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Happy anniversary
25 years anniversary for two leading GaAs chipmakers

Marketplace
Stocks soar for compound semiconductor companies

From lab to fab
Nitride LEDs ready to take their place in the market place

Larger lamps
Greater surface area lamps could be the key to DUV LEDs

Phase separation
Electroluminescence exposes AlInGaN phase separation

Plane for green lasers
Semi polar plane discovered to help production

Square lasers
Benefit for PICs

Future research

III-Vs to provide the key to high speed mobility

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Happy anniversary

This year marks a significant anniversary for two of the world's leading GaAs chipmakers, with Anadigics and TriQuint celebrating their twenty-fifth anniversaries. Both US stalwarts feature in this issue.

On page 24 you can read Anadigics' story, a topsy-turvy journey that has been strongly influenced by events in Europe.

When the company was founded in 1985 its primary goal was to provide GaAs ICs to defence companies working on the Star Wars project. But this business plan was left in tatters when communism was overthrown in Eastern Europe, and the US reacted by declining its interest in Star Wars and slashing the nation's defence budget.

Anadigics then shifted focus, targeting new markets. But it failed to clinch any major deals for several years, lost millions, strained its relationships with investors and came close to bankruptcy. It could well have gone under, had it not been for a deal struck with a UK company to provide GaAs ICs for the emergent satellite TV industry. This contract brought the company close to break-even, and held the key to winning further investment.

By then the killer application was on the horizon: the cellular handset. Anadigics wanted a partner to develop its power amplifiers with, and Europe obliged, with the company teaming up with Ericsson. It was a win-win relationship, delivering rocketing revenues and healthy products for Anadigics.

But the glory days didn't last long, with the company's MESFET being trumped by the new kid on the block, the HBT. It's been catch up time ever since, with the company continuing to also develop its satellite and cable TV businesses.

The latter of these is also being targeted by the other twenty five year old GaAs chipmaker, TriQuint. On page 15 it describes how GaAs can play a critical role in the delivery of advanced video, data and telephony services by cable. Silicon bipolar transistors have been the incumbent technology in that market for many decades, but III-Vs are making inroads by offering lower distortion, greater bandwidth and greater efficiency.

It will be interesting to see how well TriQuint, and Anadigics for that matter, fare in the cable TV market. Sales should be healthy for the foreseeable future, but if we've learnt anything from the last 25 years, it's that it is impossible to predict all the long term twists and turns in the GaAs market. Where that will be in 2035, and whether it will include two 50 year veterans TriQuint and Anadigics, is anybody's guess.

Richard Stevenson PhD
Consultant Editor

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GaAs and GaN technologies can spur high-quality delivery of advanced video, data and telephony services to the home, says TriQuint's, Chris Day.

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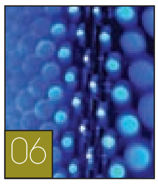
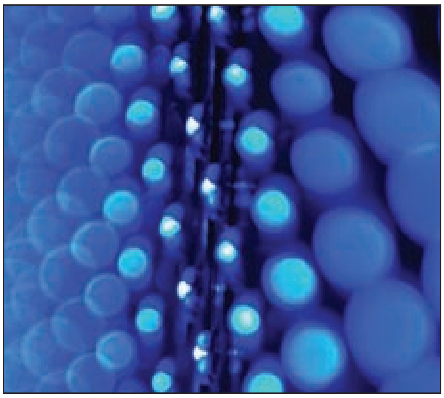


AkzoNobel go global with Trimethyl Gallium capacity

METALORGANIC plant in LaPorte Texas production capability will double during Summer 2010 in response to unprecedented LED demand.



Dutch firm AkzoNobel is a major producer of high-purity semiconductor grade indium, gallium, aluminum and zinc-based metalorganics. These are key materials used as precursors in the production of light emitting diodes (LEDs) and solar cells. The High Purity Metal Organic (HPMO) business which is part of the Functional Chemicals Business Unit has announced it intends to double capacity of it's LaPorte Texan facility.

Owing to new applications in backlight units for computer screens and LED-TVs, the market for LEDs is booming. In addition, LED technology continues to make steady progress penetrating into general lighting and many other applications. With demand for Trimethyl Gallium (TMG) already exceeding the supply, Strategy Analytics recently reported manufacturers will need to absorb a 20% price increase in the near term.

"This capacity expansion shows AkzoNobel's commitment to the attractive and high growth LED and solar industry", says Bob Margevich, Managing Director of Functional Chemicals. "This business also supports our efforts in sustainability, by focusing on applications that drive energy efficiency and lower energy usage, like LEDs and solar cells".

LED explosion could go up in smoke

STRATEGY ANALYTICS report ," Materials Shortage to Restrict Rampant LED Market ", says consumables and MOCVD equipment manufacturers will struggle to meet demands.

The market for high-brightness LEDs in LCD TV backlights will be restricted by a shortage of key semiconductor materials in the second half of 2010.

With demand for TMG already exceeding the supply, manufacturers will need to absorb a 20% price increase in the near term. A shortage of sapphire wafers is also likely in the second half of 2010.

The report outlines the challenges facing LED manufacturers in 2010, as supply constraints and increasing material prices serve to restrict the rapid market expansion. "Concerns have previously been raised over the ability of MOCVD equipment vendors to meet rapidly increasing demand," noted Asif Anwar, Director of the GaAs and Compound Semiconductor Service at Strategy Analytics. "The concern for short supply of materials will create a bottleneck for LED market growth over the short term."

Taiwanese LED manufacturers in particular need to adjust to the new reality of the supply chain. Historically, they have bargained for the price of these key materials. But the balance of power in the LED industry has changed. With competitors backed by massive corporations, such as Samsung and LG, these firms are much better positioned to absorb higher material costs and to guarantee their supply in a constrained market.

Steven Entwistle, VP of the Strategy Analytics Strategic Technologies Practice, added, "Capacity expansions already in progress should relieve these constraints by mid-2011. Until then, the average selling price of high-brightness LEDs based on GaN should hold up well."

Plasmarons 'give graphene unique properties'

PARTICLES found in graphene could hold the key to the material's development as a basis for next-generation photonics research.

An international team of researchers led by Aaron Bostwick and Eli Rotenberg of the Advanced Light Source (ALS) at the US Department of Energy's Lawrence Berkeley National Laboratory has unlocked some of the mysteries of the unique properties of graphene.

The team showed how plasmarons - a charge carrier coupled with a plasmon particle - could play an integral role in the development of super-fast computers using graphene for room-temperature applications in the future.

It revealed how the density of graphene's electrical charge carriers can be easily influenced, thereby making it relatively straightforward to tune the electronic properties of graphene nanostructures.

The team revealed how the material has no band-gap and this could be one of the unique selling points for its use in next-generation electronics.

"On the usual band-gap diagram of neutral graphene, the filled valence band and the empty conduction band are shown as two cones, which meet at their tips at a point called the Dirac crossing," Dr Bostwick commented.

As particles get close to the Dirac crossing they move as if they have no mass, travelling at a specific proportion of the speed of light. As a result, the introduction of photons could excite plasmon particles using external sources, thereby channelling the particles into specific conical bands - making the material easily manageable to meet the needs of computer development. Dr Rotenberg added that "one of the best ways to grow a flat sheet of graphene is by heating a crystal of silicon carbide (SiC) ... As the silicon recedes from the surface it leaves a single carbon layer".

Integra unveils first 50 volt GaN HEMT

GALLIUM NITRIDE-ON-SILICON technology development effort is a direct result of customer requests for smaller, more efficient power devices with broadband performance.

California based firm Integra Technologies has revealed its latest development in High Voltage Gallium Nitride on Silicon (GaN-on-silicon) technology. After nearly two years of research and development at it's wafer fabrication facility, the company has launched two new products: the IGN2731M25 and IGN2731M50. Integra claims it has developed the first high voltage GaN-on-silicon HEMT process with drain-source breakdowns exceeding 200V. High breakdown voltages enable devices to operate at higher voltages than seen in today's marketplace which translates into higher performance.

"This just demonstrates Integra management's commitment to providing superior technology and world class devices to our customers. Integra is excited by this new technology that allows us to penetrate new markets involving CW applications such as Electronics Warfare (EW) for the defence industry," said John Titizian, Integra's founder and president.

"We have years of RF expertise manufacturing high power semiconductors and with our low overhead cost structure we will continue to dominate in both price and performance. Integra further solidifies its leadership position in high power pulsed RF transistors in the S-band radar market with these two new products," added Jeff Burger, VP of Engineering and original founding member. "We continue to provide superior technology and excellent support to customers in our target market."

Skyworks keeps it quiet with latest amplifiers

NEXT-GENERATION Ultra Low-Noise Amplifiers (LNAs) will meet demanding noise and linearity requirements for multiple wireless infrastructure applications.

Skyworks has introduced two low noise amplifiers (LNAs) for multiple cellular infrastructure receiver applications including GSM, CDMA, WCDMA and LTE base stations and repeaters. The new monolithic microwave integrated circuit (MMIC) amplifiers allow infrastructure providers to meet a wide range of performance requirements with a single device that minimizes system noise figures with improved receiver sensitivity and stability. "Skyworks is pleased to be expanding our infrastructure product portfolio particularly as estimates for mobile data traffic are expected to double every year through 2014," said David Stasey, VP of 'Analog Components' at Skyworks. "These solutions are just one of several devices that help reduce the size and complexity of networking equipment while enabling greater reliability, capacity and efficiency", he added.

The SKY67100-396LF (1.7 - 2.0 GHz) and the SKY67101-396LF (0.7 - 1.0 GHz) are gallium arsenide (GaAs) enhancement mode pseudomorphic high electron mobility transistor (pHEMT) LNAs designed for low noise figure down to 0.49 dB while providing unconditional stability and high-linearity performance up to OIP3 of 34 dBm.

The addition of an internal active bias circuitry provides stable performance over temperature. These new LNAs are available in a small, low-cost, industry-standard 2 x 2 x 0.75 millimeter (mm), 8 pin, dual flat no-lead (DFN) package and are layout compatible with each using a reduced - component matching network.

RFMD adds low cost high power IPCs to portfolio

HIGH POWER INTEGRATED PASSIVE COMPONENT (IPC) TECHNOLOGY will enable foundry service customers to design integrated matching networks and other passive functions on low-cost GaAs process technology

RF Micro Devices announced it will begin providing IPC technology to customers of its Foundry Services business unit in June 2010.

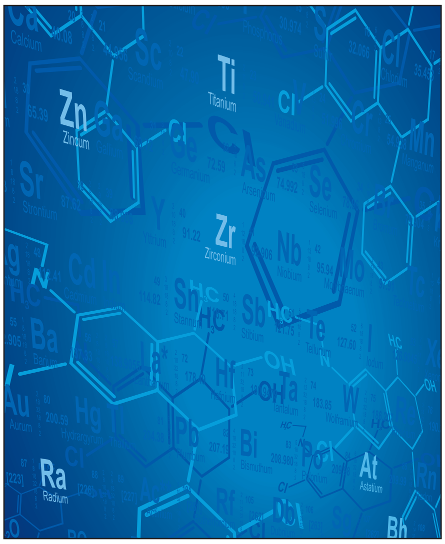
Complementary to its GaN technology and other power semiconductor technologies, the IPC is suited to the design of multi-chip modules (MCMs) and will reduce costs and achieve higher levels of integration by leveraging scale and cost structure in GaAs and GaN manufacturing.

RFMD's IPC technology provides all of the passive circuit components necessary to enable matching networks, including MIM capacitors, multi-layer stacked capacitors, thin-film resistors and inductors. Additionally, three metal interconnect layers are available for complex routing and increased current-handling capability.

Bob Van Buskirk, president of RFMD's Multi-Market Products Group (MPG), commented, "RFMD's leading compound semiconductor scale, built to serve the cellular handset market, allows us to deliver industry-leading cycle time, yields and costs.

We enable our foundry customers to take advantage of a compound semiconductor factory capable of shipping over two million RF components per day to bring speed, predictability and price advantages difficult to match."

RFMD's GaN Foundry Services business unit currently offers foundry customers access to two GaN process technologies: GaN1, targeted at high power, and GaN2, targeted at high linearity applications.



RFMD's Foundry Services business unit was formed to supply RFMD's high-reliability, high-performance and price-competitive GaN processes and associated technologies to external foundry customers immediately upon process qualification and production release.

It offers a secure website to customers for use as a collaboration tool for their work with RFMD's GaN foundry. All necessary tools and documents are current and readily available.

TriQuint GaN modules to aid U.S army missions

TRIQUINT SEMICONDUCTOR announced that it has been awarded a contract by the US Air Force Research Laboratories (AFRL) to develop new GaN modules for unmanned aerial vehicles (UAVs).

The new modules will include 20 Watt and 50 Watt devices. A challenging aspect of the program includes fitting new 20 Watt amplifiers into the same space now occupied by the fleet's existing 1 Watt devices that limit the range and broadcast power of the aircraft.

"We're very pleased to be working with the Air Force again," said TriQuint Program Manager, Doug Cole. "The contract is particularly interesting since we need to increase the power of one device 20-fold without increasing the size. We're using our proven 0.25-micron GaN process since it offers excellent power density and ruggedness–key requirements for avionic applications."

By increasing the output power of RF amplifiers in the UAVs, TriQuint will measurably increase the vehicles' operational range and mission effectiveness, allowing new UAVs to serve in areas and under conditions that were impossible for their predecessors.

TriQuint's more efficient GaN devices should also reduce the need for thermal mitigation and extend battery life in each vehicle. The AFRL have estimated that these amplifiers can extend UAV patrol time from one to three hours depending on the aircraft involved, payload and other operational conditions.

TriQuint is developing both devices using in-house resources including complete module fabrication. The firm designs and builds both integrated and multi-chip modules (MCMs) based on GaN and GaAs at its Richardson, TX facility. Mr. Cole indicated TriQuint was chosen by the AFRL for the UAV amplifier contract based on the company's detailed plan to meet the Laboratories' accelerated development schedule. Other factors included results from TriQuint's Defense Advanced Research Projects Agency (DARPA) Wide Bandgap Semiconductor (WBGS) RF GaN program, in which TriQuint led Phase II and is leading Phase III.

TriQuint also leads a DARPA contract for highly-advanced MMIC development using GaN technology in the Nitride Electronic NeXt-Generation Technology (NEXT) program.

The Air Force UAV program is divided into two primary phases. The initial phase includes developing appropriate high-power GaN amplifier MMICs. The MMIC amplifiers and other components will then be integrated into single packages to provide 20 Watt and 50 Watt Ku-band power amplifiers.

TriQuint is on track to deliver the first amplifier MMIC by August 2010.

The first 50 Watt prototype packaged assembly high power amplifier (HPA) is expected to be delivered in April 2011.

Spire ventures higher with efficient solar cell

THE 1.0cm^2 GaAs based triple junction concentrator solar cell is commercially available and is a result of a collaboration with the U.S. Department of Energy's National Renewable Energy Laboratory (NREL)

US firm Spire announced its subsidiary, Spire Semiconductor, LLC, has matched the current efficiency record for a concentrator solar cell. The record efficiency is available on a production ready cell with a photo area of 1.0 cm^2. The NREL measured the efficiency of 41.0% at 500x suns concentrated sunlight.

"This is truly an achievement," said Roger G. Little, Chairman and CEO of Spire Corporation. "We have experienced continuous improvement in our proprietary cell processing design technology throughout the NREL contract. We are excited to have matched the current world record efficiency, and we have nearly four months remaining under the subcontract to surpass this level and achieve the target 42.5% efficiency. A more efficient concentrator solar cell will provide a lower cost and more reliable source of solar generated electricity," concluded Mr. Little. Spire began working with NREL under an 18-month, $3.7 million cost share subcontract in early-2009. The goal is to develop a triple junction GaAs 42.5% conversion efficient "Triathlon" concentrator cell for concentrator photovoltaic systems.

Nitronex and Agilent join forces

THE MMIC Process Design Kit (PDK) provides all components needed to develop power amplifiers and operates up to 6 GHz. North Carolina based Nitronex has revealed that it will be providing the NRF1 MMIC PDK to Agilent for its Advanced Design System (ADS). Employing 0.5 micron GaN HEMT technology with the PDK should provide the necessary active and passive elements to enable the development of monolithic power amplifiers operating up to 6 GHz.

For active elements, the PDK offers fixed and geometrically-scalable GaN HEMTs and scalable multi-finger Schottky diodes. For passive elements, epi and TFR resistors, circular and square inductors, as well as circular and rectangular MIM capacitors are available. The PDK also offers a full transmission line library including backside vias.

"We are pleased to announce the release of our NRF1 MMIC PDK. We developed the PDK in collaboration with our strategic foundry partners who require high-performance broadband solutions through 6 GHz," said Ray Crampton, VP of Engineering for Nitronex.

"The functionality and accuracy offered by the multiple types of scalable active and passive elements included in the process design kit are enabling our strategic foundry partners, as well as Nitronex engineers, to realize the full potential of MMIC products with our NRF1 technology", he added.

Aixtron to supply LDX with two CRIUS tools

The 31 x 2" MOCVD systems will enable LDX (LongDeXin) to satisfy the GaN-HB-LED market for use in backlights. Aixtron said it has received an order from a new customer in China, LDX a joint venture by Zhejiang Longfei Industry and China Delixi Holding Group, founded in October 2009 for the purpose of strategic cooperation.

The order was placed in the first quarter of 2010, and LDX will use the systems for GaN HB-LED production. The two 31 x 2" MOCVD reactors will be delivered installed and commissioned by Aixtron in LDX's new factory in Shanghai in the second quarter of 2010. Manager of the LED project, Mr. Lin Loufei said, "Our company has decided to make a strategic investment to enter the display backlighting business. This project requires rapid in-house LED development and the manufacturing of materials for epiwafer-based high brightness LEDs.

We turned to Aixtron because of the

company's experience and the technical know-how its support team can bring to our project. The success of this venture will greatly depend on these MOCVD systems. We look forward to working with AIXTRON to quickly and efficiently bring the new reactors into full production."

Zhejiang Longfei Industry based in China, specializes in the development and production of healthcare oxygen supply equipment, meters for industry and fire alarm and linkage control systems. Its products supply China as well as North America, Japan, Turkey, Nigeria, Hong Kong and Taiwan.

Delixi Group established in 1984 and headquartered in Wenzhou, China, is one of the largest private-owned enterprises. The core businesses are production of high, medium, and low-voltage electric apparatus, transmission and transformation of power distribution, and industrial automatic control electrics.

The business scope has been further expanded to trading and logistics services, mineral energy resources, environmental protection, renewable resources and Private Equity Investment.

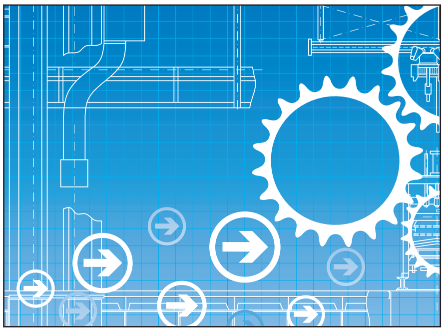
Applied Materials Announces Advanced Automation Tool

SMARTFACTORY software monitors all machines employed in the manufacturing of Solar, LED and Chip Packaging processes.

Applied Materials has launched its Applied SmartFactory MES software. Claimed to be an affordable, out-of-the-box, factory automation system, it can track and streamline the flow of materials throughout a manufacturing facility.

Designed to help accelerate the production ramp of emerging technologies, the software can be deployed in less than 60 days. It's aim is to improve quality, boost productivity and cut operational costs.

Based on its FAB300 MES technology, the SmartFactory system features pre-built, technology-specific scenarios. These monitor every machine and all work-in-progress material movements, manage production sequencing, create an audit trail,



and deliver instructions to shop floor workers via a consistent, task-focused graphical user interface.

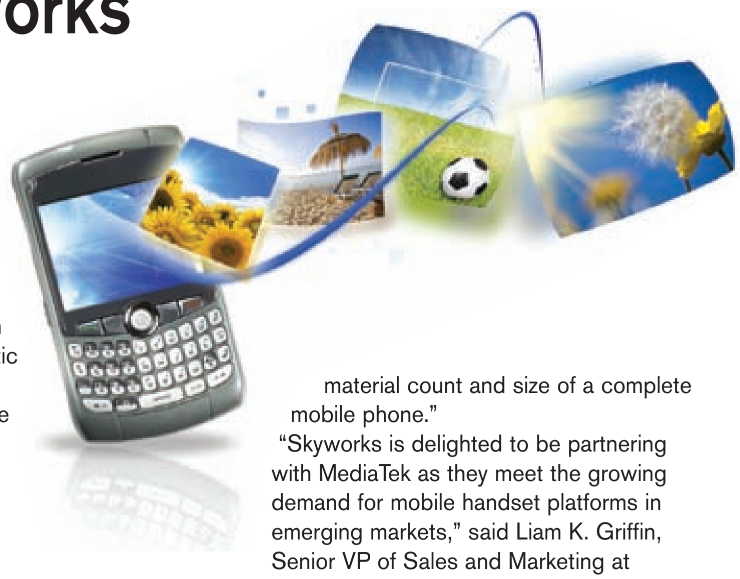
An optional APC module using Applied E3 technology interfaces directly with production equipment, enabling real-time, run-to-run (R2R) process tuning and fault detection and classification (FDC). SmartFactory is also the first MES available with integrated advanced process control (APC) capability, enabling customers to achieve higher and more consistent factory output. "The SmartFactory system is designed to help factory operations in rapidly-growing industries achieve the high yields and economies of scale that can lower manufacturing cost - key to the widespread adoption of these important new technologies," said Charlie Pappis, VP and General Manager of Applied Global Services.

Back to base with latest RFMD amps

HIGH-LINEARITY Digitally-Controlled Variable Gain Amplifiers (DVGAs) suited to wireless infrastructure applications such as cellular base stations. RF Micro Devices is marketing a new family of high linearity, 6-bit digitally controlled variable gain amplifiers (DVGAs). The latest RFDA family of DVGAs targets the cellular base station, point-to-point and CATV end markets. The RFDA DVGA product family comes in laminate multi-chip modules (MCMs) and can integrate high linearity amplifiers with a digital step attenuator (DSA) and an optional serial to parallel converter.

Delivering multiple functions and requiring few external components, developers of infrastructure transceivers can design smaller and cheaper radios with higher assembly yields. The DVGA integration path also supports future market trends toward smaller base station sizes, microcells, and remote radio heads for new infrastructure deployments. A selection of components are available with gains of up to 38dB, OIP3 up to 43dBm and a maximum operating frequency up to 4GHz. The wideband and narrowband versions cover all 2G, 3G and 4G (LTE and WiMAX) standards for base station frequency bands. The components are suitable for both receiver and transmitter designs and are offered in both parallel and serial interface versions.

MediaTek awards Skyworks for Compact Handsets



SKYWORKS has announced design wins from MediaTek in support of dual and quad band platforms targeting low-cost handsets.

MediaTek, a fabless semiconductor company for wireless communications and digital multimedia products provides chipsets to the Chinese mobile phone industry.

The products have their own baseband processor, radio, multimedia and connectivity products and the necessary software. MediaTek then leverages front-end solutions to offer a turnkey approach to manufacturers who supply handsets to consumers around the world.

Skyworks' front-end solutions for MediaTek's MT6253 platform and other customers are claimed to have the best power-added efficiency performance over a broad power range, increasing talk and extended standby times for handsets and data card modules.

Skyworks' compact and integrated total transmit products consist of a power amplifier (PA), switch module, and automatic power controller and are claimed to reduce bill-of-material costs and overall board space.

"MT6253 is our first 2.5G system-on-chip, integrating all essential electronic components, including DBB, ABB, power management unit and RF transceiver," said JiChang Hsu, Executive VP at MediaTek. "It is rapidly ramping and is expected to be one of the main, high-volume runners in the coming years.

Together with Skyworks' front-end modules, the MT6253 platform further reduces the material count and size of a complete mobile phone."

"Skyworks is delighted to be partnering with MediaTek as they meet the growing demand for mobile handset platforms in emerging markets," said Liam K. Griffin, Senior VP of Sales and Marketing at Skyworks. "Our proven, low-cost and compact solutions are ideally suited for this high growth, feature-rich handset segment where size, value and performance are key drivers."

All four front-end modules (FEMs) are compact and are suited to transmission applications. They all support Class 12 general packet radio service (GPRS) multi-slot operation.

Tecnalia to use SiC and GaN in energy usage project

The 5 year project will enable a more rational use of electrical energy in all industrial sectors, say MBN Comunicación.

Tecnalia Technological Corporation is taking part in "Consolider Rue", one of the most important research projects on power electronics within the Spanish state.

The Semiconductor Devices project involves a wide band of energy gaps for efficient energy use, with particular emphasis on renewable energies, the electric vehicle and very high frequency communications.

It is part of the "Consolider" program, a strategic policy of the Spanish Government aimed at achieving excellence in research, increasing cooperation amongst researchers and creating large groups of research.

Tecnalia is the only technological centre in the consortium and is able to provide a very clear vision of the interest of private enterprise in working with power electronics-related themes. The fundamental contribution of its Energy Unit involves applications, responding to the keen linterest in new topologies of converters for the evacuation of high-voltage, direct current energy (HVDC), for offshore wind energy.

The budget for the project is €4.56 million and is being funded by the Ministry of Science and Innovation and by the Consejo Superior de Investigaciones Científicas (CSIC). The project is coordinated by the CNM and the rest of the participants are teams from six Spanish universities ; Oviedo, Zaragoza, Madrid Polytechnic, the Polytechnic of Catalonia and the Rovira i Virgili University, apart from the Energy Unit at Tecnalia.

The principal aim is to develop the first industrial generation of wide band gap semiconductor devices that enable both important improvements in current power converters and the development of new topologies based on silicon carbide (SiC) and gallium nitride (GaN) technologies.

Craic Multi-tool has 20/20 Vision

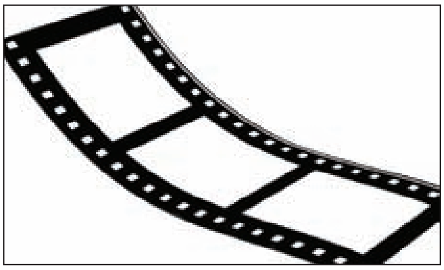
NON-DESTRUCTIVE thin film thickness measurement system will analyze many materials on both transparent and opaque substrates and find defects that others can't.

CRAIC's new Technologies has added a 20/20 Film microspectrophotometer to its portfolio and is claimed to rapidly measure the thickness of thin films including sub-micron sampling areas.

With the ability to analyze films of many materials on both transparent and opaque substrates, the 20/20 Film enables the user to determine thin film thickness using transmission or reflectance on semiconductor materials.

"Many of our customers want to measure the thickness of thin films of smaller and smaller sampling areas for rapid quality control of their products.

The 20/20 Film microspectrophotometer was built in response to customer requests for a powerful, flexible film thickness tool that can measure sub-micron areas on both transparent and opaque substrates." Said Paul Martin, President of CRAIC Technologies.



"This tool can also do a lot more than just measure thin film thickness. It can also be configured for contamination analysis, concentration and relative intensity mapping and much more," he added.

The product enables thickness measurements of films and substrates and sampling areas can range from over 100 microns to less than 1 micron. Designed for the production environment, it is claimed to incorporate a number of easily modified processing recipes, the ability to create new film recipes and sophisticated tools for analyzing data as well as options for automation including touchscreen control.

The ability to directly image and analyze films with ultraviolet, visible and NIR microscopy can also be added to this instrument.

Toshiba GaAs FETS stretch the Ku-Band

THE 18W and 30W products will be used in power amplifiers for microwave radios with the 30W GaAs FET providing 2x higher output power than its predecessor.
Toshiba has expanded its Ku-Band gallium arsenide field effect transistor (GaAs FETs) lineup with two higher output power devices rated for 18 and 30 watts (W).
The TIM1213-18L and TIM1213-30L operate in the 12.7 to 13.2 GHz range, and are suited for use in microwave radios for microwave links and satellite communications.
Other current Toshiba GaAs FETs in this frequency range feature 2W, 4W, 8W, 10W and 15W power output ratings.

"Continuing our long tradition of developing higher power amplifiers as technology advances, Toshiba is expanding our Ku-Band product family with these new devices to enable our customers to design more powerful and linear microwave radios with fewer components," said Homayoun Ghani, Business Development Manager of 'Microwave, Logic, and Small Signal Devices' in TAEC's Discrete Business Unit. Samples of the TIM1213-18L and TIM1213-30L are available now.

Cobham Joins the Military Revolution with NAVAIR

COBHAM has been awarded a contract for US$46 million from Naval Air Systems Command (NAVAIR). They will manufacture the AN/ALQ-99 Low Band Transmitter-Antenna Group for US Navy and Marine Corps EA-6B and E/A-18G electronic warfare aircrafts.

The contract continues funding for a third full rate production lot. The contract's initial award procures 60 Low Band Transmitters and an associated number of antenna assemblies in a variety of configurations. This award brings the total number of production transmitters ordered to 217 of 292 required transmitters. To date 80 transmitters have been delivered.

The AN/ALQ-99 Low Band Transmitter-Antenna Group (LBT-AG), developed by Cobham Sensor Systems, has been in production since 2005. The LBT is designed to protect strike aircraft, ships, and ground troops by disrupting enemy radar and communications.

It is flown on US Navy EA-6B Prowler and EA-18G aircraft and Marine Corps EA-6B aircraft, and is heavily used in current operations in Iraq and Afghanistan.

"This award continues a long tradition of Cobham support to the Navy's mission success," said Andy Humen, VP of Cobham Sensor Systems. "Our support to the Navy extends beyond Airborne Electronic Warfare. This Low Band Transmitter award complements our other ALQ-99 work, our success on the Next Generation Jammer, the Next Generation Airborne Electronic Attack study, and the fleet's Integrated Topside (InTop) and Surface Electronic Warfare Improvement Program (SEWIP)."

The $46 million fixed price contract was competitively procured. Deliveries will continue immediately beyond the currently contracted Full Rate Production Lot 1 and 2 efforts, and are expected to continue through 2012.

The contract also allows for up to four annual options to procure the balance of LBT-AG systems and associated spares.

UoC to make SiGe nanowires with Aixtron Black Magic tool

Aixtron has reported an order for one 4-inch Black Magic deposition system from the University of California, Berkeley, USA. Capable of both SiGe nanowire and CNT (carbon nanotube) deposition, the system will be installed in the Laboratory for Nano Materials & Electronics in the first half of 2010.

Ali Javey, UC Berkeley Assistant Professor of Electrical Engineering and Computer Science said, "The Black Magic system was selected for its unique ability to grow both SiGe nanowires and CNTs uniformly, rapidly and repeatably.

In addition, we know we can trust Aixtron as one of the world's largest manufacturers of semiconductor deposition systems to deliver reliability, safety and user-friendly operation in the equipment. This system will be very useful for our research in achieving large-scale synthesis of nanowire arrays for integrated electronics and sensors."

Research underway at the UC Berkeley Laboratory for Nano Materials & Electronics covers a range of science and engineering disciplines but focuses on the integration of synthetic nanomaterials, such as CNT and semiconductor nanowires, in novel electronic applications, such as printed electronics, sensors and flexible photovoltaics.

In 2009, Javey won the "Mohr Davidow Ventures (MDV) Innovators Award" and was also a recipient of a "2009 Young Innovators Under 35" (TR35) award by the Technology Review magazine.

Riber reports Multi-Wafer MBE6000 sale

Riber has completed the sale of one of its products to an unnamed vendor.

Molecular beam epitaxy machine producer Riber has announced the sale of one of its Multi-Wafer MBE6000 machines.
The company has sold the device to an unnamed buyer, but said that the new system will enable the company to increase their production capacity by more than 1,500 x six-inch pHEMT structures per month.

"This new sale confirms the sound quality of Riber's order backlog at this date, which totalled €11.7 million (£9.9 million), a 92 per cent increase compared to the same period of 2009," the company stated.

Riber recently reported that its first-quarter sales rose by 11 per cent to €2.9 million - compared to €2.6 million in the first quarter of 2009.

This rise was attributed in particular to a 71 per cent increase in services and accessories sales, which counterbalanced an eight and 57 per cent fall in cells/sources and systems sales respectively.

Oclaro has announced a $7.5 million investment in ClariPhy

Optical products developer Oclaro has announced an investment of $7.5 million (£5.17 million) in privately-held fabless semiconductor company ClariPhy.

The company stated that a surge in demand for broadband services over recent years has meant increased bandwidth and improved performance is now required to meet the needs of consumers and this investment is a step in the process of making this happen.
The rise in demand for services such as social networking, video sharing, voice over internet protocol [VoIP] and cloud computing have all played a part in the growth of the broadband sector and Oclaro has built itself into a market leading position in the 40 Gb per second (Gbps) sector.

However, the firm is now looking to break into the 100 Gbps long-haul and ultra-long-haul markets, with its partnership with ClariPhy forming the bedrock of this new venture.

Alain Coulder, president and chief executive officer of Oclaro, said: "Through our investment and alliance with ClariPhy, Oclaro believes it will be able to offer its customers best-in-class electronics and optical technology as a complete solution from a single source."

He stated that the company expects to see a rise in the number of transceiver solutions for optical networks comprising of digital signal processing and mixed-signal electronics as the market matures.

"By leveraging the significant 40 nm CMOS technology innovation from ClariPhy, Oclaro will focus on optimising our future optical products to further increase bandwidth, improve network performance and lower the total cost of ownership for customers," Mr Coulder added. The company is headquartered in San Jose, California and specialises in optical communications and laser components, modules and subsystems. It was formed in 2009 through the merger of Bookham and Avanex.

Meanwhile, ClariPhy is a developer of mixed-signal, advanced digital signal processing integrated circuits. It is also based in California and the firm's other investors include Norwest Venture Partners, Onset Ventures, Allegis Capital and Pacific General Ventures.

Northrop InP HEMT Raises the Frequency Bar

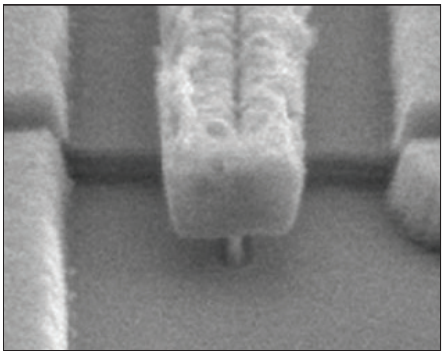
Northrop Grumman Corporation reports its Terahertz Monolithic Integrated Circuit (TMIC) operating at 0.67 terahertz (THz) more than doubles the frequency of the fastest reported integrated circuit.

The latest innovation was developed under a contract with the Defense Advanced Research Projects Agency's (DARPA) Terahertz Electronics program. The Indium Phosphide High Electron Mobility Transistor (InP HEMT) is claimed to more than double the frequency of the fastest reported integrated circuit.

A transistor amplifier magnifies input signals to yield a significantly larger output signal. In 2007, Northrop Grumman set a world record for transistor speed to provide much higher frequency and bandwidth capabilities for military communications, radar and intelligence applications.

This InP HEMT had a maximum frequency of operation of more than 1,000 gigahertz, or greater than one terahertz.

The latest development was described at the Institute of Electrical and Electronics Engineers' (IEEE) International Microwave Symposium by William Deal, THz



Electronics Program Manager for Northrop Grumman's 'Aerospace Systems' sector. He told fellow scientists the TMIC amplifier is the first of its kind operating at 670 GHz (top).

He continued, "A variety of applications exist at these frequencies. These devices could double the bandwidth, or information carrying capacity, for future military communications networks. TMIC amplifiers will enable more sensitive radar and produce sensors with highly improved resolution."

SEM micrograph showing ~ 30nm Indium Phosphide T-gate (left).

The goal of DARPA's Terahertz Electronics program is to develop the critical device and integration technologies necessary to realize compact, high-performance, electronic circuits that operate at center frequencies exceeding 1.0 THz.

The program focuses on two areas – terahertz high-power amplifier modules, and terahertz transistor electronics.

"The success of the THz Electronics program will lead to revolutionary applications such as THz imaging systems, sub-mm-wave ultra-wideband ultra-high-capacity communication links, and sub-mm-wave single-chip widely-tunable synthesizers for explosive detection spectroscopy," according to John Albrecht, THz Electronics Program Manager for DARPA.

Skyworks Retires $20.4 million of Principal Convertible Debt

As the balance sheet improves, the firm announced that 2.1 million shares will not need to be diluted.

Skyworks, a provider of analog and mixed signal semiconductors enabling a broad range of end markets, has announced that the Company retired an additional $20.4 million of convertible notes with an original maturity date of March 2012.

With the early retirement of this debt, Skyworks eliminated potential future dilution of 2.1 million shares and, at a higher level, continues to enhance its overall capital structure.

At the end of the Company's most recently reported quarter, Skyworks maintained $412 million in cash and cash equivalents with a principal value of $47 million in long-term convertible debt.

At the end of the second fiscal quarter of 2008, the company held $228 million in cash and cash equivalents and $200 million in long-term debt.

"Skyworks has generated $323 million in cash flow from operations over the past six quarters, enabling us to efficiently deleverage our balance sheet," said Donald W. Palette, CFO of Skyworks.

"This financial strategy has supported increasing business throughout the economic downturn as customers, suppliers and partners appreciate the strength of our balance sheet in today's market environment.

As a result, we intend to outperform our addressed markets and further improve our capital structure going forward."

III-Vs start propelling cable services to a new level

GaAs and GaN technologies can spur high-quality delivery of advanced video, data and telephony services to the home, says **TriQuint's Chris Day.**

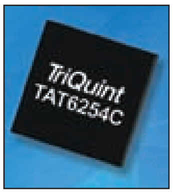
Like all consumer-driven services, the cable industry always needs to find new ways to generate cash. Higher sales can come from existing services, but long-term success hinges on investment in the new technologies that are starting to appear, such as high-definition channels, new services, "3-D TV", and video on demand.

Each of these adds a layer of complexity, and demands better performance from distribution resources alongside greater bandwidth and superior use of the bandwidth that exists today.

At TriQuint we believe that compound semiconductor technologies, principally those utilizing GaAs and GaN, will be essential ingredients in products that can meet these challenges. These III-Vs combine higher efficiency with greater linearity and a broader bandwidth, attributes that cable system designers crave, and deployment of these superior technologies will have a positive impact throughout cable systems, from headends to customer premises.

One way to understand where technology stands today is to see where we've come from. There's no doubt that the

Semiconductor technologies like GaAs and GaN are enabling CATV system operators to offer competitive 'triple play' services like high-definition TV (HDTV), Video on Demand (VOD) as well as voice and broadband data communications



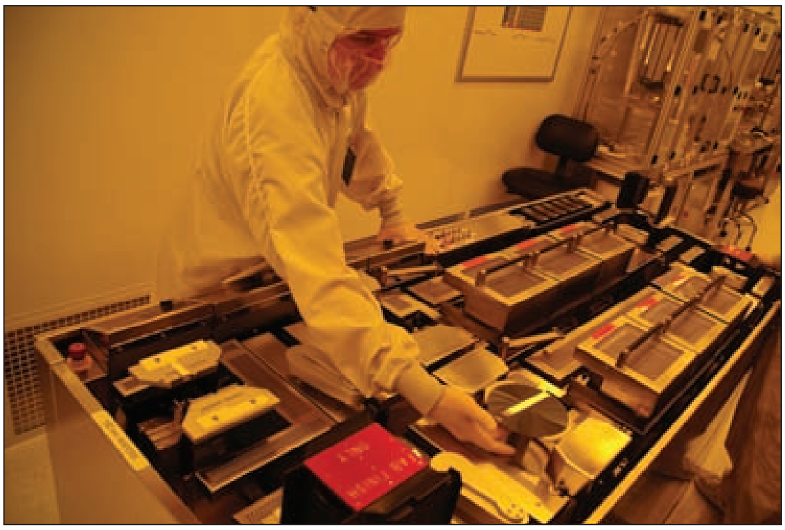
TAT6254C: FTTH / RFoG low noise amplifier for CATV receivers / triplexers. AGC to maintain +19 dBmV/ch output (+23 dBmV / high output mode). Ensures video quality / ease of design

early days of television were wondrous for some, but for many the experience was marred by poor reception. Areas that were not in a line-of-sight path to the transmitting antenna had to make do with weak, snowy pictures. Viewers resorted to erecting tall towers and adding preamplifiers, which usually helped, but often not all that much.

To address this weakness television pioneers, whose names have been lost to all but fervent followers of broadcast technology, created the first community antenna television (CATV) systems. The acronym CATV was apt as these systems allowed a community to achieve reliable reception of local stations on at least a few channels. Often these included major network channels and perhaps a public broadcast station.

CATV was enabled by finding the highest point in or around the community, erecting high-gain directional antennas, and pointing them at broadcast towers many miles away. Channels were aggregated at this "head-end", and distributed via coaxial cable to the community's residents. Although results varied, they were invariably better than those achieved by individual viewers. To maintain an adequate signal throughout the system, distribution amplifiers were periodically spaced along the path of the cable "plant". They initially employed vacuum tubes that degraded the signal with high levels of second-order distortion, but this was remedied with the bipolar transistors introduced in the 1960s.

The tremendous benefits provided by CATV systems resulted in explosive growth, and the "community" antenna television concept expanded to cover entire metropolitan areas, states, regions, and ultimately into today's Multiple System Operators (MSOs) that provide standard- and high-definition television services throughout North America. Similar models were followed across the globe, although there was a notable difference. Residents of Europe and many other countries were initially restricted to broadcasts by state-operated monopolies that inaugurated television service, and these viewers had to wait to embrace the competitive service offerings that they enjoy today.



Gallium Arsenide (GaAs) wafer processing in TriQuint's Hillsboro, Oregon 150mm facility

Growth of the cable TV service was achieved through exponential advances in every key technology, from RF devices through to the introduction of delivery via fiber optic cables, which now form the latest generation of hybrid fiber coax (HFC) networks. Significant additional contributions include signal-processing technology and improved devices, better software, advanced modulation schemes, and linearization techniques. Today, cable systems are flexible enough to provide over 80 channels of legacy analog television programming alongside digital and high-definition services, video-on-demand services, high-speed data service, and packetized telephony…and more is on the way.

Mixing old and new

From a technical perspective, cable systems are incredibly diverse. The plant of a typical system contains decades-old semiconductor technology sitting alongside its leading-edge brethren. However, it is possible to combine analog, digital, RF, microwave, and lightwave technologies, and make them all work together more or less seamlessly to provide today's high quality of service.

This approach is employed in cable hybrid amplifiers, the long-established staple of every cable distribution system. This device can be seen on utility poles everywhere, boosting signal levels throughout the system while maintaining high levels of linearity. While older silicon bipolar transistor amplifiers are still in service, the cable networks they support simultaneously employ fiber optic technology, advanced digital modulation schemes, and assorted other technologies that are at or near the state of the art. Not surprisingly, streamlining this technological alphabet soup is essential if the cable industry is to address three key objectives: meeting expectations set out by shareholders and investors; fending off competing network technologies; and wooing legions of consumers hankering after novelties such as 3-D TV.

In a larger context, the MSOs primary challenge is to deliver the greatest variety of entertainment choices with the highest performance, at the lowest cost, to the

The holy grail for lightwave is Fiber-to-the-Home (FTTH). This high-cost approach eliminates coaxial cable and all content is delivered directly to the customer through fiber optic cables. In the US, this fiber-based approach has been championed principally by Verizon, through its FiOS network that competes directly with traditional cable systems in terms of content. It has been very well received, and its limited success has spurred an increase in the speed of entrenched cable MSOs

greatest number of subscribers. The most effective way to do this is to reduce or eliminate components in the system. A classic example of implementing this advice was the introduction of the so-called "power doubler" in the mid 1980s. The power doubler reduced the need for many trunk and 'bridger' amplifiers and line extender amplifiers.

The most pervasive mixed technology in the network is employed in fiber optic distribution, which was introduced in the 1980s against a backdrop of a coax-only domain. The appeal of this lightwave technology is its far lower distribution losses compared to coaxial cables, coupled with near immunity to interference. And as this technology has evolved, the number of amplifiers required to cover a given area has diminished.

The upshot has been the removal of costly components from the distribution system, leading to improved signal quality and access to the immense bandwidth required by "triple-play" networks that offer voice, video, and data. In short, the end user is getting closer and closer to realizing the benefits provided by fiber optic technology.

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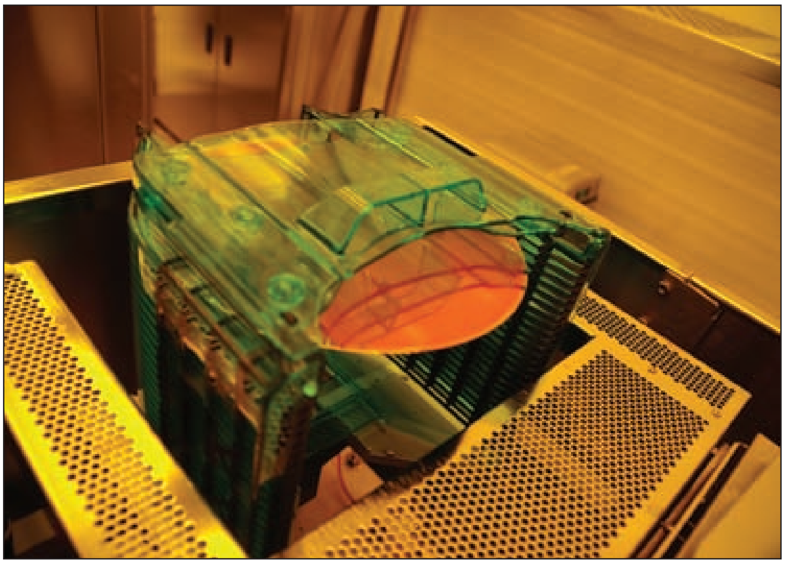
In the US, this fiber-based approach has been championed principally by Verizon, through its FiOS network that competes directly with traditional cable systems in terms of content. It has been very well received, and its success has spurred an increase in the speed of new service standards and deployments by entrenched cable MSOs. They responded with a third generation of the Data Over Cable Service Interface specification (DOCSIS), which has been developed by Cable Labs. This not only provides support for IPv6 and IPTV – it also allows customers to tap into data at up to 160 Mb/s in the downstream and 120 Mb/s in the upstream, making it competitive with VDSL and FTTH.

Although FTTH may be the ultimate data delivery technology, the edge that it has over the latest variant of DOCSIS is not a big concern for today's cable operators.

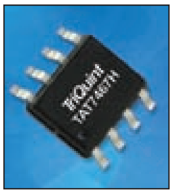
Verizon's aggressive deployment of FiOS has created the only real competitor to cable for state-of-the-art performance. An intensive marketing war has ensued between the two entities, with each side scrambling to expose chinks in the armor of the other. While they battle it out, the differences between the two are increasingly narrowing as the cable industry enhances its product offerings.

Linearization

RF linearization techniques at the circuit level have held the key to enabling optical transmitters to attain their optimum performance and arguably cement their usefulness in cable distribution. Regardless of the technique employed to amplitude-modulate light, significant distortion arises that hampers the transmission



150mm Gallium Arsenide wafer with photo resist applied in the TriQuint Hillsboro, Oregon high-volume facility



TAT7467H: Edge QAM / DOCSIS 3.0 amplifier for CATV headend applications. A true differential amplifier for medium power applications with excellent 3rd order distortion performance. 350-380mA power usage that is up to 50% better than other solutions

of information through the network. If this distortion were not reduced, it would impair the effectiveness of lightwave systems for cable applications. Even early systems required extremely high linearity, and this demand became even more stringent over the years as bandwidth and channel counts increased.

Linearization of RF and optical systems over wide CATV bandwidths is far from trivial. When performed using external discrete circuits, this goal is complicated by parasitic effects that are difficult to compensate out of the linearizer. However, if these circuits can be integrated directly on-chip, adjacent to the amplifying device, then the parasitic problem is largely eliminated. Thanks in part to the use of techniques developed by TriAccess Technologies, a company that we acquired last year, we can now linearize amplifiers for DOCSIS 3.0 and cable infrastructure using on-chip techniques.

Substantial cost savings have already resulted from linearization, because it has enabled the construction of fiber optic modulators with the necessary distortion characteristics for transmitting analog content. Looking forward, linearization is poised once again to enable cost savings, this time to benefit RF amplification needs. Integrated linearization techniques are available to enable mature GaAs technologies to compete with more expensive semiconductor options without paying the penalty of a substantial sacrifice in performance. Linearization can also enhance the already excellent performance of newer device technologies, providing an even higher level of power efficiency to the operator.

GaAs, GaN, and cable

It is safe to say that compound semiconductor technology along with advanced linearization techniques will be two key enablers for allowing all types of future cable systems to fulfill the cost, service quality and competitive challenges lying around the corner. The RF, microwave and lightwave portions of the system are already relying extensively on compound semiconductor technologies, and will increasingly do so in the coming years.

Quality check on a wafer being fabricated at TriQuint's Hillsboro, Oregon facility

On the RF side, the hybrid amplifier that has employed silicon bipolar transistors for decades to deliver the high RF output power and linearity required for Class A operation is on its way out. The performance of silicon-based hybrids has reached its limit by failing to keep up with increases in bandwidth made available to cable MSOs, which have grown from 300 MHz to 550, 870, and now 1000 MHz. In its place will be GaAs devices delivering greater performance in every key metric, combining greater bandwidth with much lower multi-carrier distortion, superior RF output power, lower noise and greater efficiency. Spurring the switch to the superior technology is a shrinking price gap between GaAs-based hybrids and their silicon rivals. The insurgent often benefits from a single RFIC that leads to improved push-pull amplifier matching and fewer distortion-induced problems such as composite carrier noise ratio.

One of the big questions hanging over cable hybrid amplifiers is this: how long will they be needed, as fiber continues its march deeper into the network? Industry prophets have long predicted the demise of this class of amplifier. However, to paraphrase Mark Twain, rumors of their death have been greatly exaggerated. The global market for cable hybrid amplifiers, while very cyclical, shows only small signs of diminishing. What's more, it is rapidly being enhanced by widespread deployment of GaAs devices. While some regions of the world are significantly built-out with cable service networks, others are just beginning. In developing nations with growing economies citizens are just starting to enjoy the luxury of discretional income, and there's no doubt that some of this will be used for entertainment, including cable TV.

In addition, suppliers of GaN-based RF power amplifiers have recently introduced their first products. Although in many respects GaN is still an emerging technology, it is still a very attractive contender, offering tremendous performance in several key figures of merit. Cost is a major concern – it is three to eight times that of GaAs devices – and this restricts GaN to use in situations demanding the highest possible performance. The higher price of GaN devices is mitigated to some degree by greater power output and other attributes, which can extend the reach from the fiber node to the customer (where the transition is made from fiber to coax) while maintaining low levels of distortion and power consumption. But it remains to be seen whether the market embraces GaN, and is willing to shell out for the greater performance that it offers.

In the aggregate of systems throughout the world, cost factors rather than leading-edge specifications are of paramount importance. This is particularly true in high-population, emerging economies such as China, India, and Eastern Europe. In these regions the monthly subscription cost, and by extension the capital cost of building new networks, governs the decision over whether to build out new networks. Silicon bipolar hybrids still dominate those markets, but the GaAs performance value is starting to take hold. The high cost of GaN-based hybrids will likely restrict their success in these desirable high-growth markets.

Other important sub-markets within cable TV are those for headend high-efficiency amplifiers and customer premise distribution. While the RF output level of the headend application is 5 to 10 dB lower than that of line extenders in coaxial distribution networks, the high density of equipment in headends makes high efficiency a sought-after premium.

Our DOCSIS 3.0 amplifiers address this issue, cutting power consumption by up to 50 percent and slashing the circuit board "real estate" required to employ these devices by up to 80 percent. These GaAs-based amplifiers are designed for use in customer premises equipment to support multi-room deployment as well as advanced in-home distribution architectures such as Ethernet over coax, the Multimedia over Coax Alliance (MOCA) standard, and for FTTH receivers. When these are used in cable hybrid amplifiers and line extender amplifiers they provide lower distortion than ever before, plus very high efficiency and low power consumption.

Taken together, these attributes benefit cable MSOs in terms of reduced operating cost and system complexity. They allow amplifiers to be smaller and more frugal with power. The latter benefit must not be underestimated, given the large numbers of hybrid amplifiers used throughout a system, and the consequent opportunity for considerable annual savings associated with operating costs. The benefit of greater efficiency also makes a difference to amplifiers at the headend, where it translates into reduced cooling requirements.

In short, the hegemony of silicon bipolar devices in hybrid amplifiers is drawing to a close. That's because this venerable technology that has played an enormous role in the growth of cable since the 1960s is no longer viable in the higher-frequency, higher-performance cable systems that will drive the industry into the future. In its place will be GaAs devices that are already enjoying rapid deployment, which combine low-cost with high performance, making them well suited to both current and future cable systems.

GaN, which has inherent characteristics that are highly desirable in cable hybrid amplifiers, is currently too expensive for use in most systems. Nevertheless, its role will continue to expand in years to come. It is destined to make an impact, because the combination of process evolution and economies of scale will enable the price reductions necessary for historically frugal-minded cable system manufacturers and operators to begin to adopt this compelling technology.

What's on tomorrow?

There are many variables that will determine the exact path of entertainment distribution to the home, including the possible entry of wireless technologies. However, there are some facets of the industry that will not change. First, the deployment of FTTH has altered the face of TV, data, and voice delivery to the home, giving traditional cable MSOs a true competitor for the first time. Distribution via satellite remains a key player, but it struggles to provide voice and data services, and its future is uncertain in those areas where established cable providers are highly competitive in terms of price and service.

In a competitive environment, the cable industry has little choice but to do whatever is necessary to retain its premier position. FTTH, from Verizon in the US and a growing number of operators in world-wide markets, will continue to gain market share as it is deployed in new regions. Together these two fierce competitors will rely on GaAs and GaN to deliver the highest levels of performance at the lowest cost.

As a result, the market for GaAs- and GaN-based cable hybrid amplifiers will continue to grow. Finally, fiber will inch its way closer and closer to the customer location in HFC systems, driving the growth of optical receivers and other system elements that also rely on III-Vs.

For consumers all of this is great news, since competition drives innovation, and innovation tends to lead to better, more varied services. From any vantage point, the home entertainment industry will be theater at its technological finest – and compound semiconductor technologies are a shoe-in for the leading roles.

TGA2807-SM: Edge QAM / DOCSIS 3.0 RF amplifier for CATV headend applications. ACPR ~2 dB better than previous generations. Standard 5x5mm QFN offers high-efficiency performance

The hegemony of silicon bipolar devices in hybrid amplifiers is drawing to a close, because this venerable technology that played an enormous role in the growth of cable since the 1960s is no longer viable

Compound semiconductor stocks soar during the last 12 months

Strong sales of LED backlit screens and mobile devices have led to substantial gains in the share prices of many III-V chipmakers over the last year. **Richard Stevenson** reports.

The behavior of the stock market is out of kilter with that of the general economy. The politicians and heads-of-state keep telling us that there is recovery, but it is fragile, and it could be a bumpy ride. The behavior of the stock market, however, suggests that business of booming. This difference arises because the stock price is strongly influenced by expectations of future business. Investors clearly think that recovery is round the corner, and thanks to their optimism we have a bull market. The Dow Jones has climbed by 20 percent over the last financial year, and the FTSE has shot up by 25 percent.

Tech stocks have faired even better. The NASDAQ composite, for example, has gained nearly 45 percent over that time frame. But that is nothing compared to most of the III-V stocks – many of these have doubled in value, or done even better over that timeframe (see "The Compound Semiconductor Share Price Leaderboard", p. 23, for the numbers).

At the top of the pack sits Veeco, a manufacturer of process equipment and metrology tools. Over the last year its share price has soared from just $7 to nearly $50 (see Figure 1), not far short of its highest value ever, just north of $65. But that record occurred in the heady days of 2001 when all tech stocks prices were incredibly high.

Veeco's rocketing shares price is a reflection of its great success in the MOCVD tool market. Sales of these growth machines have rocketed as LED chipmakers have increased their capacity to meet the growing demand for LEDs for backlighting displays in netbooks, laptops and TVs. And according to Jed Dorsheimer, an equity analyst at Canaccord Adams, Veeco's share price has also received a helping hand from investors that have now got to grips with the potential of the LED.

MOCVD tools are by far the biggest sellers in Veeco's LED and Solar Process Equipment business unit, which has delivered a sequential increase in sales in every quarter of the last year. In Q1 2009, this division netted $22 million, and since then it risen to $31 million, $53 million, $98 million and most recently $111 million. Growing this business has held the key to reversing Veeco's fortunes: In Q1 2009 the company made a loss over $22 million, but a year on this three month period produced a $26 million profit.

Orders have also mushroomed over that time frame, growing from $28 million to $212 million. The company expects to ship 75 tools this quarter, and by bringing extra capacity on line, it hopes shipments will hit 100 and 120 units in the next two quarters.

Many of Veeco's LED customers are buying its K-465i multi-wafer tool, a product has helped the company to take market share away from its main rival, Aixton. Dorsheimer estimates that Veeco has increased market share from 28 percent to 35 percent over the last year, primarily due to sales growth in China and Korea. However, although Aixtron might be loosing ground to Veeco, it is still the dominant player in the market. It has enjoyed a tremendous hike in its orders that has spurred a tripling of its share price, a performance good enough for this company to grab third spot in the table.

Veeco's launch of the K465i has helped the company to grab market share from its rival, Aixtron, which still dominates the MOCVD market

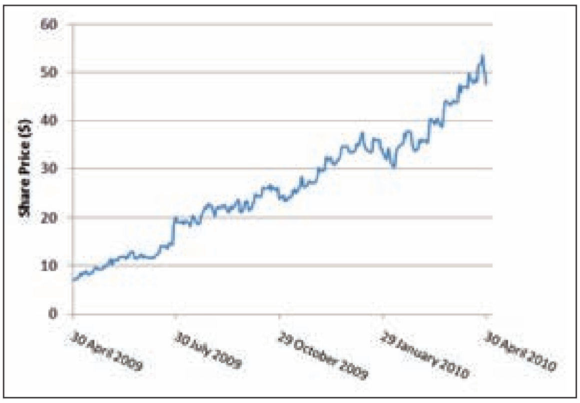


Figure 1: Veeco's share price has grown throughout the year ending 30 April 2010, reflecting ever-improving sales and order backlogs

Strong demand for MOCVD equipment allows Veeco and Aixtron to charge a high price for their tools, and ultimately generate healthy profits. However, such success can also have its downside for the incumbent players, with firms operating in related fields trying to muscle in and get their own slice of the pie. In this market the equipment maker Applied Materials is developing a GaN growth tool for LEDs, but Dorsheimer believes this development will not threaten Aixtron or Veeco. He describes Applied Materials effort as "missing this backlighting cycle". But he expects the company to have an offering for the next wave of growth, solid state lighting.

In the most recent round of quarterly conference calls Veeco was bullish about its future business, while Aixtron was more cautious. The tentativeness of the German outfit reflects uncertainty surrounding orders in 2011.

Chipmakers in China are the exception, and if they continue to place orders, then substantial MOCVD tool sales could continue throughout next year. In China MOCVD purchases are aided by a 50 percent subsidy from the government, but that could change, depending on the country's next five-year plan. If you take the optimistic view, orders could keep coming at a good pace and help to maintain high MOCVD sales that will get a further boost due to a new wave of capital expansion when the LED lighting market takes off. Taking all these possibilities into account, Dorsheimer revised his target price after Veeco's latest earning release to $62.

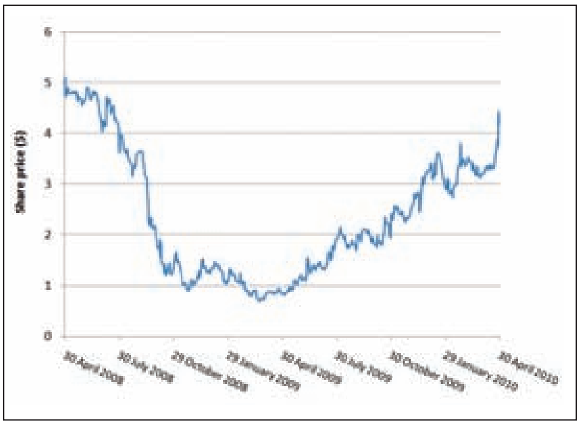


Figure 2: AXT's share price has nearly recovered from two years ago

AXT's revival

Nestled between Veeco and Aixtron in the stock leader board is AXT. This GaAs, InP and germanium substrate producer has had a topsy-turvy couple of years. Wind the clock back 12 months and the company was in last place on the leader board, but its incredibly strong performance since then has nearly brought its share price back to where it was in 2008 (see Figure 2).

This turnaround is partly due to the booming LED market, coupled to resurgence in handset sales. These factors have helped to lift AXT's quarterly revenue from $7.7 million for the first three months of 2009 to $18.6 million in the same period of this year.

There have also been changes at the top - last March founder Morris Young replaced Phil Yin as CEO. Dave Kang from the research, trading and investment-banking firm B. Riley says that change has brought about a different approach in dealing with investors, with Young keeping a far lower profile than his predecessor. Yin has certainly being through many ups and downs with the company. Back in 2000 AXT had a 45 percent share of the GaAs substrate market, but this plummeted to just 5 percent in 2004. Market share has climbed since then: It is now 25 percent, and the company is targeting 30-35 percent by 2012.

AXT's GaAs substrate sales figures are far greater than those associated with germanium, which netted $1.64 million in the last quarter. However, germanium sales could flourish if the terrestrial, concentrating photovoltaic (CPV) business takes off.

"AXT had a pretty significant opportunity in 2007, but the credit crisis pretty much wiped out all their customers," says Kang. However, he says that the cost associated with CPV is falling, and if this trend continues it can offer cheaper electricity generation than that based on silicon and thin-film cells. "Over the next year your going to hear more about terrestrial opportunities, and that will drive [AXT's] valuation."

The current share price, however, reflects the RFIC and LED markets. Kang expects AXT's valuation to continue to rise, and after listening to the recent quarterly conference call on 28 April he raised the target price from $4.90 to $7.20.

Footing the table

Every III-V company has seen improvement in its share price over the last 12 months, but the gains of some have been far more modest than those of others. Propping up the leader board are Emcore and Infinera, two companies that many analysts are only willing to talk about in private.

Like AXT, Emcore has suffered from the failure of the CPV market to take off over the last few years. During 2008 and 2009 the Albuquerque-based firm issued a raft of press releases claiming substantial orders for its triple-junction cells from firms across the globe, but in many cases these bookings never translated into sales. In the most recent set of quarterly results photovoltaic revenue was worth just $16.8 million, a $0.4 million sequential rise. But this gain resulted from a 14 percent increase in satellite business; CPV sales were down compared to the previous quarter. It's fiber-optic division brought in the remainder of its $42.4 million sales, and during those three months the company bled $11.9 million.

Infinera is also running at a loss, but this is getting smaller and the company is steadily increasing both sales and market share. Over the last year this producer of InP chips that its uses internally to build systems for fiber optic networks has steadily grown its quarterly sales from $68.9 million in the quarter ending 27 June 2009, to $83.9 million, $90.2 million and most recently $95.8 million. Losses have come down in that period, falling from $27.1 million to $7 million per quarter. There is good reason to believe that this transformation will continue. Within the telecom market there has already been an increase in sales within the enterprise market, and the system vendors, such as Infineon, are now tipped for growth. If this happens the company could soon realize annual sales of $500 million and a return to profitability.

Future success demands investment in new technologies and products, and Infinera has certainly been doing this, with R&D expense chewing up over $100 million in last four quarters. This investment has led to the fabrication of 40 Gbit/s chips that have now been passed to the systems division, and a product that could undercut rival technologies operating at this speed could be out before the end of the year. Looking further ahead, the company is developing optical switching technology that could pay dividends in the 2011-2012 timeframe.

Changes at the helm may also spur a return to profitability. Former CEO Jagdeep Singh is a tech visionary and entrepreneur with great experience in getting a start-up off of the ground, but his successor, Tom Fallen, is probably better equipped for managing operations and driving up revenues.

If Fallon executes on these fronts, Infinera could shoot up the leader board over the next 12 months. As AXT has shown, it possible to go from propping up the table one year to occupying one of the top spots the next. Tune in next year to see how Infineon and AXT fare, alongside many other players in the III-V market.

Disclaimer. Richard Stevenson holds a small number of IQE shares.

Compound semiconductor share price leaderboard

Rank	Company	Ticker	Share value, April 30, 2009 ($)	Share value, April 30, 2010 ($)	% appreciation	Change in Rank
1	Veeco	VECO	7.19	47.63	562.4	+16
2	AXT	AXTI	0.85	4.20	394.1	+20
3	Aixtron (Frankfurt)	AIX	10.2*	44.06*	332.1	+8
4	Rubicon	RBCN	9.01	27.60	206.3	+10
5	Cree	CREE	26.53	76.00	186.5	-3
6	Oclaro	OCLR	0.99	14.11	185.1**	+12
7	Finisar	FNSR	5.60	15.64	179.3	+5
8	JDSU	JDSU	5.04	13.58	169.4	+7
9	RFMD	RFMD	2.49	5.88	136.1	-3
10	IQE (London)	IQE	0.13*	0.29*	126.1	+3
11	Skyworks	SKWS	8.53	18.06	111.7	-10
12	TriQuint	TQNT	3.89	7.90	103.1	-2
13	Anadigics	ANAD	3.07	5.12	66.8	+6
14	Riber (Paris)	RIB	1.37*	2.29*	67.0	-13
15	Kopin	KOPN	2.85	4.50	57.9	-11
16	IPG Photonics	IPGP	11.25	17.73	57.6	-9
17	NASDAQ composite	IXIC	1732.47	2509.99	44.9	-8
18	Hittite	HITT	36.89	52.73	42.9	-13
19	Endwave	ENWV	2.44	3.03	24.2	-3
20	Infinera	INFN	8.22	9.75	18.6	-12
21	Emcore	EMKR	1.26	1.44	14.3	-1

* Converted to dollars using the exchange rates on 30 April of 1 EURO = 1.3315 USD and 1 GBP = 1.52993 USD
** Oclaro instigated a 5:1 reverse share split on 29 April, and the appreciation figure reflects this

Although everyone has been a winner over the last twelve months, some III-V firms have done far better than others. MOCVD equipment makers have bagged two of the top three slots thanks to strong orders from LED chipmakers looking to increase their capacity and ship more LEDs to producers of displays

Anadigics: 25 years on a roller coaster

Anadigics has packed an awful lot into its first 25 years: it has experienced the highs of pioneering 4-inch GaAs production and leading high-volume manufacturing of power amplifiers for handsets; but it has also suffered from the lows of dealing with unsustainable losses and losing market share to superior chip technology. **Richard Stevenson** tells the company's story.

In the mid 1980s the world was gripped by the Cold War. USSR and its communist allies were pointing scores of nuclear missiles at targets in the West, which had a similar arsenal in place for its adversaries. Both of these Superpowers hoped that the devastating consequences of a nuclear war would ensure peace. But this could not be guaranteed, so Ronald Reagan's Administration tried to develop a system that intercepted nuclear missiles in mid-flight. This project, which had an unofficial nickname Star Wars, focused on developing laser systems that could be attached to satellites and shoot down nuclear missiles.

If Star Wars was going to be a success, it would require the construction of novel systems incorporating a rafter of cutting edge technologies. For example, many GaAs ICs would be needed to provide amplification and manipulation of the signals used in different types of radar systems operating in various bands of the microwave spectrum. A successful program could consume many of these chips, and several start-ups specializing in GaAs IC technologies were launched to try and cash in on this emerging market.

In amongst this group was Anadigics, an East-coast start-up that has kicked on to become arguably the most revolutionary GaAs chipmaker of the last 25 years. Its trailblazing efforts have included leading the move to 4-inch GaAs manufacturing; becoming the first high-volume manufacturer of power amplifiers for handsets; and being one of the first manufacturers to move to more efficient, more reliable HBTs, by switching the transistor design from an AlGaAs to a GaInP emitter. It's a terrific list of achievements that could never have been foreseen by its three founders, Ron Rosenzweig, George Gilbert and Charles Huang, when they formed the company in Warren, NJ, in 1985.

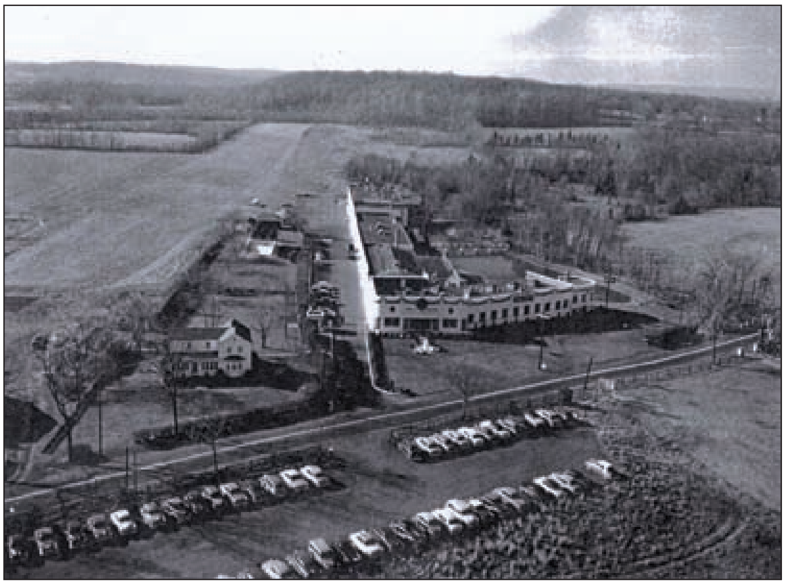
Founding a start-up was not a new challenge for Rosenzweig and Gilbert – back in 1968 they co-founded Microwave Semiconductor Corporation (MSC). "We were designing and manufacturing state-of-the-art RF and microwave transistors that were mainly used in amplification and oscillation," recalls Rosenzweig, who was the company's CEO.

MSC, which mainly targeted defense and telecommunication markets, had some III-V expertise and in 1976 it started a line of GaAs power transistors and power amplifiers. These were discrete devices that were subsequently attached to ceramic substrates.

In the late 1970s MSC was bought by Siemens. Rosenzweig and Gilbert were given five year contracts as part of the deal. Towards the end of these contracts their entrepreneurial spirit got the better of them, and these two guys in their late 40s wondered how they would see out their working life. "The encore turned out to be Anadigics," says Rosenweig.

The focus for the start-up was the manufacture of GaAs integrated circuits for defense companies contributing to the Star Wars program. "The business plan revolved around making modest quantities of high-performance niche products with selling prices in the $25 to $100 range," explains Rosenzweig, Anadigics' first CEO. If the company could ship tens of thousands of these components each year, then it had a good chance of turning in a profit.

Winning funding to kick-start Anadigics was relatively easy. In the late 1960s, when Rosenzweig and Gilbert co-founded MSC, venture capitalists were incredibly rare, but this time round there were plenty to appeal to. And what's more, this twosome had a fine track record of running a company. Within three years of its launch they had taken MSC into the public domain, and its strong performance on the NASDAQ throughout the 1970s meant that its sale netted a good return



Anadigics Warren, NJ, facility was built on a site previously used by United Technologies, which built its factory in 1953

for all its investors.

Rosenzweig knew that GaAs expertise was crucial to the company's success. He could have tried to poach former colleagues from MSC with this skill set, but he didn't want to risk upsetting his former employer. "Instead, we made a strategic decision to go out of our normal circle and get the best and brightest that was possible."

This quest turned up Charles Huang, head of the RF device division of silicon-valley start-up Avantek, a microwave component manufacturer. Huang could also bring a different, West-coast culture to the team, and Rosenzweig was delighted when this GaAs expert agreed to co-found Anadigics.

One of Huang's great strengths was his deep knowledge of metal semiconductor field effect transistors (MESFETs), the universal technology of the time. "In 1985 the HBT was still a laboratory curiosity, being funded by DARPA for various development applications," explains Rosenzweig. MESFET manufacture had the great advantage of not requiring any epitaxial steps, and was based around the implantation of ions into a semi-insulating substrate.

Piles of cash

The three founders found that they had plenty of cash to play with. They raised $8 million of first round funding in 1985, and quickly followed that up with a further $15-20 million. Today many start-ups would use this funding for development of chip designs, and outsource their manufacturing, at least initially. However, back then it was a different world, and Anadigics fitted into the philosophy of the time. "We created a vertically integrated, real-men-have-fabs company," recollects Rosenzweig, who had a further $8 million at his disposal to buy the capital equipment for the 3-inch GaAs fab.

But despite this tremendous investment, they failed to generate a profit. This was partly due to unforeseen events in Europe that were completely outside of their control. Led by the Solidarity movement in Poland, communist countries were turning to democracy, and the US government felt that it made sense to drop investment in the Star Wars program given the new world order. Sales to defense companies also received a massive blow due to cuts in the defense budget. The proportion of gross domestic product for defense was trimmed by 25 percent between 1986 and 1991, and further cuts occurred throughout the 1990s.

Anadigics clearly needed to target new markets with different products, which would have to be far cheaper. Fortunately it had already carried out some of the groundwork. "Although we had built up our business plan around Star Wars, we did not want to only be a defense company," explains Rosenzweig. From the outset the Warren outfit had also been investigating opportunities in the satellite communication market; in the cable TV market, where GaAs could be used in tuners; and in fiber optic telecommunication, where GaAs chips could be used to make laser drivers and receivers. The only application that Anadigics did not consider venturing into was GaAs ICs for logic circuits in super computers, a market that was already cornered by the likes of Vitesse and Gigabit Logic.

Although there were plenty of promising opportunities for GaAs ICs, Anadigics struggled to find a high-volume contract. At this point the company was only bringing in sales of a few million each year, nowhere near enough to generate the cash to pay for the wages of 50-60 staff, a high R&D bill, and the scores of 3-inch, $1000 GaAs substrates that were being consumed. This state of affairs resulted in a burn rate of $8 million a year. "We were grossly unsuccessful, but no different from anyone else at that moment in the field," says Rosenzweig.

By 1988 Anadigics was running out of money fast. It appealed to investors, and raised another $10 million that kept bankruptcy at bay for a couple more years. But when that additional investment ran out it was clear that the company needed a new strategy. Rosenzweig's plan was to find a strategic partner, and he found two allies in Europe: Thompson CSF and Philips. Although no business came directly from eiter of these relationships, the faith of these European partners was incredibly helpful to Anadigics, because it encouraged existing investors to part with more of their cash.

One problem still remained: uncovering the killer application. Again, Europe played a hand in Anadigics' fortunes, with British Sky Broadcasting and Sky independently launching satellite TV. "We came across a company called Continental Microwave, which had put in a contract for one million low-noise converters," explains Rosenzweig. Continental's CEO believed that this product needed to employ GaAs in the manufacture of low-noise block converters that take a set of frequencies in the Ku-band (11-12 GHz), amplify them, down-convert them to an intermediate frequency of 1 GHz, and then send the resultant signal to the set-top box.

Anadigics priced the parts at about $5 and won the order for them. To meet the subsequent demand, everyone within the company dropped what they were doing and started working on this project. "Suddenly there was the first high-volume GaAs IC market of any substance," recollects Rosenzweig.

Within three years Anadigics was churning out 5 million ICs. This required further capital equipment, but to put the volumes in perspective, this throughput is a tiny fraction compared to the 200-300 million ICs produced by the company today. Back then the process required a lot of manual labor, and yields varied substantially. "You had good yields and bad yields - it was not a very controllable process," reminisces Rosenzweig.

The $15 million annual sales generated by shipping 5 million GaAs ICs put the company on a far better financial footing. It helped spur annual revenues to $20-25 million, and made the company a viable entity that was close to turning in a profit. Winning additional financing was also far easier, and the company had a couple of additional rounds of investment.

The mobile revolution

Not long after this a product came along that changed the GaAs IC industry forever: the handset. Initially this wasn't the portable, lightweight device of today that fits easily into a pocket or handbag, but a car phone running off the automobile's battery. In this context efficiency hardly mattered, and silicon LDMOS and bipolar technologies were capable of meeting the output power requirements. However, handset manufacturers were well aware of the potential of GaAs power amplifiers, which promised to offer far higher efficiencies that would draw less power from the battery, leading to increased talk time.

Anadigics decided to try and team up with the cell phone manufacturers. The market leader of the time was Motorola, but they already had their own internal GaAs capability. So Anadigics scoured the globe trying to find a firm that would invest in the Warren outfit and pay its development costs for GaAs power amplifiers. "We wound up with Ericsson being a strategic development partner. That was very important. They didn't fund us, but they gave us the specs," recollects Rosenzweig.

When Anadigics started shipping the PAs in 1995 it entered a new era. Annual sales grew to $25-30 million, and the company was now profitable. The latter achievement had major implications – it allowed Anadigics to go public and raise a further $24 million.

"Part of the reason for raising that money was to use the proceeds to expand the fab, so that we could handle much more production," explains Rosenzweig. "Around 1997 we realized that production was not economically viable on 3-inch wafers, and we expanded to 4-inch. We were the first company to do that."

By then Anadigics' sales were dominated by GaAs PAs and revenue had rocketed to $75 million. "We were supplying Nokia with PAs, we had virtually all of Ericsson's business, and we helped Qualcomm launch the PCS industry in the US," recounts Rosenzweig. Introduction of PCS technology was a major breakthrough, because it started the era of digital cellular communication.

Anadigics was now in the incredibly enviable position of being the global leader in a rapidly expanding market, and to increase its chip production and cut manufacturing costs it built a 6-inch GaAs fab that came on-line in July 1999. This helped the company to continue to ramp up its GaAs IC shipments and realize record sales of $51 million in the third fiscal quarter of 2000.

But the glory days didn't last long. During the late 1990s handset manufacturers started migrating from batteries operating at 6 V to 4.5 V and finally 3V versions. The HBT was better suited to these lower voltages, and it also had another major plus point, higher efficiency. "Once HBTs were proven to meet the price points that the handsets required – a $1-2 power amplifier – the game was over for the MESFET in the handset market," admits Rosenzweig.

Anadigics' demise was quick. In 2000 its sales were unscathed by the HBT and were worth $172.3 million, but by 2001 - the year the dot.com bubble burst - MESFET shipments for PAs had collapsed, dragging down total annual revenue to just $84.7 million. Everyone could see this coming, and shortly after it happened Bami Bastani - who took over as CEO from Rosenzweig in October 1998 - faced a tough decision: should Anadigics exit the handset business, or become a HBT company?

He chose the latter, but he was determined that Anadigics would remain a trendsetter, rather than becoming a crowd

Anadigics' current headquarters under construction

By the fall of 1999 the company had developed a GaInP HBT process on its 6-inch line, and few months latter it was shipping InGaP HBT samples to potential customers

follower. To this end the company was not going to make a HBT with an AlGaAs emitter, which was rapidly becoming the incumbent technology, but a product with an InGaP emitter that would combine superior reliability with better high-temperature operation and improved linearity over battery lifetime.

By the fall of 1999 the company had developed a GaInP HBT process on its 6-inch line, and few months later it was shipping InGaP HBT samples to potential customers. But it took an awfully long time to convince them to buy this type of product in volume, and Anadigics went through some very tough times during the beginning of the last decade, shedding employees and recording a loss for every fiscal year between 2001 and 2006. But by 2007 Anadigics' high quality product was making significant inroads into the 3G handset market, and the company was netting quarterly sales of over $80 million.

It then committed the cardinal sin: Failing to meet customer orders. Bastani resigned shortly after the news broke, and Anadigics started searching for a new CEO.

Company chairman Gilles Delfassy took hold of the reigns as an interim measure. He also contacted a good friend of his, Mario Rivas, to see if he might be interested in the CEO role. These two industry veterans first knew each other when Delfassy was in charge of the wireless business at Texas Instruments and Rivas held an equivalent role at Motorola. Their friendship was strengthened when Rivas moved to Philips Semiconductor, because the two of them then worked together to provide the baseband and PA for Sony Ericsson handsets.

Rivas took a look at the role, and decided he was interested: "I thought that Anadigics had great technology, great people, and a great possibility. And it's down my alley as far as expertise was concerned."

When Rivas started at Anadigics on 1 February 2009, morale was rock bottom. There had been lay-offs, quarterly sales had slumped from $80 million to $30 million and the economic outlook was terrible, with the world entering its worst recession since the 1930s.

Rivas cut through the doom and gloom, telling the workforce that they were going to have fun: "We spend too much time at work not to have fun." He also fostered a stronger sense of teamwork, making it clear that every employee has an important contribution to make.
The CEO identified three goals for turning the business around: greater intimacy with customers; improved operation; and preservation of cash. "The fact that we were at 30 percent factory utilization allowed us to do a lot of improvement. It's hard to improve when you are full."

Customers are now starting to come back to Anadigics, and according to Rivas, they never had any doubts about the quality of the company's technology. Their major concern was trusting Anadigics once more with the role of being a key supplier. Thanks to their faith in the Warren fab, Anadigics quarterly sales are edging towards the $50 million mark, and an associated increase in fab utilization has allowed the company to drop its temporary introduction of one week's unpaid leave every quarter. What's more, the company has been recruiting, a move that always boosts morale.

One important change that Rivas has brought to the company is a switch to a hybrid model that combines in-house production with outsourced manufacture. "When we passed 30 percent fab utilization I announced a strategic agreement with WIN Semiconductors in Taiwan. People were scratching their heads and saying: Are you nuts?" But Rivas knows that it takes a long time for a new factory to optimize its processes for new products that satisfy customer expectations. He was already thinking about the demand for Anadigics products in 2011, and by then he expects that the company will manufacture over 1000 wafers per week, exceeding its in-house capacity.

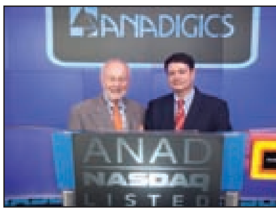
If the company were to build another fab to meet that demand, it would need to raise $100 million. "In the mean time, you have WIN Semiconductors, which has a very good technology and a very good funding base. You could look at it as free capital for us."

Rivas expects the GaAs IC business to grow over the next few years. He is targeting production of 2500 wafers per week in 2014, a level of production that will allow Anadigics to up its share of the GaAs handset market from today's single digit figure to 14 percent. If the company executes on this front, it will definitely surpass its current record for annual sales of $250 million.

"I will be pleased if we could break $500 million," says Rivas. "Then we'll have finally grown up, and no longer be an adolescent."

And let's hope that is the legacy that Rivas leaves, because when you are approaching 30 you should have thrown off the exuberance of youth, and settled down into a pattern of earning a little more every year.

Anadigics current CEO Mario Rivas (right) invited Ron Rosenzweig (left) onto the stage for ringing the closing bell for the NASDAQ on 22 April 2010



Silicon-based LEDs leap from lab to fab

Silicon offers a large, low-cost platform for making nitride LEDs, but realizing high-quality epitaxy is tough due to the stress between the two materials. However, it is possible to produce the crack-free, low-defect-density films demanded by high-power LEDs by turning to a patterned substrate and a multi-layer buffer, says **Lattice Power Corporation.**

LEDs are widely used in displays, automobiles, handsets, notebook backlighting, TV backlighting, and general lighting. The light-emitting films - InAlGaP for red LEDs, and InAlGaN for their blue and green cousins - need to be grown on a carrier substrate.

There is no good substrate to match the GaN material system, in terms of lattice constant and thermal expansion, but it is possible to grow high-quality films on sapphire, SiC and silicon.

Almost all GaN-based LEDs are fabricated on sapphire substrates, and Cree is the notable exception, using SiC substrates instead.

Massive adoption of solid-state lighting requires further advances in large-scale, low-cost manufacturing. Silicon-based GaN LEDs have been attracting researchers in universities and industry for many years, due to their promise of large-scale production and compatibility with the IC manufacturing platform. In comparison, sapphire and SiC substrates are much smaller, and they can't be processed through silicon lines.

The biggest roadblock for manufacturing high-performance GaN-on-silicon LEDs is the material stress that results from a combination of lattice mismatch and thermal expansion mismatch.

But it is possible to use special epistructures, novels substrate designs and sophisticated growth techniques to make GaN-on-silicon structures that lead to high-performance, high-reliability LEDs. At Lattice Power, which is based in Nanchang, China, we have done exactly that, and demonstrated the promise of this approach for making high-performance, lighting-class LEDs.

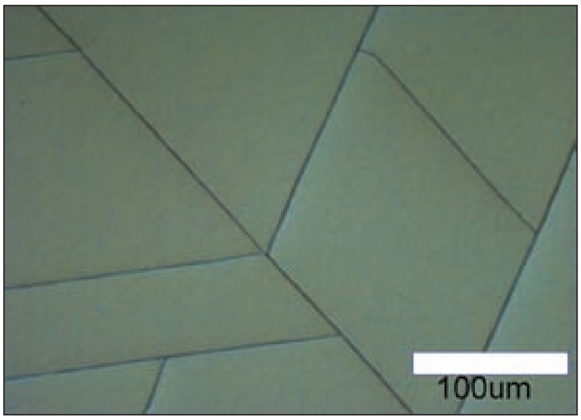


Figure 1: Cracking in GaN film grown on silicon substrate

The substrate used for GaN growth is (111) silicon. Its lattice-constant mismatch to GaN at room temperature leads to a tensile strain of +17%, but it is +40% tensile-strained following pseudo-morphological growth at around 1000 degrees Celcius, due to the thermal expansion coefficient mismatch. This results in more than a 2 μm lattice constant mismatch for a 1mm die. The upshot is that cracking occurs, sometime massively.

However, more often it causes the wafer to bow during growth, yielding wafer non-uniformity and poor device performance. In comparison, when GaN films are grown on SiC substrates, the strain caused by lattice constant offsets that caused by thermal mismatch.

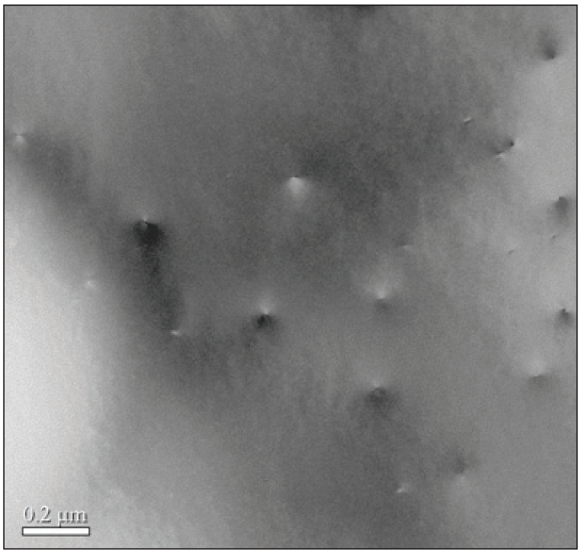


Figure 2: Low dislocation density from a GaN wafer grown on silicon substrate

If sapphire substrates are used, compressive strain in GaN film results from the lattice constant and thermal mismatch, but this does not lead to cracking.

In other words, this highly tensile strained GaN film on silicon substrate presents the biggest challenge for making high-performance, high-reliability LEDs. Figure 1 illustrates a GaN-on-silicon wafer with cracking everywhere.

Managing the stress

Successful high performance LED manufacture demands low-dislocation, crack-free films. Managing the stress is the first hurdle to overcome. Large lattice-constant mismatch between GaN and silicon leads to high dislocation densities, which can be as high as 10^9-10^{10} cm^{-2}.

Even though the GaN-based LED is far less sensitive to high dislocation densities than its GaAs or InP cousins, such a high dislocation density still causes low internal quantum efficiencies. This prevents the realization of high-power, high-reliability LEDs. But we can address this issue by introducing patterned substrates that isolate the stress caused by cracking, and a special AlGaN/AlGaN multilayer buffer structure that manages internal strain. We have found that patterned substrates are effective in containing the strain and limiting cracking propagation. The width, depth and shape of the trench are crucial levers to minimizing the stress and limit the cracking. In order to contain the stress and eliminate cracks, a deep trench is implemented, which leads to a free-standing GaN film. If there is cracking in one post, it will not propagate to next.

With this approach it is possible to realize a manufacturing yield of more than 95 percent of chips without cracking, for a chip size is 1mm or smaller and a GaN thickness exceeding 4.5 µm. A dislocation density as low as $5x10^8/cm^2$ can be routinely achieved for a GaN film on a silicon substrate.

Figure 2 demonstrates low dislocation density from a GaN wafer grown on a silicon substrate. Figure 3 shows a high quality GaN-on-silicon chip without cracking.

High performance LEDs must also have high internal quantum efficiency. For GaN-on-silicon growth, thick n-GaN layers have always been a problem, because as the epilayer gets thicker, stress increases and the wafer tends to bend and crack. We address this with a multiple special buffer layer.

The AlN layer tends to provide a good buffer for controlling the stress. We are being able to design and grow our epistructure with a 4-5 µm n-GaN layer. Figure 4 shows SEM pictures of the epi layer and quantum well design.

Preventing silicon absorption

Silicon absorbs visible light. So in order to have efficient LED operation, the silicon substrate must be liberated from the device, a thin-film, vertical structure. Figure 5 illustrates the silicon-based thin film process. GaN is grown on a prepared, patterned (111) silicon substrate.
A metal contact is deposited on the p-side of the GaN film. This acts as a light reflector adding further benefits to the device.
A bonding metal is then deposited on top of the p-metal, subsequently bonded on a carrier substrate (pre-deposited with a bonding metal). The substrate can be silicon, germanium or a metal plate. The bonding metal can be gold or one of its alloys, depending on different process designs for different applications.

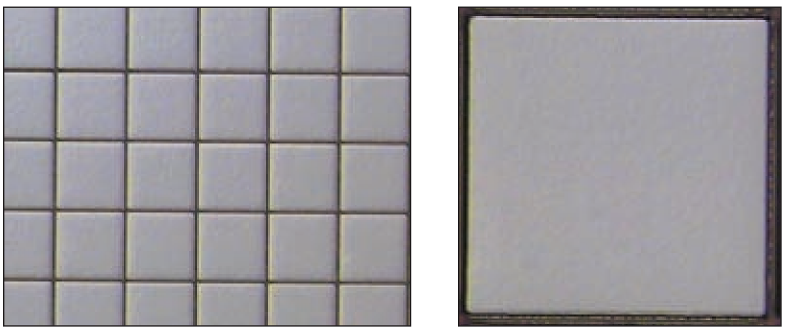


Figure 3: high quality GaN on silicon chips without cracking

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We can produce LED chips with various sizes on silicon substrates. Low operating voltage and high output power are demonstrated, and we have launched reliable products for display applications (small die), LCD backlighting (mid size die) and general lighting (large die)

The original (111) silicon substrate is then removed by wet chemical etching, followed by n-contact metal deposition. For high power devices, we will implement a surface roughening process. The LED emits through the n-GaN side. Figure 6 are actual 500 μm and 1 mm LED chips made from GaN on silicon.

We can produce LED chips with various sizes on silicon substrates. Low operating voltage and high output power are demonstrated, and we have launched reliable products for display applications (small die), LCD backlighting (mid size die) and general lighting (large die). Figure 7a is an example of a 450 nm, 1 mm chip emitting 480 mW when driven at 350mA.

Output corresponds to 100-110 lm cool-white flux at 350mA. The typical quantum efficiency as a function of current for a GaN device on a silicon substrate is shown in Figure 7b. Characteristics are no different from GaN LEDs on sapphire or SiC substrates.

This shows the GaN-on-silicon material quality is as good as that on sapphire or on SiC, and demonstrates that this class of LED is a very promising candidate for large-scale, low-cost production.

Reliability concerns?

The GaN-on-silicon substrate is highly stressed, so there are genuine concerns regarding its long-term reliability. We have conducted a long-term reliability test at three times normal operating current and a 75 degrees Celcius board temperature (approximately 110-120 degrees Celcius junction temperature).

Figure 8 details the results of 0.5mm (at 200mA) and 1mm (at 900mA) chips under a highly stressed reliability test. They show no or very little power degradation. Similar reliability is seen in GaN material grown on sapphire.

Up until now, more than 95 percent of GaN-based LEDs are made on sapphire substrates, with the majority of the remainder grown on SiC. We have been marketing silicon-based LED products for close to two years. Initial production had many issues, mainly related to production line yields.

Customers had many issues too, such as handling and packaging, which resulted from the brittle carrier material of the thin film structure. However, thanks to process

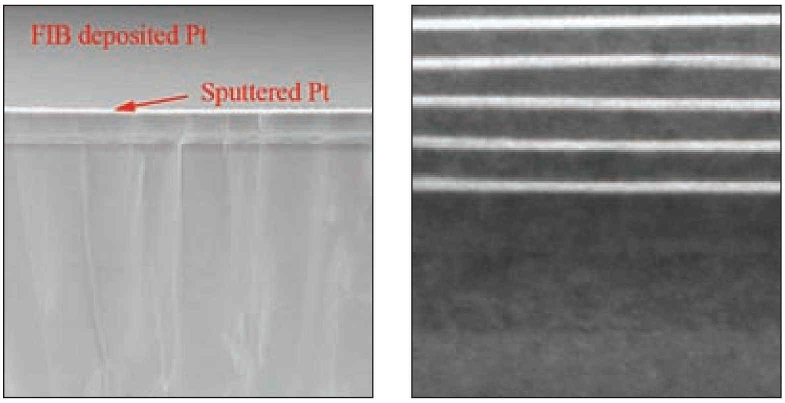


Figure 4: SEM pictures of the epi layer and quantum well design

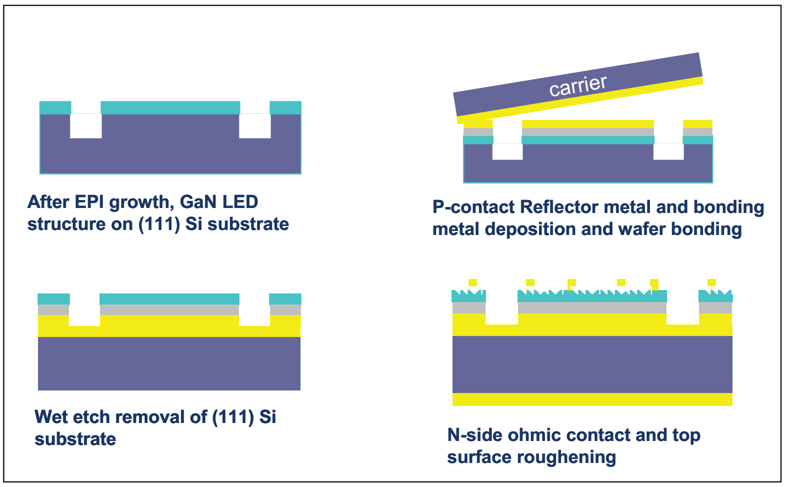


Figure 5: Lattice Power's silicon based thin film process

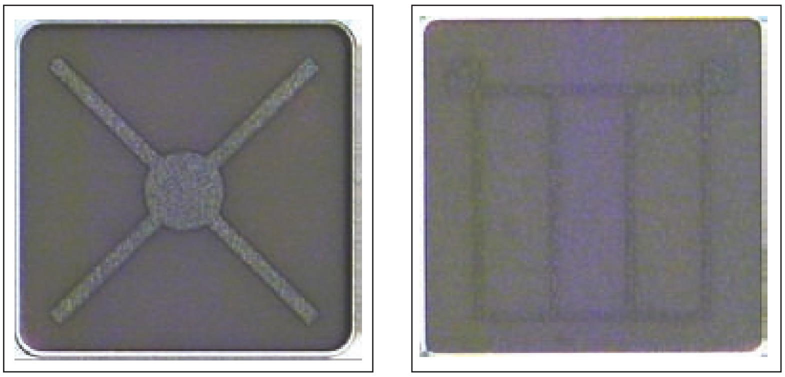
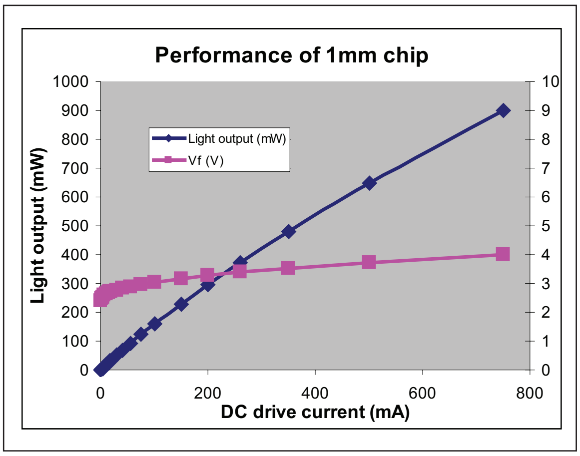
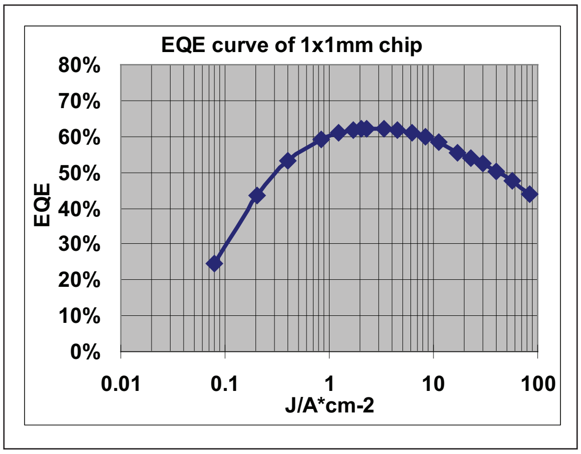


Figure 6: High-performance 500 μm and 1 mm chips made from GaN-on-silicon substrates

Figure 7a: Right) 1mm, GaN-on-silicon chips are capable of producing cool-white LEDs with a flux of 110 µm. Figure 7b: (Far right) External quantum efficiency vs. current





refinement and better control, silicon-based products are now finding more and more applications and customers.

Due to the vertical thin-film structure, silicon-based devices can be made smaller than similar performance equivalents based on sapphire. 200 µm by 200 µm devices for display application are in high demand, and they now have proven long-term reliability. What's more, the production yield can be on a par with its sapphire sisters currently in use.

To put it simply, the GaN-on-silicon LED is no different from any sapphire or SiC-based LEDs. Its application ranges from displays, backlighting and general lighting. Figure 9 is a full color display featuring our GaN-on-silicon blue and green LEDs. In this particular application, the chip size is 170 µm by 170 µm, and the blue output power is close to 10 mW at 20 mA.

Our current 2-inch GaN-on-silicon process has proved that it is possible to mass-produce this class of device, which combines high performance with high quality and high reliability. The real benefit for GaN on silicon will only be realized at far larger diameters, such as 6 inches and above. This will lead to higher capacity and utilization of standard IC processing tools and equipments, but getting there will require overcoming issues related to these large diameter platforms.

Contributors for this article from Lattice Power Corporation are Jiang Fengyi, Wangli, Wang Xiaolan, Fang Wenqing , Mo Chunlan , Liu Junlin, Tang Yingwen, Xiong Chuanbing, Cheng Haiying, Zheng Changda, Zhou Yinghua, Yan Zhanbiao, and Bo Lu (blu@latticepower.com).

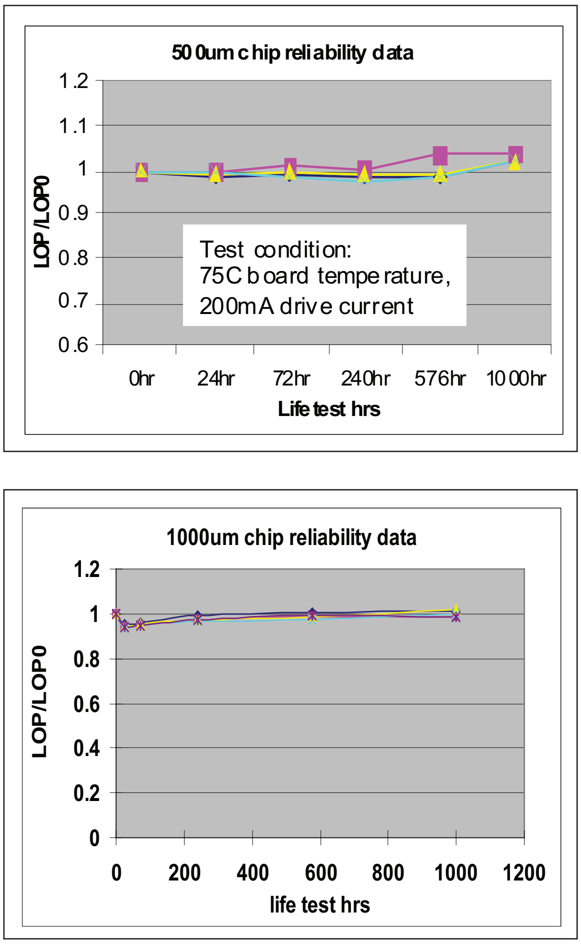


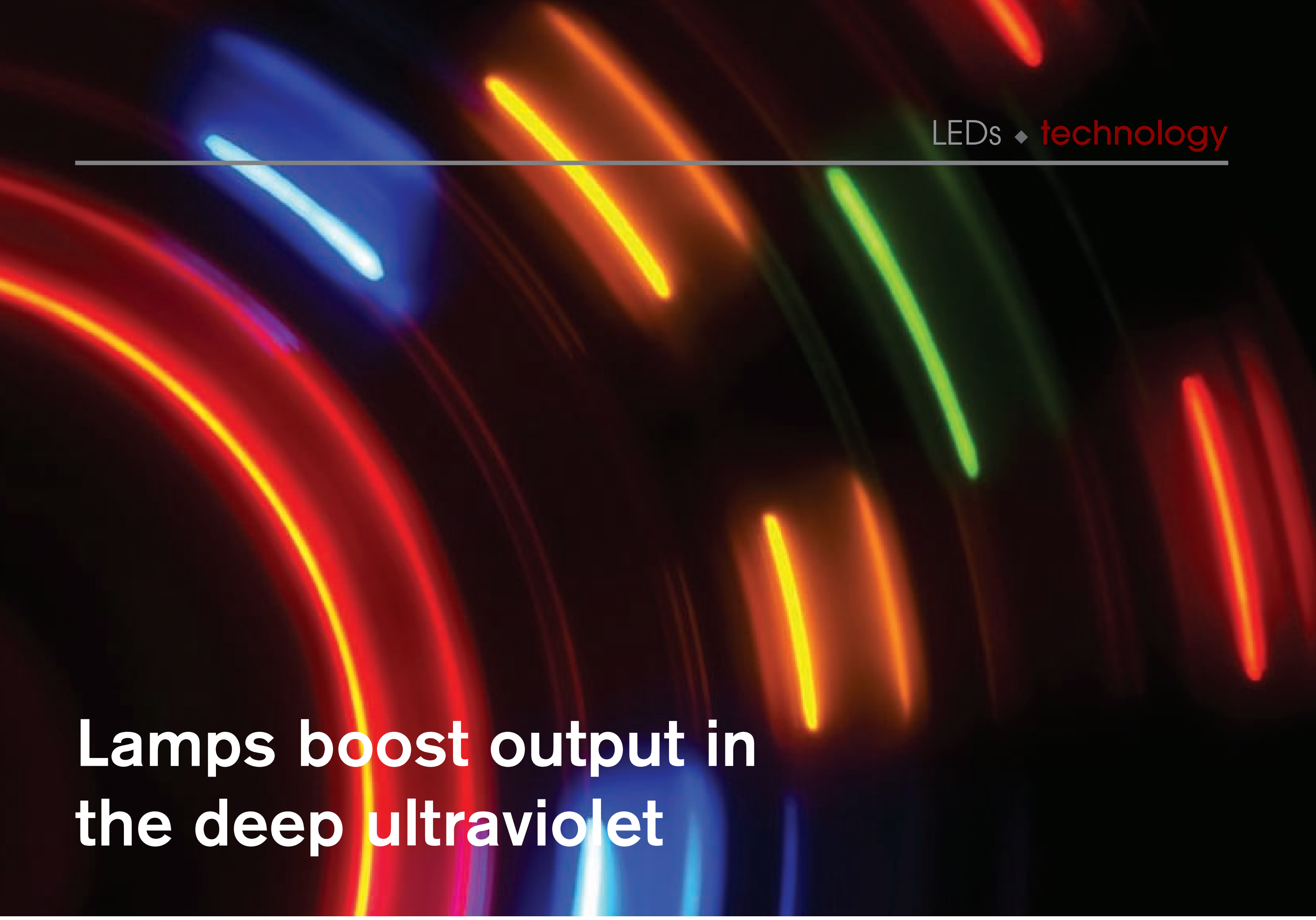
Figure 8: reliable operation of GaN on silicon LED

Figure 9: A high-density LED full color display that features blue and green GaN LEDs grown on silicon substrates

FURTHER READING

ICNS-8, Session H: Epitaxial Growth I, L_1006: "High power InGaN LEDs grown on Si substrate by MOCVD", October 18-23, 2009, ICC Jeju, Korea.

SPIE OPTO: SPIE paper number 7617-48, "High-power GaN-based Blue LEDs grown on Si substrate by MOCVD" Optoelectronic Materials, Devices and Applications, 23-28 January 2010



Lamps boost output in the deep ultraviolet

The output power of deep ultraviolet LEDs needs to rise if these devices are to be employed for water and air purification and polymer curing. One way to realize this is to turn to lamps that offer a far larger emission area, according to **Asif Khan, Qhalid Fareed and Vinod Adivarahan from the University of South Carolina and Nitek.**

Ultraviolet light in the 250-300 nm range can serve many applications, including air and water purification, polymer curing and bio-medicine. Each of these markets is fairly large, and the water purification market alone is estimated to be worth over $5 billion.

Today the main source of deep ultraviolet light for all these applications is the mercury lamp. It is not ideal however, for many reasons: it is large; bulky; requires high operating voltages; cannot be driven in pulsed mode; and its emission wavelength is fixed. On top of this, there are contamination issues arising from the use of mercury, which pose severe challenges when contemplating medical or bio-medical applications.

One attractive alternative to this lamp is the AlInGaN-based deep-ultraviolet LEDs, which can be formed on sapphire substrates that are transparent at these short wavelengths. This type of device has been pioneered by the academic group at South Carolina headed by one of us, Asif Khan, with development dating back to 2002. The key to producing the first successful devices was the combination of pulsed epitaxy and superlattice buffer layers. This mitigated strain in the epistructure that invariably leads to layer cracking when thick, high aluminum-composition AlGaN layers are directly deposited over sapphire. These thick, aluminum-rich layers are essential, because they can address current crowding in the LED that leads to localized heating, and ultimately substantial shortening of device lifetime.

Taking this approach enabled the fabrication of 280 nm LEDs that delivered 1 mW at a DC pump current of 20 mA, and showed a reduction in power output after 1000 hours of operation of only 50 percent. These results were reported in 2006, and since then they have been duplicated by several groups, including Sensor Electronics Technology and Riken. However, to date there has been little progress in terms of higher powers and longer lifetimes.

More recently, the deep UV LED research community has directed efforts in three distinct directions. One of these is the fabrication of higher power, discrete LEDs emitting

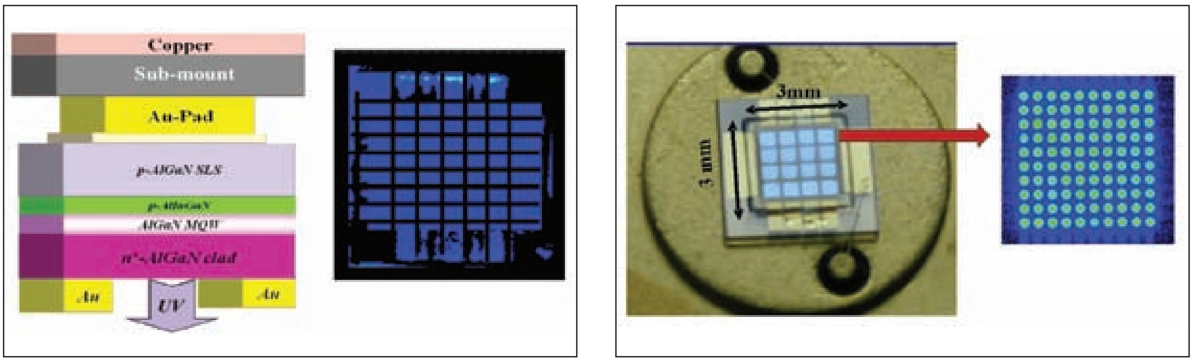


Figure 1(a). Schematic cross-sectional view of vertical deep UV lamp. To the right is an image of emission from the back n-contact side. The total emission area is 850 μm x 850 μm. Fig. 1(b). A packaged MicroLED-array-based deep UV lamp with 4x4 pixels. Each pixel has a grid of 10x10 micro-pixels each having a diameter of 20 μm. Total emission area is 700 μm x 700 μm. To the right is an expanded emission image of each pixel

around 250 nm, which is an extension of our efforts at South Carolina that resulted in sub-milliwatt power 250 nm LEDs. Recently the Riken research group has succeeded in fabricating 250 nm devices that produce 1 mW at a 20 mA pump current.

Another direction that deep UV LED research is taking is the development of low-defect AlGaN templates for subsequent deposition of deep-ultraviolet LED layers. The objective of this research is to take device efficiency beyond the 1 percent value that was realized by our efforts at South Carolina several years ago. Efforts in this direction are taking place at Nitek, a spin-off from the University of Carolina that we are all involved with (see Figure 1).

Device processing facilities used by Nitek Inc. personnel

We recently presented some encouraging results at International Workshop on Nitride Semiconductors conference that was held in Montreux, Switzerland, in the Fall of 2008. At this gathering we reported the use of pulsed lateral overgrowth to fabricate low-defect AlGaN templates with a thickness of well above 10 microns. These templates are not just beneficial to the emission efficiency - they also significantly improve thermal management, leading to an increase in device lifetime by approximately 50%.

The third goal being targeted by deep ultraviolet LED researchers is the development of large-area lamps that realize higher output powers, through a hike in drive currents to 200 mA or more. Thanks to the larger emission area of these lamps, it is possible to employ pump current densities – and levels of device heating – that are similar to those for small-area, discrete devices operating at 20 mA.

Through Nitek, we are pursuing two different approaches to making monolithic, large-area, deep ultraviolet lamps for room-temperature operation (see Figure 1). The distinction between these two approaches is a difference in current conduction geometry and the configuration of the p-electrodes.

Our first device architecture is a single, large-area pixel with vertical-current conduction geometry (Fig. 1(a)). This form of conduction is realized by removing the sapphire substrates, and then creating n-electrodes on the backside of the bottom, nitrogen-face n-AlGaN layers. In the second scheme, we have turned to a lateral-conduction geometry, and employed several micropixel electrodes to define the emission area (see Figure 1(b)). This device geometry does not require the removal of the sapphire substrate.

Both of these architectures have nearly identical emission area, and their fabrication required overcoming challenges related to materials growth, device processing and packaging. These included improving epitaxial growth uniformity and developing new device processing and packaging procedures as dictated by the large area and the vertical conduction geometry.

Our second architecture - deep ultraviolet lamps with lateral conduction - involves a 4x4 pixel geometry. However, each pixel itself comprises of 20 μm diameter micropixels. The total emission area is about 700 μm x 700 μm. These lamp chips are flip-chip mounted onto quasi-metallic carriers to improve heat sinking, and the carrier/chip assembly is bonded to a TO3-type, gold-plated metallic header. In this configuration the 280 nm lamp can realize a room-temperature output of 52 mW at a cw-pump current of 750 mA (see Figure 2). The emission spectra are very clean with a peak-to-valley ratio at 280 nm well in excess of 500.

We believe that even higher output powers are possible. An increase in output should be possible by turning to a packaging scheme that will also collect light traveling in the lateral direction due to waveguiding in the AlGaN layers. Initial measurements indicate that the room temperature lifetime for these 280 nm lamps at continuous wave operation is around 1000 hours, and this should increase with better thermal management.

Fabrication of the vertical conduction, deep ultraviolet lamps involves two new processing steps: removal of the sapphire substrate; and formation of n-ohmic contacts on the backside of the bottom n-AlGaN layer. We have pioneered the laser lift-off of sapphire from AlGaN-based deep ultraviolet LED structures that utilize an AlN buffer layer. In addition, we have developed a new processing scheme for vertical-conduction, thin-film, deep ultraviolet lamps.

Initial measurements indicate that the room temperature lifetime for these 280 nm lamps at continuous wave operation is around 1000 hours, and this should increase with better thermal management

To make a vertical conduction structure - rather than one based on lateral conduction - requires a reversing of the order of fabricating the two different contacts. The p-contacts must be formed before the n-contacts in a vertical conduction LED, and this complicates device fabrication, because the p-contact degrades due to the higher temperatures needed for the fabrication of the n-contact.

However, we have found a remedy to this problem that has led to significant improvements in deep-ultraviolet LED electrical characteristics, along with a record DC power of 6.2 mW for the 280 nm lamp driven at 260 mA (see Figure 3).

Efforts are now being directed at improving electrical characteristics and the output powers of our lamps. New packaging schemes are also being developed to improve thermal management, minimize device heating and ultimately increase device lifetimes.

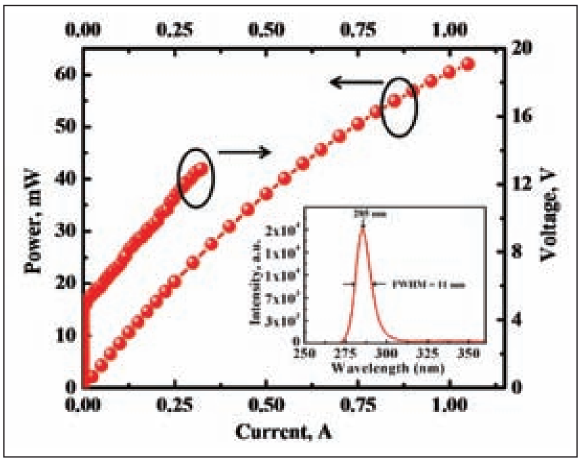


Figure 2. DC current-voltage (I-V) and current-power (I-L) characteristics of a 280 nm lateral UVC lamp operating at room temperature

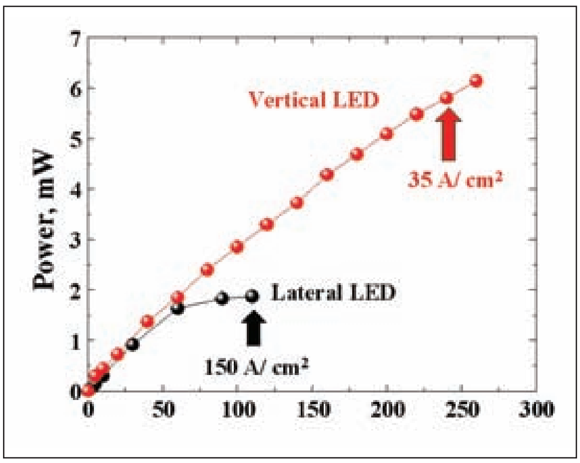
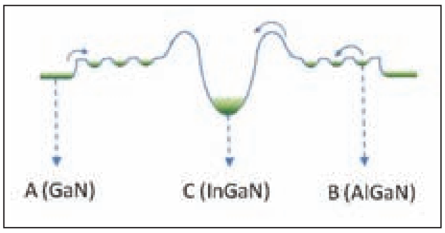


Figure 3. DC current-voltage (I-V) and current-power (I-L) characteristics of a 280 nm vertical UVC lamp operating at room temperature

Electroluminescence exposes phase separation in AlInGaN



The electroluminescence profile of UV LEDs with an AlInGaN active region varies with the temperature and drive current. According to researchers at West Virginia University, this shift in the electroluminescence peak is caused by the interplay of injected carriers with GaN, Al-rich and In-rich nanoclusters in the active region.

Scientists at West Virginia University have obtained experimental evidence of phase separation in AlInGaN layers with a few percent aluminum and indium.

Their findings contradict earlier theoretical studies by a team of Brazilian researchers that suggested that InAlGaN films - which form the active region in UV LEDs - are random alloys when aluminum and indium concentrations are very low.

Xian-An Cao and Yi Yang identified nanoscale phase separation in the AlInGaN material system through a series of electroluminescence measurements.

This duo studied an MOCVD-grown LED that comprised a sapphire substrate, a 3 μm-thick AlGaN template, a silicon-doped $Al_{0.15}Ga_{0.85}N$ cladding layer, an active region with 3 nm thick $Al_{0.06}In_{0.02}Ga_{0.92}N$ quantum wells and 10 nm-thick $Al_{0.1}Ga_{0.9}N$ barriers, and magnesium-doped $Al_{0.25}Ga_{0.75}N$ cladding and GaN capping layers.

Electroluminescence measurements were recorded at temperatures ranging from 5K to 300K, and various drive currents. These studies revealed that emission is dominated by peaks at 3.47 eV and 3.59 eV at low temperatures and currents. Heat up the device, or driver it harder, and the electroluminescence profile switches to a single peak at 3.39 eV. Cao and Yang claim that these results indicate that the active region is composed of GaN and aluminum-rich and indium-rich nanoclusters (see figure). Indium-rich quantum dot-like clusters form potential wells that are 0.2 eV deep, which are each surrounded by an aluminum-rich region that acts as a raised rim.

At low temperatures and low currents luminescence from the GaN and AlGaN phases dominates, because most injected carriers fall into the energy bands of GaN and AlGaN. Emission from InGaN is negligible, because this phase accounts for just a fraction of the active region.
Either increasing the temperature of the LED beyond 150K or cranking up the current leads to the injection of carriers that overcome the energy associated with the aluminum-rich rim and reach the InGaN phases. There they recombine radiatively. This switch in the distribution of carriers accounts for the red-shift from 3.47 eV and 3.59 eV emission to a peak at 3.39 eV.

The phase separation in ultraviolet LEDs that Cao and Yang have uncovered is undesirable, because it reduces the device's internal quantum efficiency. But this can be suppressed through strain reduction and optimization of the growth recipe.

"We plan to work with LED growers to improve the performance of UV LEDs based on quaternary alloys," says Cao. "Two specific tasks are: to design and grow lattice-matched templates and heterostructures by tuning quaternary compositions; and determining the optimal growth temperature to allow for aluminum/indium incorporation, while maintaining good structural quality."

X. A. Cao *et al.* Appl. Phys .Lett. **96** 151109 (2010)

GaAs-based detectors extend to the far infrared

A team of French researchers claims that it has fabricated the first GaAs/AlGaAs quantum cascade detector (QCD) capable of operating at very long infrared wavelengths. Development of this 15 μm detector could provide a stepping stone towards the manufacture of focal plane arrays operating in this spectral range that could be used for meteorology, atmospheric chemistry studies, and Earth observation missions.

Corresponding author Amandine Buffaz from the University of Paris, Diderot-Paris 7, says that the performance of the team's detectors are comparable to those of the incumbent technology, quantum well infrared photodetectors. However, the cascading detectors have one distinct advantage - very low dark currents that enable long integration times. The team, which also includes researchers from the Alcatel-Thales 3-5 lab, produced their detectors via MBE growth on a semi-insulating GaAs (001) substrate. The detector's epitaxial layers consist of 30 identical periods of 4 coupled quantum wells that feature AlGaAs barriers with a 232 meV conduction band offset.

Square shaped mesas with 50 μm and 100 μm sides were created with dry-etching techniques, and Au/Ge/Ni ohmic contacts were deposited onto these pixels.

The detector has a responsivity peak of 14.3 μm, and its detectivity at 25 K and an applied bias of −0.6V is 1 x 10^{12} Jones.

The detector's performance can be taken to a new level by cutting the tunneling current. "To reach that aim we will use two theoretical models of electronic transport in QCDs: a 'thermalized subbands' approach that models transport based on diffusion mechanisms; and a resonant tunneling model."

Comparing the results of each of these calculations should uncover a structure that has carrier transport dominated by diffusion rather than tunneling. Another of the team's goals is to develop detectors operating in other regions of the infrared spectrum. "The first QCD detecting in the terahertz is under study, and in the immediate future the first thermal imager based on QCD detectors should be fabricated."

A. Buffaz *et al.* Appl. Phys. Lett **96** 172101 (2010)

New plane promises to aid green lasers

Researchers at the University of California, Santa Barbara (UCSB) and Mitsubishi Chemical claim to have uncovered a superior semi-polar plane for making green lasers.

Last summer Sumitomo won the race for the green laser diode with a device built on the (20$\bar{2}$1) plane. But corresponding author Po Shan Hsu from UCSB told *Compound Semiconductor* that even better results should be possible by switching to growth on the (30$\bar{3}$1) plane.

He says that the (30$\bar{3}$1) plane offers a much wider laser diode design space.

Theoretical calculations suggest that it is possible to grow $In_{0.06}Ga_{0.94}N$ layers that are 60 percent thicker on this plane than the (2021) one.

The opportunity to grow thicker layers enables the growth of waveguide structures with sufficient refractive index contrast that do not use AlGaN, but just InGaN and GaN.

Eliminating AlGaN cladding layers is a big deal. "Growth of thick AlGaN layers are unfavorable because they can increase device voltage, decrease device lifetime, reduce device yield and reduce reactor stability," says Hsu.

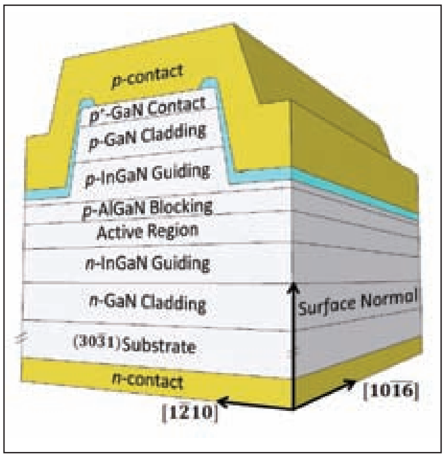
What's more, AlGaN layers usually require supperlattices, and this increases epiwafer growth times and ultimately manufacturing costs.

The team used MOCVD growth on free-standing GaN substrates provided by Mitsubishi Chemical to fabricate their blue InGaN/GaN laser diodes on the (3031) plane.

These devices produced a threshold current of 5.6 kA/cm^2 and a clear lasing peak at 445 nm. Electroluminescence of the laser shifted by just 4 nm when the current density was cranked up from 0.3 kA/cm^2 to 6.0 kA/cm^2.

This very small shift in wavelength suggests that the device is capable of being driven at high modulation rates. The laser's operating voltage was 9.9 V, a relatively high value that is probably due to unoptimized p-contacts and doping profiles.

Shifting the emission of these lasers from the blue to the green is one of the next goals for the team. This requires an increase in the indium-content of the active region. The team is looking into this, and investigating how indium incorporation on the (30$\bar{3}$1) plane compares to that on other semi-polar planes. Po Shan Hsu *et al*. Appl. Phys. Express **3** 052702 (2010)



Growth of lasers on the (30$\bar{3}$1) plane enables the fabrication of structures free from AlGaN cladding layers. Lasers that do not contain AlGaN cladding layers can have lower operating voltages and last longer.

PICs could benefit from square lasers

A team of researchers at the Chinese Academy of Sciences has built the first square microlasers featuring output ports on opposite corners.

These devices that are produced by planar processes could provide a key building block for the fabrication of photonic integrated circuits (PICs).

The shape of microdisk lasers governs the direction of their emission. Square lasers with output ports in the corners were investigated, because this design can realize highly confined modes while still producing directional emission.

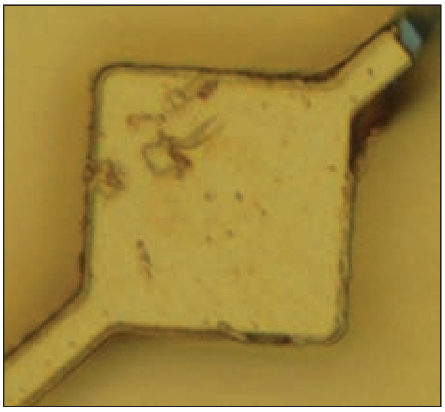
Fabrication of the structures begins by using plasma enhanced CVD to deposit an 800 nm-thick SiO_2 film onto the top of epitaxial laser structures grown on InP. Photolithography defines the profile of the laser, before plasma and wet etching techniques remove the oxide film. A second SiO_2 layer is then deposited, with further photolithography and etching steps defining a window in the cavity. The addition of Ti/Au and Au/Ge/Ni contacts creates n and p-type electrodes.

A 1514 nm laser created by this process delivered 4.8 μW at a 72 mA injection current. "It's only a concept device, and the threshold current and output power are not good enough for making photonic integrated circuits yet," explains coresoponding author Yong-Zhen Huang.

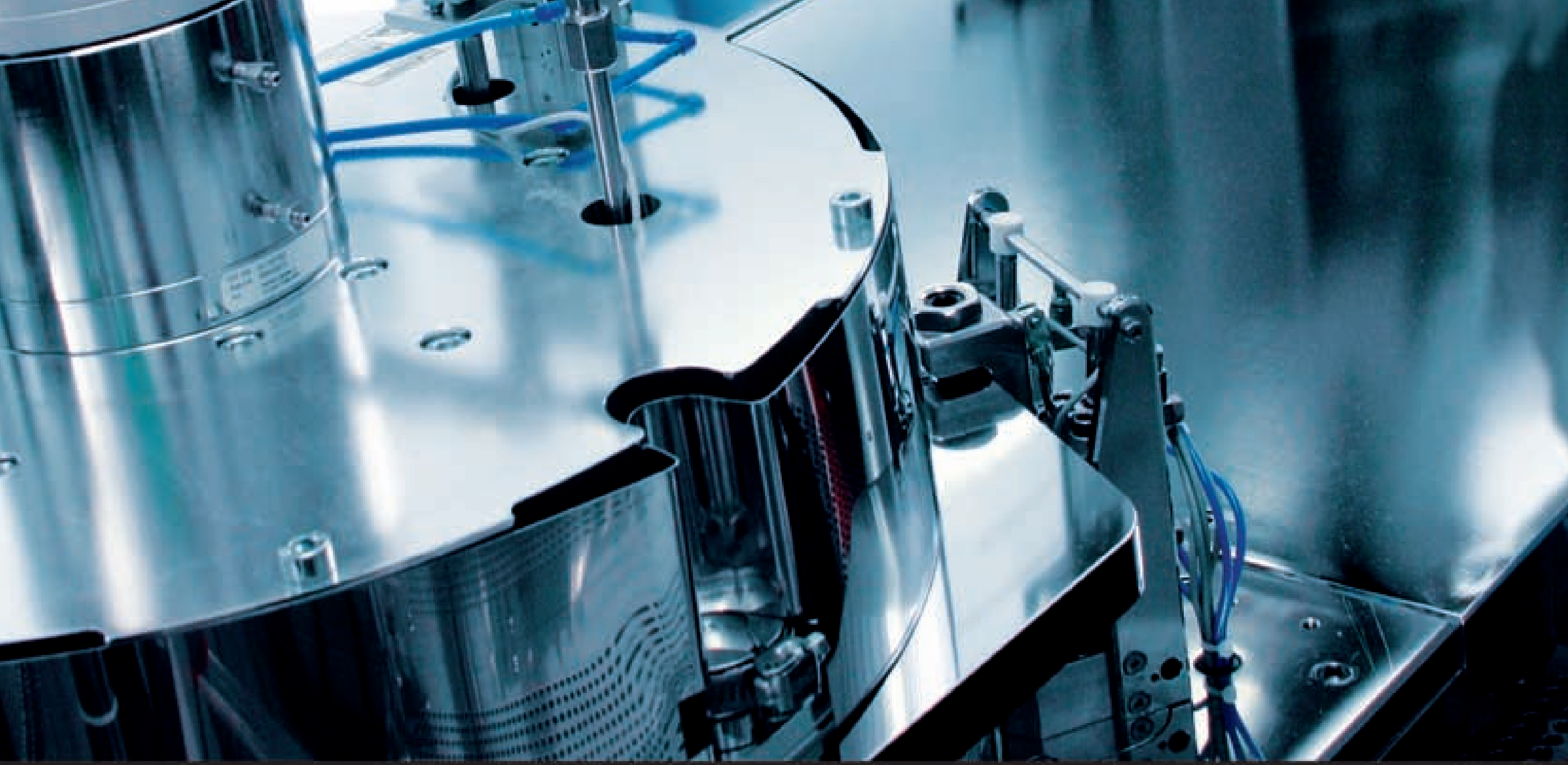
He says that the team will now focus on reducing the threshold current and increasing the output power of its microlasers.

"We are now investigating coupled circular resonators, which can have over 99 percent coupling efficiency, according to finite-difference time-domain simulations," says Huang.

K-J. Che *et al* Electron. Lett. **46** 585 (2010)



The two-port square microlaser has 20 μm sides and output waveguides on opposite corners. Credit: CAS.



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