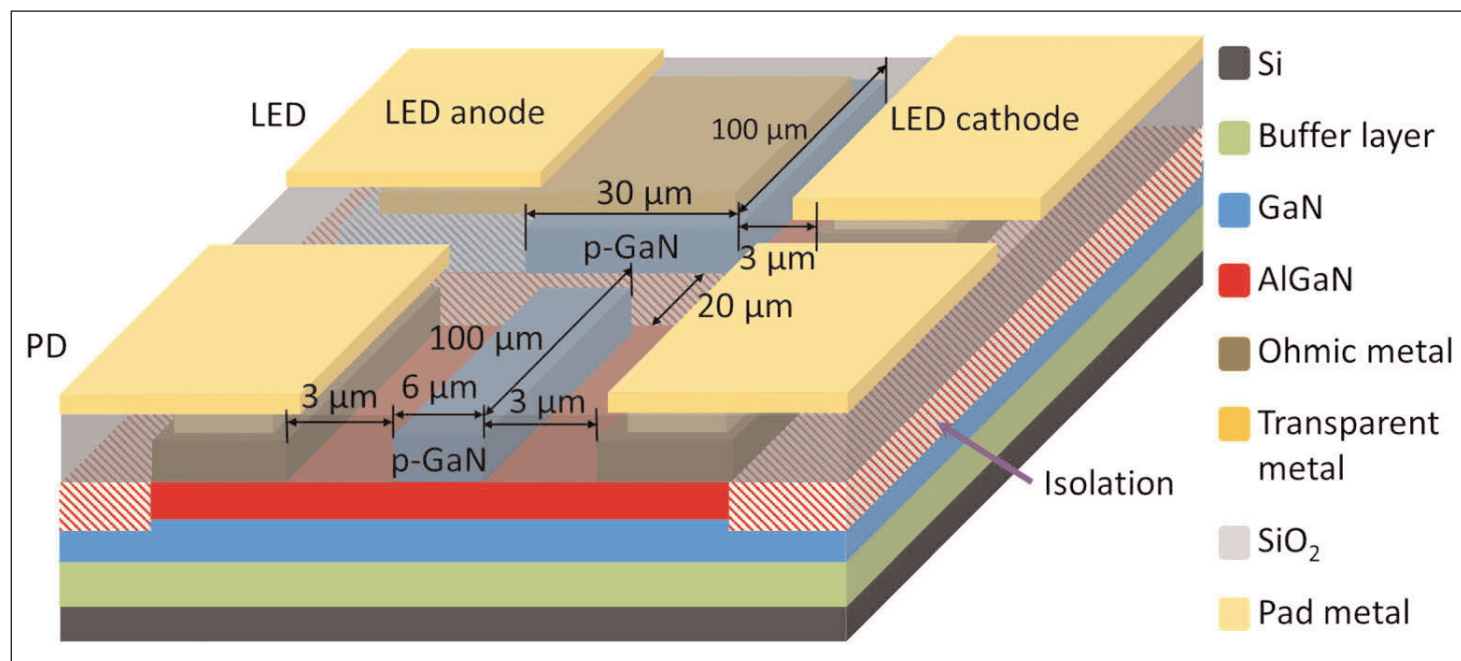
The aluminium gallium nitride (AlGaIn) materials were grown on 6-inch (111) Si, using metal-organic chemical vapor deposition (MOCVD). The layer compositions were 5 $\mu\text{m}$  GaN buffer, 400nm intrinsic i-GaN, 10nm Al<sub>0.2</sub>Ga<sub>0.8</sub>N barrier, and 70nm p-GaN cap. The structure is similar to that used for high-electron-mobility transistors (HEMTs). The HKUST team sees the format as enabling a low dark current measurement in the final photodetectors.

The photodetector was operated in a phototransistor-like way with a 6 $\mu\text{m}$ x100 $\mu\text{m}$  p-GaN 'optical gate' between a pair of ohmic contacts (see Figure 1). The 30 $\mu\text{m}$ x100 $\mu\text{m}$  LED produced photons from the

recombination of holes supplied by the p-GaN anode, and electrons from the two-dimensional electron gas (2DEG) that forms near the AlGaIn/GaN interface. In HEMTs, and the HKUST photodetector structure, the 2DEG constitutes the channel whose resistance can be controlled by external means (electrostatics, photons, etc).

The HKUST team explains: "Mimicking the conventional transistor operation, the current in the channel is controlled by the gate bias through the gate capacitor coupling. In our integrated system, modulation of the current in the 'channel' of the photodetector by the spatially separated 'optical gate' by the LED is realized by the transmission of UV light in the SiO<sub>2</sub>, GaN and AlGaIn between LED and photodetector."

The fabrication sequence was: p-GaN patterning for the LED anode and photodetector gate; titanium/aluminium/nickel/gold ohmic contact deposition for the LED cathode and photodetector AlGaIn contacts; device isolation with fluorine ion implantation; passivation with 50nm plasma-enhanced chemical vapor deposition (PECVD) silicon dioxide (SiO<sub>2</sub>); transparent nickel/gold ohmic contact deposition and annealing on the LED p-GaN anode; and, thick nickel/gold contact pad deposition.



**Figure 1. Schematic of monolithically integrated LED and photodetector on p- GaN/AlGaIn/GaN/Si platform.**

Under 5V bias, the photodetector demonstrated a low dark current of  $3.9 \times 10^{-7} \text{ mA/mm}$  and a photocurrent of  $0.43 \text{ mA/mm}$  from illumination with  $0.024 \text{ mW/cm}^2$  power UV light  $\sim 365 \text{ nm}$  wavelength from a commercial LED. The researchers describe the photo-to-dark current ratio of  $1.1 \times 10^6$  as being "excellent".

The team adds: "The low dark current is attributed to the depletion of 2DEG at the AlGaIn/GaN interface resulting in a high-resistivity channel underneath the p-GaN layer, despite a 5V bias applied." The UV illumination creates a conductive 2DEG channel under the gate. The "ultrahigh" responsivity of the photodetector was  $3.5 \times 10^5 \text{ A/W}$ .

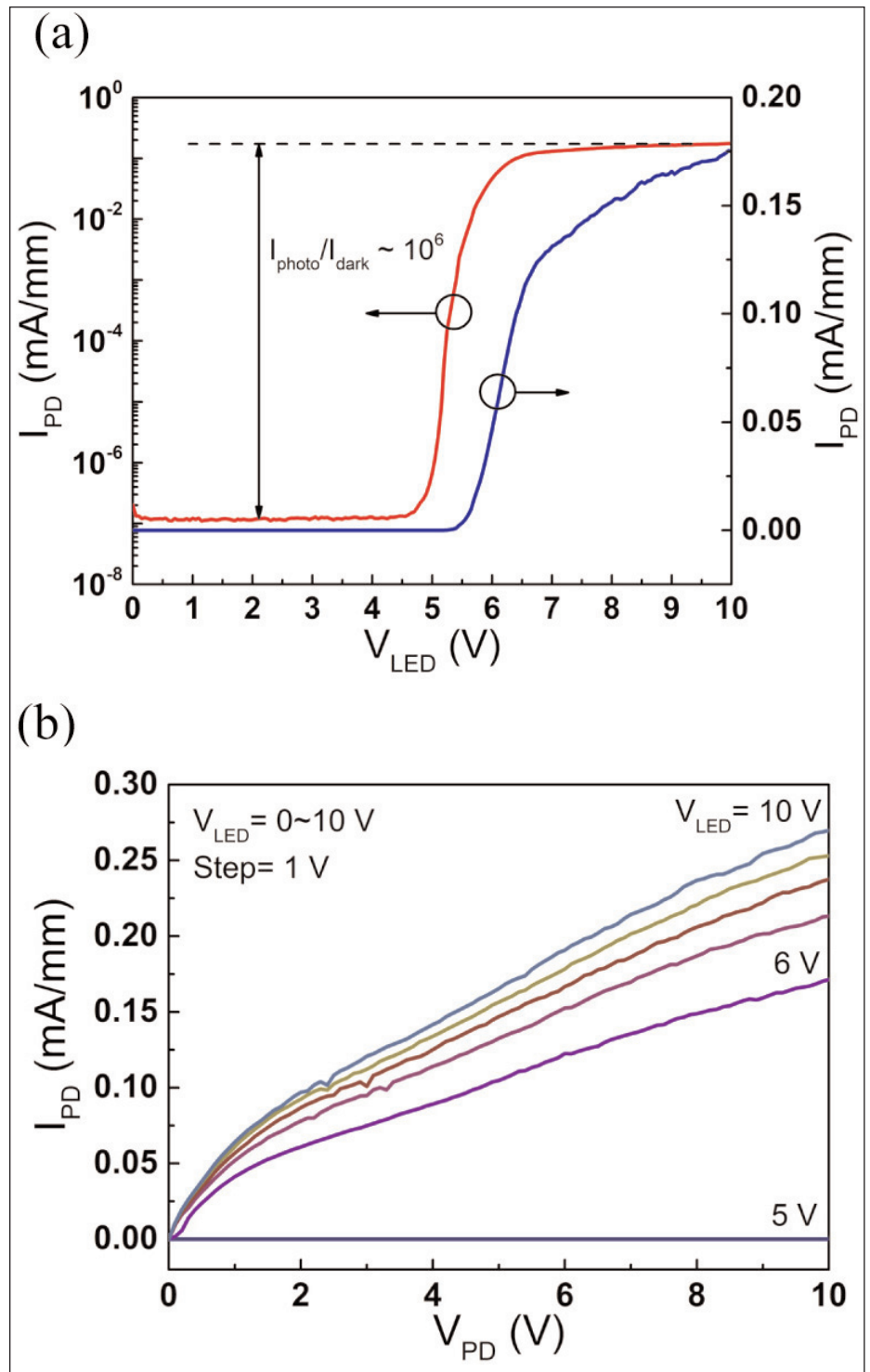
The researchers sees these features as enabling the photodetector to achieve "high-sensitivity light detection on signals from the on-chip small-size LED light source even if with a relatively low output power".

The LED had a high turn-on voltage at  $\sim 4.65 \text{ V}$ , with current injection under forward bias tending to saturate at high biases of  $\sim 10 \text{ V}$ , due to the lateral access regions. The current injected at  $10 \text{ V}$  was  $267 \text{ A/cm}^2$ .

The spectral peak of the LED was around  $360 \text{ nm}$  wavelength with a full-width at half maximum (FWHM) of  $7 \text{ nm}$ . The photodetector spectral response cuts off for wavelengths longer than  $400 \text{ nm}$ , raising the prospect of visible-blind applications. [Visible light wavelength range:  $380\text{--}750 \text{ nm}$ .]

The LED- photodetector combination in a sense operated in a transistor-like way with the LED bias being the gate potential and the photodetector current being the channel (Figure 2). The coupling efficiency (PD/LED current ratio) was  $0.022$  at  $5 \text{ V}$  photodetector bias, which compares very favorably with  $1.1 \times 10^{-6}$  for a reported silicon opto-coupler,  $\sim 1 \times 10^{-4}$  for a GaN-based integrated device, and  $\sim 4 \times 10^{-3}$  for an AlGaIn-based integrated device.

The 'frequency response' of the LED-PD system was tested in a circuit using a Si MOSFET to inject current into the LED. The rise and fall times of the response to a square wave signal were  $0.41 \text{ s}$  and  $0.36 \text{ s}$ , respectively. Since the resistance-capacitance delay of the photodetector was estimated at around  $100 \text{ ns}$ , the main delay factor seems to be a "persistent



**Figure 2. (a) Photocurrent (semi-log and linear scales) of photodetector at 5V bias versus LED bias. (b) Photodetector photocurrent versus voltage drop on photodetector under varying LED bias.**

photoconductivity effect in AlGaIn/GaN heterostructure". The team plans to work on optimizing the p-GaN etch step and the passivation in an effort to eliminate trapping effects, enhancing the response speed. The researchers also suggest that adding a bias to the p-GaN gate of the photodetector could be another avenue to faster response. ■

<https://doi.org/10.1364/OE.418843>

Author: Mike Cooke



# Ultraviolet shines for AlN conductivity

**Above-bandgap illumination enhances the post-implantation anneal process, giving 30x better conductivity.**

Researchers at North Carolina State University (NCSU) and Adroit Materials in the USA have boosted free-electron concentration and hence conductivity in silicon-implanted aluminium nitride (AlN) by using ultraviolet (UV) illumination during the activation anneal [M. Hayden Breckenridge et al, *Appl. Phys. Lett.*, vol118, p112104, 2021].

AlN has an ultra-wide bandgap of 6.1eV, which is an attractive property for high-power and high-voltage electronics, along with the potential for deep-UV optoelectronics in the ~200nm wavelength range. Wide-bandgap materials are challenging in terms of enabling high electrical conductivity.

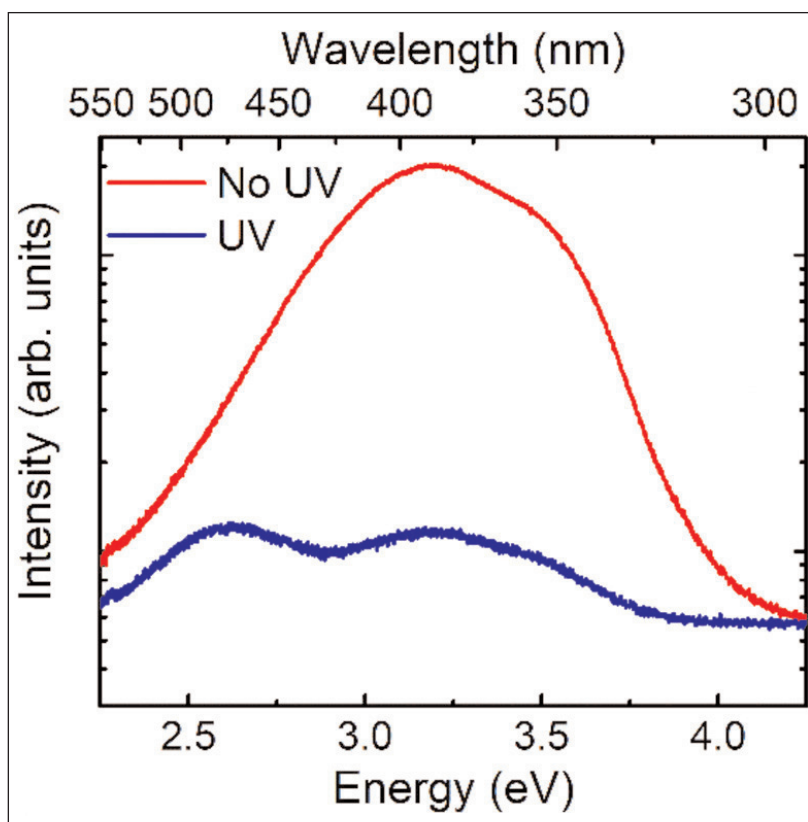
Improving conductivity in AlN involves reducing the densities of threading dislocations and aluminium vacancy-silicon (VAI-nSi) complexes. These defects reduce the effectiveness of silicon as a doping agent through trapping electrons, 'self-compensation', of the shallow ~70meV donor state, reducing conductivity.

The UV illumination was designed to generate excess minority carriers whose presence shifted the formation energy of VAI-nSi complexes upwards, reducing their density. The generation of holes needed UV photons with energies higher than the 6.1eV bandgap (i.e. wavelengths shorter than 200nm). The theoretical designation of the technique is 'defect Quasi Fermi Level' (dQFL) control.

The researchers used AlN substrates with a low dislocation density of less than  $10^3/\text{cm}^2$ . The single-crystal AlN was processed from boules grown by physical vapor transport (PVT). A homoepitaxial AlN layer was added by using nitrogen-rich metal-organic chemical vapor deposition (MOCVD).

The n-type doping was through silicon ion implantation with  $10^{14}$  atoms/ $\text{cm}^2$  at 100keV energy. The AlN substrate was tilted at  $7^\circ$  during implantation to avoid the channeling effects of ions easily passing through aligned gaps in the lattice structure.

The doping was activated through annealing at  $1200^\circ\text{C}$  for 2 hours in nitrogen at 100Torr pressure. The temperature is viewed as being low, below the value needed for the system to reach thermodynamic equilibrium.



**Figure 1. Room-temperature photoluminescence spectra for Si-implanted AlN annealed without (red) and with (blue) UV illumination.**

The sample was illuminated with UV light from a 1kW mercury-xenon lamp. The UV illumination decreased mid-gap photoluminescence (Figure 1), suggesting successful suppression of the generation of compensating VAI-nSi point defects during post-implant annealing.

Contacts for electrical measurements were electron-beam evaporated vanadium/aluminium/nickel/gold in a van der Pauw format. The contacts were annealed after deposition at  $850^\circ\text{C}$  for a minute in nitrogen.

Conductivity for samples annealed under various samples was measured at a range of temperatures between 300K (room temperature) and 725K (Figure 2). The UV-annealed sample demonstrates a factor of 30 improvement in conductivity across the temperature range, compared with samples annealed at the same temperature but without UV. Higher annealing temperatures closer to 'equilibrium' showed worse perform-

ance as room temperature was approached.

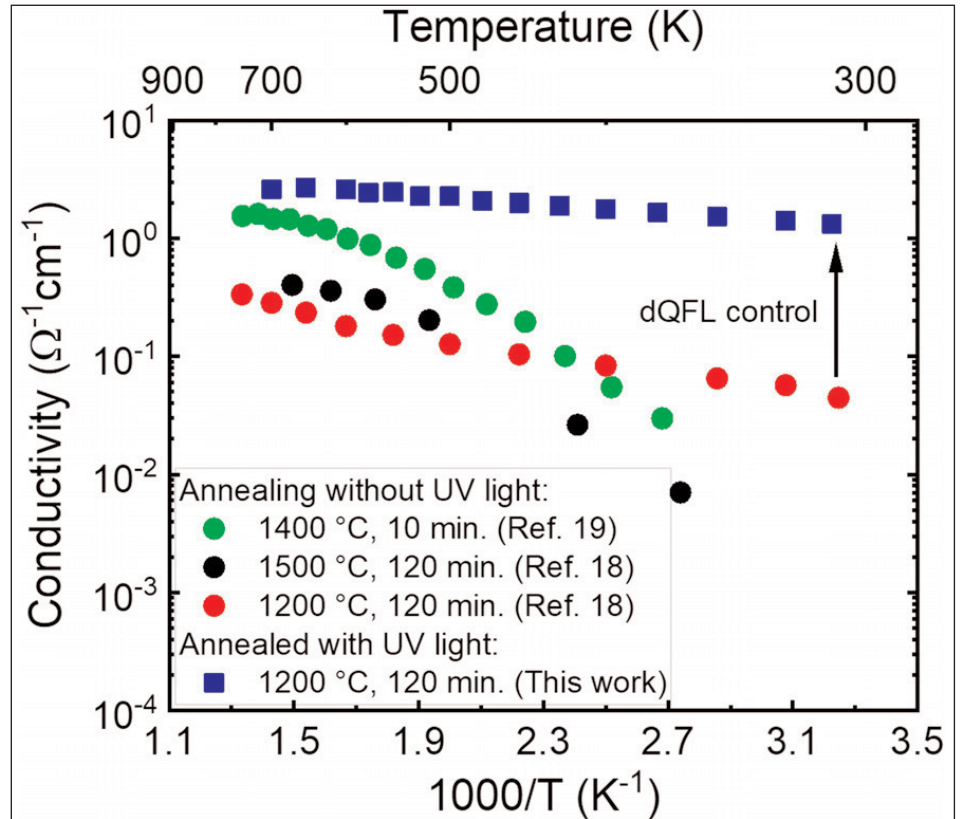
Using the temperature dependence of the conductivities, the researchers estimated the compensation ratio of the UV-illuminated sample at 0.2, compared with 0.9 for the sample annealed at 1200°C without UV.

Room-temperature Hall measurements were not expected to give reliable results due to the implants giving a Gaussian donor concentration and mobility varying with depth. Hence hot-probe AC measurements were performed.

At temperatures above 400°C, the free-electron concentration was estimated at  $5 \times 10^{18}/\text{cm}^3$  (assumed averaged over a 200nm layer) with a  $1 \text{ cm}^2/\text{V-s}$  mobility. The sheet carrier concentration was  $\sim 1 \times 10^{14}/\text{cm}^2$  close to the silicon dose.

The researchers comment: "Although a high conductivity exceeding  $1/\Omega\text{-cm}$  at room temperature was demonstrated in AlN by ion implantation, the measured carrier mobility was about 100 times lower than that can be achieved in the epitaxial doping despite the low compensation ratio."

The sample 1200°C annealed without UV had a sheet carrier concentration  $\sim 1 \times 10^{13}/\text{cm}^2$  at a similar mobility. The low mobility is something that one would clearly



**Figure 2. Temperature-dependent conductivities for Si implanted AlN samples annealed with and without UV light at various temperatures.**

like further information on in the hope that it could be improved, allowing for even higher conductivity. ■

<https://doi.org/10.1063/5.0042857>

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Author: Mike Cooke

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# Cool thermoelectric/LED assembly

Active thermal management increases high light output power by up to 35%.

**H**uazhong University of Science and Technology and Wuhan Polytechnic University in China have developed a blue light-emitting diode (LED) on thermoelectric cooler (TEC) assembly process with a view to improving high-power performance [Shuang Li et al, IEEE Transactions on Electron Devices, vol 68, issue 4 (10 March 2021), p1753]. The LED chips were directly solder-attached to the cold-side substrate of the TECs, avoiding the use of thermally resistive organic adhesives.

LEDs suffer from thermal degradation at high input power due to Joule and radiant heating effects. Apart from reduced light output power, thermal issues can reduce reliability and lifetimes of devices, along with shifting the emission wavelength. Emission intensity can fall by 1% with a 1°C increase in temperature. The researchers comment: "The heat dissipation problem is one of the technical choke points to the development of high-power LEDs."

Thermal management through passive heat dissipation can be inadequate in such circumstances, and various active cooling methods might help, using fans, liquid flow, etc. Solid-state TECs use the Peltier effect to pump heat away from devices. Such devices use semiconductor materials and a bias to achieve cooling. The team sees TECs as an attractive option "due to its clean, no noise, high reliability, and cost-effective advantages".

Previous attempts to combine TECs with LEDs have used organic adhesives, which are relatively resistive to heat flow. By contrast the new assemblies used direct solder attachment to the TEC cold-side substrate, improving the potential cooling effect. A further advantage to avoiding organic adhesives is that such materials suffer thermal aging effects, impacting reliability.

The researchers used aluminium oxide ( $\text{Al}_2\text{O}_3$ ) ceramic substrates with direct plated copper circuit wiring to which were attached the LEDs and TECs

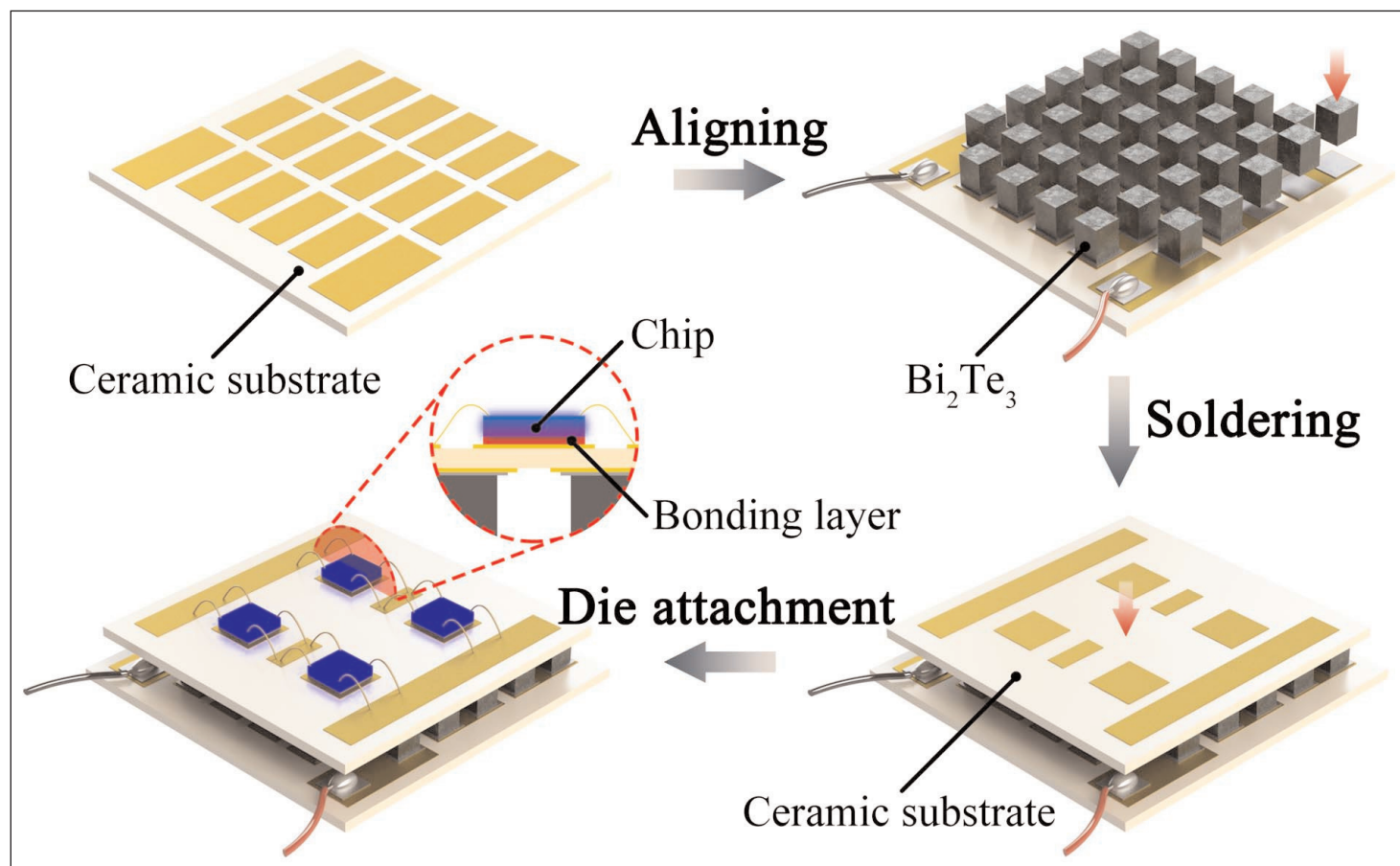
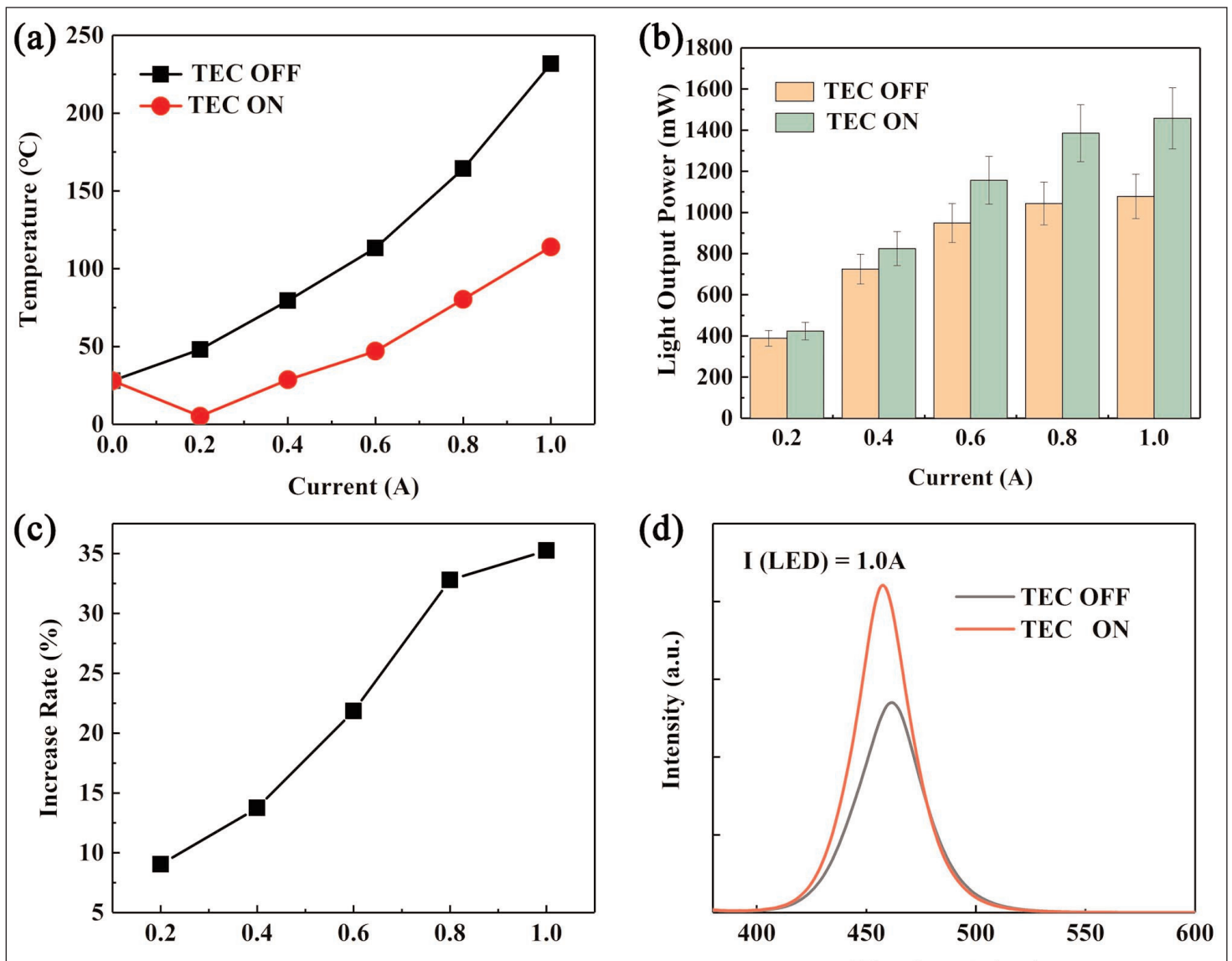


Figure 1. Fabrication process of chip-on-TEC for high-power LED packaging.



**Figure 2. (a) Maximum temperature, (b) light output power, and (c) percentage light output power increase rate with TEC on. (d) Light intensity spectrum of LED at 1.0A injection.**

(Figure 1). The TE structure consisted of bismuth antimonide telluride selenide p- and n-type materials ( $p\text{-Bi}_{0.5}\text{Sb}_{1.5}\text{Te}_3/n\text{-Bi}_2\text{Te}_{2.7}\text{Se}_{0.3}$ ). The individual TE elements measured 1mm x 1mm x 2mm.

The elements were aligned in a rubber mold and attached to the hot-side copper/ceramic substrate with tin (96.5%)–silver (3%)–copper (0.5%) solder paste, soldered at 260°C for 20s. The cold-side substrate was also attached with solder paste and soldered at 260°C for 20s.

The cold-side substrate was plated with titanium/copper/nickel/gold wiring before coating with tin (48%)–bismuth (52%) solder paste and attachment of 452nm-wavelength LEDs, using a reflow process.

The cooling effect of the TEC increased with injected current to around 2A, after which there was not much added benefit. The bias voltage reached 3.1V at 2.5A injection. The current–voltage relationship was approximately linear. For the injection currents of 0.5, 1.0, 1.5 and 2.0A, the cold-side temperatures

were 4.0°C, –7.9°C, –19.9°C and –25.8°C, respectively, according to thermal infrared imaging. The ambient temperature (0A) approached 30°C (27°C=300K?).

The use of the TEC with 1.5A injection increased the performance of the high-power LEDs in terms of light output power at a given current (Figure 2). The percentage improvement in performance increases as the injection current increases to 35.25% at 1.0A.

It is also to be noted that the peak wavelength is longer with the TEC turned off. Such a red-shift is a well-known effect of increased junction temperature.

Simulations suggested that the LED without the TEC turned on could reach a temperature of 244°C at 1.0A injection. The calculations also suggested that with the TEC on this would be reduced to 150°C. Experimental temperature measurements with a thermal infrared imager gave 232°C with the TEC off, and 114°C with the cooler on. ■

<https://doi.org/10.1109/TED.2021.3062314>

Author: Mike Cooke

# HfO<sub>2</sub> gate insulator for N-polar GaN

**Metal-oxide-semiconductor capacitor study probes high-k dielectric potential.**

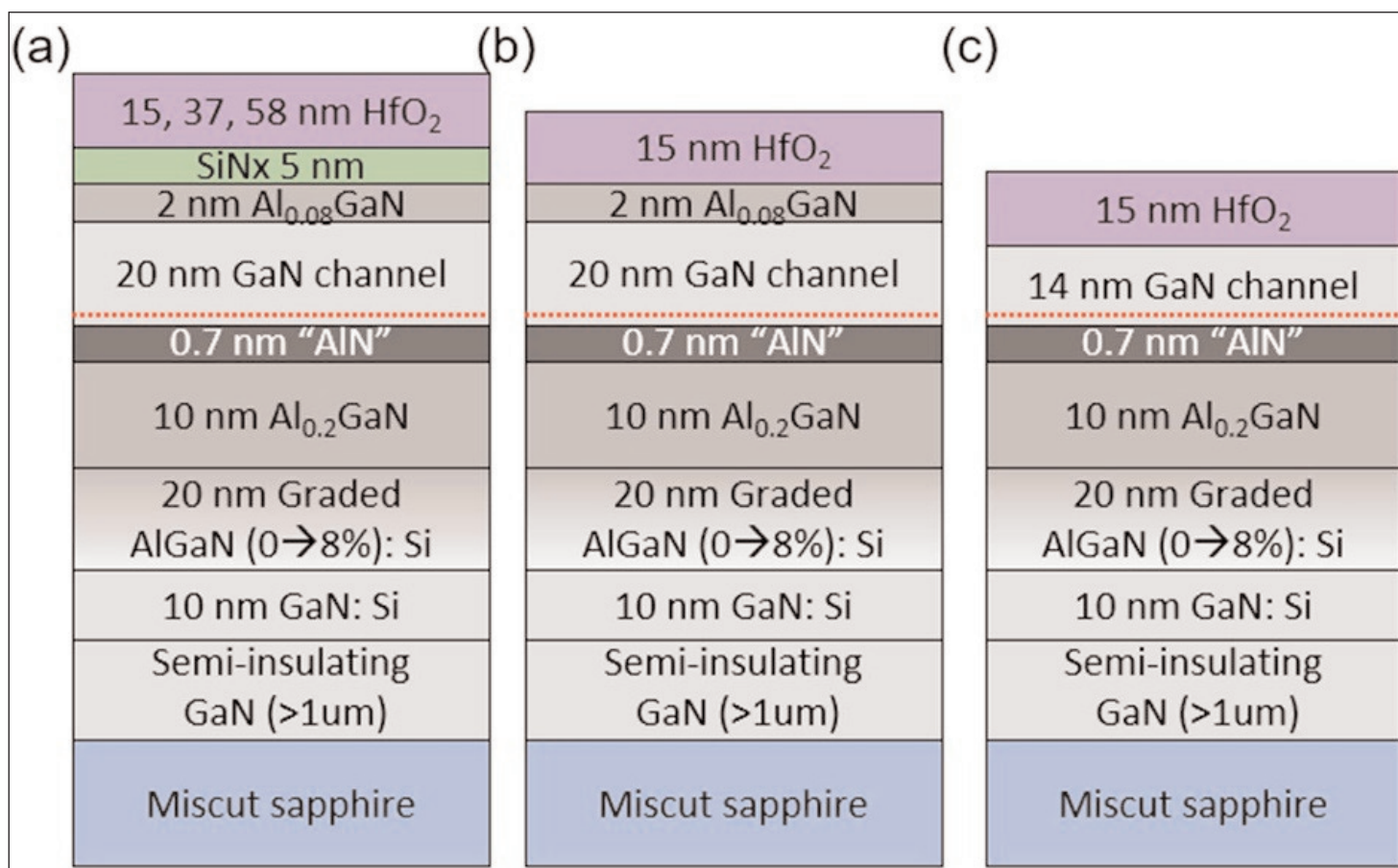
University of Michigan and University of California Santa Barbara (UCSB) in the USA have been studying the potential of hafnium dioxide (HfO<sub>2</sub>) as a gate dielectric for high-power and high-frequency nitrogen-polar aluminium gallium nitride (AlGaN) transistors, using capacitance–voltage (C–V) measurements [Christopher J Clymore et al, *Semicond. Sci. Technol.*, vol36, p035017, 2021].

The N-polar orientation of AlGaN heterostructure is seen as advantageous in terms of providing a natural back-barrier against current leakage into the substrate, encouraging the confinement of carriers in the two-dimensional electron gas (2DEG) channel. N-polar high-electron-mobility transistors (HEMTs) have achieved superior power-added efficiency (PAE) performance at very high microwave frequencies up to 94GHz over that of Ga-polar devices. Such frequencies are used in radar applications.

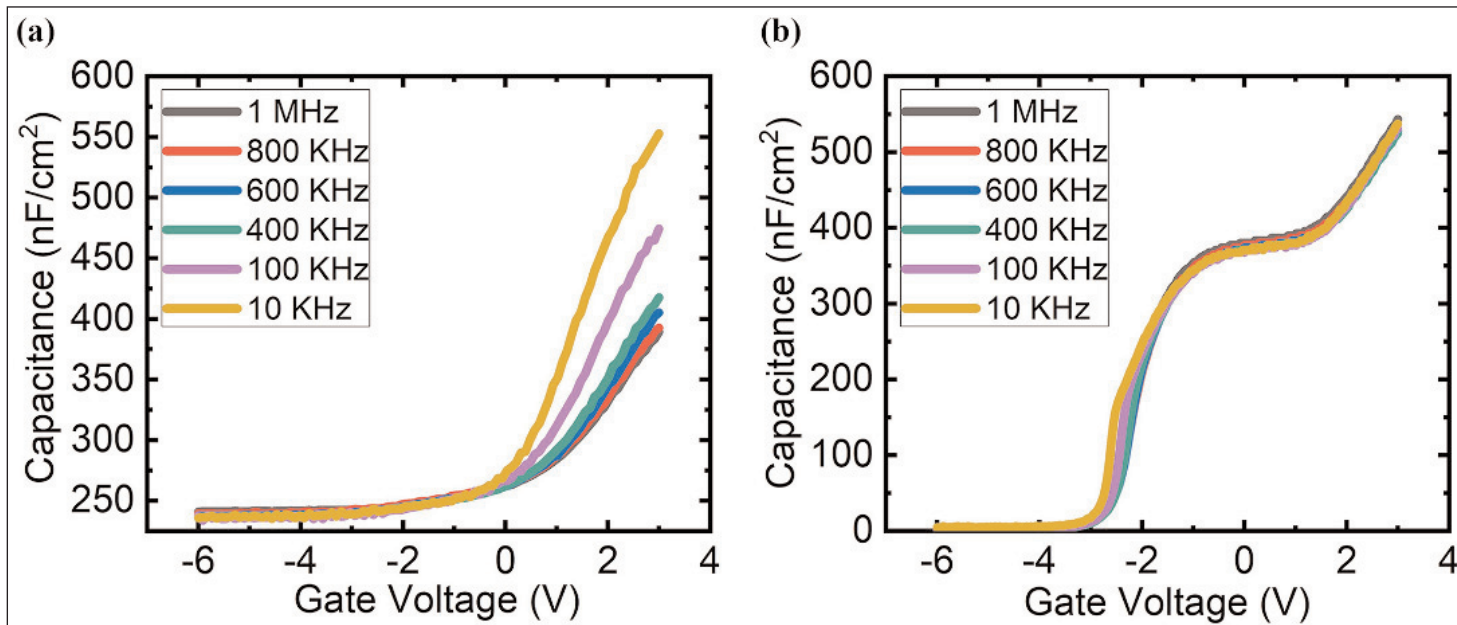
To further enable high frequencies and high-power operation, metal-oxide-semiconductor (MOS) gates insulated with high dielectric constant ( $\kappa$ ) materials such as HfO<sub>2</sub> are needed to support reduced gate lengths with good electrostatic control, while avoiding short-channel effects.

The N-polar AlGaN MOS capacitor (MOSCAP) structures were grown on miscut sapphire by metal-organic chemical vapor deposition (MOCVD — see Figure 1). The researchers comment: “A graded Si-doped AlGaN back-barrier is typically used in these heterostructures to suppress current dispersion caused by hole traps at the interface with net negative polarization charge.”

The variations in the studied samples involved the upper layers. A 2nm Al<sub>0.08</sub>Ga<sub>0.92</sub>N layer was designed to reduce gate leakage. Silicon nitride (SiN<sub>x</sub>) dielectric was grown in-situ in the MOCVD chamber as a protection layer in fabrication.



**Figure 1. Studied structure schemes: (a) HfO<sub>2</sub> on SiN, (b) HfO<sub>2</sub> on AlGaN after removal of SiN (MOSCAP-B), and (c) HfO<sub>2</sub> on GaN after removal of SiN and AlGaN cap layers (MOSCAP-C).**



**Figure 2. C-V profile measured at different frequencies on (a) MOSCAP-B and (b) MOSCAP-C.**

The HfO<sub>2</sub> was deposited after electron-beam evaporation and 820°C annealing of ohmic titanium/aluminium/nickel/gold contacts. The HfO<sub>2</sub> was applied in a blanket 250°C plasma-enhanced atomic layer deposition (PEALD) process. The gate electrode was titanium/gold.

The capacitance–voltage (C–V) behavior was found to be far from ideal at frequencies below 800kHz, which the researchers attributed to slow hole traps. The threshold was also shifted by about 8V, suggesting the presence of negative fixed charges in the dielectric. Annealing at 400°C in argon was found to bring the low-frequency C–V behavior closer to the ‘ideal’. The annealing also reduced high-frequency 1MHz hysteresis from ~3V down to ~1.1V.

A dielectric constant for the annealed HfO<sub>2</sub> was extracted using different layer thicknesses — the value was close to that reported elsewhere for the material. Varying the HfO<sub>2</sub> thickness was also found to affect the carrier density of the 2DEG that would form the channel in a field-effect transistor. As the dielectric became thicker, the carrier density reduced. The reduction was attributed to the negative charge in the dielectric.

Some samples were studied with the SiN<sub>x</sub> protection and also the AlGaN top barrier removed, using wet and plasma etching, respectively. The surface damage from the inductively couple chlorine plasma etch was repaired using an ultraviolet ozone treatment, along with a hydrofluoric acid final etch.

Removal of the AlGaN cap was found to be necessary to achieve pinch-off. The team comments: “These MOSCAPs showed much lower pinch-off voltage which is due to a combination of higher gate capacitance, because of lower distance between gate and the channel, and a thinner GaN channel which leads to lower 2DEG density in the channel.”

The C–V measurements gave a calculated value for the carrier density at  $4.9 \times 10^{12}/\text{cm}^2$ .

The problem with HfO<sub>2</sub> deposition on the AlGaN cap was attributed to pinning of the Fermi level, “perhaps due to chemical reaction between oxygen in HfO<sub>2</sub> and aluminum in AlGaN and formation of a poor-quality Al<sub>2</sub>O<sub>3</sub> at the interface”. ■

<https://doi.org/10.1088/1361-6641/abe21c>

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# GaN power market to reach \$1.1bn in 2026, after doubling in 2020

Consumer segment growing at 69% CAGR to \$672m, telecom & datacom at 71% to \$223m, and automotive at 185% to \$155m, says Yole Développement.

The gallium nitride (GaN) power market doubled during 2020 and will reach \$1.1bn in 2026, driven by the consumer applications segment, forecast market analyst firm Yole Développement in its report 'GaN Power 2021: Epitaxy, Devices, Applications and Technology Trends'.

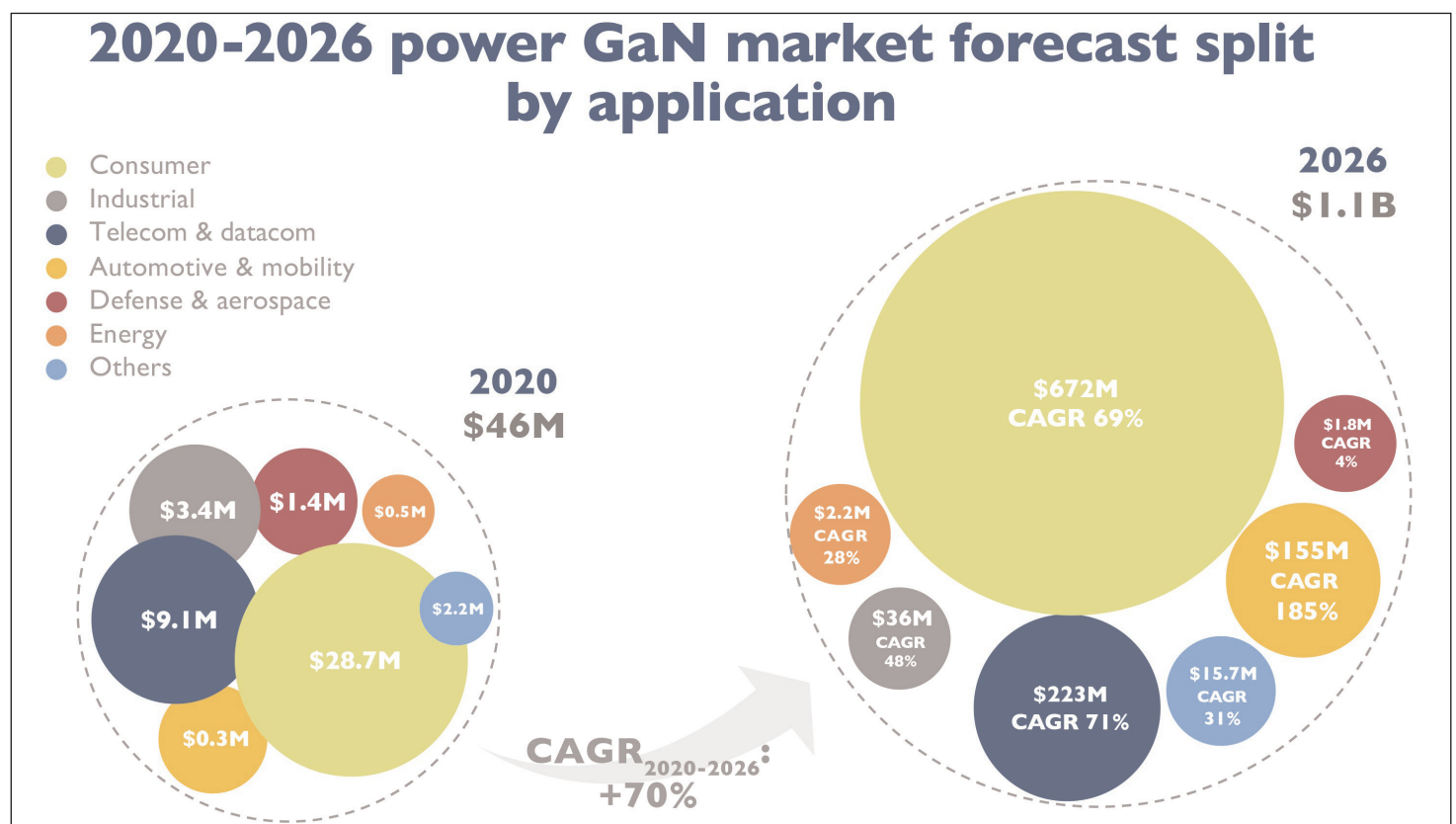
In 2020, the power GaN market doubled due to penetration of GaN devices into smartphone fast-charger applications. The adoption of GaN in the smartphone market is fueled by system compactness, high efficiency, and adapter multi-functionalities, says Yole. Fast charging is likely to be the killer application for the GaN power device market, it adds.

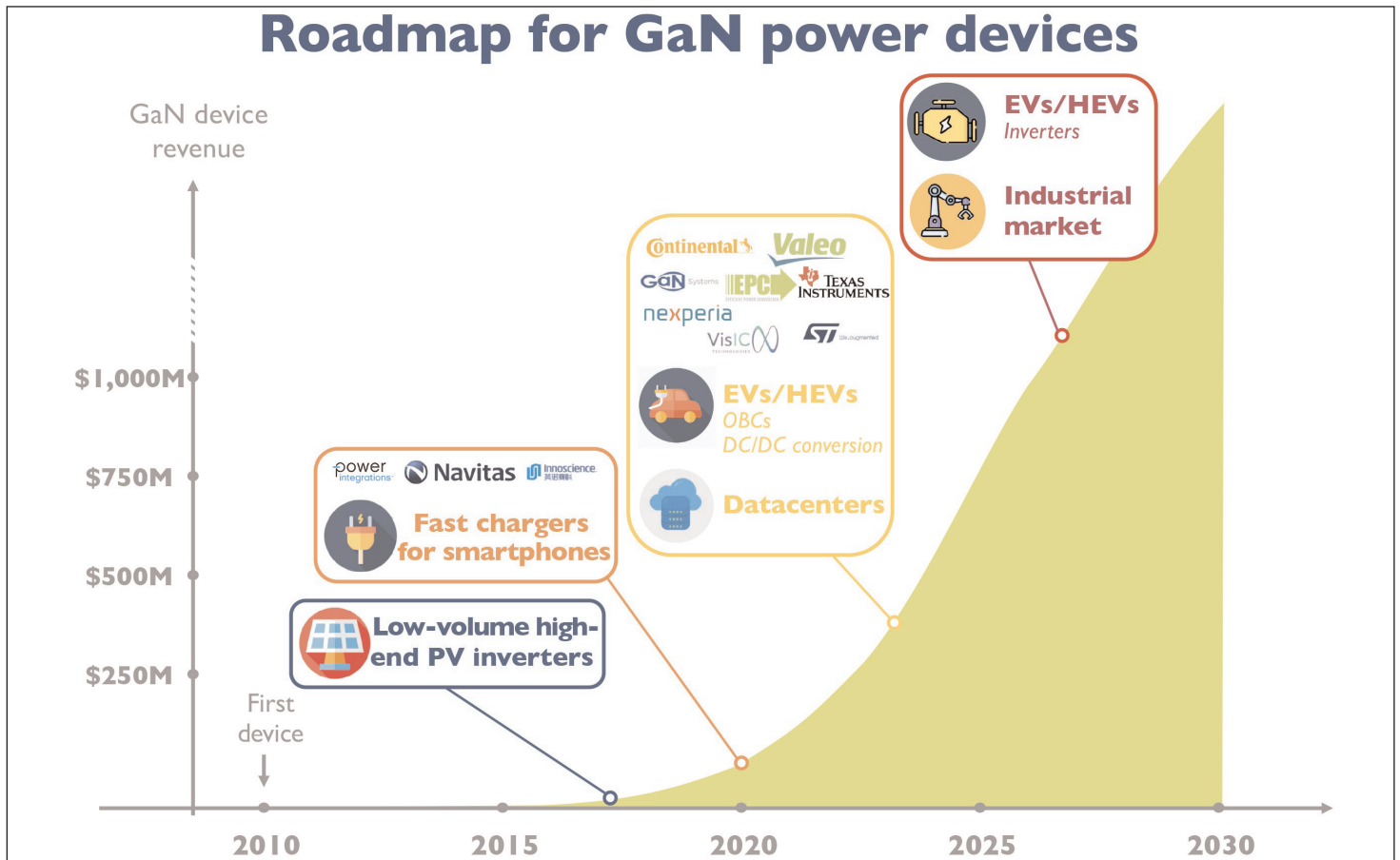
"Following Oppo's adoption of GaN in its 65W inbox fast chargers for its Reno Ace flagship model in late 2019, several phone original equipment manufacturers (OEMs) and accessory charger providers released GaN-solution

design wins for their fast chargers in 2020," notes Ahmed Ben Slimane PhD, technology & market analyst, Compound Semiconductors and Emerging Substrates.

In 2020 several companies, such as Xiaomi, Lenovo, Samsung, Realme, Dell and LG (as well as other Chinese after-market companies), adopted GaN technology. So far, at least 10 smartphone OEMs have launched more than 18 phones with an inbox GaN charger. This growth will continue in the after-market as well, with companies like Apple, Xiaomi, and Samsung opting for an out-of-the-box charger solution, says the report.

Yole hence expects the consumer power supply segment to be the main market driver, growing at a compound annual growth rate (CAGR) of 69% from almost \$29m in 2020 to about \$672m in 2026 (61% of the total GaN market).





"While GaN continues its ascension in the mass consumer market, the markets for telecom & datacom and automotive & mobility will benefit from the 'economy of scale effect' and price erosion," says Ahmed Ben Slimane. "Indeed, in these markets where reliability and cost are paramount, Yole expects that GaN penetration will see increasing volumes starting from 2023–2024 [contributing to overall market growth in the mid- to long-term]."

"In the telecom & datacom market, which requires more efficient, smaller power supplies amidst tighter regulations for energy consumption, data-center and telecom operators are already interested in GaN devices," notes Poshun Chiu, technology & market analyst specializing in Compound Semiconductor and Emerging Substrates. Following the first small-volume adoption of GaN-based power supplies by Eltek, Delta and BelPower in recent years, Yole expects greater penetration by GaN, driving the telecom & datacom segment to grow at a 71% CAGR from just \$9.1m in 2020 to over \$223m in 2026.

"The automotive & mobility market is also paying lots of attention to GaN, following big incentives for the electrification of cars and the interest in increasing driving range through system efficiency optimization," says Chiu.

In the long term, in cases where GaN has proven its reliability and high-current capabilities at a lower price, it can penetrate the more challenging EV/HEV (hybrid electric vehicle) inverter market and the conservative industrial market, which could create remarkable high-

volume opportunities for GaN, says the report.

Players such as EPC, Transphorm, GaN Systems, Texas Instruments and Nexperia are AEC qualified. In particular, Nexperia and VisiC are working on GaN solutions for xEV inverters to compete with silicon carbide (SiC) and silicon. Also targeting GaN for EVs is major integrated device manufacturer (IDM) STMicroelectronics, which has strengthened its position and product portfolio through its collaboration with TSMC plus the acquisition of a majority stake in Exagan.

Starting from 2022, GaN is expected to penetrate in small volumes into applications such as on-board chargers (OBCs) and DC/DC converters, mainly related to sampling by OEMs and tier-1s. Yole hence expects that the automotive & mobility market will rise at a 185% CAGR to more than \$155m in 2026.

### Technology trends

In terms of technology trends, more new players have entered the market with GaN-on-silicon (GaN-on-Si) enhancement-mode (E-mode) high-electron-mobility transistor (HEMT) technology, targeting the booming fast-charger segment. GaN-on-Si is considered to be the platform to expand capacity for foundries in the coming years. Notable investments have hence been made in GaN epitaxy and fabs to increase GaN device fabrication capacity. However, challenges remain in the epitaxial deposition for larger wafer size. ■

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# Flexible indium phosphide DHBT frequency boost

A wafer-scale process has resulted in record performance for flexible electronics.

**S**outheast University and Nanjing Electronic Devices Institute in China have claimed the first demonstration of wafer-scale fabrication of high-frequency indium phosphide (InP) double heterostructure bipolar transistors (DHBTs) transferred to a flexible substrate [LiShu Wu et al, *Semicond. Sci. Technol.*, vol36, p03LT02, 2021].

The team reports: "The cut-off frequency  $f_T = 337\text{GHz}$  and maximum oscillation frequency  $f_{MAX} = 485\text{GHz}$  are obtained, which represents the highest result ever reported in the field of flexible electronics to date."

Flexible electronics is deployed in areas such as displays, solar cells, wearable electronics and bio-medical devices. Existing flexible electronics suffers from limited frequency performance, below the speed and bandwidth needed to access wireless communications/Internet of Things (IoT) technology. InP-based technology allows access to higher frequencies through much higher electron mobility.

Although new technologies such as graphene have enabled  $f_T$  values of  $198\text{GHz}$  ( $28.2\text{GHz } f_{MAX}$ ), the best flexible electronics performance previously was also achieved with InP, using high-electron-mobility transistor structures, achieving  $160\text{GHz } f_T$  and  $290\text{GHz } f_{MAX}$ .

The researchers contrast their wafer-scale achievement with previous reports, none of which "have yet been demonstrated to achieve high-performance flexible electronics at multi-gigahertz range on wafer scale, which will also limit the abroad application of RF flexible electronics."

The DHBT material was grown on 3-inch InP substrate using molecular beam epitaxy (MBE) — see Figure 1. The material was fabricated into single-finger DHBTs, using a  $0.5\mu\text{m}$  process. Wet etching was used to define three stacked mesas for the DHBT,

Emitter contact	InGaAs	200nm	Si
Emitter	InP	200nm	Si
Base	InGaAs	35nm	C
Set-back	InGaAs	30nm	Si
$\delta$ -doping	InP	50nm	Si
Collector	InP	150nm	Si
Collector contact	InGaAs	50nm	Si
Sub-collector	InP	200nm	Si
Etch-stop	InGaAs	100nm	Undoped
Substrate	InP		Semi-insulating

Figure 1. Layer structure of the InGaAs/InP DHBT.

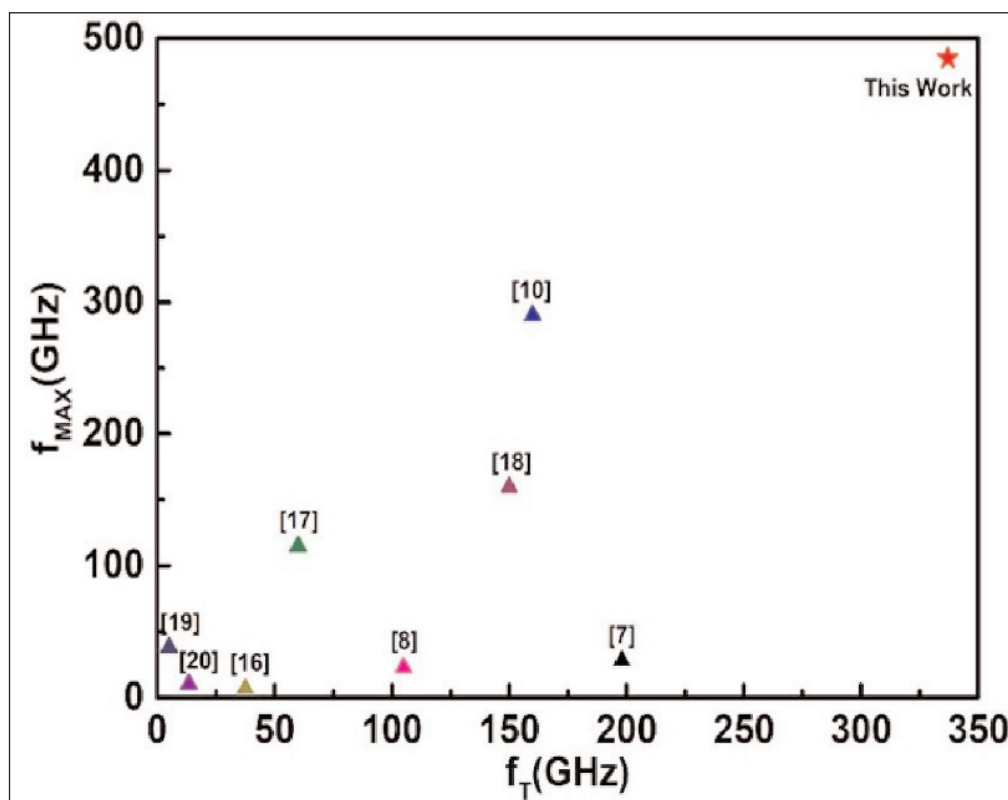


Figure 2. Comparison of  $f_T/f_{MAX}$  with previously reported semiconductor transistors on flexible substrate.

**Figure 3. (a) Optical image of 3-inch InP DHBTs on flexible substrate. (b)  $f_T/f_{MAX}$  performance mapping under same measurement condition.**

using self-aligned techniques to define the base contact. The emitter/collector metals were titanium/platinum/gold, and the base was platinum/titanium/platinum/gold. Further steps included device isolation, planarization/passivation with benzocyclobutene, reactive-ion etch to expose metal terminal posts, and pad deposition.

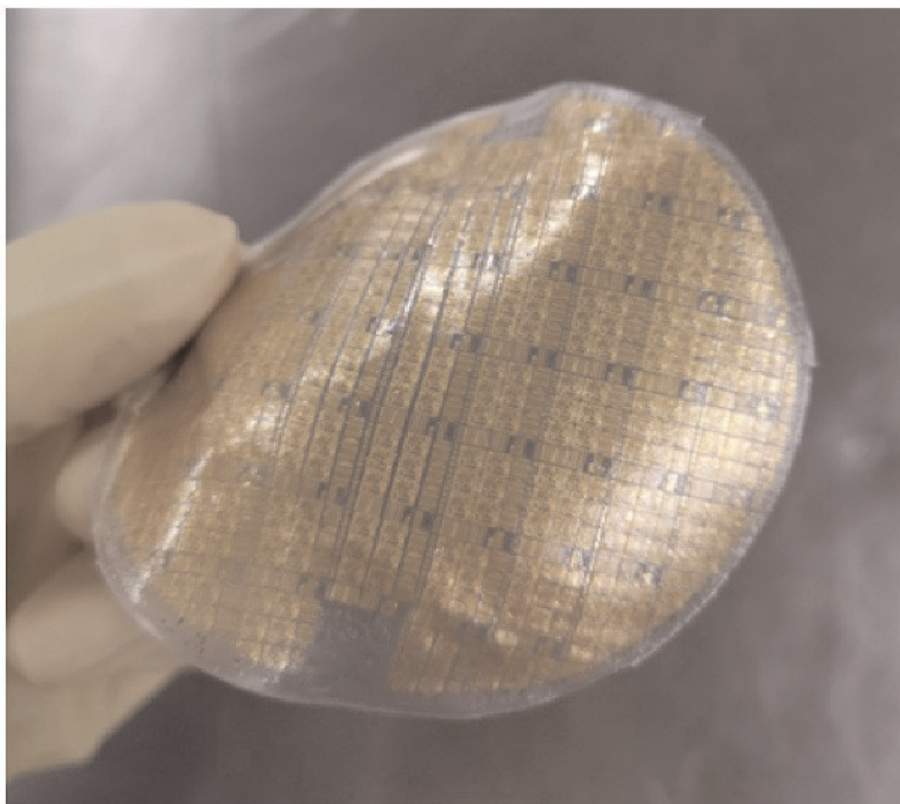
The transfer to flexible substrate involved temporary adhesion to sapphire carrier to enable removal/thinning of the InP substrate using mechanical lapping, followed by selective wet etching with a solution based on hydrochloric acid. The indium gallium arsenide (InGaAs) stop layer was removed with a solution based on orthophosphoric acid. The 2 $\mu\text{m}$ -thick device was then permanently bonded to the flexible substrate, and the sapphire carrier was removed.

DC measurements showed some degradation in performance in terms of collector current relative to devices not transferred to flexible substrates. The researchers attribute the degradation to poor thermal conductivity of the flexible substrate, about a factor of three lower than for InP. Self-heating can severely impact transistor performance. The maximum gain of 31 was only slightly impaired relative to the non-flexible devices.

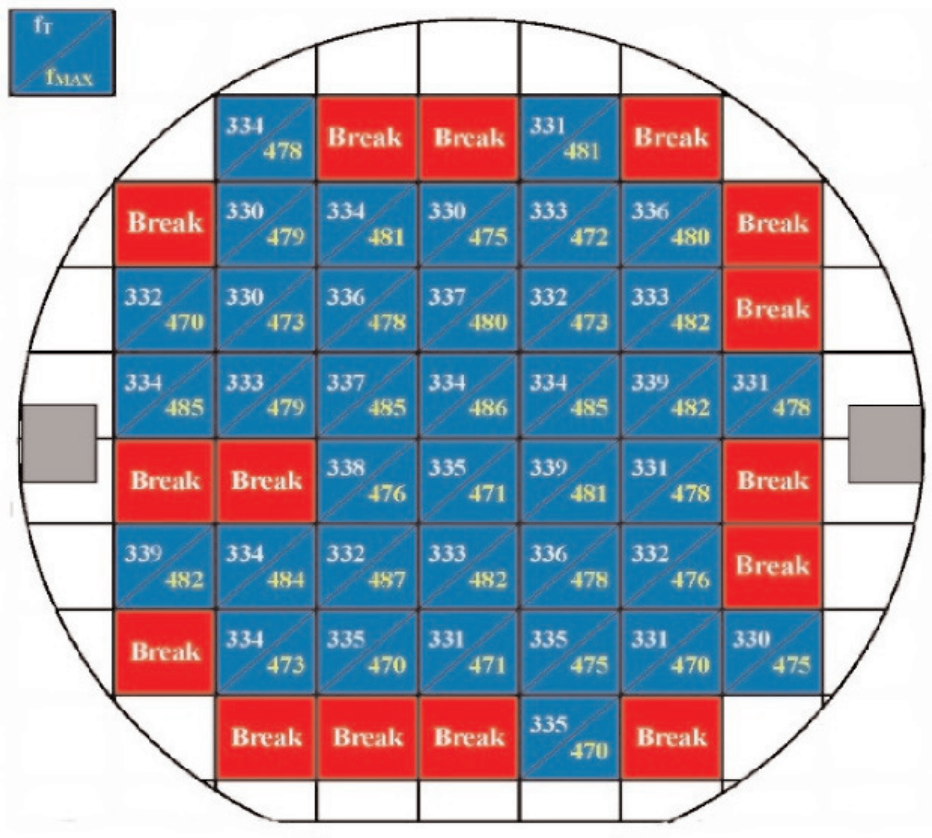
The frequency performance was measured up to 40GHz.

A conventional DHBT achieved an extrapolated  $f_T$  of 385GHz with an  $f_{MAX}$  of 570GHz. The DHBT on flexible substrate registered an  $f_T$  of 337GHz and an  $f_{MAX}$  of 485GHz. The researcher compared their work with other reports (Figure 2).

(a)



(b)



The process yield was around 73%, with most failed devices being on the periphery of the wafer (Figure 3). The failure was attributed to local defects. The frequency performance of the resulting devices varied only slightly. ■ <https://doi.org/10.1088/1361-6641/abe05b>  
 Author: Mike Cooke

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[www.aixtron.com](http://www.aixtron.com)

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Via Falzarego, 820021 Baranzate (Mi),  
Italy  
Tel: +39 02 383 41 51  
Fax: +39 02 383 06 118


[www.lpe-epi.com](http://www.lpe-epi.com)

**Evatec AG**

Hauptstrasse 1a,  
CH-9477 Trübbach,  
Switzerland  
Tel: +41 81 403 8000  
Fax: +41 81 403 8001

[www.evatecnet.com](http://www.evatecnet.com)

**FHR Anlagenbau GmbH  
(Vital Materials subsidiary)**

Am Hügel 2, D-01458   
Ottendorf-Okrilla,  
Germany

Tel: +49 35205 520-0

E-mail: sales@fhr.de

E-mail: sales@vitalchem.com

[www.fhr.biz](http://www.fhr.biz)

Vital Materials is the world's leading  
producer of rare metals as well as  
the first Chinese manufacturer to  
deliver G11 rotary ITO target. Vital is  
also one of the world's three major  
supplier of infrared materials, a key  
supplier of compound semiconductor  
substrates, and a strategic partner  
of the world's largest thin film solar  
manufacturer.

**LPE S.p.A.**

Via Falzarego, 8  
20021 Baranzate (Mi), Italy  
Tel: +39 02 383 41 51  
Fax: +39 02 383 06 118

[www.lpe-epi.com](http://www.lpe-epi.com)

**PLANSEE High Performance  
Materials**

6600 Reutte,  
Austria  
Tel: +43 5672 600 2422  
info@plansee.com

[www.plansee.com](http://www.plansee.com)

**Plasma-Therm LLC**

10050 16th Street North,  
St. Petersburg, FL 33716,  
USA  
Tel: +1 727 577 4999  
Fax: +1 727 577 7035

[www.plasmatherm.com](http://www.plasmatherm.com)

**Riber**

31 rue Casimir Périer, BP 70083,  
95873 Bezons Cedex,  
France  
Tel: +33 (0) 1 39 96 65 00  
Fax: +33 (0) 1 39 47 45 62

[www.riber.com](http://www.riber.com)

**SVT Associates Inc**

7620 Executive Drive,  
Eden Prairie, MN 55344, USA  
Tel: +1 952 934 2100  
Fax: +1 952 934 2737

[www.svta.com](http://www.svta.com)

**Temescal, a division of Ferrotec**

4569-C Las Positas Rd,  
Livermore, CA 94551, USA  
Tel: +1 925 245 5817  
Fax: +1 925 449-4096

[www.temescal.net](http://www.temescal.net)

**Veeco Instruments Inc**

100 Sunnyside Blvd.,  
Woodbury, NY 11797, USA  
Tel: +1 516 677 0200  
Fax: +1 516 714 1231

[www.veeco.com](http://www.veeco.com)

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## 7 Wafer processing materials

**Kayaku Advanced Materials Inc**

200 Flanders Road,  
Westborough, MA 01581, USA  
Tel: +1 617 965 5511

[www.kayakuam.com](http://www.kayakuam.com)

**Praxair Electronics**

(see section 5 for full contact details)

**Versum Materials**

8555 S. River Parkway,  
Tempe, AZ 85284, USA  
Tel: +1 602 282 1000

[www.versummaterials.com](http://www.versummaterials.com)

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## 8 Wafer processing equipment

**Evatec AG**

Hauptstrasse 1a, CH-9477 Trübbach,  
Switzerland  
Tel: +41 81 403 8000  
Fax: +41 81 403 8001

[www.evatecnet.com](http://www.evatecnet.com)

**EV Group**

DI Erich Thallner Strasse 1,  
St. Florian/Inn, 4782,  
Austria  
Tel: +43 7712 5311 0  
Fax: +43 7712 5311 4600

[www.EVGroup.com](http://www.EVGroup.com)

EV Group is a technology and market leader for wafer processing equipment. Worldwide industry standards for aligned wafer bonding, resist processing for the MEMS, nano and semiconductor industry.

#### Logitech Ltd

Erskine Ferry Road,  
Old Kilpatrick, near Glasgow G60 5EU,  
Scotland, UK  
Tel: +44 (0) 1389 875 444  
Fax: +44 (0) 1389 879 042  
[www.logitech.uk.com](http://www.logitech.uk.com)

#### Plasma-Therm LLC

(see section 6 for full contact details)

#### SAMCO International Inc

532 Weddell Drive,  
Sunnyvale, CA,  
USA  
Tel: +1 408 734 0459  
Fax: +1 408 734 0961  
[www.samcointl.com](http://www.samcointl.com)

#### SPTS Technology Ltd

Ringland Way,  
Newport NP18 2TA, UK  
Tel: +44 (0)1633 414000  
Fax: +44 (0)1633 414141  
[www.spts.com](http://www.spts.com)

#### SUSS MicroTec AG

Schleißheimer Strasse 90,  
85748 Garching, Germany  
Tel: +49 89 32007 0  
Fax: +49 89 32007 162  
[www.suss.com](http://www.suss.com)

#### Synova SA

Ch. de la Dent d'Oche,  
1024 Ecublens, Switzerland  
Tel +41 21 694 35 00  
Fax +41 21 694 35 01  
[www.synova.ch](http://www.synova.ch)

#### TECDIA Inc

2700 Augustine Drive, Suite 110,  
Santa Clara, CA 95054, USA  
Tel: +1-408-748-0100  
Fax: +1-408-748-0111  
Contact Person: Cathy W. Hung  
Email: [sales@tecdia.com](mailto:sales@tecdia.com)  
[www.tecdia.com](http://www.tecdia.com)

#### Veeco Instruments Inc

(see section 6 for full contact details)

## 9 Materials & metals

#### Goodfellow Cambridge Ltd

Ermine Business Park, Huntingdon,  
Cambridgeshire PE29 6WR, UK  
Tel: +44 (0) 1480 424800  
Fax: +44 (0) 1480 424900  
[www.goodfellow.com](http://www.goodfellow.com)

#### PLANSEE High Performance Materials

6600 Reutte, Austria  
Tel: +43 5672 600 2422  
[info@plansee.com](mailto:info@plansee.com)  
[www.plansee.com](http://www.plansee.com)

#### TECDIA Inc

2700 Augustine Drive, Suite 110,  
Santa Clara, CA 95054,  
USA  
Tel: +1 408 748 0100  
Fax: +1 408 748 0111  
[www.tecdia.com](http://www.tecdia.com)

## 10 Gas and liquid handling equipment

#### Cambridge Fluid Systems

12 Trafalgar Way, Bar Hill,  
Cambridge CB3 8SQ,  
UK  
Tel: +44 (0)1954 786800  
Fax: +44 (0)1954 786818  
[www.cambridge-fluid.com](http://www.cambridge-fluid.com)

#### CS CLEAN SOLUTIONS AG

Fraunhoferstrasse 4,  
Ismaning, 85737,  
Germany  
Tel: +49 89 96 24000  
Fax: +49 89 96 2400122  
[www.csclean.com](http://www.csclean.com)

#### Entegris Inc

129 Concord Road,  
Billerica, MA 01821, USA  
Tel: +1 978 436 6500  
Fax: +1 978 436 6735  
[www.entegris.com](http://www.entegris.com)

#### IEM Technologies Ltd

Fothergill House, Colley Lane,  
Bridgwater, Somerset TA6 5JJ, UK  
Tel: +44 (0)1278 420555  
Fax: +44 (0)1278 420666  
[www.iemtec.com](http://www.iemtec.com)

#### Vacuum Barrier Corporation

4 Barton Lane,  
Woburn, MA 01801,  
USA  
Tel: +1 781 933 3570  
Fax: +1 781 933 9428  
[www.vacuumbarrier.com](http://www.vacuumbarrier.com)

**VACUUM  
BARRIER**   
CORPORATION

Vacuum Barrier's vacuum-jacketed dynamic and sealed SEMIFLEX LN2 pipe delivers LN2 at bulk tank pressure in two-phase condition for on-demand supply. Our liquid/vapor phase separators deliver low-pressure LN2 to each use point for on-demand supply. Combine with SEMIFLEX Triax LN2 pipe eliminates two-phase flow to all use points.

#### Versum Materials

8555 S. River Parkway,  
Tempe, AZ 85284,  
USA  
Tel: +1 602 282 1000  
[www.versummaterials.com](http://www.versummaterials.com)

## 11 Process monitoring and control

#### Conax Technologies

2300 Walden Avenue,  
Buffalo, NY 14225,  
USA  
Tel: +1 800 223 2389  
Tel: +1 716 684 4500  
[www.conaxtechnologies.com](http://www.conaxtechnologies.com)

#### k-Space Associates Inc

2182 Bishop Circle  
East, Dexter,  
MI 48130,  
USA  
Tel: +1 734 426 7977  
Fax: +1 734 426 7955  
[www.k-space.com](http://www.k-space.com)

#### KLA-Tencor

One Technology Dr,  
1-2221I, Milpitas,  
CA 95035,  
USA  
Tel: +1 408 875 3000  
Fax: +1 408 875 4144  
[www.kla-tencor.com](http://www.kla-tencor.com)

**LayTec AG**  
Seesener Str.  
10-13,  
10709 Berlin,  
Germany



Tel: +49 30 89 00 55 0  
Fax: +49 30 89 00 180

[www.laytec.de](http://www.laytec.de)

LayTec develops and manufactures optical in-situ and in-line metrology systems for thin-film processes with particular focus on compound semiconductor and photovoltaic applications. Its know-how is based on optical techniques: reflectometry, emissivity corrected pyrometry, curvature measurements and reflectance anisotropy spectroscopy.

### Vacuum Barrier Corporation

4 Barton Lane, Woburn, MA 01801, USA

Tel: +1 781 933 3570  
Fax: +1 781 933 9428

[www.vacuumbARRIER.com](http://www.vacuumbARRIER.com)

**VACUUM  
BARRIER VBC**  
CORPORATION

Vacuum Barrier's vacuum-jacketed dynamic and sealed SEMIFLEX LN<sub>2</sub> pipe delivers LN<sub>2</sub> at bulk tank pressure in two-phase condition for on-demand supply. Our liquid/vapor phase separators deliver low-pressure LN<sub>2</sub> to each use point for on-demand supply. Combine with SEMIFLEX Triax LN<sub>2</sub> pipe eliminates two-phase flow to all use points.

### WEP (Ingenieurbüro Wolff für Elektronik- und Programmentwicklungen)

Bregstrasse 90,  
D-78120 Furtwangen im  
Schwarzwald, Germany  
Tel: +49 7723 9197 0  
Fax: +49 7723 9197 22

[www.wepcontrol.com](http://www.wepcontrol.com)

## 12 Inspection equipment

### Bruker

Oestliche Rheinbrueckenstrasse 49,  
Karlsruhe, 76187, Germany  
Tel: +49 (0)721 595 2888  
Fax: +49 (0)721 595 4587

[www.bruker.com](http://www.bruker.com)

### KLA-Tencor

160 Rio Robles, Suite 103D,  
San Jose, CA 94538-7306, USA  
Tel: +1 408 875-3000  
Fax: +1 510 456-2498

[www.kla-tencor.com](http://www.kla-tencor.com)

## 13 Characterization equipment

### J.A. Woollam Co. Inc.

645 M Street Suite 102,  
Lincoln, NE 68508, USA  
Tel: +1 402 477 7501  
Fax: +1 402 477 8214

[www.jawoollam.com](http://www.jawoollam.com)

### Lake Shore Cryotronics Inc

575 McCorkle Boulevard,  
Westerville, OH 43082, USA  
Tel: +1 614 891 2244

Fax: +1 614 818 1600

[www.lakeshore.com](http://www.lakeshore.com)

## 14 Chip test equipment

### Riff Company Inc

1484 Highland Avenue, Cheshire,  
CT 06410, USA

Tel: +1 203-272-4899

Fax: +1 203-250-7389

[www.riff-co.com](http://www.riff-co.com)

### Tektronix Inc

14150 SW Karl Braun Drive,  
P.O.Box 500, OR 97077, USA

[www.tek.com](http://www.tek.com)

## 15 Assembly/packaging materials

### ePAK International Inc

4926 Spicewood Springs Road,  
Austin, TX 78759,  
USA

Tel: +1 512 231 8083

Fax: +1 512 231 8183

[www.epak.com](http://www.epak.com)

### Gel-Pak

31398 Huntwood Avenue,  
Hayward, CA 94544,  
USA

Tel: +1 510 576 2220

Fax: +1 510 576 2282

[www.gelpak.com](http://www.gelpak.com)

### Wafer World Inc

(see section 3 for full contact details)

### Materion Advanced Materials Group

2978 Main Street,  
Buffalo, NY 14214,  
USA

Tel: +1 716 837 1000

Fax: +1 716 833 2926

[www.williams-adv.com](http://www.williams-adv.com)

## 16 Assembly/packaging equipment

### CST Global Ltd

4 Stanley Boulevard,  
Hamilton International  
Technology Park,  
Blantyre, Glasgow G72 0BN,  
UK

Tel: +44 (0) 1698 722072

[www.cstglobal.uk](http://www.cstglobal.uk)

### Kulicke & Soffa Industries

1005 Virginia Drive,  
Fort Washington,  
PA 19034,  
USA

Tel: +1 215 784 6000

Fax: +1 215 784 6001

[www.kns.com](http://www.kns.com)

### Palomar Technologies Inc

2728 Loker Avenue West,  
Carlsbad, CA 92010,  
USA

Tel: +1 760 931 3600

Fax: +1 760 931 5191

[www.PalomarTechnologies.com](http://www.PalomarTechnologies.com)

### PI (Physik Instrumente) L.P.

16 Albert St . Auburn ,  
MA 01501, USA  
Tel: +1 508-832-3456,  
Fax: +1 508-832-0506

[www.pi.ws](http://www.pi.ws)

[www.pi-usa.us](http://www.pi-usa.us)

### TECDIA Inc

2700 Augustine Drive, Suite 110,  
Santa Clara,  
CA 95054,  
USA

Tel: +1 408 748 0100

Fax: +1 408 748 0111

[www.tecdia.com](http://www.tecdia.com)

## 17 Assembly/packaging foundry

### Quik-Pak

10987 Via Frontera,  
San Diego, CA 92127, USA  
Tel: +1 858 674 4676  
Fax: +1 8586 74 4681  
[www.quikicpak.com](http://www.quikicpak.com)

## 18 Chip foundry

### CST Global Ltd

4 Stanley Boulevard, Hamilton  
International Technology Park,  
Blantyre, Glasgow, G72 0BN,  
UK  
Tel: +44 (0) 1698 722072  
[www.cstglobal.uk](http://www.cstglobal.uk)

### United Monolithic Semiconductors

Route departementale 128,  
BP46, Orsay, 91401,  
France  
Tel: +33 1 69 33 04 72  
Fax: +33 169 33 02 92  
[www.ums-gaas.com](http://www.ums-gaas.com)

## 19 Facility equipment

### RENA Technologies NA

3838 Western Way NE,  
Albany, OR 97321, USA  
Tel: +1 541 917 3626  
[www.rena-na.com](http://www.rena-na.com)

### Vacuum Barrier Corporation

4 Barton Lane, Woburn, MA 01801,  
USA  
Tel: +1 781 933 3570  
Fax: +1 781 933 9428  
[www.vacuumbARRIER.com](http://www.vacuumbARRIER.com)

**VACUUM  
BARRIER VBC**  
CORPORATION

Vacuum Barrier's vacuum-jacketed dynamic and sealed SEMIFLEX LN<sub>2</sub> pipe delivers LN<sub>2</sub> at bulk tank pressure in two-phase condition for on-demand supply. Our liquid/vapor phase separators deliver low-pressure LN<sub>2</sub> to each use point for on-demand supply. Combine with SEMIFLEX Triax LN<sub>2</sub> pipe eliminates two-phase flow to all use points.

## 20 Facility consumables

### PLANSEE High Performance Materials

6600 Reutte,  
Austria  
Tel: +43 5672 600 2422  
info@plansee.com  
[www.plansee.com](http://www.plansee.com)

### W.L. Gore & Associates

401 Airport Rd, Elkton,  
MD 21921-4236,  
USA  
Tel: +1 410 392 4440  
Fax: +1 410 506 8749  
[www.gore.com](http://www.gore.com)

## 21 Computer hardware & software

### Crosslight Software Inc

121-3989 Henning Dr.,  
Burnaby, BC, V5C 6P8,  
Canada  
Tel: +1 604 320 1704  
Fax: +1 604 320 1734  
[www.crosslight.com](http://www.crosslight.com)

### Semiconductor Technology Research Inc

10404 Patterson Ave.,  
Suite 108, Richmond,  
VA 23238,  
USA  
Tel: +1 804 740 8314  
Fax: +1 804 740 3814  
[www.semitech.us](http://www.semitech.us)

## 22 Used equipment

### Brumley South Inc

422 North Broad Street,  
Mooresville,  
NC 28115,  
USA  
Tel: +1 704 664 9251  
Email: sales@brumleysouth.com  
[www.brumleysouth.com](http://www.brumleysouth.com)

As an ISO 9001 registered global leader in the remanufacturing of wafer inspection systems, Brumley South Inc specializes in designing,



installing and supporting upgrades for ADE, Nanometrics, Dryden and KLA-Tencor Surfscan tools, polystyrene latex sphere calibration standards, particle deposition systems, and semiconductor parts and service.

### Class One Equipment Inc

5302 Snapfinger Woods Drive,  
Decatur, GA 30035,  
USA  
Tel: +1 770 808 8708  
Fax: +1 770 808 8308  
[www.ClassOneEquipment.com](http://www.ClassOneEquipment.com)

## 23 Services

### Riff Company Inc

1484 Highland Avenue,  
Cheshire, CT 06410,  
USA  
Tel: +1 203-272-4899  
Fax: +1 203-250-7389  
[www.riff-co.com](http://www.riff-co.com)

### TECDIA Inc

2700 Augustine Drive, Suite 110,  
Santa Clara,  
CA 95054 ,  
USA  
Tel: +1-408-748-0100  
Fax: +1-408-748-0111  
Contact Person: Cathy W. Hung  
[www.tecdia.com](http://www.tecdia.com)

## 24 Resources

### Al Shultz Advertising Marketing for Advanced Technology Companies

1346 The Alameda,  
7140 San Jose,  
CA 95126, USA  
Tel: +1 408 289 9555  
[www.alshultz.com](http://www.alshultz.com)

### SEMI Global Headquarters

San Jose, CA 95134,  
USA  
Tel: +1 408 943 6900  
[www.semi.org](http://www.semi.org)

### Yole Développement

69006 Lyon,  
France  
Tel: +33 472 83 01 86  
[www.yole.fr](http://www.yole.fr)



# event calendar

If you would like your event listed in *Semiconductor Today's* Event Calendar, then please e-mail all details to the Editor at [mark@semiconductor-today.com](mailto:mark@semiconductor-today.com)

**6–10 June 2021**

(postponed from 28 March –1 April 2021)

**OFC 2021:**

**Optical Networking and Communication Conference & Exhibition**

— now an online, virtual event

**E-mail:** [OFC@csreg.zohodesk.com](mailto:OFC@csreg.zohodesk.com)

[www.ofcconference.org](http://www.ofcconference.org)

**7–10 June 2021**

**2021 IEEE MTT-S International Microwave Symposium (IMS2021) and Microwave Week (virtual event to follow on 20-25 June 2021)**

Georgia World Congress Center,  
Atlanta, GA, USA

**E-mail:** [IMS@xpressreg.net](mailto:IMS@xpressreg.net)

[www.ims-ieee.org](http://www.ims-ieee.org)

**9–13 June 2021**

(postponed from 21–25 June 2020)

**APEC 2021: IEEE Applied Power Electronics Conference and Exposition**

Phoenix, AZ USA

**E-mail:** [registration@apec-conf.org](mailto:registration@apec-conf.org)

[www.apec-conf.org](http://www.apec-conf.org)

**14–17 June 2021**

**44th Workshop on Compound Semiconductor Devices and Integrated Circuits held in Europe (WOCSDICE)**

**15th Expert Evaluation and Control of Compounds of Semiconductor Materials and Technologies (EXMATEC)**

Bristol, UK (online conference)

**E-mail:** [email@wocsdice-2021.com](mailto:email@wocsdice-2021.com)

**E-mail:** [email@exmatec-2021.com](mailto:email@exmatec-2021.com)

[www.wocsdice-exmatec-2021.com](http://www.wocsdice-exmatec-2021.com)

**20–24 June 2021**

**International Congress on Photonics in Europe — co-located with LASER World of PHOTONICS**

ICM (Internationales Congress Center München),  
Munich, Germany

**E-mail:** [info@photonics-congress.com](mailto:info@photonics-congress.com)

[www.photonics-congress.com/en](http://www.photonics-congress.com/en)

**21–24 June 2021**

**LASER World of PHOTONICS 2021**

Messe München,  
Munich, Germany

**E-mail:** [info@world-of-photonics.com](mailto:info@world-of-photonics.com)

[www.world-of-photonics.com/en](http://www.world-of-photonics.com/en)

**22–24 June 2021**

(postponed to 24–26 Aug 2021)

**Strategies in Light 2021**

Santa Clara Convention Center,  
Santa Clara, CA, USA

**E-mail:** [registration@endeavorb2b.com](mailto:registration@endeavorb2b.com)

[www.strategiesinlight.com](http://www.strategiesinlight.com)

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**4–9 July 2021 (postponed from 14–19 June 2020, then 4–9 July 2021, to 2022)**

**ICMOVPE XX:  
20th International Conference on Metal  
Organic Vapor Phase Epitaxy**

Stuttgart, Germany  
E-mail: [info@icmovpexx.eu](mailto:info@icmovpexx.eu)  
[www.icmovpexx.eu](http://www.icmovpexx.eu)

**22–25 July 2021 (postponed from 22–25 July 2020 then 12–15 March 2021)**

**International Congress on Advanced  
Materials Sciences & Engineering (AMSE)**

Vienna, Austria  
E-mail: [eve@istci.org](mailto:eve@istci.org)  
[www.istci.org/amse2021](http://www.istci.org/amse2021)

**1–5 August 2021**

**SPIE Optics + Photonics 2021  
– Conference and Exhibition**

San Diego Convention Center,  
San Diego, CA, USA  
E-mail: [customerservice@spie.org](mailto:customerservice@spie.org)  
[www.spie.org/opstm](http://www.spie.org/opstm)

**24–26 August 2021 (postponed from  
9–11 February 2021, then 22–24 June 2021)**

**Strategies in Light 2021**

Santa Clara Convention Center,  
Santa Clara, CA, USA  
E-mail: [registration@endeavorb2b.com](mailto:registration@endeavorb2b.com)  
[www.strategiesinlight.com](http://www.strategiesinlight.com)

**1–3 September 2021**

**CIOE 2021:  
23rd China International Optoelectronic  
Exposition**

Shenzhen World Exhibition & Convention Centre,  
China  
E-mail: [cioe@cioe.cn](mailto:cioe@cioe.cn)  
[www.cioe.cn/en](http://www.cioe.cn/en)

**12–17 September 2021 (postponed to 2022)**

**19th International Conference on  
Silicon Carbide and Related Materials  
(ICSCRM 2021-2022)**

Davos, Switzerland  
E-mail: [info@icscrm2021.org](mailto:info@icscrm2021.org)  
[www.icscrm2021.org](http://www.icscrm2021.org)

**13–15 September 2021**

**ECOC 2021 (47th European Conference on  
Optical Communication)**

Bordeaux Exhibition Centre, Bordeaux, France  
E-mail: [sales@ecocexhibition.com](mailto:sales@ecocexhibition.com)  
[www.ecocexhibition.com/ecoc-exhibition-2021](http://www.ecocexhibition.com/ecoc-exhibition-2021)

**22–24 September 2021**

**LASER World of PHOTONICS INDIA 2021**

Bengaluru, India  
E-mail: [info@world-of-photonics-india.com](mailto:info@world-of-photonics-india.com)  
[www.world-of-photonics-india.com](http://www.world-of-photonics-india.com)

**10–14 October 2021**

**27th International Semiconductor Laser  
Conference (ISLC 2021)**

Potsdam, Germany  
E-mail: [islc@fbh-berlin.de](mailto:islc@fbh-berlin.de)  
[www.islc2021.org](http://www.islc2021.org)

**~~10–15 October 2021~~**

**(postponed to 13–18 February 2022)**

**24th European Microwave Week (EuMW 2021)**

ExCel, London, UK  
E-mail: [eumwreg@itnint.com](mailto:eumwreg@itnint.com)  
[www.eumweek.com](http://www.eumweek.com)

**17–21 October 2021 (postponed to Fall 2022)**

**4th International Workshop on Gallium  
Oxide and Related Materials (IWGO 2021)**

Nagano, Japan  
E-mail: [secretary@iwgo2021.org](mailto:secretary@iwgo2021.org)  
[www.iwgo2021.org](http://www.iwgo2021.org)

**24–28 October 2021**

**(postponed from 13–17 September 2020)  
13th European Conference on Silicon  
Carbide and Related Materials  
(ECSCRM 2020-2021)**

Vinci International Convention Centre, Tours, France  
E-mail: [ecscrm-2020@univ-tours.fr](mailto:ecscrm-2020@univ-tours.fr)  
[www.ecscrm-2020.com](http://www.ecscrm-2020.com)

**7–9 November 2021**

**8th IEEE Workshop on Wide Bandgap Power  
Devices & Applications (WiPDA 2021)**

Crowne Plaza Redondo Beach and Marina,  
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[www.wipda.org](http://www.wipda.org)

**16–19 November 2021**

**SEMICON Europa 2021  
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[www.semiconeuropa.org](http://www.semiconeuropa.org)

**13–15 December 2021**

**67th IEEE International Electron Devices  
Meeting (IEDM 2021)**

San Francisco, CA USA  
E-mail: [info@ieee-iedm.org](mailto:info@ieee-iedm.org)  
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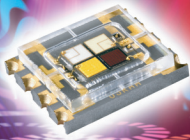


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