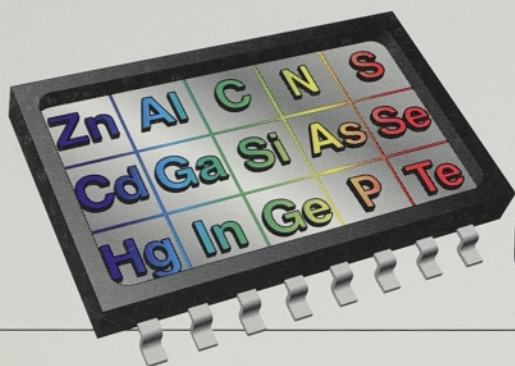




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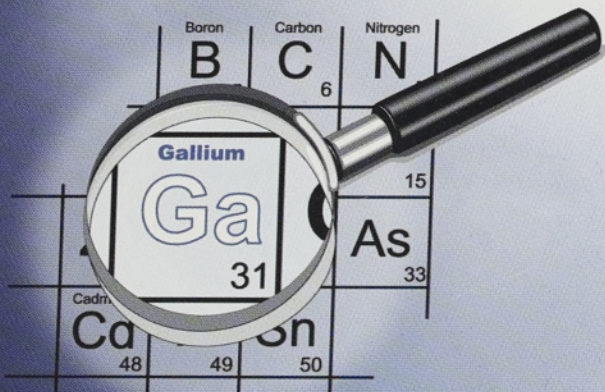
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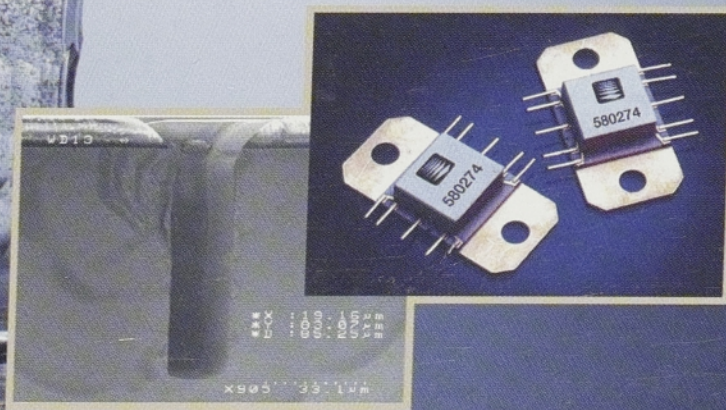
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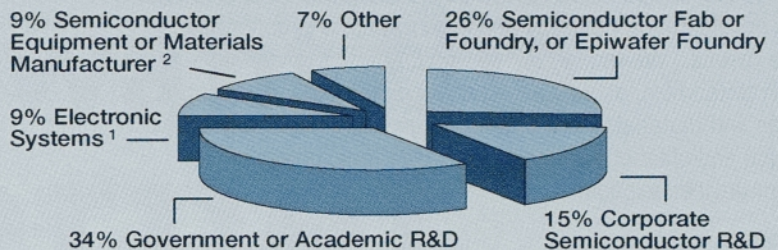
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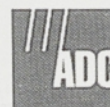
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Will design and develop optical solutions for fiber optic telecommunication products, and participate in all phases of the program including feasibility, prototype, production evaluations, product certification and product launch. Must possess a M.S. or Ph.D. in Optics, Physics or related field and have experience with fiber optic subsystems, understand coupling issues for both single and multimode fibers.

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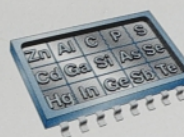


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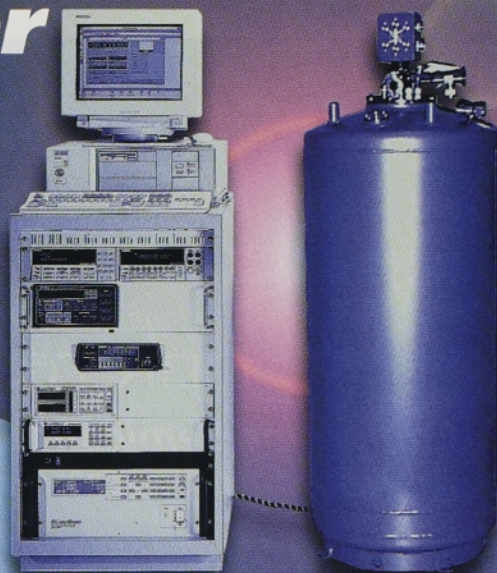
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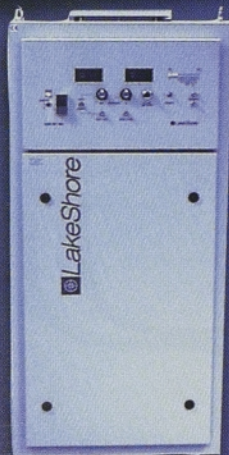
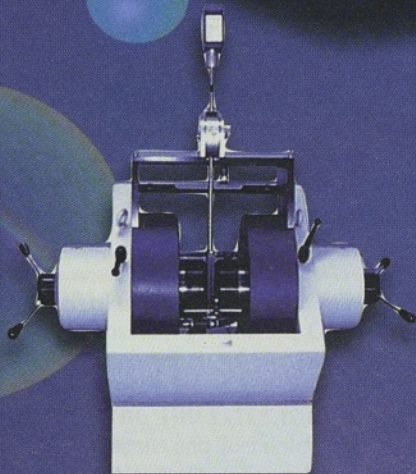
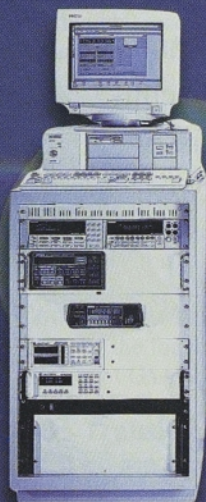


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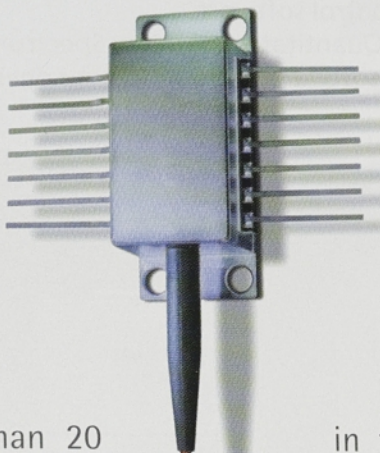
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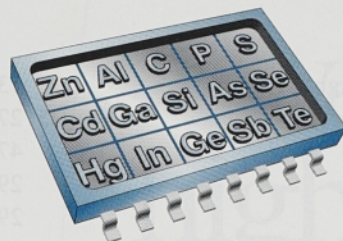
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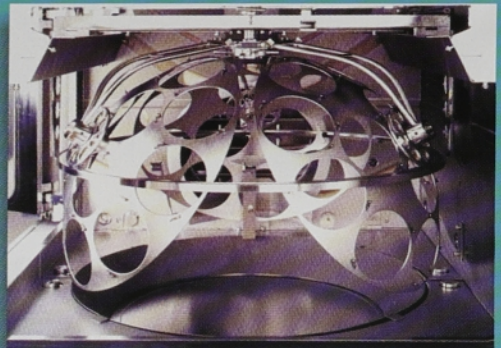
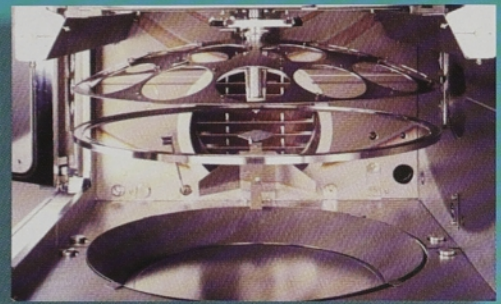
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2001—A Happy New Year?

TIM WHITAKER

For the compound semiconductor industry, 2000 has been a bumper year. When all the counting is complete, sales for the entire industry during 2000 could exceed \$15 billion, compared to around \$11 billion in 1999. However, the stock market turmoil in the last few months of 2000 has resulted in doom-and-gloom predictions for the coming year. Spending is being slashed in the fiber-optics industry, sales of wireless handsets are slowing down, the GaAs industry is facing an over-capacity situation that will force down prices . . . is it time to find a new industry?

When the dust has settled, and the United States finally has a new President, the situation will be broadly similar to the start of 2000: there will be a huge level of demand for components from the wireless and fiber-optic communication industries. Regarding the wireless market, Earl Lum of CIBC World Markets says "I don't think the demand for compound semiconductor devices has lessened at all."

To a large extent, the last few months have brought a sense of reality back to the industry. Earlier in the year, when many companies were performing extremely well, predictions of very high growth rates became commonplace. Investors also began to believe that companies could sustain or increase these growth rates, quarter after quarter. When growth targets—and expectations of investors—were not met, as happened to many companies towards the end of the year, the stock prices were hammered.

Consider the wireless handset market. At the start of 2000, says Earl Lum, sales projections for the year were somewhere just above 400 million units. "Then, some analysts got too excited about the first quarter numbers, and started talking about shipments in the 475–500 million range," he says. "But now things have settled down and we're back to a consensus figure of around 420

million. The only slowdown that occurred was a slowdown in the unrealistic and over-aggressive projections that had been made at the beginning of the year." A number of companies (notably Anadigics) were hit by inventory corrections, where customers asked them to stop shipping parts due to a lack of other components, but the underlying trend is still very positive.

Others concur. "The demand for handsets is much larger than the manufacturers are able to sustain right now," says Ray Jodoin, principal analyst with Cahners In-Stat's Global Wireless Service. Jodoin does not see any component slowdown; in fact, lack of certain types of components is one reason that handset manufacturers can't make enough products. "The industry went from a little over 250 million handsets last year to over 400 million in 2000. That kind of expansion certainly strains the supply pipeline," he says. "But there is absolutely nothing that I know of on the demand side that would indicate that things are slowing down, in fact just the opposite."

At the end of November, Allied Business Intelligence (Oyster Bay, NY) summarized the findings of their "Wireless Data Networking 2000" report as follows: "Despite some recent poor news concerning the slowdown in wireless, the reality is that wireless is still growing at a rapid pace. Overall, wireless subscribers of every type will continue to grow, while the deployment of infrastructure supporting both narrowband and broadband wireless applications will also continue to flourish."

The outlook is equally positive in the fiber-optics industry, even though the failure of a number of leading players to sustain their meteoric growth rates resulted in

a big stock sell-off towards the end of the year. "Investors are shooting first and asking questions later," says Jim Jungjohann of CIBC World Markets. "Any little negative statement is having a dramatic ripple down effect on stock prices."

Jungjohann believes that concerns over a slowdown in capital equipment spending have been over-blown. "We don't see any capital equipment slowdown flowing down to the optical component sector," he says. "We do anticipate that the long-distance service provider market will be extremely volatile, and will undergo a consolidation phase in the next two years. That volatility will have some very near term impact on component suppliers, but in aggregate the overall demand equation is very

much intact." In other words, there continues to be a huge demand for bandwidth, driven by factors such as the continuing development of the Internet, international deregulation, and the move towards the all-optical network. "We remain confident that the first companies to rebound from the recent market lulls will be those in the telecom equipment sector, driven by the sheer demand for bandwidth," says Jungjohann.

Supporting these views are market research firms such as RHK, which recently estimated that the worldwide market for optical components used in terrestrial DWDM and optical networking applications will grow from \$5 billion in 2000 to nearly \$24 billion by 2004—corresponding to a compound annual growth rate of 48%.

In short, despite the recent turmoil on Wall Street, demand within the compound semiconductor industry will continue to grow rapidly, and we look forward to a prosperous New Year.

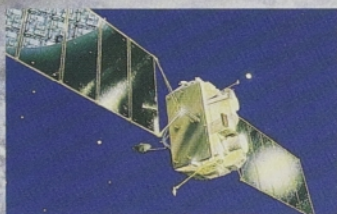
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Global Semiconductor Market Tops \$200 Billion; Rapid Growth for Compound Semiconductors

Spurred by sales of communications products and continued strong demand for PCs, the global semiconductor market will exceed \$200 billion for the first time in 2000, and will grow to \$319 billion in the next three years, according to the Semiconductor Industry Association (SIA).

Among the semiconductor product categories, the optoelectronics market, which includes laser devices and image sensors, will follow a steep growth ramp of 68% to end this year at \$10 billion, and is predicted to almost double in the next three years to \$19 billion. Sales of analog semiconductors, key components for telecommunications, will grow in-line with the industry during the next three years. The sector will increase 39% this year, growing to a market of \$47 billion in 2003.

The findings, part of the SIA's annual semiconductor forecast, estimate that global semiconductor sales during 2000 will reach \$205 billion, an increase of 37%, and will subsequently grow by 22% to \$249 billion in 2001 [see Table]. However, the industry will experience a cyclical downturn in 2002, with only 10% growth, due to over-capacity and falling prices in the DRAM market.

"Responding to the challenges associated with redefining and revitalizing the global communications system will propel the semiconductor industry toward the \$1 trillion goal in the next decade," says the SIA's Wilfred Corrigan, chairman and CEO of LSI Logic. "The PC is still a major growth driver, but for much of the industry there are faster growth opportunities associated

Global Semiconductor Market Forecast

	2000	2001	2002	2003
Value of Shipments (\$ billion)	204	249	274	319
Growth from previous year	+37%	+22%	+10%	+16%

SIA

with the new information-based economy." Corrigan added that the wide variety of communication opportunities in markets distributed around the globe would help temper and moderate future semiconductor business cycles.

The Semiconductor Cycle and the GaAs Industry

Sales of compound semiconductor devices are included in the SIA statistics, but are not broken out as a separate category. Consensus estimates from other sources indicate that 2000 compound semiconductor sales will exceed \$15 billion, equivalent to 7.5% of total semiconductor sales. The rapid growth of the optoelectronics sector and the GaAs industry indicate that sales of compound semiconductors will grow more rapidly than silicon semiconductors, so that compound semiconductors could reach \$30 billion, or nearly 10% of the worldwide total, by 2003.

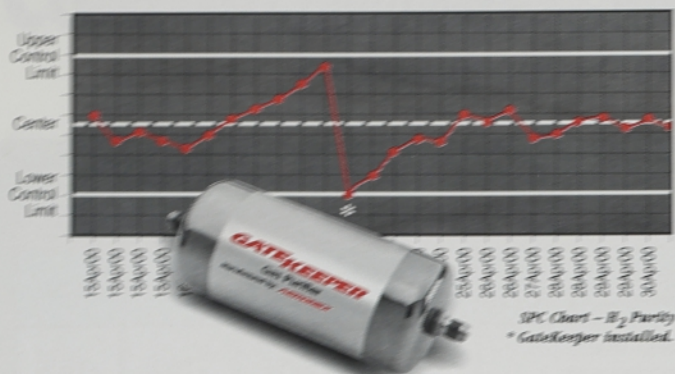
But, in the meantime, some analysts are predicting that the GaAs industry could soon experience a cyclical downturn in the value of shipments, even though the number of parts shipped, particularly for wireless communication applications, will continue to grow at a rapid rate. It is thought that the large number of fabs currently being built around the world, especially in Taiwan, could create an over-capacity situation that would lead to fierce price competition. Essentially, problems can be expected if the worldwide GaAs fab capacity grows at a much higher rate than market demand. However, there are other factors that will limit the output of the new and existing GaAs fabs in the coming year or two, most notably the availability of GaAs substrates. It seems that the substrate supply shortage will prevent a glut of GaAs capacity, and keep global GaAs production broadly in step with market demand.

Infineon to Divest Osram Opto Semiconductors

Infineon Technologies (Munich, Germany) plans to sell off its stake in Osram Opto Semiconductors as part of its increased focus on core businesses for Si DRAM storage products and components for fast growing communications markets. At a recent press conference, Infineon's President and CEO Ulrich Schumacher said the company will shed its optocoupler and optoelectronic semiconductor holdings. These include Osram Opto Semiconductors, a joint venture between Infineon and Osram to develop LED lighting.

"The optocouplers business has nothing to do with our strategic target segments," said Schumacher. "We also have 49% in the opto joint venture with Osram for LEDs, which we will divest. We are in discussions with several interested parties and think we are pretty close to a solution. We hope to close [negotiations] in the next quarters and definitely by next fiscal year [September 2001]." By shedding the units, Infineon will lose about \$680 to \$770 million in revenue, but "will raise an attractive amount of capital," added Schumacher.

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Lucent Microelectronics Spin-Off Will Be Named Agere Systems

The company formed by the spin-off of the Microelectronics Group of Lucent Technologies will be known as Agere Systems. As the leading worldwide manufacturer of communications semiconductors, Agere will be comprised of two major divisions—integrated circuits and optoelectronic components. Lucent plans an initial public offering for up to 20% of the new company by Q1 2001, and intends to spin off the remaining shares in a tax-free distribution by the summer of 2001. For more details, see CS 6(6), p.8. Agere Systems is the only company with both optoelectronics and integrated circuits capabilities in-house together with the systems expertise to develop end-to-end net working solutions that address the convergence of photonics and electronics.

Big Business Briefs

General Electric (GE) plans to acquire **Honeywell** in a deal worth \$45 billion. The two giant companies have various diverse interests in compound semiconductors: GE Lighting is involved in GELcore, a joint venture with Emcore that develops LED-based lighting products, while separate units of Honeywell are leading manufacturers of VCSELs and sapphire substrates.

Lockheed Martin has completed the sale of its Aerospace Division, including **Sanders**, to **BAE Systems North America** for \$1.67 billion. Sanders operates a GaAs fab in Nashua, NH and also fabricates IR imaging products including GaAs-based QWIPs and HgCdTe arrays.

Mitel to Separate Out Its Semiconductor Business

Mitel is planning to split into two units by March 2001, separating its high growth semiconductor unit from its slumping communications systems business. Mitel Semiconductor, headquartered in Kanata, Canada, manufactures a broad range of communication ICs using internal silicon bipolar and CMOS processes. The company also manufactures optoelectronic components, including VCSELs and parallel fiber modules, at its facility in Jarfalla, Sweden, which was acquired from ABB HAFO in 1996.

The split will allow the market to award a higher valuation to Mitel's semiconductor unit, based on a projected sales growth next year of 30%. The split will also improve competitive issues, since the largest customers of the semiconductor unit are the major competitors for its communications systems business.

Nokia Paints a Rosy Picture of the Wireless Market

At its annual analyst meeting in December, Nokia, the world's leading mobile phone manufacturer, allayed some of the industry's fears about slowing sales in the wireless market. The company reiterated previous statements that it expected worldwide handset sales to exceed 400 million units in 2000, and to reach approximately 550 million in 2001. Nokia believes its handset market share is over 30%, close to twice that of the number two player. The company extended its revenue growth target of 25–35% to include 2003, and expects revenue growth in the first half of 2001 to be in the upper range of 25–35%.

Nokia also accelerated its estimate for future subscriber growth, stating that the 1 billion milestone for global subscribers may now be reached during the first half of 2002 rather than by end of 2002 as previously predicted. There will be an estimated 700 million phone owners worldwide at the end of 2000.

"In the mobile world, the best is yet to come," said Jorma Ollila, Nokia's Chairman and CEO. "The opportunities in the future are enormous as we enter an unprecedented time when mobility, Internet, digitized media and other content can be combined and become available to almost anyone, anytime and anywhere."

Other Highlights

- Nokia's target network markets will grow at about 30% annually over the next 3 years, reaching approximately EUR 90 billion (~US\$ 79 billion) in 2003.
- The market for replacement handsets is growing rapidly: Nokia estimates that 40–50% of buyers in 2000 were users upgrading their existing phones, and that this figure will increase to 70–80% in subsequent years.
- Nokia expects the market of Internet-enabled handsets to reach about 60 million in 2000, rising to 200 million in 2001. WAP handsets will represent some 180 million of the total.
- Nokia estimated that there will be around 100,000 3G base stations shipped in 2001, rising to 300,000 base stations in 2002. Large scale deliveries of W-CDMA base stations will commence in the second half of 2001, with mass commercial launches in 2002.
- Nokia is targeting a 35% share of the third generation W-CDMA market. The company recently signed a supply contract with AT&T Wireless Services (AWS) valued at more than US\$1 billion over four years, making it the largest ever infrastructure supply agreement for Nokia.

NTT DoCoMo Buys Stake in AT&T Wireless

Japan's biggest mobile phone company, NTT DoCoMo, will spend \$9.8 billion to get a 16% stake in AT&T Wireless, which will be spun-off from AT&T next year. By mid-2001, DoCoMo will be the first carrier in the world to implement a W-CDMA 3G network, with service available in Japan. AT&T intends to become the first national wireless carrier in the US to introduce W-CDMA, and will also license I-mode technology from DoCoMo - this allows users to exchange email and browse websites using their handsets.

RHK: "Market for DWDM Components to Quadruple in Four Years"

The worldwide market for optical components used in terrestrial DWDM and optical networking applications will grow from \$5 billion in 2000 to nearly \$24 billion by 2004 according to RHK, a telecom market research firm based in San Francisco, CA. Drivers include the underlying growth in systems, the increasing optical content of modules and the higher price of next-generation components. RHK's study predicts a 130% growth rate in 2000 for the market overall, with no single product category growing less than 80%. A growth rate of 90% is expected in 2001.

RHK says specific product segments will exhibit triple-digit growth year-over-year. New products such as Raman gain modules, 40 Gb/s active components and tunable lasers will be deployed in optical networks starting in 2001. Together with next-generation products for optical bandwidth management, these new products will grow in excess of 200% per year to over \$4 billion in sales in 2004.

"This spectacular year-over-year growth is being driven by double-digit growth in DWDM systems, multiplied by the impact of numerous system performance improvements such as higher channel counts and faster transmission speeds, and by the increasing complexity of optical modules," said John Lively, senior analyst for optical components at RHK.

* In a separate study prepared for Nortel Networks, RHK has estimated that the global demand for Internet bandwidth could soar 300-fold in the next 8–10 years, corresponding to an annual growth rate of 200%. By July 2001, there will be some 800 million Internet users, compared to 380 million in November 2000.

CIR Identifies Rapid Growth for Tunable Lasers

Communications Industry Researchers (CIR), a consulting firm based in Charlottesville, Virginia, is predicting that the US market for tunable lasers will grow from \$5 million in 2000 to \$1.2 billion by 2004. According to the authors of "Optical Components Markets: 2000–2004", tunable lasers allow network providers to cut down on fixed wavelength laser inventories and provide improved fault and bandwidth provisioning management. In addition, this type of device could enable novel ways of all-optical switching, and CIR believes that this functional versatility will fuel the rapid growth.

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UEC Introduces Third Generation AlInGaP LEDs

United Epitaxy Company (UEC) has developed a new third generation AlInGaP LED structure that doubles the light output compared to its previous AlInGaP devices. Operating in the 560–650 nm range, the new emitters feature a combination of several technologies, including a MQW active region, a current confining structure, and surface roughing, which reduces total internal reflection and improves light extraction from the device (see Figure). The combination of a current confining layer and a ring electrode help to increase efficiency. The device also features a high reflectivity distributed Bragg reflector (DBR) to reflect light emitted in a downward direction back towards the top of the device, preventing absorption by the GaAs substrate.

The luminous efficiency of the new LEDs is in the 20–30 lm/W range. UEC says this is comparable to the best commercially available transparent substrate (TS) AlGaInP LEDs, which typically employ a wafer bonded transparent GaP substrate as the support. Expected to be in production from January 2001, UEC says its new device also exhibits very good electrical and thermal characteristics, with a typical forward voltage of less than 2.75 V at 100 mA.

According to sales director Jack Yeh, UEC is already working on a wafer-bonding approach for its next generation of AlGaInP LEDs. "The next devices will employ a transparent adhesion layer to bond the LED epiwafer to a totally transparent substrate such as a sapphire wafer or glass," says Yeh. "The luminous intensity of the new AlGaInP LEDs will be higher than the commercially available (TS) AlGaInP LEDs." The new wafer-

bonded LED is expected to be available in the fourth quarter of 2001.

UEC is also working on InGaN-based blue and green LEDs, and has developed a new treatment to activate Mg, commonly used as a p-type dopant in GaN. Activation is usually achieved by thermal annealing in a nitrogen atmosphere at a temperature above 400°C. UEC has filed two patent applications for its own approach, which uses a microwave oven treatment in air at a temperature of less than 100°C for about one minute.

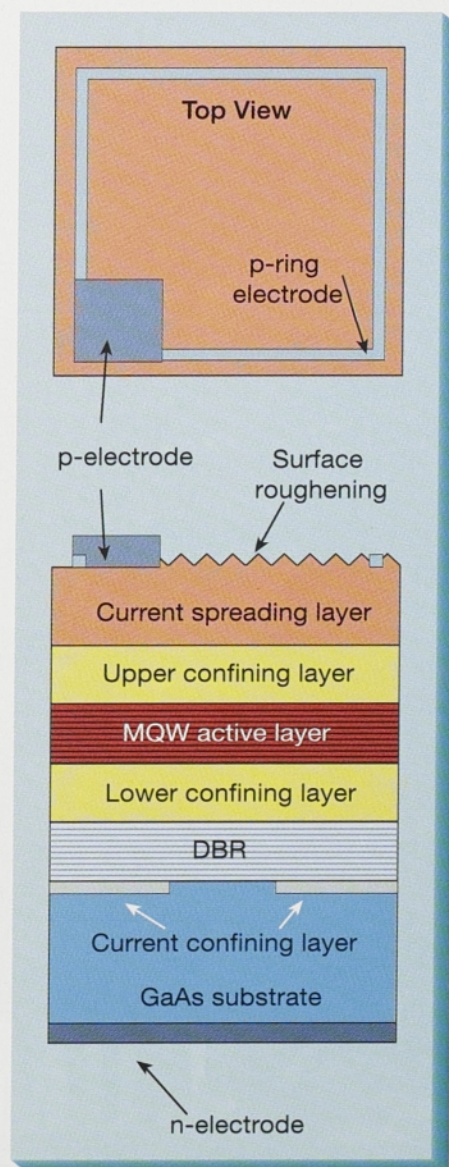
In more news, UEC has also expanded its HBT epitaxial capabilities. Several recently installed MOVPE reactors are now operational and several more will be delivered in the next few months. UEC recently began offering 4- and 6-inch InGaP HBT epiwafers, and is also developing InGaP PHEMT epiwafers.

Further Details on UEC's Patent Dispute with LumiLeds

As we described in a previous issue, UEC is involved in an on-going patent lawsuit in which LumiLeds Lighting is claiming infringement by UEC of US patent no.5008718 [see CS 6(7), p. 19].

We have received further details to clarify the circumstances leading to the lawsuit. In early 1998, HP told UEC and its customers that UEC was in violation of the 718 patent. HP then sued Robert G. Allen Company (RGA), a US distributor of UEC's AlInGaP products. In February 1999, a consent judgment was entered—RGA agreed that UEC's AlInGaP devices infringed the 718 patent, and agreed to stop selling these products.

However, UEC denies that its products infringe the 718 patent. In September 1999, UEC filed a lawsuit against HP alleging unfair business practices and seeking declaratory relief that the 718 patent is invalid, unenforceable and not infringed. In July 2000, HP, Agilent and LumiLeds filed a counter-claim against UEC, asserting that UEC's products infringe the 718 patent—this was the lawsuit previously described in our magazine.



Top view and cross-section of UEC's new third-generation AlInGaP LED structure

Correction: Chip-Shaping Technology for Blue and Green LEDs

In our last issue, we described how Cree has doubled the brightness of its nitride-based LEDs using a chip-shaping approach [see CS 6(8), p.11]. This was described as "Cree's new patent-pending InGaN-on-SiC LED design". In fact, Cree licensed this technology from Osram Opto Semiconductors, and we apologize for this error.

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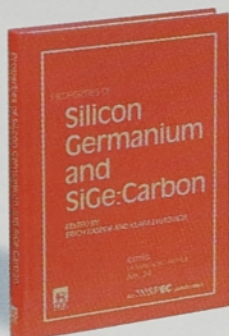
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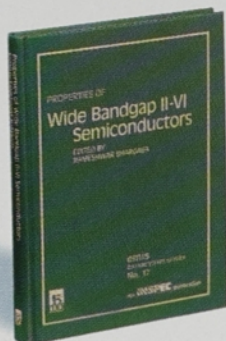
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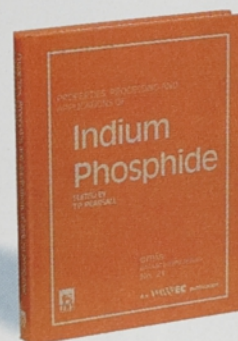
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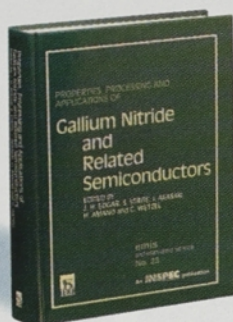
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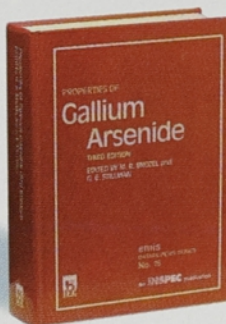
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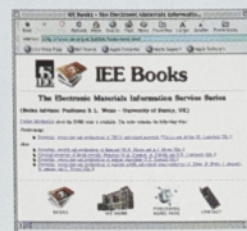
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Toyoda Gosei Announces Violet LEDs, Comments on Patent Case

Toyoda Gosei (Nagoya, Japan) has claimed that it has become the first company to mass-produce violet LEDs. Operating at 380 nm, the new GaN-based LEDs will replace UV lamps that are used to activate optical catalysts in air purifiers. Toyoda Gosei will supply the LEDs to Toyota for use in several of its new model automobiles. The LEDs provide more efficient activation of the titanium oxide optical catalyst in the air purifier, which decomposes organic substances in the air into water and carbonic acid. Eventually, violet LEDs will be used in home appliances and lighting equipment, and the company is targeting annual sales of 1 billion yen (~US\$9 million) in two to three years.

Toyoda Gosei is currently involved in several lawsuits with Nichia over alleged LED patent infringements. In July, the Tokyo District Court ordered Toyoda Gosei to suspend production and sales of certain types of nitride-based LEDs [see CS 6(7) p.18]. The company says it

developed violet LEDs "without using any knowledge subject to court action," and has applied for 20 patents relating to violet LED technology.

Toyoda Gosei recently commented on the Tokyo ruling in favor of Nichia, which relates to a patent describing the electrode arrangement of nitride-based LEDs (Japanese patent no. 2748818). This case, the third of six lawsuits filed by Nichia against Toyoda Gosei, claimed infringement against the patent by the latter company.

"Toyoda Gosei finds it regrettable that its claim of non-infringement was rejected in the ruling, and will continue to assert that claim through appeal procedures," read a statement issued by the company. "It will also continue to pursue its claim regarding the invalidity of the patent in question."

In the ruling, the court awarded Nichia a sum of 100 million yen (around \$900,000) and ordered Toyoda Gosei to stop manufacturing and selling the offending LEDs. Toyoda Gosei has stated that the ruling will have little or no impact on its ongoing business. "This ruling relates to the electrode arrangement of former Toyoda Gosei products and does not apply to any products currently manufactured or sold by Toyoda Gosei," the statement continues. "The ruling therefore does not affect our current LED manufacturing or sales, and so will not cause any inconvenience to our customers."

Uniroyal Opens Facility, Announces New Products

Uniroyal Optoelectronics has opened its LED wafer fab in Tampa, Florida, after completion of a \$35 million phase 1 building program. The highly automated facility is being used to manufacture InGaP-based blue and green LEDs, as well as red AlInGaP devices.

A second phase of construction, which will complete the build-out of the remaining 33,000 sq. ft. of the company's 77,000 sq.ft. facility, has already begun. This work includes expanding capacity for epitaxial, fabrication and testing processes as well as increasing the facility infrastructure and support. The new facility will have room for approximately twenty new MOCVD reactors. The first new system is scheduled for delivery in January and an additional four reactors to arrive in the April to June time frame. The expansion, which is expected to be complete in mid-2001, also includes a R&D facility.

Uniroyal is now manufacturing InGaP-based LEDs on 2-inch sapphire wafers. These POWER-Ga(i)N™ devices are available as blue (450 and 470 nm), cyan (505 nm) and green (525 nm), and can achieve brightness levels of 1.5-2 mW for unencapsulated bare die at 20 mA. At longer wavelengths, the company's AlInGaP devices are available in die or 3-inch epiwafer form. Red (626 nm) and red-orange (621 nm) LEDs are now in production, and other colors are expected by mid-year 2001. The POWER-BR(ite)™ AlInGaP LEDs are grown on GaAs and use a buried DBR structure to prevent absorption by the substrate. Very high brightness exceeding 180 mcd has been achieved for unencapsulated bare die at 20 mA.

Uniroyal has also invested in specialized test equipment that is capable of providing known good die in high volume, a feature that the company believes is unique in the industry. Three levels of product are currently offered; these are whole undiced wafers (thinned or unthinned) that are sample tested; diced wafers that are either sample tested or 100% tested; and die that are 100% tested and sorted according to defined parameters.



Intelligent Epitaxy Technology, Inc.

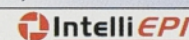
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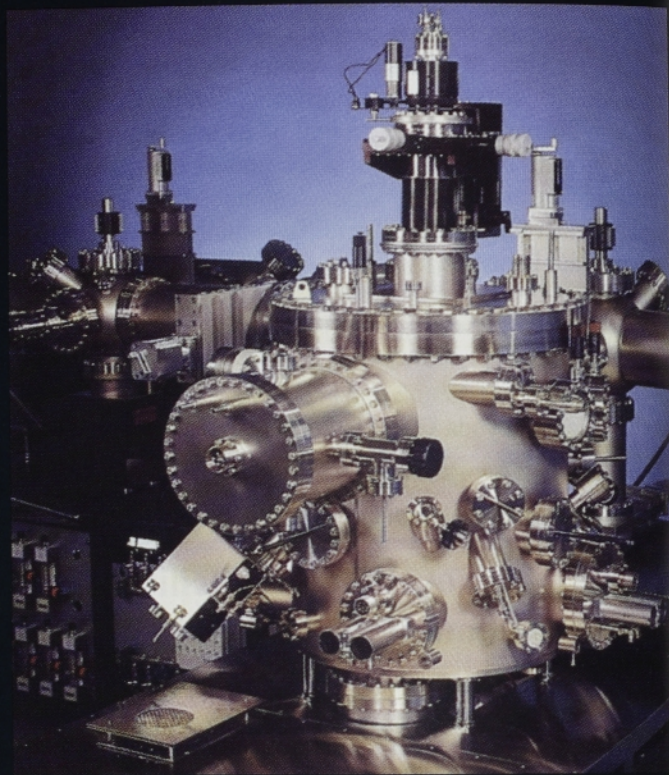
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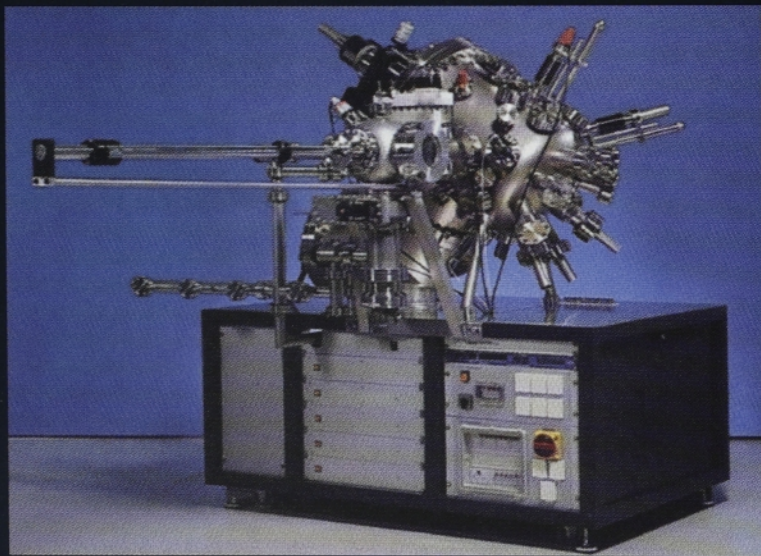
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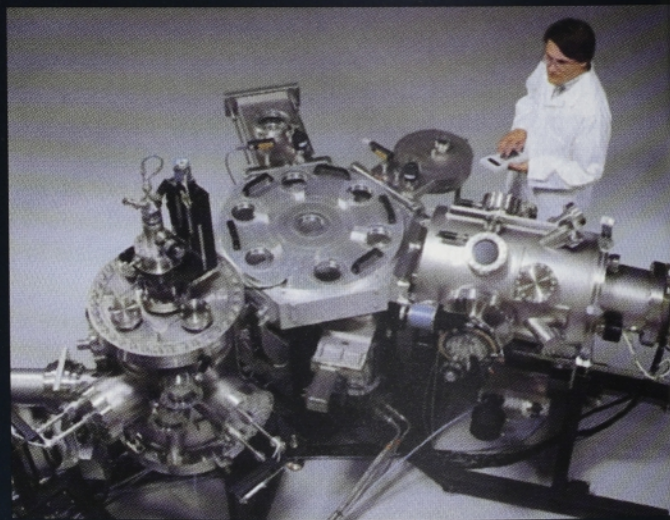
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LumiLeds Increases Brightness of AlGaInN LEDs

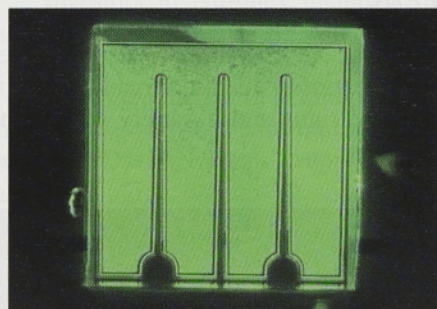
LumiLeds Lighting (San Jose, CA) has doubled the optical output power and efficiency of its AlGaInN high-flux blue and green LEDs. The company's new 470 nm blue LED has an output of 100 mW (5–8 lm), and the 540 nm green LED provides 40 mW (10–20 lm). A blue/green variant is rated at 70 mW (15–25 lm). In comparison, standard 5-mm blue LEDs provide a radiant flux of around 10 mW. LumiLeds says it is working on the next variant, and has already demonstrated blue devices with outputs of 180 mW.

The improvements are the result of performance advances in the company's high power LED chip and package design, which employs a flip-chip bonding arrangement to allow light to

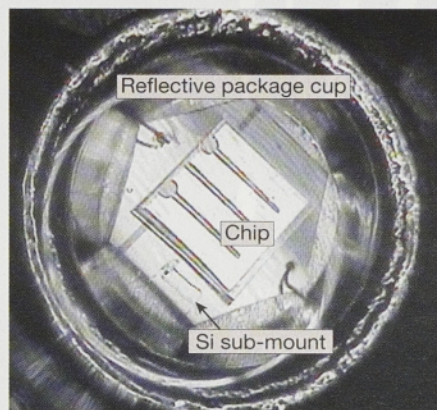
be emitted through the transparent sapphire substrate. At the same time, heat dissipation in the package is reduced in the large area ($1 \times 1 \text{ mm}^2$) high power chip by bump-bonding to a silicon sub-mount, which reduces the thermal resistance to 12°C/W . Finger contacts, which have been used in previous designs, are employed for the p-electrode to improve current spreading [see figures]. This helps to reduce the series resistance associated with the large area of the device to less than 1 ohm (at a drive current of 350 mA).

"These [new devices] are the highest flux LEDs on the market," says Frank Steranka, LumiLeds' materials research manager. "We continue to push the envelope to get increased light output and efficiency in our materials and LED packages."

In more news, LumiLeds has announced an product development agreement with Swarco Futurit, a leading LED-based traffic signal manufacturer. The first product—a retrofit LED traffic lighting signal developed for the European, Asian and South American markets—is now available. In addition to energy savings and lower maintenance costs, LumiLeds says the LED signals reduce the occurrence of so-called "phantom effect"—a visual disturbance caused by sunlight reflection that creates the appearance that the signal is on in an off-state.



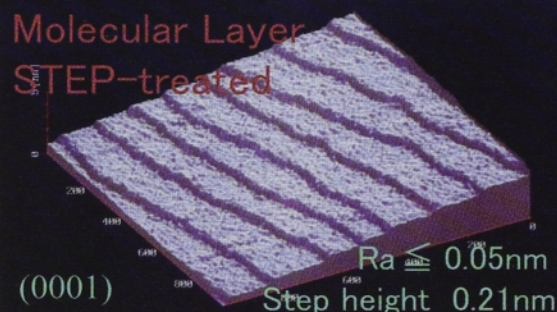
LumiLeds



LumiLeds

LumiLeds' new AlGaInN LEDs employ several features to enhance the optical output power and efficiency. (top) Finger contacts reduce the series resistance in these large-area devices. (bottom) The LED is flip-chip bonded to a silicon sub-mount to improve heat dissipation: light is emitted through the transparent sapphire substrate.

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Feature Articles

on

*GaAs Processing
& Packaging*

Beginning on page 56

Opto Tech Completes New Manufacturing Facility

Established in December 1983, Opto Tech Corporation is one of the world's leading manufacturers of optoelectronic chips and components. The company's 17,000 m² facility on the Hsinchu Science-Based Industrial Park, Taiwan, has recently been augmented by a much larger facility (73,000 m²) which was completed in October 2000. Opto Tech specializes in LED and sensor chips, and system products such as LED displays and LED traffic signal sub-systems.

The company is the largest manufacturer of LED chips in Taiwan, with an output of 1.7 billion chips per month. With the completion of the new facility, this figure is expected to rise to around 2.5 billion/month. Around 85% of the company's production volume is comprised of visible LED chips, with the rest being infrared emitters.

The company also manufactures a wide range of silicon-based sensor products including photodiodes, photo-transistors,

thermopile sensors and Hall devices. Many of these sensors are combined with infrared LED chips to form photo-couplers, solid state relays or optical interrupters. These are widely used for remote control of televisions, VCRs and air conditioner units as well as in security alarm systems.

Most epitaxial wafers are purchased externally, from either Japan or the US, although Opto Tech does make epiwafers for silicon devices.

Around 40% of Opto Tech's LEDs are classified as high brightness products (AlInGaP or AlGaAs) with the remainder being low to medium brightness. The company does not currently sell nitride-based LEDs, but has these products under development.

Opto Tech also manufactures a range of LED-based system products, including



Full-color outdoor display manufactured by Opto Tech, composed of modules containing red, green and blue LEDs.

full-color RGB outdoor displays (see Figure), traffic signals, variable/dynamic message signs and a variety of lighting products.

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NITRIDE NEWS

\$9.5 M Funding for Nitronex

Nitronex (Raleigh, NC), a 2-year old spin-off from North Carolina State University, has received \$9.5 million in first-round financing, which it says will be used to develop the first GaN devices integrated with silicon CMOS devices. Nitronex is using MOCVD to grow low defect density GaN epilayers on Si substrates using pendeo-epitaxial growth, which reduces the number of dislocations (typically 10^9 /cm²) in the epilayer by up to 4 orders of magnitude for subsequent device layer growth.

Pendeo-epitaxy is a proprietary technique developed at NCSU that removes the need for SiO₂ masks used in conventional lateral epitaxial overgrowth (LEO) [see CS 5(2), p. 16]. Rather than growing GaN through windows in a SiO₂ mask placed on an underlying GaN layer, the pendeo-epitaxy technique uses "posts" etched into the GaN. By optimizing the growth conditions, lateral growth of low dislocation density material is possible. Nitronex believes this approach will allow direct integration of high performance GaN components such as MES-FETs, HEMTs and HBTs with silicon devices.

Investors in Nitronex included venture capital companies and individuals such as RF Micro Devices' CEO and president, David Norbury, who has also taken a seat on the Nitronex board. Norbury is credited with helping to transform RF Micro Devices from similar start-up status into a GaAs manufacturer worth \$289 million. "David Norbury's support advances Nitronex's business and technology growth by an order of magnitude," said Bob Lynch, CEO of Nitronex. "His interest in Nitronex validates not only GaN as a material, but Nitronex as the company that will make GaN-based wireless products a reality."

Sterling Expands SiC Substrate Production Ten-Fold

Sterling Semiconductor, a subsidiary of Uniroyal Technology Corporation (UTC), has begun installation of additional crystal growth furnaces for the production of SiC wafers. The expansion is expected to increase Sterling's SiC production by a factor of ten when the installation is completed in 2001. Sterling also plans to add additional crystal growth furnaces to expand its R&D effort.

"Increasing the capacity of Sterling's SiC wafer production is one of the key elements of Uniroyal's investment in SiC," says Robert Soran, UTC's president and COO. "We continue to be encouraged by the fact that demand for SiC products exceeds supply, and this expansion is intended to meet the needs of customers requiring 4H, 6H and semi-insulating SiC wafers. Wafers will also be used internally by Sterling for the development of SiC devices."

Sterling's expansion plans also include a new 50,000 sq.ft. facility in Northern Virginia that will allow consolidation of its current operations in Sterling, VA and Danbury, CT.

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Cree Buys UltraRF

Cree is to acquire UltraRF, a manufacturer of LDMOS and bipolar RF power semiconductors for wireless infrastructure applications. The deal establishes a broad RF power technology platform for Cree, which already has a strong capability in SiC and GaN RF power devices. UltraRF is a division of Spectrian Corporation of Sunnyvale, California, and is being acquired for 908,000 shares of Cree common stock and \$30 million cash. The deal is expected to close by the end of the year.

Cree says the acquisition will enable immediate revenue-producing applications for RF products and also provide additional design, packaging and distribution channels for SiC- and GaN-based devices. The company will also sign a 2-year contract to supply Spectrian with semiconductors and a one-year agreement to jointly develop high linearity and gain driver modules, high efficiency LDMOS power modules and SiC MESFETs.

"The LDMOS technology offered today by UltraRF provides the solution in the 0.8 to 2.4 GHz range for wireless infrastructure," said Neal Hunter, chairman and CEO of Cree. "As we focus on the emerging opportunities at frequencies above 2 GHz and the build-out of third and future generations of wireless infrastructure, we believe that LDMOS technology, combined with Cree's demonstrated SiC and GaN RF products, could provide a total solution for applications above 2 GHz. By incorporating LDMOS, SiC and GaN device technologies, Cree will be the first company to offer a complete suite of products that aims

to significantly reduce the cost and increase the performance characteristics of available devices."

Cree Endows UCSB Chair in Solid State Lighting

Cree recently pledged a total of \$2.2 million to the University of California at Santa Barbara (UCSB), of which \$1.2 million will be donated to UCSB's College of Engineering to endow the Cree Chair in Solid State Lighting and Displays. The funds will also support research in the field of GaN-based electronic materials and devices. Cree says it will not receive technology rights as a result of the donations.

RF Nitro Demonstrates First GaN-based Multi-Watt Tunable Source

RF Nitro (Charlotte, NC) has demonstrated multi-watt AlGaIn/GaN HEMT-based voltage controlled oscillators (VCOs) with high efficiency. Varactor-tuned oscillators implemented using distributed networks oscillated at 3 GHz with 2.7 W output power, 27% efficiency, 3.5-30.0 V supply voltage range with nominal (6%) tuning bandwidth. The phase noise at 6 GHz was comparable to that of VCOs built using GaAs FET-based amplifiers.

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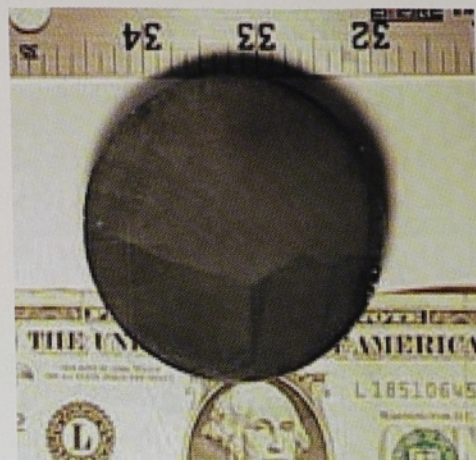
Galtech Reports Progress in Bulk CdTe Growth

Galtech Semiconductor Materials Corp. recently announced what it described as "very exciting" results from tests of large diameter (>2-inch) CdTe boules grown using the company's proprietary horizontal Bridgman (HB) growth techniques. Evaluation of 10-mm thick wafers, at an un-named US Government laboratory, were deemed to be of moderately high to high quality, based on an expert comparison with commercially available material. While not completely single crystal, the boule contained large areas that were single crystal, as shown in the photo.

Galtech reported that their own evaluation revealed three crystals and no rotational twins, which they consider to be a demonstration of "superior crystal growth and very good commercial potential". The largest crystal of the three seen in each sample accounts for approximately 70% of the total volume in each sample. Speaking on behalf of Galtech, William Tunnell, said; "This is significant because it means that we should be able to obtain higher yields than the current industry average

for high grade CdTe that ranges from 5% to 15%. This is significant and very encouraging considering this boule was not seeded. In other processes, even when the boule is seeded the result is, many times, a large number of crystals growing in the boule (i.e. a polycrystalline structure). We expect to do much better in future runs of boules that are seeded."

Galtech also reported that crystalline material in the boule demonstrated high resistivity, which is said to be unusual for undoped CdTe. The ability to achieve high resistivity is important for detector applications. Tunnell said; "The fact that we demonstrated high resistivity without the addition of a doping agent emphasizes the superior quality of the crystalline structure of the boule we produced and gives us the confidence that resistivity can be improved even more in the future with the addition of a doping agent." He also noted that the X-ray diffraction rocking curve was 15 arc seconds, which he said further supports the conclusion that the quality of the crystalline material in the boule was high.



Large diameter CdTe wafer fabricated by Galtech.

Applications

Galtech, a 3-year old R&D company based in Provo, Utah, is developing CdTe with an eye on applications in the areas of medical imaging, commercial and military aerospace, and nuclear emissions monitoring. Examples include CdZnTe flat panel dynamic receptors for digital X-ray machines that can operate without film and can produce streaming video images. Medical imaging is a large and growing market currently in excess of \$3 billion in annual equipment sales. "The potential for a large volume of CdZnTe to be sold in this market is very good given the proper mix of performance and price," said Tunnell.

In the aerospace area, Galtech plans to join the supply chain for HgCdTe-based IR detectors for guidance and night vision devices. According to Tunnell, "military usage of HgCdTe has been shrinking due to a reduction in military spending. This drop has been partially made up by the continuing need for sensor arrays used in weather monitoring devices such as on board earth orbit satellites. While demand has been declining, so too have the number of suppliers capable of supplying high quality CdTe materials to this market. This has led to a continuing desire of aerospace contractors to find additional material suppliers." He also said that a new market is emerging for CdZnTe materials in X-ray and gamma-ray detectors in the nuclear industry.

Applied Optoelectronics Opens New Manufacturing Facility

Applied Optoelectronics (AOI) has completed the first phase of its move into its new manufacturing facility, located in Sugar Land, Texas. The company's 24,000 sq.ft. manufacturing facility will consolidate the fast-growing company's administrative offices, laboratories and three production lines in one headquarters.

The new production capability will allow AOI to enhance volume shipments of its single-mode DFB quantum cascade lasers with emission wavelengths of 4.6 and 5.2 μm . Using technology licensed from Lucent [see CS 6(6), p. 21], these lasers are suitable for sensing applications, including carbon dioxide and ammonia. The new plant also provides production capacity for AOI's planned line of mid-infrared photodetectors and VCSELs.

The new facility includes 6000 sq.ft. of class 1,000 and 10,000 clean room space. At the end of the year the company will initiate phase two of its move by taking delivery of three new multi-wafer MBE systems, including two 3 $\times$ 2-inch systems and a 4 $\times$ 4-inch system, slated for operation in January 2001. To accommodate its rapid growth, AOI also plans to start construction of a second building by April 2001, to contain more than 50,000 sq.ft. of clean room and office space.

In more news, AOI has received the 2000 SBIR Technology of the Year Award for its mid-infrared (3.3–4.2 μm) semiconductor laser, which was developed with SBIR funding from the BMDO, the US Air Force and the National Science Foundation.



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GaAs Building Boom Hits Japan

The GaAs industry in Japan has seemed curiously quiet over the past two years, seemingly standing still while first the US and then Taiwan went on a spending spree for new GaAs fabs.

It is possible that this phase is now over. On December 6, **Matsushita Electronics** announced that it will invest 22 billion yen (\$198 million) to build a new six-inch GaAs fab at its Uozu plant in Toyama Prefecture. Construction will begin in January, and the facility will be ready for operation in June 2002. This is the company's second compound semiconductor production facility, and when finished it will have a monthly capacity of 6,000 six-inch wafers. Annual production is expected to reach 60 billion yen (\$540 million), allowing Matsushita to more than double its compound semiconductor output. The company said the new fab is intended to keep up with surging demand from mobile appliance makers.

This will be the first six-inch fab in Japan, and it comes as somewhat of a surprise. Most observers expected the Japanese manufacturers to expand their capacity by using the new foundries that are springing up in Taiwan. And many throughout the industry will be relieved to see that the target completion date is not until mid-2002. At present, it is doubtful that there are enough GaAs substrates to fill this fab which, when operating at full capacity, will rank among the industry's biggest.

Matsushita is not the only Japanese GaAs company on the move. As we reported previously, **Fujitsu Quantum Devices** is spending approximately \$48 million to increase capacity at its four-inch GaAs fab in the Yamanashi prefecture from the current 4,000 to 5,200 wafers per month [see CS 6(6), p. 31]. The company also plans to outsource some of its production so as to achieve a combined capacity equivalent to 8,000 four-inch wafers per month by the end of the 2002 fiscal year. And in August **New Japan Radio Corporation** announced

that it planned to increase production of GaAs MMICs for use in mobile communications terminals. NJRC operates a four-inch GaAs fab in Kawagoe and assembles and tests ICs at its subsidiary Saga Electronics. The company is aiming to boost sales from 1.6 billion yen (\$14.5 million) in fiscal 1999 to 2.6–2.7 billion yen (\$23.6–24.5 million) in fiscal 2000.

More recently, **Mitsubishi Electric** announced plans for expanding its production of compound semiconductor devices, addressing both the high frequency and optical markets. The company will invest more than 15 billion yen (\$135 million) in equipment and facilities during the current fiscal year, and reports that it plans to maintain at least the same level of spending in future years. A seven-fold increase in the production of high-frequency devices for wireless transceivers and cell phone power amplifiers is also being targeted; this will bring Mitsubishi's output of these parts to 11 million units per month by 2005.

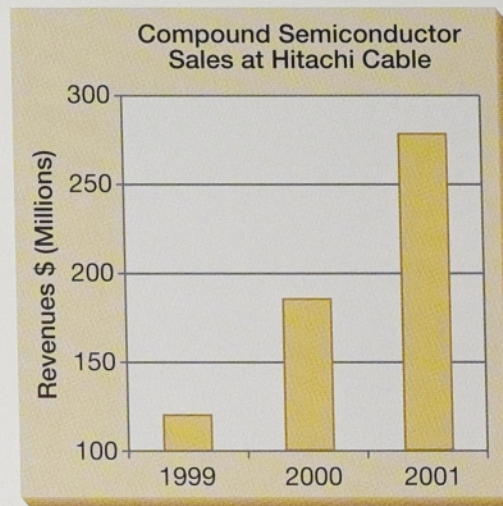
Production has already been increased at **NEC Electron Devices**. In a recent statement to the press, senior management revealed that GaAs IC shipments had risen to the equivalent of 5,000 four-inch wafers per month in the fall of 2000, compared to 3,000 wafers/month in the spring. The company also plans to spend 3 billion yen (\$27 million) to expand the production lines of NEC Kansai in Otsu to meet the growing demand for fiber-optic and wireless components.

After the increase in capacity, the company predicts that monthly shipments of its 5-inch GaAs wafer products will grow 40% to reach the equivalent of 5,000 four-inch wafers, and its 3 and 4-inch wafer production will rise to 1,000 four-inch equivalent wafers/month.

"As the popularity of the Internet and the volume of wireless communications continues to rise, the construction of fiber-optic networking infrastructure needs to accelerate," said a company

spokesperson. "Therefore, the demand for laser diodes, photosensitive components, cellular phone GaAs ICs, and high frequency components can be expected to stay high."

Of course, many more GaAs wafers will be required to support all that additional production. Accordingly, **Hitachi Cable** recently announced that it was increasing its compound semiconductor spending for fiscal 2000 from the initial 7.2 billion yen (\$66.7 million) to 12.0 billion yen (\$111.1 million). The company will expand the production capacity of its Takasago plant by June 2001 to be able to produce 45,000 semi-insulating LEC GaAs wafers and 24,000 epiwafers per month. These figures represent 130% and 200% increases, respectively. On the opto side, Hitachi Cable plans to increase production of semiconducting wafers grown by the VGF method to 95,000 pieces per month and to increase epiwafer capacity to 59,000 wafers per month. These figures represent increases of 50% and 70%, respectively. The company anticipates compound semiconductor sales will increase from 13 billion yen (\$120.4 million) in fiscal 1999 to more than 20 billion yen (\$185.2 million) in fiscal 2000 and over 30 billion yen (\$277.8 million) in fiscal 2001, which equates to a compound annual growth rate of more than 50%.





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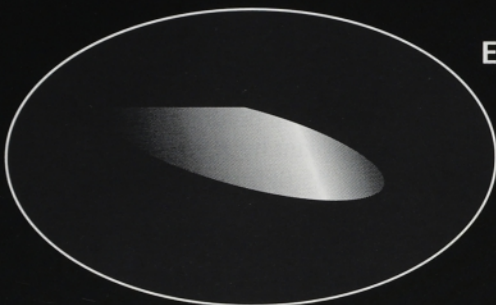
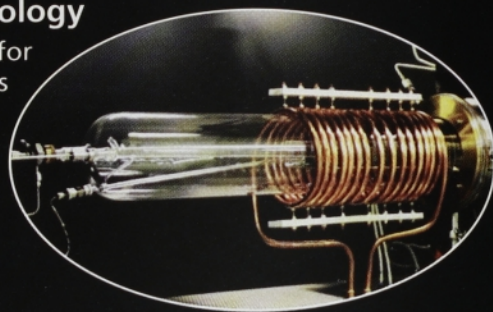
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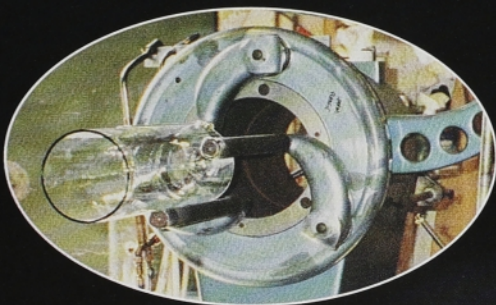
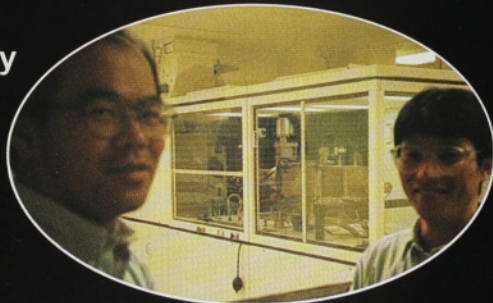


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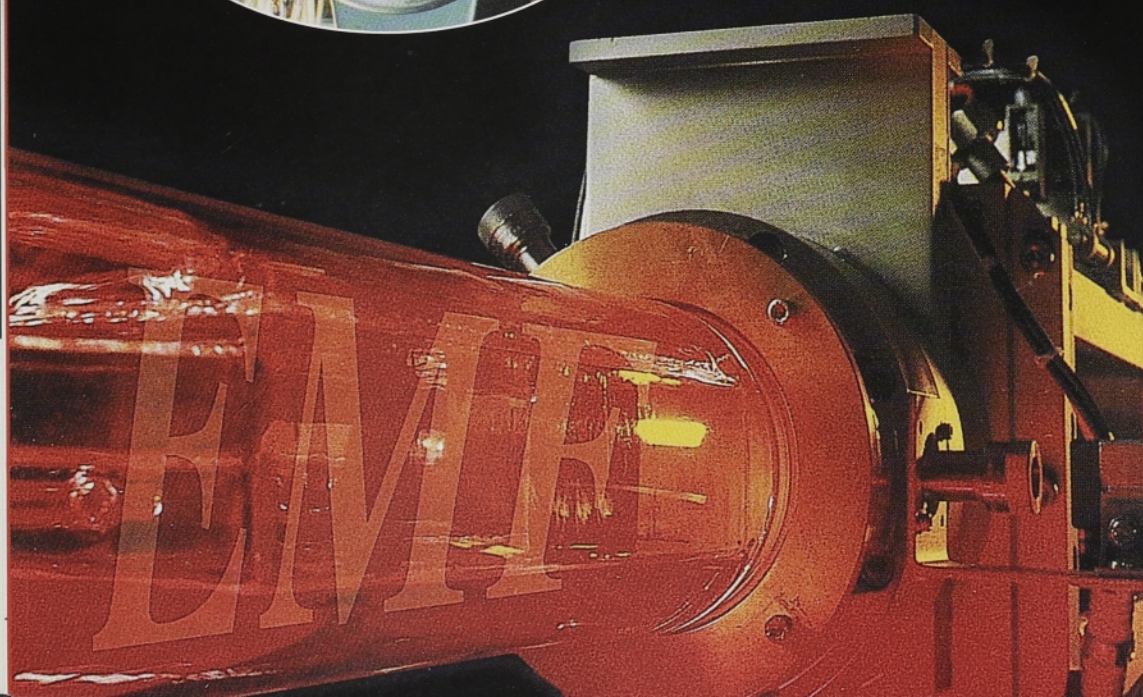
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Japanese Laser Update

Hamamatsu Photonics is expanding its production facilities in Miyakoda, Japan to include a second building for the manufacture of semiconductor lasers. The new building will be completed in February 2001, and operations will begin in October of the same year.

Products include diode pumped solid-state lasers used in materials processing, 50 mW CW lasers for laser printers, and range finders. Also under development are high power stacked laser arrays for use in laser machining, medical treatment and information processing.

The new plant is being implemented to accommodate the company's targeted sales of 1.5 billion yen (US\$13.6 million) in the first year of operations, followed by a projected 6 billion yen (US\$54.5 million) three years later.

Sharp recently released a new high-output infrared semiconductor laser and hologram laser. The first is the GH07812A2C, a 160mW infrared semiconductor laser for use in up to 16x CD-R drives. The company has also introduced the GH5R412A3C, a 4.8mm-thick hologram laser for use in 16x CD-R and 40x CD-ROM drives. They are sample-priced at 1,400 yen (\$13.08) and 2,200 yen (\$20.56), respectively. When the production ramp is finished the company hopes to ship a combined total of 500,000 units per month.

Matsushita Electronics has developed a 1.55-micron high-output DFB semiconductor laser for use in long-distance optical fiber communications systems. The company says it has employed a proprietary mass-transport grating technique to evenly form micro elements and independently control the thickness of deposition layers. As a result the laser can generate an output of 180mW, nearly two times the level of its predecessor. It also exhibits a reduced spectrum width of 0.3MHz or less, nearly 50% narrower than conventional

lasers. The DFB laser also achieves a relative intensity noise of less than -160dB/Hz. The company has filed applications for five domestic and five overseas patents for the technology.

NTT reports that it has developed a light source that allows more than 1,000 channels to be carried over optical fiber. The "super-continuum" light source uses the company's proprietary technology for taking advantage of a phenomenon in which the number of frequencies increases explosively when strong light transmits through glass and other transparent substances. When light travels through an optical fiber which transmits four or five types of light with wavelength intervals of 12.5GHz, light with more than 1,000 wavelengths is generated. The company has developed an optical fiber specifically designed to generate super-continuum light, as well as a light source which is a mode synchronizing laser, a semiconductor laser for generating multiple types of light with low noise factors through the fiber.

Mitsubishi Electric has developed a semiconductor laser for 10Gbps Ethernet communications, and will bring it to the market in spring 2001. The 1.3-micron DFB laser has a unique active layer that enables direct modulation, obviating the need for a semiconductor modulator and a Peltier cooler. It can be used at temperatures ranging from 0 to 70°C. The laser module uses less than 1/4 the number of components required of conventional modules and achieves 20% reduction in size and 95% cut in power consumption. In related news, Mitsubishi recently announced plans to increase production of optical devices to roughly 9 million units per month by 2005, compared to around 1 million units/month at present. 40 Gb/s laser diodes and other optical components will be commercialized in 2001, with 80 Gb/s components on the drawing board.

Nitride News

Higher Brightness Yellow InGaN LED from Nichia

Nichia Chemical recently announced it was introducing a yellow LED with an InGaN active layer that features a luminous intensity of 5cd at 20mA, three times the brightness of 575nm yellow LEDs now on the market. Nichia says that the variation of luminous intensity across the temperature range of -30 to 80°C is much less than with AlInGaP LEDs. The new LED is expected to go into outdoor applications such as message signs. Volume production is scheduled to begin in December.

100GHz GaN Transistor Reported

Japan's Nitride Consortium reports that it has achieved a 100GHz GaN HEMT. The device was designed using a 0.25-micron process, conducive to use in commercial production, and can process signals as high as 130GHz. The Nitride Consortium, which was instituted by the New Energy and Industrial Technology Development Organization (NEDO), consists of Ritsumeikan University, Matsushita Electronics, Sharp, NEC, and the Osaka National Research Institute. Through a three-year project which will end in fiscal 2001, the consortium is developing high-output devices, monolithic ICs, and milliwave RF devices for use in cellular phone base stations using widebandgap compound semiconductors.

Sapphire Production to Increase

Kyocera says it plans to double single crystal sapphire production for blue LED wafers and LC projector heatsink wafers. The company will invest 1 billion yen (\$9.3 million) to establish production at its Nagano Okaya plant, in addition to its existing Shiga plant, in order to increase total capacity to 40,000 2-inch wafers per month. Kyocera is aiming to boost single crystal sapphire sales from 3.5 billion yen (\$32.7 million) in fiscal 1999 to 8.0 billion yen (\$74.8 million) in fiscal 2001.

Motorola Qualifies E-mode HFET Process

Motorola's Semiconductor Products Sector has completed qualification of an enhancement-mode (E-mode) HFET wafer process, a single power supply technology designed for linear transmitter and receiver circuits in low-voltage portable wireless applications.

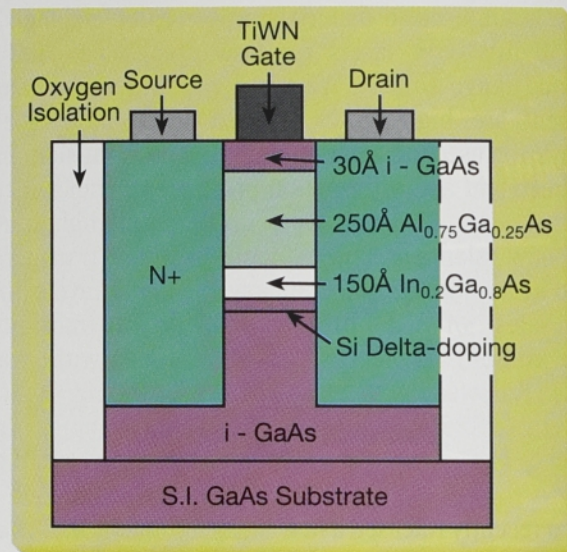
"Motorola's advanced E-mode GaAs technology provides advantages over depletion-mode PHEMT devices," said Karl Johnson, director of Motorola's Compound Semiconductor Technologies Laboratory. "Because of its low off-state leakage current, this true E-mode device allows elimination of the drain-supply switch required for depletion-mode PHEMT and MESFET devices."

"Single-supply power amplifiers have become the new paradigm in portable phone handsets due to the recent availability of near-zero threshold voltage PHEMT and HBT technologies," added Jim Oakland, Wireless Transmitter Solutions Division. "The need to reduce product cost and size is also a high priority. E-mode GaAs technology helps to reduce the cost and size of the end product by eliminating both the negative voltage generator and the drain-supply switch within the handset power amplifier section, as well as eliminating additional passive components."

Motorola has demonstrated several ICs based on the E-mode HFET technology, including a three-stage PA designed for 1900 MHz TDMA applications featuring +30 dBm of output power and 42% PAE. The technology also has a high Schottky turn-on voltage of +1.8 V at 1 mA/mm, compared to +0.8 V for a comparable D-mode or near-zero threshold PHEMT device. For small signal

applications at 900 MHz, a single-stage PA with a noise figure of 1.2 dB and associated gain of 18.5 dB has also been demonstrated.

E-mode HFET products, which will be manufactured in Motorola's CS-1 6-inch wafer fabrication facility in Tempe, Arizona, are expected to be available by February of 2001.



Cross-section of Motorola's E-mode heterostructure FET, which operates from a single supply voltage.

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RFMD Announces Production Orders from Motorola

RF Micro Devices has begun production shipments of GaAs HBT power amplifiers for Motorola's Talkabout™ T900 two-way data pager. RFMD's RF2173 chip is currently in high volume production for two-way data applications and GSM handsets, and is designed as a final RF amplifier in GSM handheld digital cellular equipment and other applications in the 800–950 MHz band.

"We believe the RF2173 helps Motorola produce a very low cost, small-size pager with outstanding battery efficiency," said Greg Thompson, RFMD's director of sales. "We anticipate the RF2173 will be featured in additional Motorola two-way data paging products in the future."

New Devices

TRW Develops Satellite Upconverter

Redondo Beach, CA. TRW has developed a compact lightweight (~1 oz) GaAs upconverter IC for use in the Astrolink global broadband telecommunications system, which is slated to begin service in 2003. The upconverter complements the company's recently introduced downconverter LNA [CS 6 (6), p. 35], and is used to convert payload signals at lower frequencies to Astrolink's Ka-band downlink frequency of 20 GHz for transmission to Earth. The upconverter converts frequencies ranging between 200 MHz and 5 GHz to frequencies between 18 and 21 GHz. Included in the device are a 2X frequency multiplier, filters, upconverter macrocell IC, output amplifier and voltage regulator.

Microsemi Launches InGaP HBT PAs

Santa Ana, CA. Microsemi has introduced 3 V single supply InGaP HBT power amplifiers designed for use as a final RF amplifier in W-CDMA and CDMA2000 applications, spread spectrum systems and other linear applications in the 1800 to 2000 MHz band. The MWS series features 27 dBm of linear output power, 28 dB of linear gain and 40% linear efficiency.

Direct Conversion Modulator from RFMD

Greensboro, NC. RF Micro Devices has introduced a quadrature modulator IC designed for application in W-CDMA, CDMA, GSM-EDGE/EGSM and TDMA/TDMA-EDGE base stations. Operating from a 5 V supply and manufactured using RFMD's GaAs HBT process, the RF2484 features carrier and side-band suppression of 35 dBc over temperature, in addition to a noise figure of better than -152 dBc/Hz. Production quantities are expected by January 2001.

Alpha Wins Orders from Sony, Metricom

Alpha Industries has received a high-volume production order for GaAs RF switches from Sony for use in the company's newly released wireless handsets, which enable data and wireless Internet access. "This is Alpha's first product to be designed into a Sony wireless handset, and it represents yet another important success in our strategy of diversifying our wireless OEM customer base," said Alpha's president and CEO, David Aldrich.

In the past fiscal quarter, Alpha has diversified its wireless customer base by substantially increasing production-volume semiconductor shipments to Mitsubishi, Samsung and Siemens, in addition to placing power amplifiers and switches in Motorola's three recently announced new phones. In the wireless infrastructure market, Alpha posted significant increases in sales to Alcatel, Ericsson and Nokia, increasing its presence in both 2.5 and 3G platforms.

In more news, Alpha is delivering additional volume shipments of GaAs switches to Metricom (San Jose, CA) for its Ricochet mobile data system. Ricochet currently allows users access to 128 kb/s wireless Internet in nine metropolitan areas across the United States. "The GaAs and RF content that we are providing ensures seamless communication between the individual user's modem and the pole-top transceiver, allowing complete wireless Internet mobility from their laptop computers and Personal Digital Assistants," said David Aldrich.

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WIN Produces Asia's First 6-inch GaAs MMIC Wafers

WIN Semiconductors, a Taiwanese GaAs foundry, has successfully processed what it claims to be Asia's first 6-inch GaAs MMIC wafer, using a 2 μ m linewidth InGaP/GaAs HBT process. In July, WIN finished construction of its new 6-inch GaAs facility, located in the Hwaya Technology Park, and installed processing equipment in its 20,000 sq.ft. clean room. Test runs commenced in September.

Production at the new plant will begin during the 1st quarter of 2001, with output rising to 30,000 wafers per year by the end of 2002. The company aims to produce 100,000 wafers per year by 2004, with annual revenues expected to exceed \$0.5 billion. WIN has 70 employees and plans

to increase this number to 400 when fully operational.

WIN was founded in October 1999 to provide GaAs HBT and PHEMT foundry services for communication device manufacturers and microwave design houses. The company will offer 2- μ m and 1- μ m InGaP HBT processes for L-band applications, primarily for PCS/cellular phones, but also for wireless LANs (potentially including Bluetooth) and two-way pagers. WIN will also manufacture 0.15-, 0.35- and 0.5- μ m PHEMT ICs suited to applications in the Ku-, Ka- V-bands, including LMDS, satellite communications, automotive sensors, CATV and point-to-point radio links, in addition to fiber-optic communications.

Infineon Introduces InGaP HBT Process for Bluetooth/Home RF

Infineon has introduced the company's first InGaP HBT power amplifiers for Bluetooth, home RF and WLAN applications compliant with the IEEE 802.11 standard. The new PAs support long range, 100 m (class 1), and short-range (class 2 and 3) Bluetooth applications, and add to the company's range of MESFET and HEMT processes.

The HBT PAs are manufactured in Infineon's 6-inch GaAs facility in Munich, Germany. Flip-chip die and small package PAs are available for integration into Bluetooth modules, modems and other applications requiring small footprint components. Typical device performance includes a PAE value of 50% at 2.4 GHz. In class 3 mode (10 m distance), the current consumption is less than 15 mA at a supply voltage of 3.2 V and an input power of 3 dBm.

"Our advanced InGaP HBT process has proven reliability and achieves the high yield required for volume market applications, such as the emerging Bluetooth standard," said Ewald Pettenpaul, general manager and VP of Infineon's GaAs business unit. "Infineon's Bluetooth PAs achieve the best RF performance compared to the competition for class 1 Bluetooth applications."

Infineon Unveils SiGe BiCMOS Process

Infineon Technologies has demonstrated its new low power SiGe BiCMOS process by introducing a phase locked loop (PLL) IC operating at 10 GHz. At mobile phone operating frequencies, the device offers excellent RF performance while reducing supply current by 50% compared to conventional Si BiCMOS designs, says the Munich-based company. The new B7HFc process combines RF bipolar transistors with transit frequencies up to 75 GHz with an analog 0.35 μ m CMOS process. In addition to the PLL, the B7HFc process enables analog, mixed signal and integrated RF products, including 1.8 GHz LNAs with minimum noise figures of 0.65 dB, mixers, transceivers and analog/digital converter circuits.

Atmel Offers 82 GHz SiGe Foundry Process

Atmel has upgraded the frequency of its high-volume production SiGe process to 82 GHz. Known as SiGe2, the new technology offers a noise figure of 1.5 dB at 5 GHz, with operation at either 2.5 or 4.0 V. The new process will be made available to the company's foundry customers from its 6-inch SiGe wafer fabrication facility in Heilbronn, Germany.



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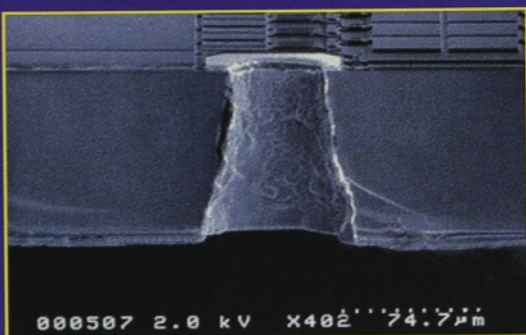
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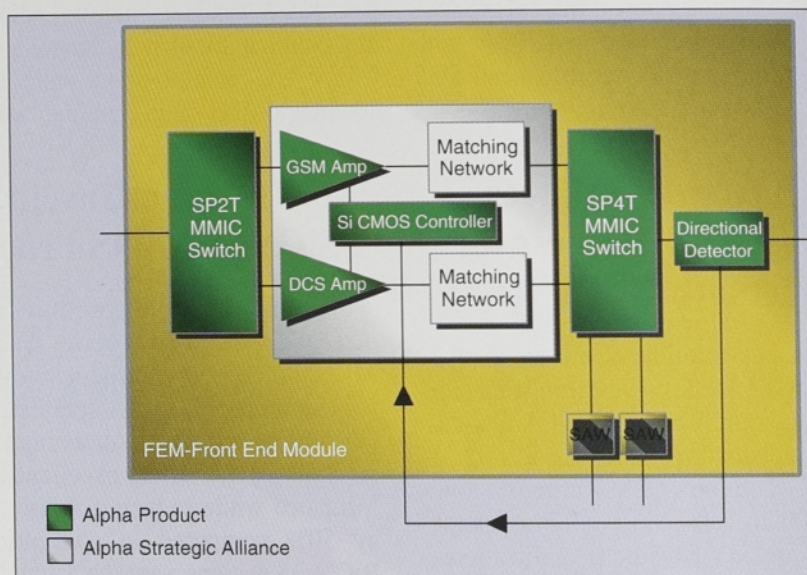
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Alpha Unveils Multichip Integration Platform

Alpha is sampling a new manufacturing, packaging and design technique that combines various RF components into a single module. The Alpha Integration Platform™ (aiP™) integrates the company's HBT, PHEMT and RF discrete semiconductors with additional passive RF components, and is designed to reduce design and manufacturing lead times for the company's OEM customers. While Alpha recently introduced a multichip module packaging

approach designed for fiber-optic components [see CS 6(7), p.8], the aiP™ packages are aimed at wireless applications under 3 GHz.

Alpha's new package platform integrates SAW filters, passive devices and 50 ohm matching network circuitry from its strategic suppliers with the company's GaAs switches, PAs and Si CMOS controller components to make complete front-end RF modules (see figure).



Schematic showing Alpha's new aiP™ front end module integration scheme, which includes its GaAs single pole 2- and 4-throw switches, amplifiers for dual mode GSM and DCS operation, and Si CMOS controller. Matching network circuitry and SAW filters are provided by the company's strategic suppliers.

"The leading OEMs in wireless and broadband are seeking partners who can supply more of the RF content and help them to reduce the number of passive and active components in their product offerings," said David Aldrich, Alpha's president and CEO. "They are increasingly focused on designing the architecture, ergonomics and feature set, while looking to Alpha to provide essentially a 'black box' of functionality that gets them to market quickly and lowers their overall system cost. Alpha's aiP will enable our OEM customers to migrate from their traditional reliance on customized solutions for every platform toward re-use of existing designs."

At the same time, the company has announced a roadmap leading towards full integration of the RF front-end, with as many as four or five functions packaged into a single module. According to director of marketing Ron Cavalieri, the advent of tri-band handsets and 3G is placing a bigger emphasis on the role of switching circuitry, which is driving increased integration of functions to reduce the component count. "In future switches to control transmit and receive functions, in addition to band selection and multiple filters, will all be placed on-chip," he says. "This will considerably simplify the RF front end design and ultimately benefit OEMs."

TRW and JPL Introduce 215 GHz InP LNAs

A new family of InP MMICs LNAs has been developed by TRW and NASA's Jet Propulsion Laboratory, intended to increase data rates, reduce the size and increase the performance of satellite communications and remote sensing payloads. Designed for operation in the 100 to 215 GHz range and fabricated using TRW's 0.07 μm gate HEMT process, the new InP MMIC LNAs offer the highest frequency performance yet reported.

TRW says the frequency of the chip is significant because earlier this year the international spectrum allocation body, the ITU, opened spectrum in the 70–180 GHz frequency bands to future radio, satellite communications, radar and radio astronomy applications.

"TRW's mature InP chip technology positions us to develop smaller, more sensitive and more power-efficient instruments for remote sensing applications such as radio astronomy and atmospheric sounding," said Dwight Streit, TRW's VP and executive director, Advanced Semiconductors. "The chips' high frequencies also enable higher data rates for commercial wireless communications links, while their low-noise figures improve the quality of those links."

TRW's family of devices includes a three-stage, single-ended 112 to 120 GHz LNA providing 15 dB of gain and a noise figure of 4 to 5 dB, or 14 dB of gain and 7 dB noise figure when operating in the 165 to 190 GHz range. A six-stage, single-ended LNA operating at 160 to 215 GHz offers 15 to 27 dB of gain, with a measured module noise figure of 8 dB at 170 GHz operation. TRW recently completed a high-volume facility to produce InP devices, which is expected to be online by mid-2001 [see CS 6 (7), p. 6].

Endwave Wins Contract with Nokia for Transceivers

Endwave Corporation (Sunnyvale, CA) has signed a multi-million dollar contract with Nokia Networks to deliver transceivers for Nokia's new FlexiHopper microwave radios. These will be used in point-to-point and point-to-multipoint broadband cellular networks.

Endwave's transceivers employ MMICs and flip-chip MCIC (multi-chip integrated circuit) technology to combine multipliers, amplifiers, up- and down-converters, frequency sources, IF and control circuitry [see CS 6(8), p. 53]. The contract is a follow-on to an original supply agreement between Nokia and TRW Milliwave—the latter company merged with Endgate Corp. to form Endwave earlier this year.

"FlexiHopper microwave radios contribute significantly to our capability to quickly deploy cellular networks, which is crucial for our operator customers," said Pekka Soini, VP and general manager for Wireless Broadband Systems at Nokia Networks. "We chose Endwave because of its technology and volume manufacturing capability to produce superior, customized transceivers."

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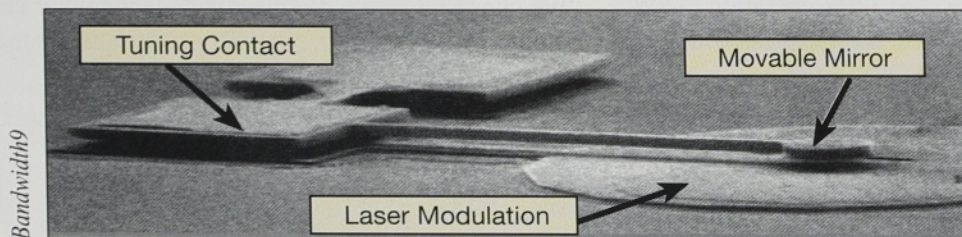
Bandwidth9 Receives \$80 Million in Funding, Introduces Tunable Products

Bandwidth9, a 2-year-old start up company based in Fremont, California has received \$80 million in equity financing from its major shareholders and venture capitalist companies. Bandwidth9 manufactures long wavelength VCSELs [see CS 6(5), p. 65], and recently announced a new tunable VCSEL product. The funding will be used to launch new products and continue its expansion of production capacity at its fully integrated manufacturing facilities.

Bandwidth9 recently announced its plan to introduce a line of tunable optical transmission modules enabling next-generation wavelength-on-demand systems for remotely provisioning bandwidth through metro WDM infrastructures. The flexible modules allow for new designs for efficient optical cross con-

nects, metro transport systems, and optical access systems. The products can act as replacements for many as 60 fixed wavelength laser sources in metro systems, and cover either the C band (1530–1564 nm) or the L band (1580–1620 nm); they will be available for select customers by year-end. The initial product is a completely integrated evaluation card that consists of a broadly tunable, directly modulated VCSEL source that is directly modulated at speeds up to 2.5 Gb/s.

The Bandwidth9 tunable VCSEL has a fixed bottom mirror, an MQW active region, and a top mirror fabricated into a cantilever structure. Applying a small voltage to the top mirror causes the cantilever to move up or down, which changes the length of the laser cavity and hence the wavelength of operation.



SEM of Bandwidth9's tunable VCSEL structure.

Siros Technologies Announces High Power Density VCSEL

Siros Technologies Inc. (San Jose, CA) has demonstrated a VCSEL with an emission power density of 5 mW/mm², which should provide the potential for this technology to be used in optical data storage applications. The Siros team coupled a VCSEL with a very small aperture laser (VSAL) to achieve 80 times the power density of previous demonstrations of small aperture VCSELs. Siros owns the intellectual property rights to the VSAL technology, which was originally developed by Lucent Technologies, and is key to producing spot sizes as small as tens of nanometers in diameter. According to Siros, the VCSEL/VSAL technology outperforms traditional edge-emitting lasers due to superior characteristics, greater power output, smaller size and simplified manufacturing and testing.

ADC Ramps Capacity for Tunable and Pump Lasers

Management at ADC stated that the company is shipping 980 nm pump lasers and tunable lasers to 10 customers, while another 30 customers are evaluating products. ADC is on track to double its capacity of its Broadband Connectivity segment, and expects to continue this expansion into 2001 as demand for optical components continues to ramp up.

Cielo Expands VCSEL Manufacturing Facilities

VCSEL manufacturer Cielo Communications plans to expand its headquarters in Broomfield, Colorado with the acquisition of a 23,000 sq.ft. facility, a move which will double the company's available space. "We are expanding our product development, VCSEL development and manufacturing facilities to ramp up production of new products and technologies," said Mike Cowley, president and CEO. "The expansion is an important step in Cielo's plan to be a clear leader in integrated optical subsystems for the telecommunications market."

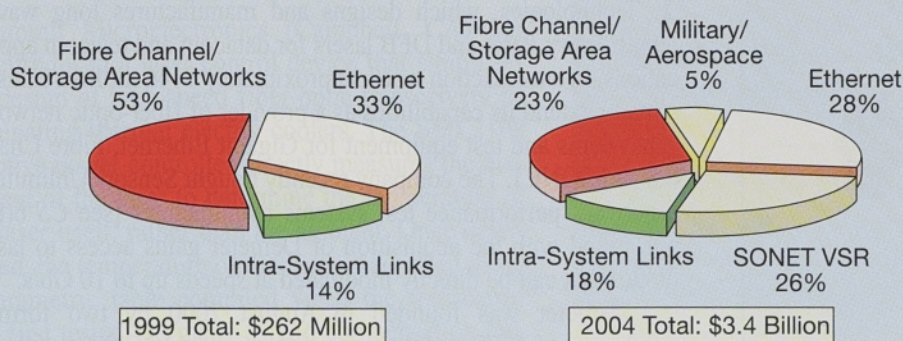
Slated for completion in January 2001, Cielo's additional space will be used for corporate offices, product development and EMI test facilities. The existing buildings will house the company's manufacturing and support activities.

Euro-VCSEL Spin-Offs

Two new European companies have been formed to commercialize VCSEL technology. **ULM Photonics** is a joint venture between researchers from the University of Ulm, Germany, and Scott Communications Technology (SCT), a US subsidiary of the Schott Group. The start-up will commercialize oxide-confined VCSEL products, including single devices, linear arrays and large-scale two-dimensional arrays [see CS 6(5), p.60].

Avalon Photonics Ltd (Zürich, Switzerland) is a spin-off from the Optoelectric Devices Group of CSEM (the Swiss Center for Electronics and Microtechnology). CSEM has been producing VCSEL arrays for 5 years [see CS 5(6), p.34], and Avalon Photonics aims to address the short reach high bandwidth datacom market. In November, the company received \$14 million in venture capital funding.

VCSEL Transceiver Market



Source: ElectroniCast Corp.

According to ElectroniCast, the VCSEL transceiver market will experience a compound annual growth rate of 67% through 2004, reaching a total of \$3.4 billion, compared to \$262 million in 1999. One of the main drivers for this dynamic growth is the rapid advancement of datacom standards such as Gigabit Ethernet and Fibre Channel; new standards including 10 Gigabit Ethernet and 2 Gb/s and 10 Gb/s Fibre Channel are expected to follow soon. VCSELs are also expected to penetrate telecom applications, specifically very short reach (VSR) 10 Gb/s SONET links between networking equipment. The report, "VCSEL Transceiver Global Market & Technology Forecast", is available from ElectroniCast—see www.electronicast.com.

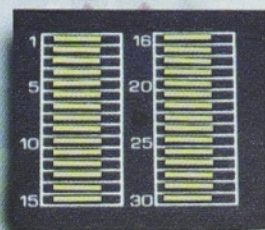
Agility Introduces High-Power, C-band Tunable Laser

Agility Communications is sampling a new high-power, C-band tunable laser (1525–1565 nm) designed for DWDM optical networks that reduces the inventory required for fixed wavelength lasers and allows network providers to dynamically provision bandwidth. Agility recently received \$70 million in funding to help commercialize its tunable laser technology [see CS 6(8), p. 34]. Offering a CW output power of 4 mW, the Agility 3040 can be tuned to more than 100 ITU channels (50 GHz). Based on the company's sampled grating DBR laser, the 3040 is hermetically sealed with an integrated digital controller and control software. An external wavelength locker can also be integrated for wavelength stabilization.

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Finisar Acquires Demeter Technologies

Finisar Corporation (Sunnyvale, CA) has acquired Demeter Technologies, which designs and manufactures long wavelength Fabry Perot and DFB lasers for datacom and telecom applications, in a transaction worth approximately \$146 million. Finisar aims to extend its capabilities as a provider of fiber-optic network subsystems and test equipment for Gigabit Ethernet, Fibre Channel and SONET. The company recently bought Sensors Unlimited, a network performance test systems manufacturer [see CS 6(6), p.41], and with the acquisition of Demeter gains access to laser diodes that can be directly modulated at speeds up to 10 Gb/s.

Demeter was founded in August 2000 by two former employees of AXT, and the company has one MOCVD reactor in leased manufacturing space at AXT's facility in El Monte, California. Finisar has issued 1.2 million of its shares to AXT as part of AXT's warrant for shares in Demeter.

"As a vertically integrated manufacturer of FP and DFB lasers, Demeter will play a key role in our strategy to bring new low cost solutions for datacom networks and metropolitan access," said Jerry Rawls, Finisar's president and CEO.

Sanders Forms TeraConnect

TeraConnect, a company formed to develop and commercialize optical and optoelectronic devices, has been spun-off from Sanders, a Lockheed Martin company based in Nashua, NH. Funding of \$40 million was provided by three venture capital companies. TeraConnect will use the investments to accelerate the development of optical components, including VCSELs, for data communications applications.

"TeraConnect will initially manufacture high bandwidth optical components for high performance router, server and telecommunications infrastructure applications," said Jon Ciemiewicz, Sanders' program manager.

Currently located at Sanders, the new company will move into leased premises nearby in Nashua, NH by the end of the year. A core team of Sanders employees has transferred to TeraConnect. The company plans to continue using Sanders' GaAs fabrication facilities while its own facilities are being developed, says Ciemiewicz.

Global Crossing and Lucent Begin 40 Gb/s Network Trial

Lucent Technologies and Global Crossing have begun a trial of Lucent's 40G time division multiplexing (TDM) optical technology, which is designed for both long-haul and metro networks. Lucent's system delivers 40 Gb/s of capacity, or around 8 million one-page emails per second. The trial is being conducted across a 71 km (~45 miles) fiber link connecting Brussels and Antwerp in Belgium, and is a critical component of Global Crossing's European network. Global Crossing is also conducting live network testing of Lucent's WaveStar LambdaRouter—the industry's first high-capacity, all-optical switch capable of routing 10 times more traffic than currently travels across the worldwide Internet each second.

Laser Temperature Controller Could Eliminate Coolers

Summit Microelectronics (Campbell, CA) has introduced a laser control device that simplifies the design of high-speed fiber-optic transceivers by eliminating thermal electric coolers. The SML2108 adaptive power controller directly measures the bias current of the laser to determine the temperature of the laser itself, rather than the ambient. Once determined, the temperature of the laser is adjusted using a parametric table compiled when the transceiver was first tested. As many as 256 compensation factors are generated to drive the modulation current source to keep the laser operating in the required range.

"The design of high-speed fiber-optic transceivers has been complicated by the lack of a means of adjusting the modulation current of the laser based upon the temperature of the laser itself to maintain a constant extinction ratio," said Rick Orlando, president and CEO of Summit. "This has led to the widespread use of thermal electric coolers to attempt to hold the laser at a constant temperature, an approach which increases the footprint, cost and power consumption of the transceiver."

Sparkolor Secures \$13.25M Funding

Sparkolor Corporation, a developer of optical networking components and modules based in Santa Clara, California, has raised \$13.25 million in its first round of funding. The company is developing products, the first of which will be a tunable laser, with a focus on volume production at low cost. Sparkolor has a patented optical structure that unites active and passive optical functions in a configuration optimized for high-yield manufacturing. The company claims its tunable laser product will replace the entire fixed wavelength solution in use today i.e. laser plus wavelength locker plus modulator.

Novalux Leases Second Manufacturing Facility

Novalux has signed a lease for an additional 100,000 sq.ft. facility in Sunnyvale, California. Founded 2 years ago, the company manufactures a proprietary surface emitting laser with an extended laser cavity, known as the NECSEL [see CS 6(5), p. 20]. The new site adds to an existing class 10 clean-room facility incorporating a 4-inch GaAs line, and will be used to accommodate wafer processing and the expansion of Novalux's automated laser assembly and packaging operations. The company expects to begin manufacturing in the new facility in the spring of 2001.

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IQE Buys Wafer Technology

IQE plc, a leading epiwafer supplier based in Cardiff, UK, has acquired Wafer Technology Limited, a global supplier of compound semiconductor substrates and high purity polycrystalline materials, for approximately GBP 43 million (~US\$63 million).

Wafer Technology employs 57 people and has a 37,000 sq.ft. facility in Milton Keynes, UK. The company employs both Vertical Gradient Freeze (VGF) and Czochralski growth techniques to manufacture its range of GaAs, InP and other specialist III-V substrates in diameters ranging from 2 to 4 inches, which are supplied worldwide to major manufacturers of electronic and optoelectronic devices. Wafer Technology is also a key supplier of high purity bulk GaAs and InP polycrystalline feedstock to the rest of the industry. The company has long-term supply agreements in place for its critical raw materials, particularly high purity metals.

The deal will provide IQE direct access to key InP wafer products, which are critical for most light emitting and detecting devices in fiber-optic systems as well as next-generation electronic components for higher speed communication systems.

"The combination of Wafertech and IQE will provide the compound semiconductor industry with a unique materials product range," says Martin Lamb, CEO of Wafer Technology Ltd. "The availability of both epitaxial services and bulk materials within the group will position us well to take full advantage of the accelerated growth we are seeing in the industry."

IQE Forms Silicon Epiwafer Division

IQE has also formed a new subsidiary, IQE Silicon Compounds Ltd., which will be Europe's first independent provider of outsourced epitaxial services to the silicon semiconductor industry. Commencing in Q1 2001, the company will supply selective and buried layer Si epitaxy for BiCMOS and bipolar process, as well as SiGe products and other epiwafer services for the fiber-optic and wireless communications industries.

IQE Silicon Compounds will operate from a new facility currently under construction in Cardiff, in close proximity to IQE's existing operations. The first major customer for the new company is Bookham Technologies, a leading manufacturer of optical components and circuits based on Si wafers.

"As materials requirements become even more sophisticated to enable faster, more efficient circuits and components, epitaxy is becoming ever more important as a critical step in the manufacturing chain," says Drew Nelson, chairman of IQE plc. "Our goal is to provide the highest quality outsource epitaxial wafer services across the range of materials demanded by the customer base."

Former Bio-Rad Business Now Known as Accent Optical Technologies

Accent Semiconductor Technologies (Bend, OR) has changed its name to Accent Optical Technologies, Inc. The company was formed in April 2000 and acquired certain assets related to the semiconductor and optoelectronic metrology business of Bio-Rad Laboratories, Inc. in July 2000.

"There are two important reasons for a name change," says Bruce Rhine, CEO, chairman and president of Accent Optical Technologies, Inc. "First we will focus on the optoelectronic market where we anticipate tremendous growth, and second, optics is a common thread throughout our process control and measurement tools regardless of the markets we serve." The company has formed two primary divisions, one for the silicon industry and the other that serves the compound semiconductor market.

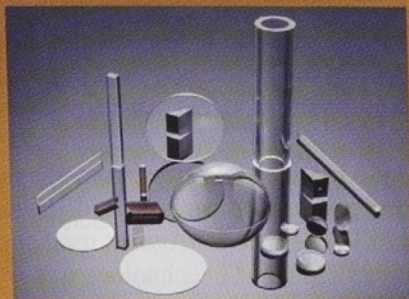
New Products

Trikon Technologies (Newport, UK) has introduced a high-temperature electrostatic chuck for plasma etching of InP. "Accurate temperature control during plasma etching of compound wafers is critical," says John Macneil, VP of Technology. "Most electrostatic chucks cannot effectively clamp compound semiconductor wafers for hot processes, leading to slower plasma etch processes and limited choices of etch chemistries. Up until now the only alternative was mechanical clamping, but this introduces particulates and causes wafer breakage, dramatically reducing yields and throughput." These problems can be avoided by employing uniform heating to the company's existing electrostatic chuck, he says.

Space Electronics, Inc. (San Diego, CA) has released its new line of Shason Instruments Power Amplifier Automated Reliability Test Sets (PAARTS). These systems are capable of performing 3-temperature life tests on discrete transistors, MMICs, hybrid microwave ICs and RF/microwave module assemblies. The Shason Instruments test system consists of hardware and software used to initiate, supervise, and record temperature, electrical, and RF performance parameters automatically throughout the test duration. The devices-under-test (DUTs) do not have to be identical circuits or even circuits of similar design and function since each DUT has independent bias, temperature, and RF control. Space Electronics is a part of the Electronic Components Group of Maxwell Technologies.

Aeronex (San Diego, CA) has introduced a new inert gas purifier system for the purification of ammonia in high flow-rate point-of-use applications. The GateKeeper Model 10M removes moisture, oxygen and other contaminants and does not require the use of heat or power. The purifying media can be regenerated, and does not contain organics that can outgas.

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Agilent Orders Applied Epi MBE System

Agilent Technologies (Santa Rosa, CA) has ordered an Applied Epi GEN200 MBE system, which can process four 4-inch wafers or seven 3-inch wafers. Agilent will use the system to support the manufacture of ICs for use in its test and measurement equipment. The GEN200 incorporates an automated UHV multi-wafer handling cluster tool modeled after proven silicon architecture, and is enhanced by Applied Epi MBE components, electronics and process-control software.

Optillion, Sumitomo Electric Order Aixtron Reactors

Optillion, a new start-up company based in Kista, Sweden, has just ordered two Aixtron MOCVD systems—an AIX 2400G3 and a multiwafer AIX 200/4—to produce and develop InGaAsP-based laser structures. Optillion was founded in December 1999 to develop and manufacture components for fiber-optic systems.

Sumitomo Electric (Itami, Japan) has purchased an Aixtron AIX 2400/2600G3 multiwafer MOVPE reactor for the manufacture of epiwafers used in telecommunication components.

Agilent Buys Production MBE Systems from VG Semicon

VG Semicon (a wholly owned subsidiary of Thermo Electron Corporation) has received orders from Agilent Technologies for three V150 MBE systems which will be used to equip Agilent's new six-inch wafer fabrication line in Fort Collins, Colorado [see CS 6(8), p.18]. Agilent intends to produce products for CDMA, GSM, and 3G mobile handsets based on its enhancement-mode HEMT (E-PHEMT) technology. According to Agilent the first phase of the fab is planned to be in full production by the end of 2002 and is expected to initially produce 48,000 six-inch wafers per year.

"We are very pleased to have received this order from one of the most important wireless technology companies," said David Williams, Managing Director of VG Semicon. "Agilent used our V100 MBE system to develop its E-PHEMT technology and to be selected again as Agilent's MBE vendor for their expansion is very significant for us."

Agilent's order was received in Q3 2000 and was included in the previously announced record orders of \$42.9M for VG Semicon in the first 9 months of 2000.

Daido Air Products Opens New Organometallics Facility

Daido Air Products Electronics, Inc. (DAP)—a joint venture between Air Products and Chemicals, Inc. and Air Water, Inc.—has opened a new facility at its Specialty Chemicals Center in Tsukuba, Japan (near Tokyo) for handling organometallic chemicals used in compound semiconductor manufacturing.

The facility provides DAP with enhanced local organometallic transfill and analytical capabilities, with future opportunity for chemical production. DAP sources its organometallic chemicals from Epichem Ltd., and is the exclusive supplier of Epichem organometallic products in Japan, a cooperative relationship that extends back to 1993 when Air Products began marketing these products in Japan.

"With the market for organometallic chemicals in Japan estimated to be US\$25 million, our new [transfill] capabilities at Tsukuba will further enhance our ability to provide full service to our customers," says Isamu Handa, president of DAP. DAP is a leading supplier of gases, chemicals, equipment and services to the Japanese electronics industry, while Air Water is Japan's second largest industrial gases company.

JMAR Increases Output of XRL Source to 18 W

The proprietary semiconductor lithography system developed by JMAR Technologies (San Diego, CA) has achieved an output of 18 W of 1 nm wavelength X-ray radiation. The company believes that its Picosecond X-ray Light Source (PXS) will



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"Almost all of the high-speed, short-gate circuits now in use are being made with direct-write electron beam nanolithography processes," said John Carosella, president of JMAR's Nano-Light Division. "These processes are very slow and, as a result, the chips they produce are very expensive. We believe our X-ray source technology can effectively remove this roadblock to progress."

"Our performance test results indicate that a point source X-ray lithography system using JMAR's current PXS and collimator technology, combined with commercial X-ray stepper systems, provides the basis for manufacturing high-speed GaAs circuits at production rates many times faster than current electron beam lithography systems, and at a much lower per-unit cost," continued Carosella.

Kyma Develops GaN Epitaxial Substrate

Kyma Technologies, a developer and supplier of nitride substrates based in Research Triangle Park, North Carolina, has grown 50 mm-thick, 2-inch epitaxial GaN layers on sapphire wafers using a proprietary PVD process [see CS 6(8), p. 13]. "Our initial goal was to grow free-standing 2-inch GaN wafers, but we have encountered a lot of interest from companies for the GaN epi-wafers," said Chief Scientific Officer Jerry Cuomo.

Cuomo says Kyma has plans to grow 150 μm thick, free standing GaN substrates in the near future using the PVD process. Kyma's PVD reactor is capable of growth at rates of 1 μm per minute and greater, says Cuomo, although the present epi-wafers are not grown at this rate. The company will begin shipping samples by the end of the year, with production quantities available in the first quarter of 2001.

Kyma has also received its first major contract with a leading aerospace company for shipment of freestanding 2-inch AlN substrates, which will be used to make high frequency, high power devices for electronic warfare/radar applications.

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An Elemental Problem with the Gallium Supply

*Spot market prices have reached \$1,500 per kilogram.
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Limited supplies and increasing demand have pushed the spot market price for gallium (99.9999% or "6N" purity) to \$1,500 per kilogram, more than 120% higher than one year ago. GaAs wafer manufacturers, who may each require 20 tons of gallium or more per year, typically avoid the high prices in the spot market by using long-term guaranteed price contracts with the major gallium suppliers. However, even these high volume consumers have seen their prices rise 33–40% over the past 12 months. One wafer manufacturer told *Compound Semiconductor* that his company has watched their best price rise from \$555/kg to \$745/kg in the last six months. And one of the largest manufacturers of 6" GaAs wafers said that his company could get price confirmation from their main gallium supplier only through the first quarter of next year, leading him to speculate that "by the third or fourth quarter of 2001, we'll probably be paying \$1,000/kg".

These higher gallium prices translate into a 10% or more increase in the cost of producing GaAs wafers. Wafer manufacturers also recently learned that arsenic prices will be going up as much as 50% next year—see box, page 47. In past years, the wafer manufacturers would have been forced to bear the burden of these higher costs on their own. Their customers would not only reject higher prices, but they would also expect wafer prices to be reduced on an annual basis. This year, however, the fabs may be slightly less demanding. Several new GaAs fabs are under construction and many existing fabs are being expanded. One wafer supplier, who did not wish to be identified, told us, "everyone can see that market demand for GaAs wafers is much higher, so without any pressure from our side our customers have been letting us know that they are willing to pay us the same price for a guaranteed wafer supply next year."

Nevertheless, if gallium prices continue to rise it could spell serious trouble for the compound semiconductor industry. A recent report issued by Roskill on "The Economics of Gallium"[1] raises several issues. Most alarming is the fact that world demand for gallium is forecast to rise to 350 tons[2] in 2008, nearly dou-

ble current consumption rates. Some even predict that demand will double in the next two years. Unless supplies are expanded, a shortage of 45–125 tons a year could emerge.

But Roskill also has some good news to report. Planned capacity increases by the major gallium producers are expected to cover much of the looming shortfall, albeit not before 2002. Another important source is the recovery of gallium from GaAs scrap. Recycled gallium already meets 50–60% of world demand.

And while some continued upward price pressure seems inevitable in 2001, Roskill predicts that the situation is unlikely to get completely out of hand. They cite reports from Dow, one of the world's largest gallium purifiers, indicating a commitment to stable prices. Echoing this sentiment, a spokesperson for

the Semiconductor Materials Group at Dow told *Compound Semiconductor* "It is very important for the market to keep the proper price level. High prices will cause the market for compound semiconductors to shrink and help growth of competing materials or devices."

Gallium and our Industry

The classic laws of supply demand explain why gallium prices have risen so quickly and dramatically. Consumption has been increasing by 25–50% per year over the past few years, due to exploding markets for RFICs and optoelectronic applications. But no new gallium extraction plants have been added. And extraction is the key. Purification of gallium is a fairly simple process.

[1] *The Economics of Gallium*, Sixth Edition is published by Roskill Information Services Ltd., 2 Clapham Road, London SW9 0JA, UK. TEL [44] 20 7582 5155, FAX [44] 20 7793 008, E-mail info@roskill.co.uk, Web www.roskill.co.uk. Published 2000. 78 pages with 36 tables and 3 figures. \$2,000.

[2] "Ton" in this article refers to a metric ton (or tonne), which is equal to 1,000 kilograms or 2,205 pounds.

The price of 6N gallium has risen more than 80% since 1995, which is approximately when the current GaAs boom began.

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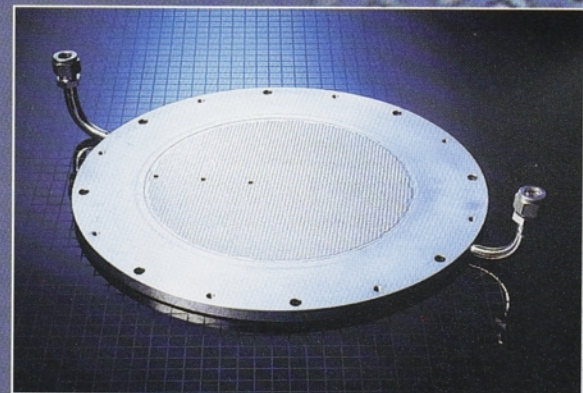
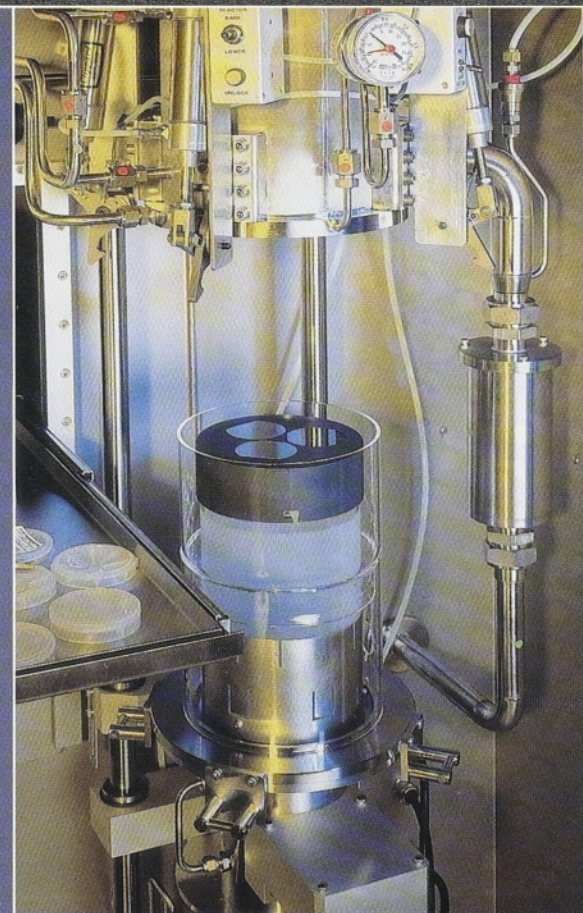
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But if it is to be economically viable, the extraction of gallium from bauxite ore has to be done at an aluminum refining plant. Therefore, anyone wishing to enter the business has to start by winning the confidence of an aluminum company. But they may be reluctant, fearful of the possibility that the gallium extraction process, generating somewhere between \$1–\$10 million in revenue per year, might somehow contaminate the aluminum process, which can generate around \$1 billion in revenue per year. It is easy to see why new gallium extraction plants cannot be set up overnight.

The U.S. Geological Survey (USGS) estimates that 95% of the world's production of gallium metal is consumed in the compound semiconductor industry. All of the other critical metals—e.g. aluminum, arsenic, and phosphorus—have other major industrial uses. This is true even of indium, the majority of which is consumed in the production of solders and indium-tin-oxide (ITO) thin films in liquid crystal displays (LCDs).

According to data obtained from the USGS and *American Metal Markets* magazine, the price of 6N gallium has risen more than 80% since 1995, which is approximately when the current GaAs boom began [see Figure 1]. In contrast, indium prices have dropped 50% over that same period. But demand for indium is slackening, as LCD production has slowed somewhat, and new thin film technologies that require less indium have been adopted. It should also be noted that there may be quite a gap between the "official" prices which are reported to the analysts and the real prices that are negotiated by large buyers of gallium. "The published prices give some indication of the direction in which the actual transaction prices are going," says Deborah Kramer of the USGS. However, she notes that only the major buyers and sellers know what the "real" price is at any given time.

Gallium Extraction

The major gallium extractor is GEO Specialty Chemicals, which acquired the former Rhône Poulenc gallium operation from Rhodia in September 1999 for approximately \$23 million. GEO operates a gallium extraction plant in Stade, Germany and a gallium purification plant in Salindres, France. GEO also has an option to acquire a dormant gallium extraction facility built by Rhone-Poulenc near Pinjarra, Australia. This plant, which was mothballed in 1997, has capacity for approximately 50 tons per year. The option expires in 2002.

GEO executives have expressed a firm commitment to the gallium market. In the first half of this year gallium accounted for less than 15% of GEO's sales of \$88.4 million, but contributed one-third of their operating income of \$9.6 million. Edward Freshman, Director of Corporate Development at GEO, told *Compound Semiconductor* "we are in this for the long run, and are working to do the right thing for all our customers".

GEO's efforts thus far have included expanding the capacity of the Stade plant by 50% since the acquisition, and doubling the capacity of the Salindres plant in 2000.

A complicating factor for GEO and all the other players in the gallium market is the fact that from 1997–1998 there were significant shipments of stockpiled gallium from Kazakhstan entering the market. It appears that this had the effect of masking the real rate at which demand was increasing. Now that the full extent of the problem is visible, GEO has dipped into its stockpiles to fill orders. Freshman says this has meant that GEO has not had to turn any existing customers away.

But capacity expansion will be required for a long-term solution. Capacity at the Stade plant has been raised from 24 tons to 34 tons per year, and further improvements that should allow it to extract another 5–6 tons are in the works. There are also plans for additional extraction plants, although the company is not yet ready to disclose details. Freshman says, "discussions are ongoing with a number of major aluminum companies. We recognize the need to build a number of extraction plants in the future." Re-commissioning the Pinjarra plant is one obvious option, but Freshman indicated that other options are being explored as well. Announcements are expected within the next few months. "Unfortunately, current demand forecasts indicate supplies will be tight throughout most of 2001," says Freshman. However, the

Even a cursory examination of the worldwide production figures reveals a very large gap between current primary production and the amount of gallium required. Therefore the industry relies heavily on recovery of gallium from scrap GaAs to meet its needs.

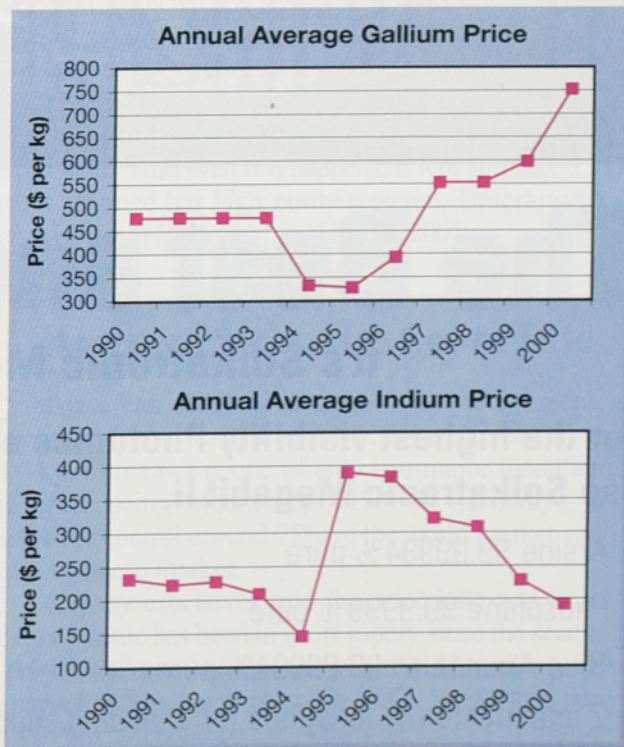


Figure 1. Pricing trends for gallium and indium metal



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company anticipates that their new plant or plants will be operational by early 2002, providing substantial relief.

The fact that the Pinjarra plant remains dormant rankles some wafer manufacturers, who have accused GEO of manipulating the price of gallium. However, recommissioning it is a major task, perhaps equal to the job of setting up a new plant in a different location, which would have the additional advantage of being closer to the primary markets for gallium. Hard facts about Pinjarra are difficult to find, but the knowledge that Rhone-Poulenc shut it down just months after opening it seems to suggest that its design may not be entirely suitable.

Freshman also notes that recent demand has been higher than anyone could have anticipated. He also explained that most of GEO's principal gallium customers signed yearly blanket orders with fixed prices in 2000 and have only seen prices increase marginally for incremental quantities shipped in the second half of this year. "We have monitored spot pricing closely this year and we are concerned by the dramatic increase, especially since the summer. This has been a characteristic of the gallium business, and correlates closely with the drawdown of gallium inventories in Japan. While Freshman refused to comment on the issue, there have been suggestions from other quarters that some of the wafer manufactures are now exacerbating the problem by hoarding.

Recycling's Role

Even a cursory examination of the worldwide production figures reveals a very large gap between current primary production and the amount of gallium required [see Figure 2]. The USGS estimates that the worldwide annual primary production capacity in 1999 was around 150 tons, whereas actual primary production was around 75 tons. However, world demand for gallium in 1999 exceeded 165 tons.

How to make up for the shortfall? The industry relies heavily on recovery of gallium from scrap GaAs to meet its needs. For every 100g of gallium used to produce a GaAs or GaP boule, as much as 80g may be available for recycling. Gallium-containing waste is generated at many points in the wafer manufacturing process. Whole boules might be scrapped if they don't meet specifications. Also, some GaAs remains in the crystal puller or furnace after the boule is removed, which may be recycled.

Significant amounts of GaAs waste are generated when the boule is sliced—for example, the seed and tail might make up as much as 25% of the total volume. And a tremendous amount of GaAs dust is created when the wafers are sawed (the wafers are just 675 μ m thick, while the thinnest saw blades are ~300 μ m thick).

Production of LEDs by LPE and VPE also produces substantial amounts of gallium-containing waste. Dow Chemical has become one of the world's largest suppliers of high purity gallium by relying heavily on recycling. In 1999 the company consolidated its gallium operation into a new refinery at Akita, on the same campus as Dow Semiconductor, a subsidiary that makes GaAs wafers and LED chips. When the production ramp-up is finished, total capacity will be 100 tons per year of 6N and 7N material. Most of the plant's output is derived from processing smelter residue and recycling, and the rest is obtained through refining crude gallium metal imported from Russia, Hungary and elsewhere.

There are two processes for reclaiming gallium. In one, the scrap GaAs is dissolved in a hot acidic solution, and then neutralized with a caustic solution to precipitate the gallium as gallium hydroxide, which is filtered from the solution and washed. The gallium hydroxide is redissolved in a caustic solution and electrolyzed to recover 4N to 5N gallium metal. The other method is to use a thermal process to melt and separate the gallium and arsenic. Although slightly more costly, this procedure is more environmentally friendly because the arsenic is also reclaimed and can be resold in metallic form. Some wafer manufacturers can recycle their own scrap, but it is more common that it be sold to a company that specialized in recycling GaAs, or even back to the gallium supplier.

While expansion in primary production and purification facilities is the only viable long-term solution, recycling may help to ease the pain until the new capacity comes on line. One slightly harried executive at a wafer supplier stated: "if I could say one thing to the other wafer manufacturers and the major epiwafer growers, it would be to encourage them to get all of their scrap out into the market as quickly as possible. But still, this will only be scratching the surface of the problem." And even if it happens, it will still take a long time to have it returned as high purity material. Unfortunately for all concerned, there is little relief in sight for 2001.

Figures Relating to Worldwide Gallium Supply and Consumption

	Production	Consumption	Primary Production Capacity	Year-end Price
	Metric tons			\$/kg
2000(e)	80	185	158	\$750
1999	75	165	153	\$640
1998	60	150	153	\$595
1997	72	140	155	\$595
1996	55	135	145	\$425
1995	61	140	145	\$425

Figure 2. A summary of worldwide gallium production and consumption.

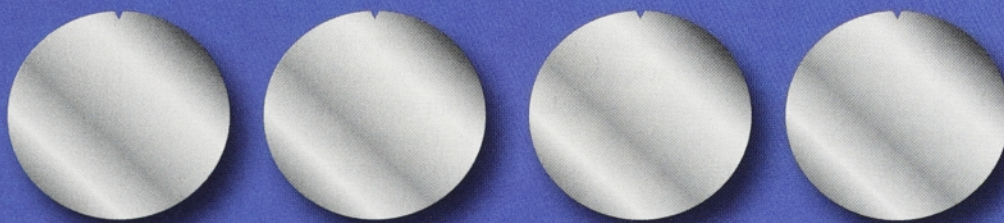
Arsenic Prices Also Set to Rise

Furukawa has informed its major high purity arsenic customers that prices will rise by 50% next year, to around \$200/kg. Furukawa is one of only two major manufacturers (the other being Metaleurop PPM of Germany), and is believed to control around 75% of the world market and 95% of the Japanese market.

Company executives said the price hike was necessary because arsenic has been in short supply since the second half of 1999. Furukawa is currently spending \$21 million to triple the capacity of its arsenic plant in Iwaki, to 180 tons per year.

In April Metaleurop announced that its PPM high-purity metals plant in Germany would increase its production to 60 tons per year.

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Wafer-Level Testing of DFB Lasers*

The ability to test edge-emitting lasers at the wafer level before fabricating cleaved, facet-coated chips provides valuable information and improved manufacturing control.

WILLIAM R. HEFFNER¹ and ALEX ROBERTSON²

Lucent Technologies

Microelectronics Group

¹Reading, PA, USA; ²Breinigsville, PA, USA

The enormous demand for fiber-optic components has forced manufacturers to improve their fabrication, assembly and test procedures. Lucent has established an automated assembly and test facility at its Breinigsville site to build optical sub-assemblies that are incorporated into laser and transponder modules. The facility has the flexibility to yield a variable product mix in response to fluctuations in customer demand [see CS 6(6), p. 13].

A key ingredient of such a manufacturing line is the availability of world-class laser and detector chips and other opto-electronic devices with the desired performance levels. However, to measure the operating characteristics of edge-emitting lasers it is necessary to fabricate cleaved and optically coated facets, and this processing effort is wasted in the case of devices with unsuitable performance. In contrast, parameters obtained from wafer-level testing can reduce such problems and improve inventory management.

At Lucent, a wafer-level testing methodology for DFB lasers—in particular the electro-absorption modulated laser (EML)—has been developed that circumvents some of the previously assumed barriers to facetless wafer-level testing of

edge-emitting laser devices. These new wafer-level tests are providing the Lucent Microelectronics Group with expanded manufacturing and design capability through the testing of device performance parameters for both lasers and modulators while these devices are embedded in the wafer. This revolutionary technique provides a greater efficiency in the manufacturing process and is on a par with most of the advantages of VCSEL device fabrication processes.

While the wafer-level parameters are not expected to be identical to their final facet-coated chip values they show excellent correlation between several important wafer and chip parameters. Below, we describe how we measure facetless, in-wafer laser and modulator characteristics on our wafers, and review the correlation and successes we have had during implementation in production.

The Importance of Wafer-Level Testing

While wafer-level testing has been employed extensively in the manufacture of InP-based semiconductor lasers at Lucent Technologies, these tests monitor and measure the output of the individual processes, such as epitaxial growth or the width of the active waveguide. The actual performance of the semiconductor device as a laser is a complex function of the structural and material properties imparted to the wafer during fabrication. While statistical models are employed to predict laser performance from these individual process parameters, until recently, laser manufacturing has not had access to a wafer-level test directly measuring the performance of the device as a lasing diode.

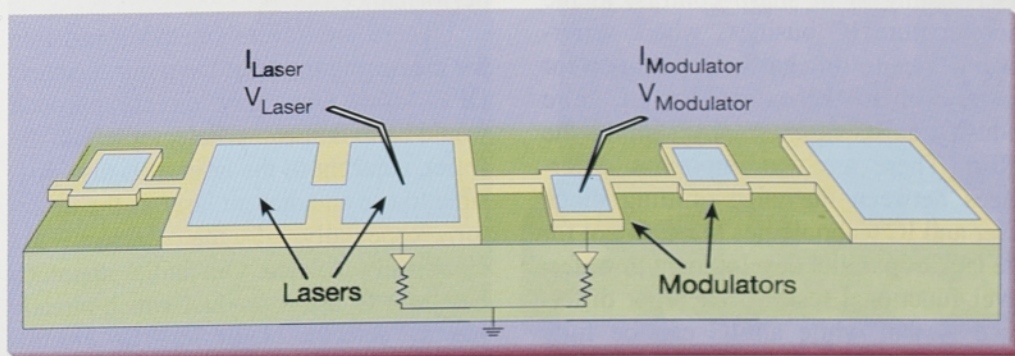


Figure 1. Schematic of wafer-level testing of electro-absorption modulated lasers (EMLs). Devices are paired on the wafer. The modulator acts as a built-in detector for the laser light, providing characteristics for both devices.

*A version of this paper was presented at the 2000 International Conference on Indium Phosphide and Related Materials (IPRM) held in Williamsburg, VA. See Proceedings, page 435.

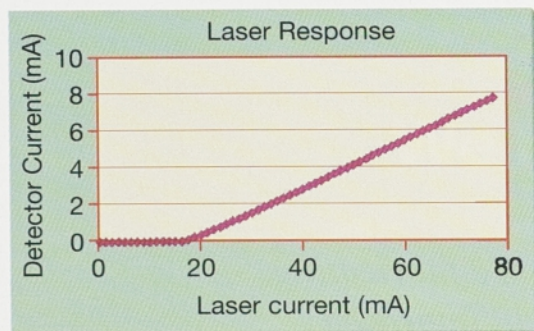


Figure 2. Photocurrent from the laser detected by the modulator biased at -2 volts, as a function of laser drive current.

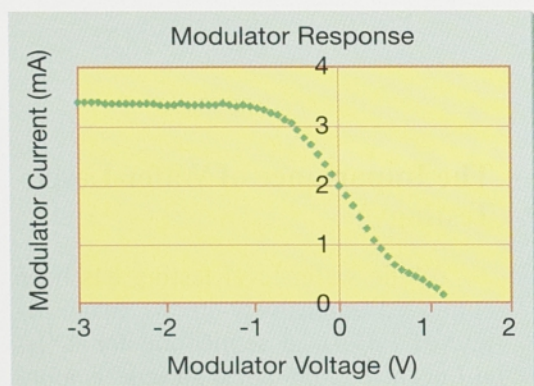


Figure 3. Modulator current as a function of modulator bias voltage with the laser biased at 25 mA above threshold.

The benefits of being able to assess device characteristics at the wafer level are numerous. These include (i) a shorter interval between fabrication and the detection of processing defects, and (ii) improved management of wafer inventory and order fulfillment. The ability to carry out wafer-level testing of VCSELs is a major advantage in the fabrication of this type of device.

The post facet-cleave approach to laser testing is in sharp contrast to the more mature IC business where wafer-level device testing has been going on for years, even to the extent that an entire industry exists to externally support the effort. There are two important differences between the edge-emitting diode laser and IC technologies that account for the lack of parallel development in wafer-level functional testing. The first difference is that while an IC can be fully functional before being sliced from its parent wafer, an edge-emitting semiconductor laser requires a cleaved and opti-

cally coated facet to attain its designed electro-optic performance.

The second distinction is that while the output of an IC is an electrical signal, the output of a laser is light, which requires some sort of optical detector to measure it. Etched facets, turning mirrors and integrated detectors have been incorporated into the wafer processing for some laser devices [1,2] where etched facets are acceptable. However, if the device is a distributed feedback (DFB) laser or a distributed Bragg reflector (DBR) laser, it is possible to circumvent both of these issues without resorting to etched facets.

We have developed a method appropriate for wafer-level testing of such devices, and have introduced it into our manufacturing procedure for the electro-absorption modulated laser (EML).

Facetless Testing of EML Devices

In the DFB laser, an internally embedded grating is used to control the wavelength and provide single mode operation. While the laser facets provide much of the optical feedback and are certainly required to achieve the final device performance, the grating itself will provide enough feedback for the device to achieve lasing. In fact, the performance without facets provides a more direct measure of the electro-optic properties of the wafer than does the fully fabricated laser chip, where facet cleaving actually adds considerable variation to the final performance.

There are several methods possible for measuring the light from our facetless DFB laser. One very direct approach would be to fabricate a detector within the wafer, adjacent to the laser. It is also possible to use an adjacent laser as the detector, especially if the devices are electrically isolated. Our initial approach has been to use a product which already has a "detector" built in. The electro-absorption modulated laser (EML) is a device that integrates a DFB laser with a modulator on the same chip [3]. Under

sufficient reverse bias (less than -2 volts) the modulator will absorb essentially all of the light passing into it, providing an ideal photodetector. By utilizing the modulator as a detector we have access to characteristics of both the laser and the modulator. To first order, we can treat the laser under test as a symmetric AR-AR DFB laser. A sketch of the wafer testing of an EML device is illustrated in Figure 1.

Testing is performed after the p-contact metals have been applied. N-metals, which are applied to the wafer after thinning, are not required for testing. The high n-doping in the substrate enables an adequate, though non-Ohmic, contact through the wafer prober's chuck. The n-side Schottky contact introduces a voltage offset not present in the fully metalized device, but this is not a serious limitation. The laser diode is a current-driven device and the most important information is contained in the "light"-current response, independent of voltage offsets. For the modulator, which is operated in a voltage-driven mode, the offset must be compensated.

Laser and Modulator Performance Results

Figure 2 and 3 show examples of the wafer-level test data taken from laser and modulator sections at an individual device site on the wafer. Figure 2 displays the photocurrent from the laser detected at the modulator biased at -2 volts vs. the laser pair drive current. This curve allows the extraction of both an in-wafer lasing threshold current (I_{th}) and a slope. Due to the symmetry of the layout, the slope represents half the conversion efficiency between the photon creation and detection (re-absorption) processes.

Figure 3 displays the modulator current as a function of modulator bias voltage with the laser biased at 25 mA above threshold. Here, the n-side contact introduces an offset in the voltage from that expected for a fully metalized chip. Thus, attempts to extract parameters relevant to modulator performance such as extinction ratio and inflection voltage (which are defined in terms of

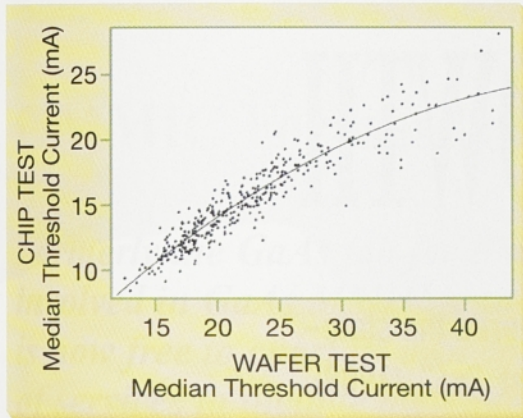


Figure 4. Correlation of wafer median threshold current (I_{th}) measured on-wafer and for cleaved, facet-coated chips. Median values across each wafer are shown for a large collection of EML wafers. The solid line indicates the best fit to a quadratic with an $R^2 = 0.88$.

specific voltages or voltage operating points) will require compensation for this voltage offset.

Both laser and modulator response are sampled at a variety of sites across the wafer using a semi-automatic probe station. The raw current and voltage traces from each site are collected and stored in an Oracle relational database for subsequent analysis and extraction of relevant parameters.

Since the facetless, in-wafer performance of our devices is expected to differ somewhat from that of the cleaved, facet-coated chips, their relevance to one another must be extracted through correlation. Saving the raw data permits us to re-extract parameters and refine our analyses as our understanding of the correlation evolves.

An example of the correlation we have been able to obtain between in-wafer parameters to their chip counterpart is shown in Figure 4. Here the median in-wafer lasing threshold is plotted against the median chip threshold current for a large collection of EML wafers. The data includes a wide range of threshold performance, many taken from development wafers prior to process optimization. In fact, the excellent correlation achieved early in our initial investigations enabled us to exploit feedback from the in-wafer testing into the design cycle, shortening the design interval.

Conclusions

We have introduced a method for in-wafer electro-optic testing of DFB lasers prior to the facet formation. The method is ideally suited for devices with integrated laser and modulator such as our EML device, but can be adapted to any device with sufficient internal optical feedback. Without facets, the in-wafer results can not be expected to equal their faceted chip counterparts, but correlation with certain parameters such as the threshold current (I_{th}) is shown to be excellent. A major advantage of the in-wafer test lies in its ability to provide direct information about the wafer's electro-optic performance well in advance of the usual chip level data. This information is very valuable in maintaining and improving product quality and consistency in the manufacturing line.

Acknowledgements

We would like to thank the able colleagues and managers who have contributed to and supported this effort.

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OMMIC Focuses On GaAs

Formerly the GaAs fab for Philips Semiconductors, OMMIC has been actively involved in GaAs MMIC foundry production for over 20 years. The new company is now free to chart its own course as part of Philips, and has expanded its range of services to include merchant epiwafer supply.

RICHARD DIXON

As the former Philips Microwave Limeil, OMMIC has a long association with GaAs technology. In the late 1960's, Philips produced its first Gunn diodes, and research into GaAs-based MMICs and digital ICs began in 1972 at Philips Research Laboratories. In 1990 Philips' GaAs operations subsequently became Philips Microwave Limeil, and in 1996 the GaAs fab for Philips Semiconductors based in Limeil-Brévannes on the outskirts of Paris.

OMMIC, the most recent incarnation, now operates as an independent wholly owned Philips subsidiary. The company is well known as a GaAs MMIC foundry service for Philips Semiconduc-

tors and external customers. Since its inception at the beginning of 2000, it has also begun supplying 4- and 6-inch GaAs epiwafers.

According to CEO Willem Haverkamp, OMMIC was formed to provide a focus on GaAs activities and strengthen the company's presence in fast growing markets, especially fiber optic ICs and high volume supply of epiwafers. "Both the importance of the fiber optic components market and the technical competence and long experience we have in-house is such that Philips Semiconductors has decided to remain a very close partner to OMMIC," says Haverkamp.

Processing Capabilities

OMMIC provides access to its technologies via its foundry service and design team. It also sells a range of standard products, and began offering GaAs epiwafers at the beginning of the year. The company's standard products are primarily PHEMT-based ICs used in fiber optic and wireless communications.

The company has a base of about 40 key customers for MMICs, a number of which require high-reliability products for applications such as space payloads or optical interfacing. MMICs are currently manufactured using MESFET and PHEMT processes on 3-inch

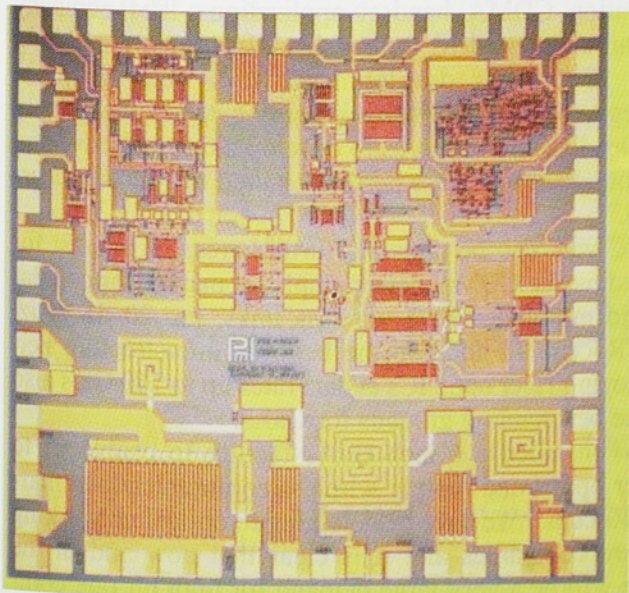
GaAs substrates, although OMMIC says it intends to move to 4- or 6-inch MMIC processing within 12 months.

MESFETs are being gradually phased out, says marketing and sales manager, Derek Smith. "OMMIC's MESFET production is now quite limited and more emphasis is being placed on PHEMTs," says Smith. "We still use the MESFET structure for some older generation products such as modulators, RF front ends and a switching matrix, but all our new work is with PHEMTs."

The majority of the foundry's work is for standard products and low to mid-volume ASIC contracts consisting of up to some hundreds of thousands of units per year. OMMIC is a qualified (ISO 9001) supplier of standard MMIC products based on PHEMT processes for high power, low noise applications. These include 2.5 to 40 Gb/s data rate digital ICs such as transimpedance amplifiers, laser/modulator drivers, multiplexers and demultiplexers, in addition LNAs and PAs used in millimeter-wave links for LMDS, cellular base stations and satellite communications.

Enhancement/Depletion-Mode PHEMTs

Announced in 1995, the company's enhancement-depletion (E/D) mode PHEMT structure was one of the world's first production E/D PHEMT processes. This process enables transistors with a negative gate source threshold voltage and others with a positive gate-source



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Type	Applications	Gate Length	F_t (extrinsic)	Status
PHEMT	E/D mode	0.18 μm	73 GHz	Released
	High power	0.15 μm	100 GHz	Released
	Ultra low noise	0.12 μm	90 GHz	In development
MHEMT	E/D Mode	0.18 μm	>150 GHz	In development

PHEMT and MHEMT processes for high frequency MMICs offered by OMMIC. All MMICs are grown on 3-inch GaAs substrates, and epiwafers are available on 4- and 6-inch substrates. The company is also planning to introduce HEMTs based on 4-inch InP substrates.

threshold voltage on the same circuits, allowing the chip area and power consumption to be optimized and the mixing of analog and digital functions on the same chip.

OMMIC's E/D process employs a gate length of 0.18 μm and is capable of producing MMICs with cut-off frequencies (F_t) of 73 GHz. Currently these devices are being evaluated by the European Space Agency. Last year the company introduced a 0.15 μm process with a cut-off frequency of 100 GHz for power PHEMTs destined for 40 Gb/s driver amplifiers and millimeter-wave PAs.

OMMIC is developing E/D mode HEMTs with cut-off frequencies above 150 GHz

Metamorphic and InP HEMTs

Also under development at OMMIC are PHEMTs based on a 0.12 μm process for ultra low noise applications, and 0.18 μm gate length processes for cut-off frequencies above 150 GHz using high indium content E/D mode HEMT structures on both GaAs and InP substrates.

"The GaAs-based metamorphic HEMT is equivalent in performance to InP HEMTs because the amount of indium that can be achieved in the channel is similar," says chief technology officer, Marc Rocchi. "InP HEMTs are also ideally suited to growth by MOVPE, and OMMIC has experience in InP MOVPE growth dating back to 1986."

Part of this development work will be performed with Philips Semiconductor and is aimed at very high bit rate fiber optic applications. According to Rocchi, InP HEMTs will be grown in-house on 3- and 4-inch InP substrates by MOVPE. "OMMIC intends to commercialize these technologies, predominantly for digital ICs required in optical network systems operating at 40 Gb/s and above, most likely by the end of 2001," he says.

Microwave Packaging—Flip Chips

OMMIC has also recently developed and qualified a flip chip bonding process for use in fiber optic IC packaging technologies. The system uses bump bonds placed on the chips to connect the pads of a MMIC to a substrate or soft board.

According to Derek Smith, this is the best way to preserve IC performance at high frequencies of operation. "Many of

the large manufacturers are installing pick and place equipment for flip chip bonding on high frequency boards," says Smith. "OMMIC's process provides low inductance and allows the flipping of the chip to remove the need for wire or through substrate via hole bonding."

Supply of Epiwafers

As a company with a long tradition of epitaxial R&D, OMMIC can claim an impressive number of firsts, including the construction of the world's first 5 × 3-inch MOVPE reactor for GaAs epitaxy in 1986. OMMIC now operates from a 15,000 sq.ft. clean room at Philips' 250,000 sq.ft. site, and grows epilayers for PHEMTs on 3-inch substrates for captive production of MMIC PAs and LNAs used in base station applications and LMDS.

At the beginning of the year, OMMIC began selling large quantities of 4- and 6-inch GaAs epiwafers based on PHEMT structures. Six-inch epiwafers are produced on two high capacity MOVPE reactors dedicated to high volume applications. Following an initial ramp up phase, the company has now reached a production rate of 300 wafers starts per week.

HBTs

OMMIC also manufactures HBT epiwafers on 6-inch GaAs substrates using its GaInP/InGaAs heterostructure design for third generation CDMA handset applications. The company benefits from its internal IC wafer fab's infrastructure and long experience in process development, says Peter Frijlink, OMMIC's epitaxy manager. "This synergy between the epitaxy and IC groups has allowed us to develop a cost effective and fast turn-around HBT process perfectly suited to epiwafer characterization."

OMMIC will also be pursuing further areas of interest for GaAs, including the CDMA power amplifier market for cellular handsets and millimeter-wave wireless links, i.e. 20–45 GHz, says Marc Rocchi. In addition, he believes infrastructure networks employing fiber optic ICs at data rates up to 160 Gb/s also represent the best hunting grounds for GaAs.

"Philips installed a 6-inch GaAs facility to enable us to pursue fiber optics and mobile wireless communications markets," says Rocchi. "We have been talking to optical networking infrastructure companies and it is clear that now and in the future there will be a very large demand for high bit rate components, and this is a rare instance where silicon really will have difficulties competing."



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Polycrystalline ingots, slices or granules

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n-type : S or undoped

p-type : Zn doped

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Sputter Deposition of Metal on Compound Semiconductor Wafers with Minimum Damage

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High-speed gallium arsenide metal-semiconductor field-effect transistors (MESFETs) commonly utilize thin refractory metal films, in a self-aligned gate process, as the ion-implantation mask for the formation of source and drain regions. These refractory metal films, typically titanium (Ti) or titanium-tungsten (TiW), are deposited by DC magnetron sputtering, a possible source of plasma-induced damage to the sensitive GaAs substrate. It is important to quantify such process-induced damage on these devices so that we can understand, and thereby reduce or eliminate, the causes of damage. Recent publications include a comparative study on various techniques of plasma etching of refractory metal contacts on GaAs [1].

This article reports our extensive study on the effects of plasma-induced surface damage caused by sputtering Ti (or TiW) on GaAs substrates in three different magnetron sputtering systems. We measured the damage from the increased sheet resistance (R_{sh}) of the thin surface conducting layer on these substrates after plasma processing, as well as from reduced saturation source-drain current (I_{dss}) in MESFET devices. Post-processing anneals were used to recover from the damage. The results of this study helped us determine which types of sputter deposition tools produced minimal damage, and why.

Experimental Setup

The deposition of Ti and TiW films on ion-implanted and annealed GaAs sub-

strates took place on three different sputtering systems using pure Ti and compound TiW (90% W : 10% Ti) targets. All three tools were configured for DC magnetron sputtering in a stationary mode. Two of the tools, System A and System C, had mechanical shutters positioned between the target and the substrates. The target was always ignited with the shutter closed in these systems to shield the wafer from the initial plasma strike. After plasma stabilization, the shutter opened to commence film deposition. The third tool, System B, did not have shutters. System A also had the capability of changing the target-to-substrate (T-S) distance over a specific range without breaking vacuum.

The substrates used for these tests were 100mm n-type GaAs wafers. Ion implantation and annealing yielded a thin surface conducting layer on these substrates. Before depositing metal films, a contactless sheet resistance measurement [2] tool from Lehigh Electronics, Inc. measured R_{sh} maps of these wafers. After sputter deposition of the metal films under various processing conditions, a wet etch bath (15% overetch) completely etched off the film. We used hydrofluoric acid (HF) for Ti film removal and a hydrogen peroxide-deionized water mixture for TiW film removal. The measured increase in R_{sh} after removal of the deposited film was indicative of the amount of damage. The damage (ΔR_{sh}) here is defined as the difference between the pre- and post-process R_{sh} .

	Damage, ΔR_{sh} (Ω/sq)	
	Individual	Average
System A (with shutter)	11.5	10.7
	9.8	
System B (no shutter)	48.6	50.3
	52.0	

Figure 1. Comparison of damage caused by high power Ti deposition in Systems A and B.

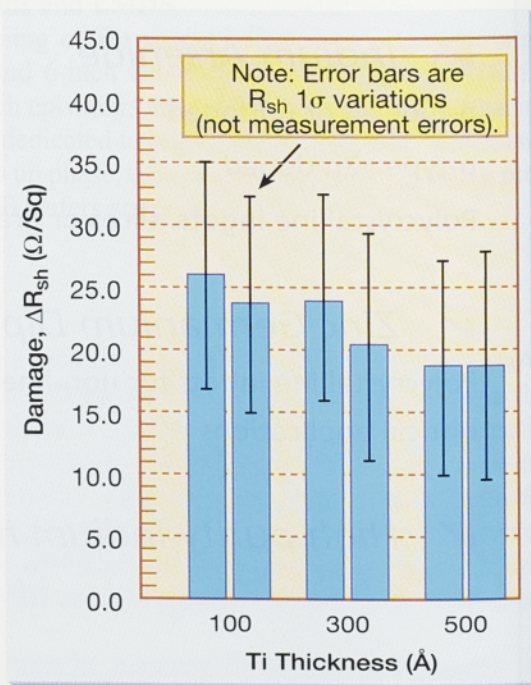


Figure 2. Damage plotted as a function of deposited Ti thickness in System B.

In all the tests, we used a pre-measured n-type GaAs control wafer which did not undergo film deposition. We placed it in the wet etch bath at the same time as the metallized wafers and re-measured its R_{sh} to ensure that the wet etchant did not remove any GaAs. In all cases, the increase in R_{sh} was $< 6 \Omega/\text{sq}$.

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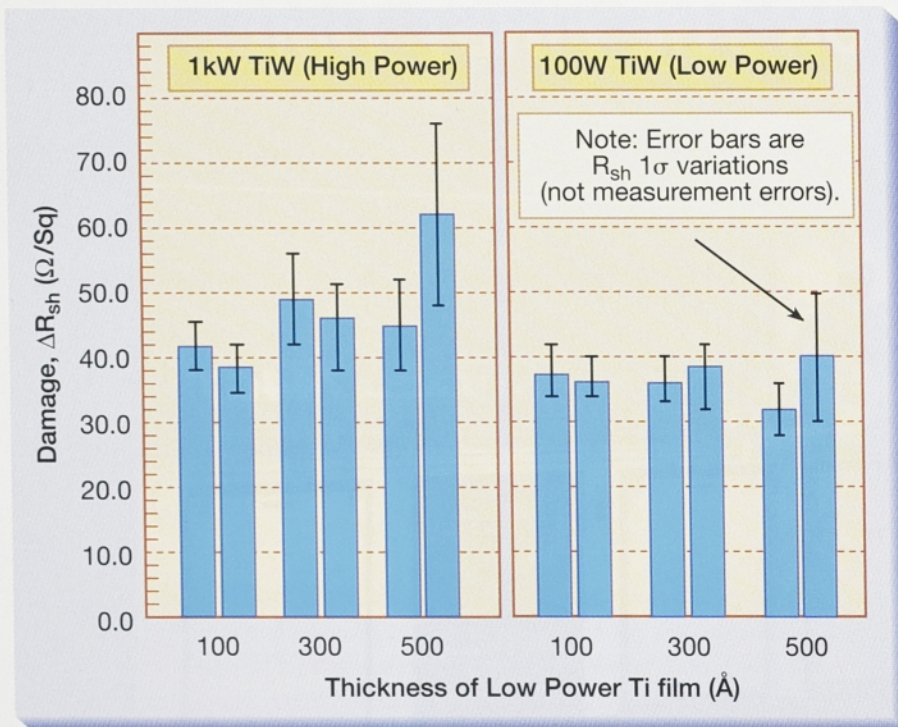


Figure 3. Damage from low power and high power 1000Å TiW on top of various thicknesses of low power Ti films in System B.

Results And Discussion

1. Effect of shutters on damage

In the first experiment, System A (with shutters) and System B (no shutters) ran two wafers each from the same batch. A relatively high power, 1000W, was used to deposit 250 Å Ti on all the wafers. Figure 1 summarizes the results of damage from high power Ti. These values indicate that damage from a shutterless system is about 5× that from a shuttered one.

2. Effect of Ti thickness on damage

Next, System B deposited different thicknesses of Ti film at a relatively low power of 100 W on n-type monitor wafers. Figure 2 shows the resulting ΔR_{sh} values where wafer surface damage decreased with increasing Ti thickness. We speculate that the rise in substrate temperature during an extended deposition of thicker films may have resulted in some annealing of the initial damage.

3. Effect of TiW overlayer on damage

In the third experiment, we studied the damage from high power and low power 1000Å TiW films deposited on top of 100Å, 300Å and 500Å low power Ti films using System B. The results (see Figure 3) indicate that deposition of the TiW film caused additional damage even for thicker

Ti films. As expected, higher power TiW films also caused more damage. This additional damage may be attributed to the substrate being exposed to a strike plasma potential twice, first for Ti and again for TiW.

4. Mechanism for plasma-induced damage

The fourth experiment, using System B and a range of different process powers and pressures, demonstrated that most of the damage occurred within 1 second of deposition when there was hardly any film deposited on the wafer. Figure 4 shows the results for very short deposition times at these different process conditions. At low power and high pressure, we saw less damage than at high power, low pressure conditions due to decreased ion bombardment of the substrate in the first case. We speculate that the high strike voltage of the plasma (~ 1000 V) caused most of the damage.

5. Damage anneal studies

Annealing the damaged wafers can repair this sputter-induced damage. In the next experiment, the shutterless System B metalized the gate of a MESFET device. Sputter-induced damage in the channel region degraded I_{dss} at zero gate bias [3]. Figure 5 shows the results of annealing a device wafer at about 300°C. where the I_{dss} current improved with increased bake time, stabilizing after a ~3-hr anneal.

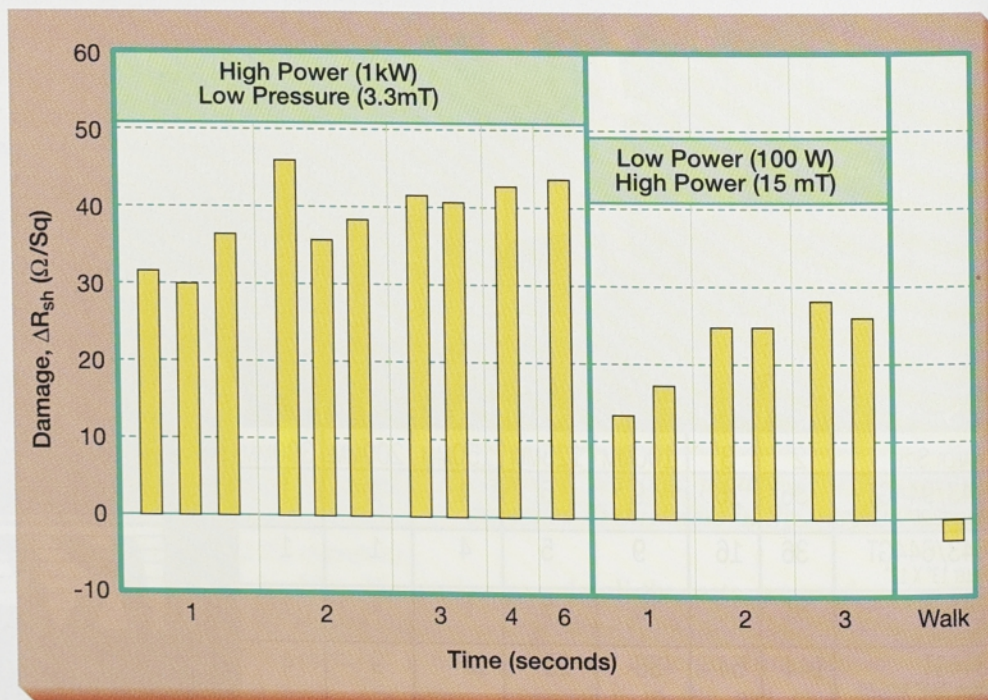


Figure 4. Damage from high power-low pressure and low power-high pressure Ti depositions as a function of very short deposition times using System B. The wafer designated as "walk" was a control wafer run through the system without turning on the target power.

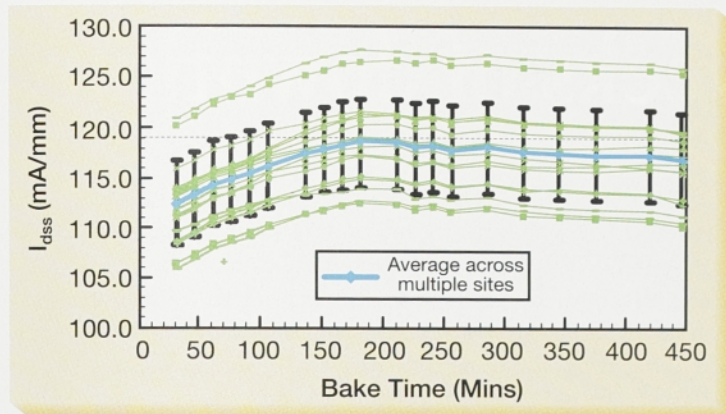


Figure 5. Annealing of a MESFET device at about 300°C showing repair of sputter induced gate damage in the channel region. Sputtered metal was deposited using System B. Error bars are 1σ values measured across the wafer.

6. Designed experiment on damage with shuttered system

Even when we used a system with a shutter to protect the substrate from the plasma strike, we saw a small amount of damage. Using System C, we ran a design of experiments (DOE) on sputter-induced damage for deposition of 250Å Ti on n-type wafers as a function of the process power, pressure, and T-S distance. Figure 6 (a-c) shows the R_{sh} response surfaces plotted versus pressure and T-S spacing, power and T-S spacing, and power and pressure.

These results show that the damage increased as (1) the target-to-substrate distance decreased, (2) the target power increased, and (3) the process pressure decreased. Lower pressure meant larger mean free paths and fewer collisions. Both lower pressure and smaller T-S distance meant fewer collisions, thus more energetic species arriving at the substrate. Higher target power also increased the number of energetic species arriving at the substrate. The resulting increased ion bombardment of the substrate in all three cases led to increased damage.

Conclusions

This study of damage on n-type GaAs substrates yielded the following conclusions:

- Plasma strike voltage is the primary cause of plasma-induced damage.
- This damage occurs within one second of plasma ignition. In some cases, an annealing effect occurs for longer depositions, resulting in some improvement.
- Use of a mechanical shutter significantly reduces the damage. A glow start or pressure spike in a shutterless system could also lower the strike voltage, and therefore the damage.
- Increased ion bombardment, caused by higher power, lower pressure and shorter T-S spacings, increase the damage.
- A 3-hr, 300°C anneal may repair the worst damage.
- Even shuttered systems indicate some damage.

The ultimate solution for zero damage may be to utilize a low voltage, downstream plasma technique, such as electron cyclotron resonance (ECR), an inductively coupled plasma (ICP), or ionized physical vapor deposition (IPVD).

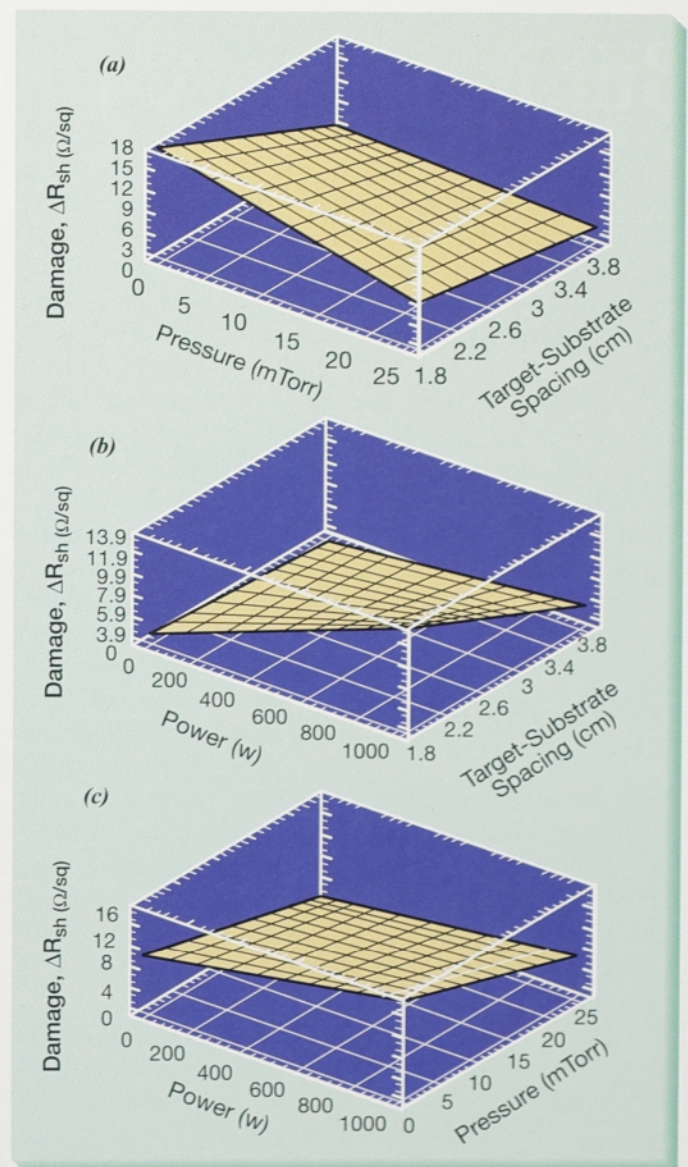


Figure 6. Response surfaces of sputter induced damage. System C (with a shutter) was used in all cases. (a) Response surface as a function of pressure and target-to-substrate spacing. (b) Response surface as a function of target power and target-to-substrate distance. (c) Response surface as a function of target power and pressure.

Acknowledgements

The authors would like to thank D. Stolpe for his support with processing and testing.

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- [2] "Modern GaAs Processing Methods", Ralph Williams, Artech House, Boston, 1990, p. 4.
- [3] "Modern GaAs Processing Methods", Ralph Williams, Artech House, Boston, 1990, p. 60.

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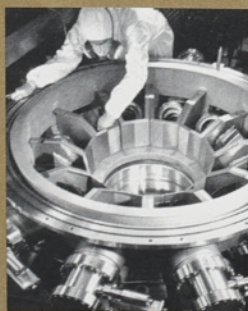
The V150 was developed by the same team of engineers who designed the V100 so we had a good starting point. Our aim was to increase throughput by scaling the system geometry, reduce downtime by increasing reliability, decrease turn round time and increase productivity by making the process more stable. So what does this mean in technological terms?

RAPID INSTALLATION

The V100 already has a reputation of being the fastest production MBE system to install. With this in mind, we designed the V150 so it can be up and running in less than a third of the time needed for competitive systems. Part of this is due to the highly efficient bake system used by all VG Semicon products. The V150 has a bakeout enclosure that surrounds the whole system so it can be quickly and efficiently baked at 200°C with no cold spots. Our competitors cannot fully bake their systems. They use a makeshift collection of inefficient flexible bakeout covers, tapes and foil coverings. Since any bake is only as good as the coldest part of the system, you'll probably be amazed to hear that parts of their systems are never heated. It's no wonder they take three times longer to bake than the V150.

RAPID TURN ROUND

MBE system turn round involves venting the system, cleaning the deposition chamber, reloading source material, pumping down and baking. With a reliable system it doesn't have to be done too often, but minimizing the time taken is still vital for improving system throughput. VG Semicon's unique and exclusive chamber seal technology means the V150 is the first production MBE system ever that allows easy removal of the entire source



assembly. This gives you unprecedented access to the entire source area and growth chamber walls, for faster source replenishment and easy clean up.

Our competitors, on the other hand, rely on individual source replenishment and awkward chamber clean up through small ports. With reloading and cleaning done in a fraction of the usual time, the V150 source flange is simply re-attached and the chamber pumped down - no time-consuming and complicated bolt sequence to worry about. Combine this with the V150's rapid bake and its no wonder the V150 can be turned around in 30% of the time it takes our competition. In a high volume application this can increase overall productivity by more than 10%!

HIGH STABILITY

Open conical sources of Ga and In suffer from variation in flux over time. Simply stated, the flux drops because of material depletion as the source is used. For standard MBE processing this predictable behavior necessitates routine recalibration to ensure constant growth rates. VG Semicon's ThermoCell™ range was designed to dramatically reduce the requirements for calibration. In fact our Ga ThermoCell™ is ten times more stable than our competitors' conical cell design and it virtually eliminates shutter-related flux transients.

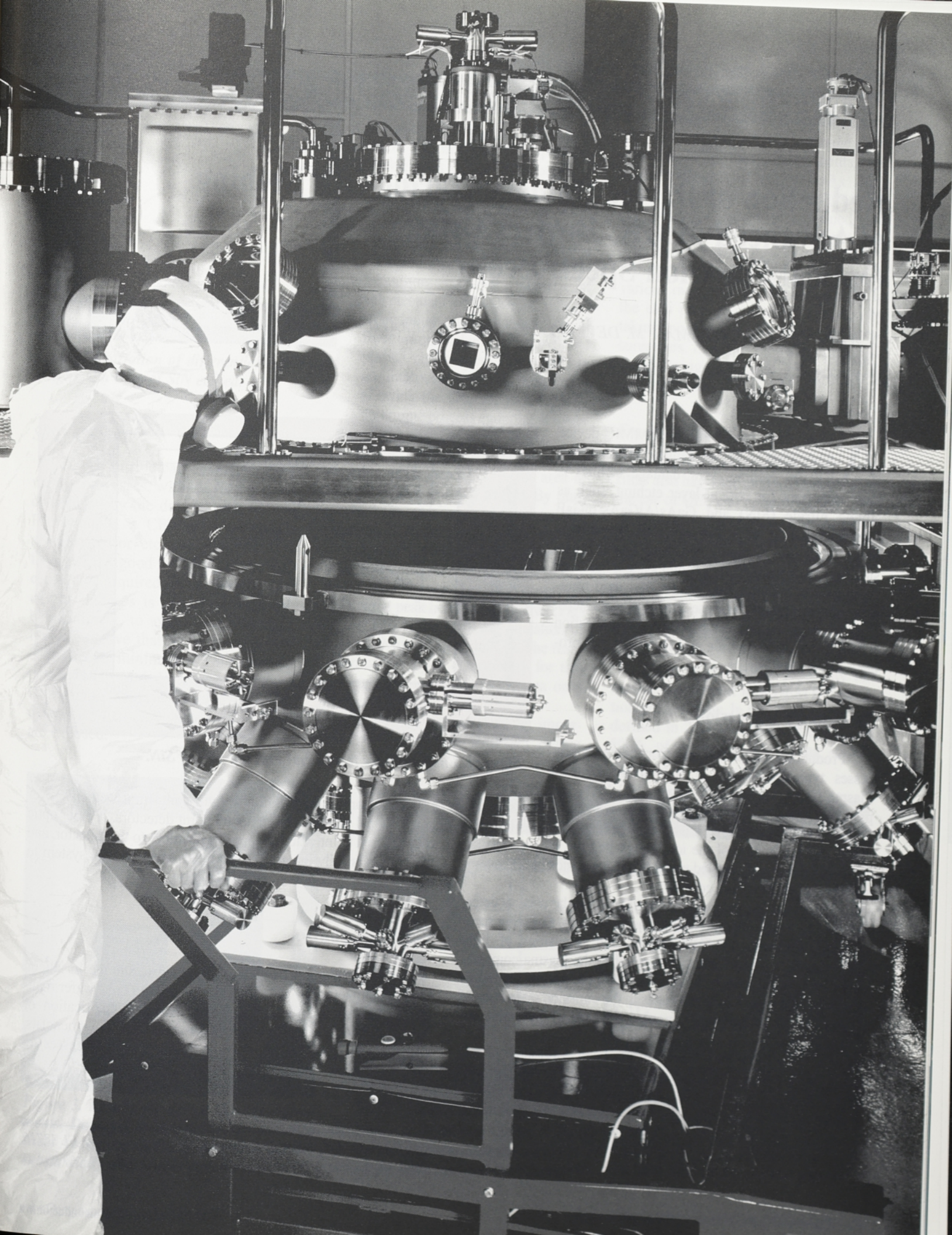
The V150 is designed to be more reliable, more stable and more productive than any other system on the market. It's no wonder we're market leaders. We're making the engineering choices to ensure that you're ahead of the game.

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Reduction of Device Damage During Dry Etching of Advanced MMIC Devices Using Optical Emission Spectroscopy

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An important consideration in MMIC device fabrication is device damage induced during dry etching. Low damage etching is most important for critical layer etching, such as silicon nitride (SiN) and GaAs/AlGaAs/InGaP frontside etching when the transistor structure is being fabricated. A highly versatile Optical Emission Spectroscopy (OES) endpoint system has been developed to monitor the process and help minimize device damage for these critical process steps. Data is presented that demonstrates its application for both the silicon nitride and frontside etch processes described earlier.

Technology Discussion

Production based SiN and frontside etch processes typically utilize an Inductively Coupled Plasma (ICP) source. In this work, a 2 MHz coil provides power to generate a high-density plasma: a separate 13.56 MHz power supply is used to independently bias the substrate and hence control the ion energy and the process results. Wafers were actively cooled using an electrostatic clamping subsystem and He backside cooling.

Optical Emission Spectroscopy (OES) can be used to determine the process endpoint during plasma etching. Emission spectroscopy examines the wavelengths and intensities of light emitted from a plasma and correlates it to the plasma composition. The spectral lines from key species in the plasma are monitored as a function of time. Changes in the emission intensities of these key species during the process are used to determine the etch endpoint.

The OES endpoint system that has been developed for this work employs a CCD spectrometer. This configuration was chosen to provide

- multi-wavelength capability,
- good resolution over a wide spectral range, and
- fast data acquisition through solid state circuitry.

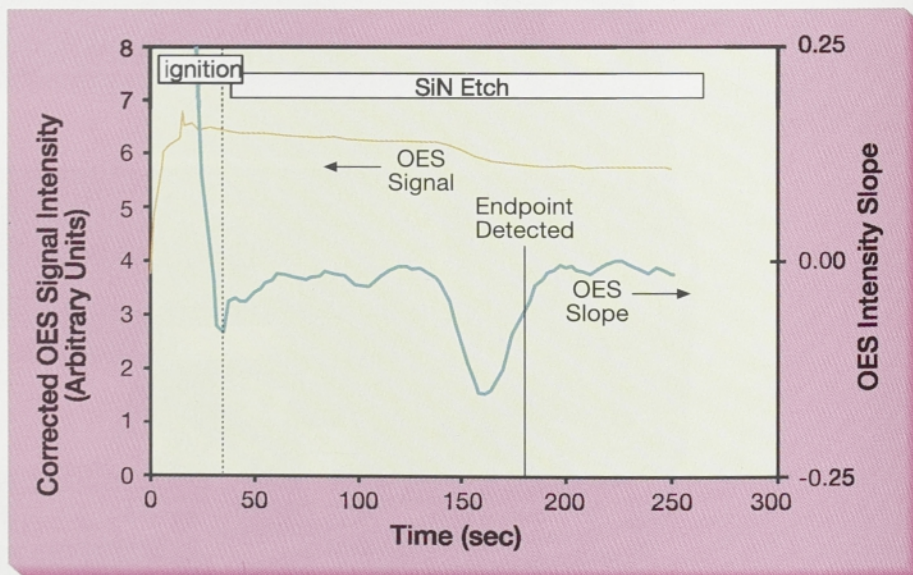


Figure 1. Endpoint trace from 1 cm² exposed area of SiN.

This configuration offers significant improvements over conventional single wavelength endpoint detectors. A fiber optic cable is used to interface the process chamber to the detector, and the system is fully integrated into the process control system to allow for true production implementation.

Process Results

Although the use of OES is a proven technique in silicon wafer manufacturing, its utility in production GaAs wafer manufacturing has only recently been shown. The fabrication of MMIC devices is one area where OES offers significant benefits, especially for critical etches. Results from two such processes are discussed below.

* Unaxis USA, Inc., 10050 16th Street North, St. Petersburg, FL 33716.
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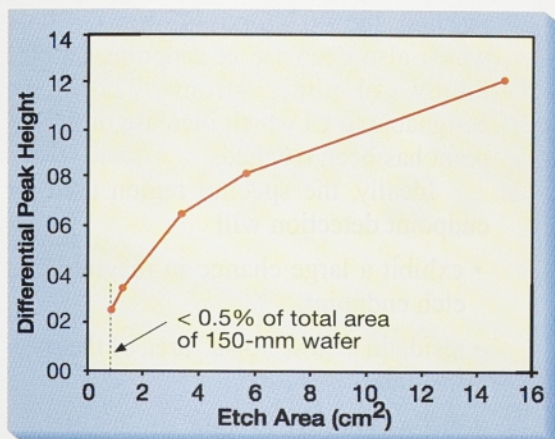


Figure 2. Variation of differential signal peak height with area of SiN etched.

Silicon Nitride

Silicon nitride can be etched using various processes, with the best process determined by the desired etch results. For example, a CF_4 -based process is appropriate for etching relatively thin films where good uniformity and CD control are required. Even though a low dc bias process is used to reduce ion bombardment, to avoid device damage it is imperative that the degree of over etch is also minimized. This requires precise end point detection. The challenge is to achieve reliable endpoint detection when only small areas of SiN are exposed.

The multi-wavelength capabilities of the CCD-based OES system allow for not only the primary wavelengths to be monitored (in this instance CN bands at $\sim 388\text{nm}$), but also appropriate background regions of the spectrum. Subtracting out the adjacent plasma background and using a signal ratio technique, allows significant enhancement of the signal change at endpoint while reducing signal fluctuations due to inevitable plasma instabilities. This results in an improved signal-to-noise ratio allowing the detector to accurately determine process endpoint at lower SiN loads.

Figure 1 shows the endpoint trace recorded while etching a $\sim 1\text{cm}^2$ area of SiN ($< 1\%$ of a 150-mm wafer). By plotting both the raw signal and the signal differential, it can be seen that etch endpoint for this area was clearly detected. Repeating this experiment over a number of different sample areas yields a plot of differential peak height vs. SiN area (Figure 2). This graph gives an indication of the sensitivity of this technique. The resolution of end point detectability for this configuration is $< 0.5\%$ open area on a 150-mm wafer.

In order to demonstrate the importance of minimizing over-etch during

SiN etching, experiments to determine the effect of over-etch on damage were performed. In these experiments, the sheet resistance of doped GaAs films was measured prior to processing. Once measured, the wafers were cleaned with HCl followed by 1 kA SiN deposition. The samples were then etched using a standard low damage SiN process with various over-etch times. Damage due to the etch process was then estimated by taking post-etch sheet resistivity measurements. Figure 3 shows that the measured damage increased with increasing over-etch time.

Frontside Etch

Frontside etching of transistor level films also has been shown to benefit from the use of OES end point detection. Typical material systems include GaAs/InGaP, AlGaAs/GaAs as well as GaAs/AlGaAs. As device requirements become more stringent, these underlying layers are becoming thinner, requiring more precise process control. OES offers the user an additional technique for providing this added control.

An example of this capability has been demonstrated in a HEMT fabrication process flow. In this case a gate was defined in $2500\text{\AA}$ of GaAs stopping on $500\text{\AA}$ of $\text{Al}_{0.25}\text{Ga}_{0.75}\text{As}$ using a SiN

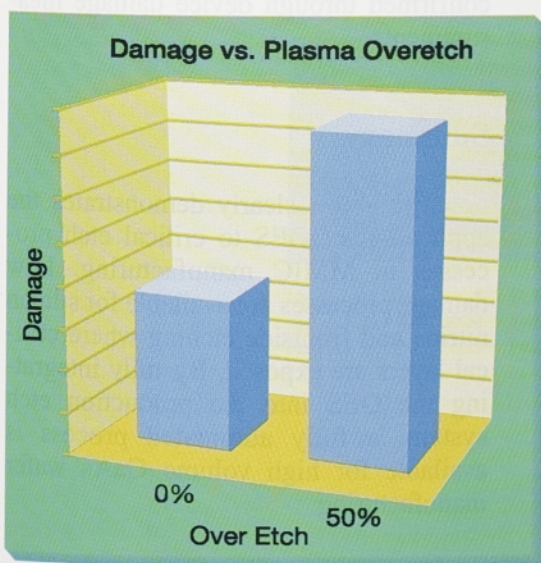


Figure 3. Results for device damage experiments. Damage, as determined by post-etch sheet resistivity measurements, increases substantially with longer etch times.

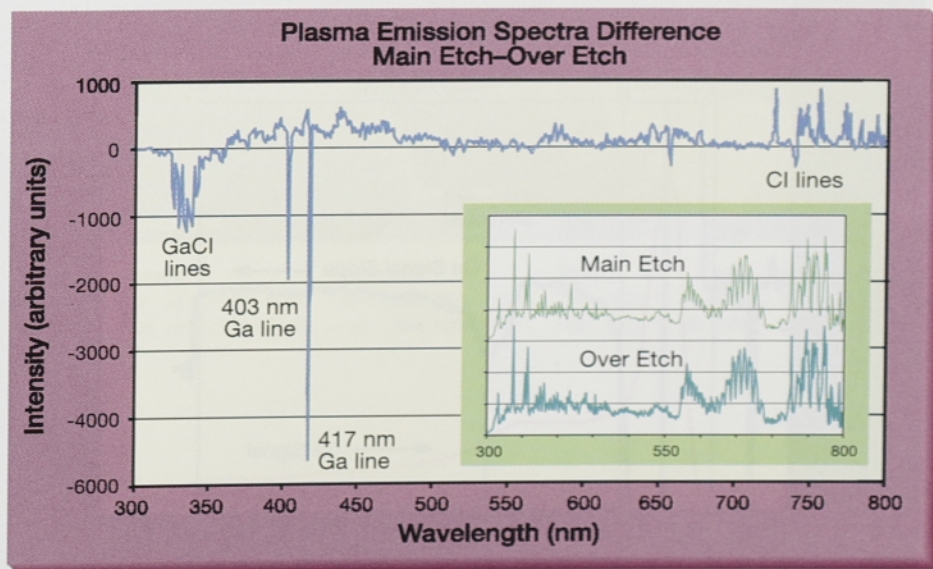


Figure 4. Difference spectra from the HEMT etch process highlighting emission changes between the main etch and over-etch steps. Inset shows raw spectra for main and over-etch steps.

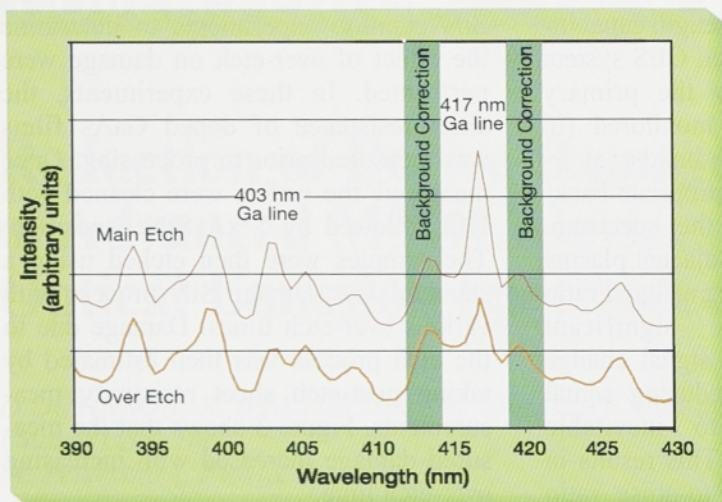


Figure 5. Expanded plasma emission spectra from the HEMT etch process during the main etch and over-etch segments of the process. The 417-nm Ga line used to determine the emission endpoint, and shaded areas were used for background correction.

mask. A process has been previously developed having a low GaAs etch rate with a high GaAs:AlGaAs etch selectivity to minimize over-etch into the AlGaAs stop layer. Details regarding this process have been described elsewhere¹.

In order to set up the emission endpoint system for this application it was necessary to first collect emission spectra during the etch and over etch portions of the HEMT etch process. To obtain these spectra, a test wafer was etched and the

peaks attributable to both the process gases as well as the etch products. From the two spectra inset in Figure 4 an endpoint strategy is not obvious.

In order to detect more subtle changes between the two spectra, it is helpful to construct a difference plot. Figure 4 also shows the difference between the main etch and over-etch spectra. The difference plot shows four regions that are candidates for endpoint detection: the 325–342nm band assignable to GaCl emissions that decrease once endpoint is

emission data collected. The inset in Figure 4 shows the emission spectra from two points in the process. The top spectra was collected at the beginning of the process (while the GaAs layer was being etched) while the bottom spectra was collected later in the process when the GaAs layer had already been removed (an over-etch condition). For process reasons nitrogen was added to the etch and hence the spectra are relatively complex with emission

reached, the 403- and 417-nm Ga lines which also decrease at endpoint, and the family of lines from 725–792nm assignable to Cl which increase once endpoint has been reached.

Ideally, the spectral region used for endpoint detection will

- exhibit a large change in magnitude at etch endpoint,
- reside in a “low noise” area of the spectra, and
- be assignable to one of the etchant gases or etch products.

Applying these criteria, both the 403- and 417-nm Ga lines are good candidates for endpoint detection. Figure 5 shows an expanded view of the emission spectra for both of these lines during the etch and over-etch conditions. For this work, the 417-nm Ga line was monitored to detect the process endpoint while the two shaded regions on either side were used for background correction.

Using this algorithm, an endpoint trace for the HEMT etch process is shown in Figure 6. Using the derivative from the corrected Ga signal, a clear, distinct endpoint time was determined. Using the fully automated endpoint system in conjunction with a highly uniform process, etching was completed prior to damaging the thin AlGaAs underlayer. This was confirmed through device damage measurements.

Summary

The above clearly demonstrates the application of OES to critical etch processes in MMIC manufacturing. Low damage processes are available for silicon nitride and frontside etching where critical layers are exposed. By fully integrating the OES into the production etch system, a fully automated process is available for high volume GaAs wafer manufacturing.

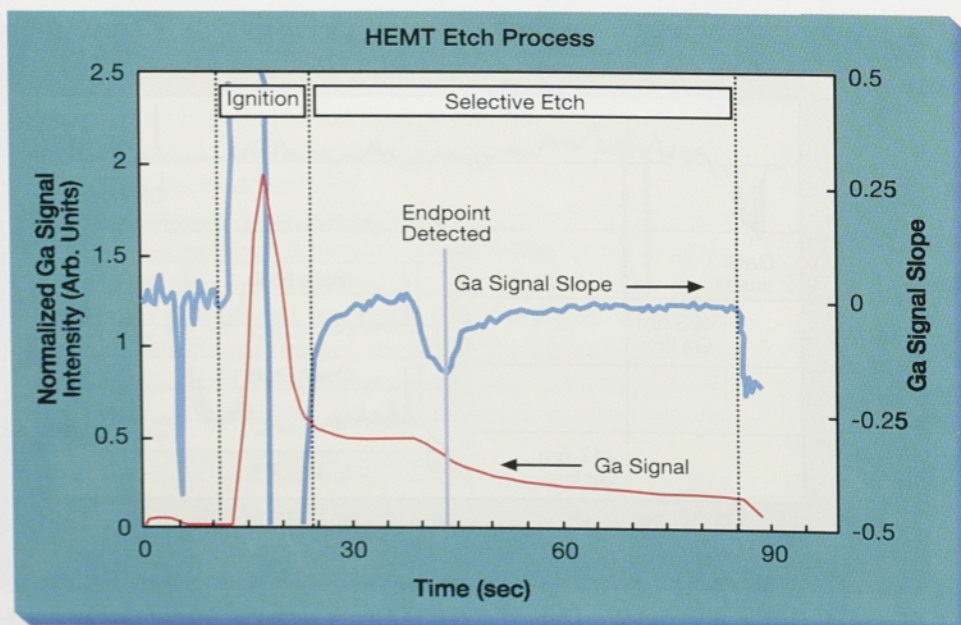
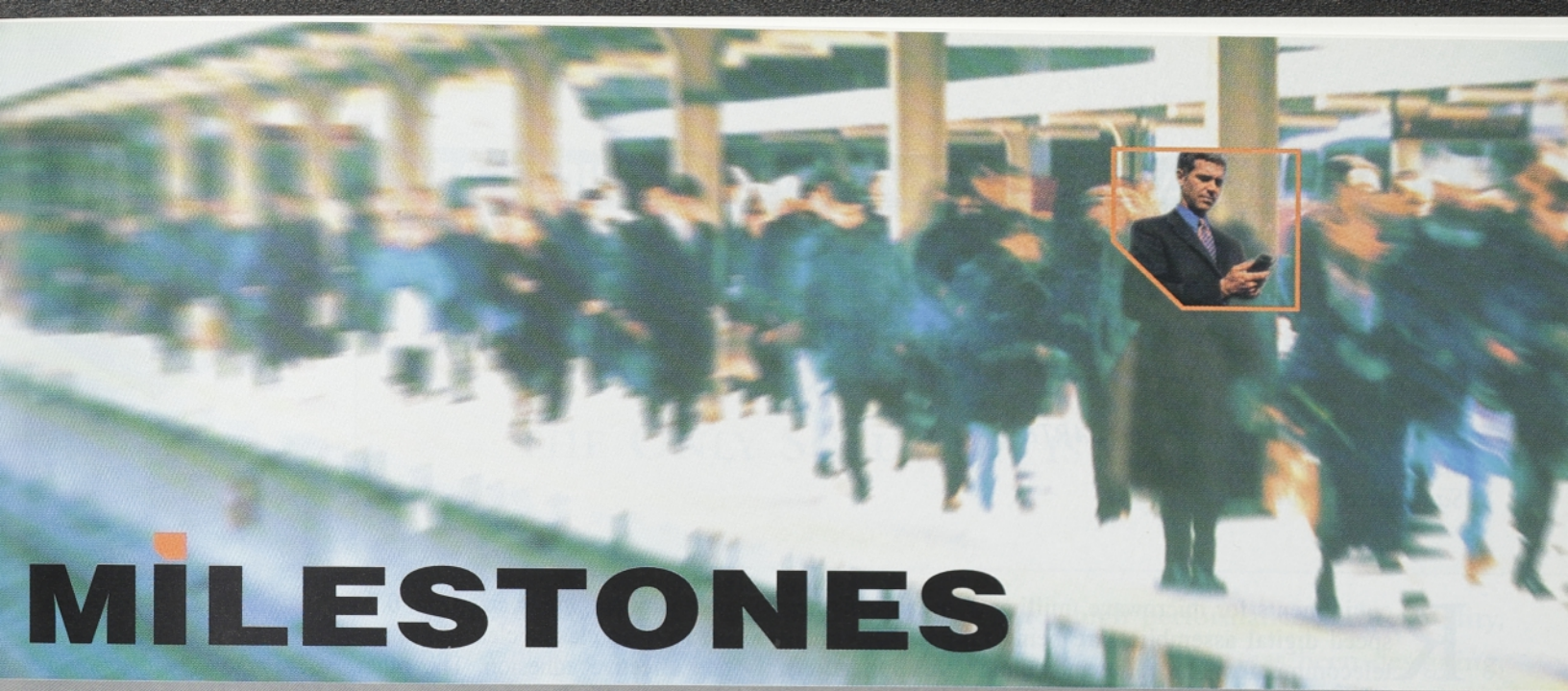


Figure 6. Optical emission endpoint trace for HEMT process using the 417-nm Ga line.

¹ J. Lee, et. al, *Proceedings from Mantech 2000*, p. 13.



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Packaging Requirements for GaAs MMICs

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San Diego, California

Requirements for microwave, millimeter-wave and high-speed digital assemblies are being introduced through telecommunications, radar and automotive applications. In telecommunications, satellite up- and down-links operate at frequencies from 1 through 30 GHz, while digital radios that connect one cellular phone cell to another operate in the 10–40 GHz range. Also, multiplexer and demultiplexer circuits for fiber-optic systems operate at 10 and 40 Gbit/s, translating to bandwidth requirements of up to 50 GHz. New radar systems are being developed with complicated microwave front-ends including large phased arrays. Collision avoidance radar and adaptive cruise controls are currently being used for automotive applications in the 24–100 GHz range.

Monolithic microwave integrated circuits (MMICs) manufactured from GaAs—including amplifiers, mixers, detectors, attenuators and analog-to-digital converters—are being used in these applications. In each case, packaging provides a means of protection for the chip with the goal of being electrically transparent to the device.

MMIC Packaging

In most applications, the MMIC is a building block in an assembly. In a microwave front end, it can be a low noise amplifier or a power amplifier. In digital circuits, the MMIC can be the multiplexing or demultiplexing function, limiting amplifier or driver amplifier. The balance of the components in the assembly may be filters, couplers, mixers or optical converters. Most, if not all, of these components are available in pre-packaged form or do not require packaging at all.

Traditionally, however, manufacturers have integrated these components with bare MMIC die in a multichip module or hybrid assembly. This approach has significant challenges as production volumes increase to address the needs of high volume markets. In addition to the requirements for clean room assembly facilities, the die is attached eutectically with gold/tin solder or with silver filled conductive epoxy. The conductors on the die, which range in size from 1 to 4 mil square, are wire-bonded with

gold wire ranging in size from 0.7 to 1.3 mil diameter. Also, die requires plasma cleaning to remove contaminants and facilitate effective adhesion. The other components, as mentioned above, mostly do not require such precise handling and require only standard assembly techniques. Lastly, most microwave assemblies also require hand tuning to optimize the performance of the device after final assembly. As a result, most customers for the high volume assemblies are now requiring

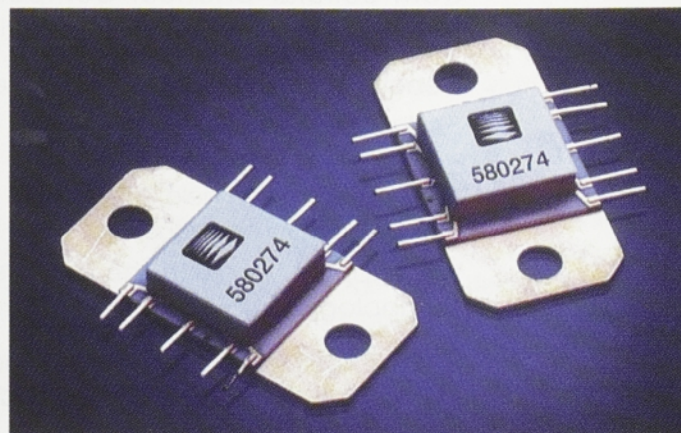


Figure 1. StratEdge's low-cost ceramic (LCC) package, designed for DC to 23 GHz operation.

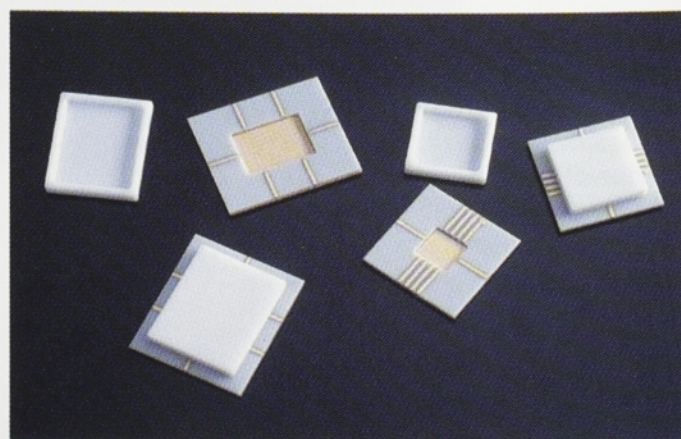
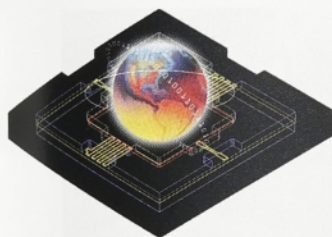


Figure 2. StratEdge SE50 packages, designed for VSAT, LMDS and point-to-point radio applications at DC to 50+ GHz. The packages have a copper/moly/copper laminate base and a ceramic lid.

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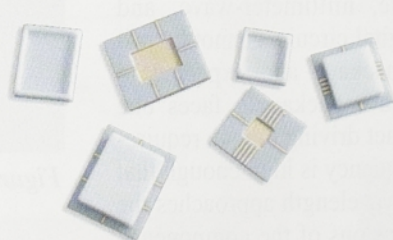
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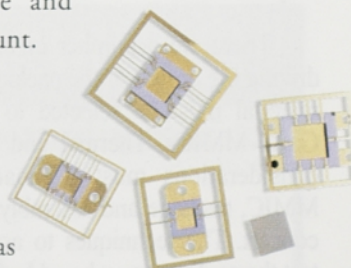
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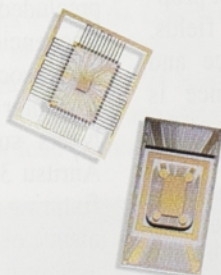
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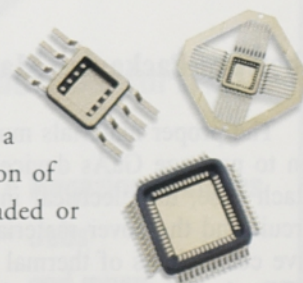


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S T R A T E D G E

pre-packaged MMICs to facilitate manufacturing in a conventional assembly environment. The packaged MMIC also provides a pre-tuned and pre-tested known good device resulting in lower tuning requirements and higher assembly yields.

Once the decision to package a MMIC is rendered, there are five common package requirements to consider:

- The package must provide electrical interconnection between components and subsystem.
- It must protect the circuit from any corrosive environment (even air or water is corrosive to some circuit components).
- It must protect the circuit from general contamination or foreign material (that is, particles that may damage components or change electrical response).
- The package must protect the circuitry from mechanical damage.
- The package must provide or assist in thermal management of heat generated by the circuit.

There are a number of requirements driving the design of the package. Suitable material must be selected to work with GaAs MMICs. Thermal and mechanical considerations must be made for the MMIC, package and assembly to work in concert. The techniques to assemble and test the package must be addressed, and for commercial applications, low costs need to be achieved. The package must be electrically transparent to the device. Mismatches caused by the interconnections from the internal circuitry to the next assembly must be minimized through sound microwave transmission line design.

Choice of Packaging Materials

The proper materials must be chosen to package GaAs devices. The die attach base, the electrical interconnect circuit and the cover material must all have coefficients of thermal expansion (CTE) that closely match the CTE of the GaAs chip. This prevents the GaAs chip from cracking or lifting off of the

package during thermal cycling. For many applications requiring high thermal dissipation, the die attach base must also possess excellent thermal conductivity. Lastly, all the materials must be carefully selected for proper electrical characteristics at microwave and millimeter-wave frequencies. This requirement normally precludes the use of plastic packages because of their relatively high electrical loss characteristics at microwave frequencies. A standard construction that has been employed for several years is shown in Figures 1 and 2. These packages utilize a copper-tungsten or copper-moly composite metal base with a 96% alumina ceramic electrical circuit layer.

Electrical Circuit Design Considerations

Microwave, millimeter-wave, and high-speed digital circuits cannot be just placed in a package and expected to work. Microwave packaging faces one fundamental fact driving unique requirements: the frequency is high enough that the electrical wavelength approaches the physical dimensions of the components. Below 2 GHz, the wavelength of the signal is much larger than the circuit dimensions; thus the circuit is described in lumped electrical values of resistance, capacitance, inductance, and conductance. At microwave frequencies, the circuits are transmission lines that propagate as electric and magnetic fields. Element definition is impedance and electrical length. The impedance is defined by the dielectric constant of the material and dimensions of the conductor elements. For lowest loss transmission from one circuit to another, the impedance must be matched, with the standard impedance being 50 ohms.

Designing electrical circuit transitions for microwave and millimeter-wave frequencies requires the use of fundamental electromagnetic equations and is assisted by linear and three-dimensional simulation tools. The conductors in the electrical circuit layer have high electrical conductivity to reduce transmission losses. This is achieved through the use of



Figure 3. Network analyzer testing.

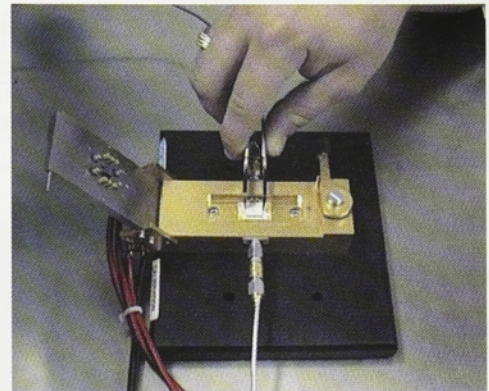


Figure 4. Custom electrical test fixture.

gold as a conductor and by not using, or not having, an exposed refractory layer. The alumina ceramic substrate material must be held to tight mechanical tolerance and dimensional stability. Co-fired ceramic technology has generally been precluded from use at millimeter-wave frequencies because of the large shrinkage associated in processing that results in poorer electrical yields. Network analyzers such as the Agilent 8510 and Anritsu 360 in conjunction with custom fixturing are used to verify the performance of the electrical circuit transitions, as shown in Figures 3 and 4. The electrical performance required for these applications has been achieved and is illustrated in Figure 5.

Leaded and Leadless Packages

The ease of attaching a package to an assembly results in shorter manufacturing times. Leaded packages as shown in

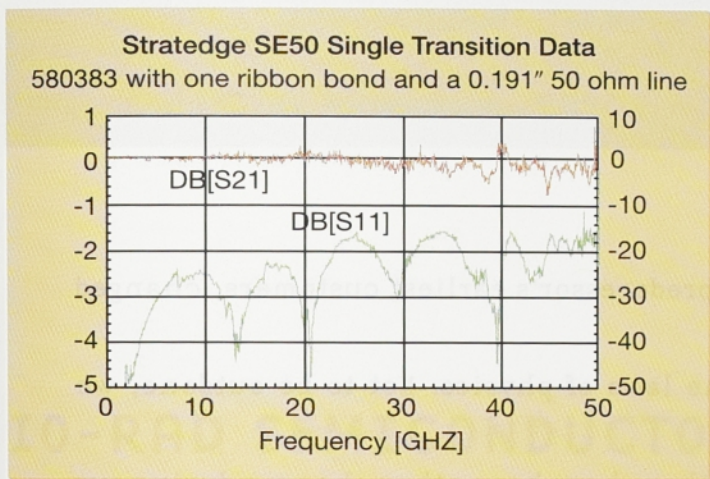


Figure 5. Electrical data for the StratEdge SE50 package.

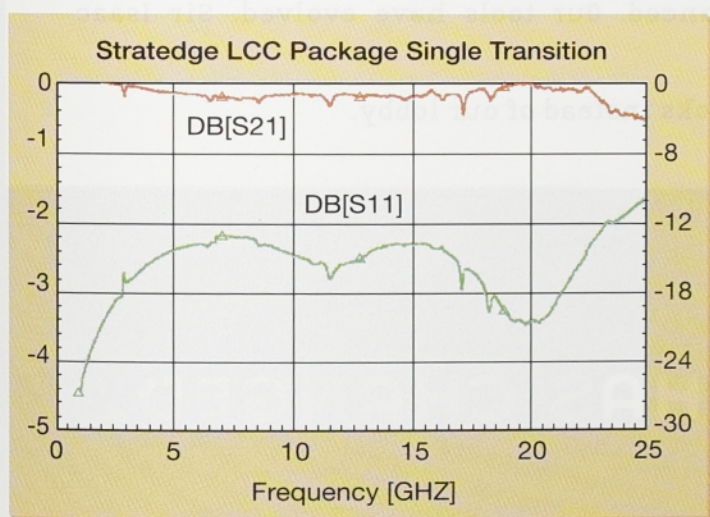


Figure 6. Electrical data for the Stratedge LCC leaded package.

Figure 1 allow the leads to be soldered in place, but are limited in frequency to about 23 GHz (see Figure 6). Leadless packages as shown in Figure 2 can operate in excess of 50 GHz but require wire or ribbon bonding as the external means of attachment. For high-speed digital applications, the same operating frequency rules apply but with much higher lead counts (see Figure 7).

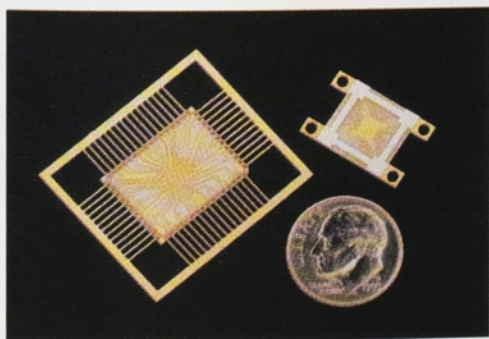


Figure 7. Examples of high-speed digital packages manufactured by StratEdge.

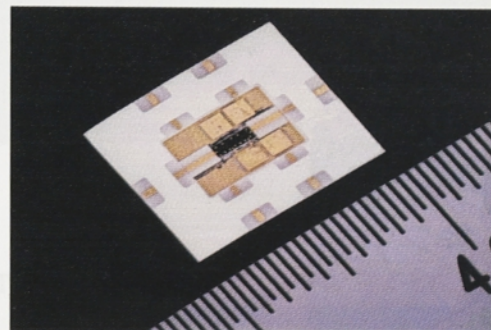


Figure 8. Assembled StratEdge SEC package.

Summary

Packaged GaAs MMICs fulfill the needs of today's microwave, millimeter-wave and high-speed digital assemblies. Packages that meet the mechanical and thermal requirements have successfully achieved the goal of being electrically transparent to the chip. The use of packages to house a GaAs MMIC device allows an ease of installation at the higher assemblies (see Figure 8). The precise chip attach and wire bonding is performed in a package instead of on a board so that the package can then be tested as a component. The packages are very rugged and provide a high level of protection to the fragile GaAs chip. These packages have been successfully used in high volume production applications on the order of hundreds of thousands per year since the mid-1990's.

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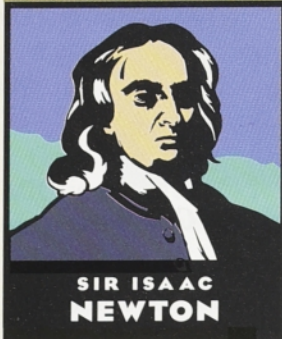
1688 John Worgan opens his shop for the sale of mathematical instruments.

1703 The first telescopic level is created for Sir Isaac Newton.

1714 A mechanical model of the solar system, called an "orrery" after the Earl of Orrery for whom it was created, is shown to His Majesty George I.

1795 The equatorial telescope is created for the Armagh Observatory.

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Plasma Etch Damage Considerations in GaAs Device Fabrication

L.G. JERDE and P.F. WERBANETH
Tegal Corporation
Petaluma, California

Plasma etch processes are an integral part of modern GaAs device fabrication. Medium density and high density plasma reactors are used in production GaAs fabrication lines to etch photoresist materials, dielectric films, active device layers, and interconnect metals. Damage potentially introduced by applying plasma etch patterning to GaAs structures has been extensively studied. A review of the literature reveals the several broad damage mechanisms that are responsible for degrading GaAs device performance. In this paper we summarize the important mechanisms for GaAs etch plasma damage, discuss the plasma etch process parameters that influence damage, and illustrate how reactor design can be critical to ensuring that GaAs plasma etch processes run damage-free.

Introduction

The twin trends of the high growth rate of the GaAs IC fabrication industry and the rapidly growing dependence of the Industry on plasma etching make understanding and eliminating plasma etch induced degradation of the electronic properties of gallium arsenide devices (i.e., plasma etch damage) a very high priority. Since the device performance degradation mechanisms that give rise to damage vary somewhat from one device

type to another, and since these mechanisms differ from those observed in silicon-based devices, plasma etch damage in GaAs devices is a research area that is complimentary to, rather than a subset of, the work that has been performed to understand plasma etch damage in silicon processing. Because the damage mechanisms do differ, plasma etch reactor designs for GaAs etching, to effectively eliminate plasma damage, may therefore need to be complementary to, rather than completely overlap, the tools now used for CMOS processing.

Damage Mechanisms

The literature on plasma etch induced damage in gallium arsenide covers a considerable range of experimental work. This experimental work has been performed using most of the possible plasma reactor types, upon a variety of GaAs-based devices and structures, utilizing a wide assortment of diagnostic techniques, in order to identify, characterize, and determine the relative importance of the numerous possible damage mechanisms [1-17].

The plasma etch reactor types that have been chiefly employed for GaAs device applications are electron cyclotron resonance (ECR) systems, inductively coupled plasma (ICP) configurations, and reactive ion etch (RIE) chambers. Among the various GaAs devices and structures that have been utilized in damage studies are MESFETs, HBTs, HEMTs, Schottky diodes, in-plane gated (IPG) quantum wire transis-

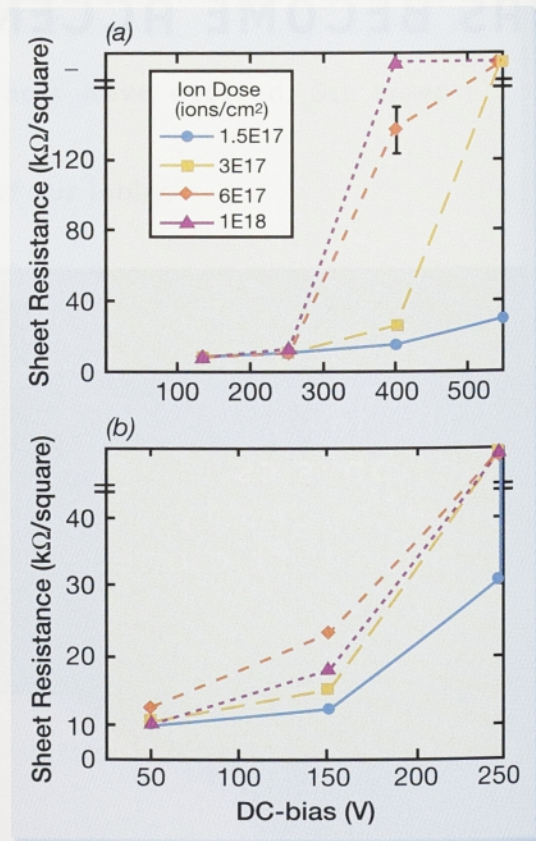


Figure 1. Sheet resistance vs. DC bias for samples exposed to: (a) RIE SF₆/Ar plasma and (b) ECR SF₆/Ar plasma [After reference 8].

tors, transmission lines, conducting wires and bulk substrates.

Diagnostic techniques used to study damage include deep level transient spectroscopy (DLTS), photoreflectance spectroscopy (PR), EMA (electric microwave absorption), XPS, photoluminescence and reflection high energy electron diffraction (RHEED). The list continues with cathodoluminescence, TEM, Rutherford back scattering, Raman scattering, diode ideality factor and barrier height,

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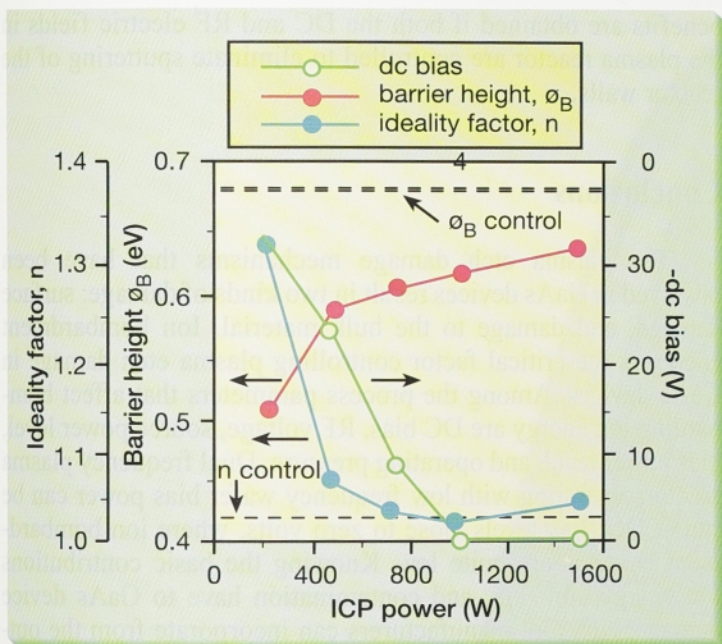


Figure 2. Schottky barrier heights and diode ideality factors from n-GaAs diodes that were exposed to ICP Ar plasmas (2 mTorr, 15 s, 50 W RF) at different ICP source powers prior to TiPtAu deposition [After reference 7].

C-V, forward and reverse I-V, gate leakage current, contact resistivity and sheet resistance.

The plasma etch induced damage mechanisms that have been observed in GaAs devices are conventionally classified into two broad damage types: surface damage, and damage to the bulk material. Surface damage consists of residues, contamination, texturing, amorphization, and stoichiometry shifts. Damage to the bulk material consists of implanted ions, displaced atoms and the formation of dangling bonds, broken bonds, recombination centers and traps.

Our purpose here is not to explain the precise mechanisms by which these various defects are formed, nor is it to understand how they degrade the electrical performance of GaAs devices. Rather, our goal is to understand how these defects depend on the action of the plasma etch processes, and the parameters therein, used to fabricate the devices. Understanding this, we can then ensure that GaAs plasma etch reactor designs, and the etch processes run in these reactors, are engineered and are run in a way that does not create plasma induced damage.

Process Parameter Dependencies

The reported process parameter dependencies for plasma etch induced GaAs damage include ion energy, DC bias and RF voltage, plasma source and wafer bias powers, ion currents, gas chemistries, etch pressure, and the duration that the device structures are exposed to the etching plasma.

Ion bombardment energy, and any of the process parameters that affect it, are crucially important in controlling plasma etch

damage in GaAs devices. Among the process parameters that affect bombarding ion energy in plasma etch reactors are DC biases, RF voltages, source power levels, bias power levels, and etch pressures.

For example, Shul and coworkers studied a variety of plasma etch gas chemistries in both ECR and RIE reactors. They characterized the sheet resistance in thin conducting layers of p-type GaAs to determine the effect of damage on the majority carrier transport properties [8]. They found the dependence of sheet resistance on DC bias to be that resistance remains essentially unchanged until a well defined threshold value is reached. Sheet resistance then increases with DC bias for bias values beyond the threshold level [see Figure 1].

Similarly, Lee and coworkers utilized diode ideality factor and barrier height measurements in Schottky diodes fabricated on the surface of n- and p-type plasma etched GaAs to study the effects of ion induced near-surface damage in Ar discharges using both ECR and ICP reactors [7]. Their results showed that the damage depended strongly on both the source power and DC bias in these reactors, and that these dependencies indicated that the observed damage increased with increasing ion energy [see Figure 2].

Ion flux is reported as important in controlling plasma etch induced damage only when the energy of the bombarding ions exceeds the relevant damage threshold. When the energy is below the threshold the contribution of ion flux to damage is minimal.

The number of plasma etch induced defects remaining after the completion of the etch is the net difference in the integrated generation and removal rates during the etch (with the removal principally being that of etching away some of the previously damaged material). This being the case, low etch rate processes generally exhibit a strong dependence of defects on etch process exposure time.

It is reported that if damage is occurring during the etch then the exposure time to the etch plasma can also be important in controlling the extent of GaAs damage. In these circumstances

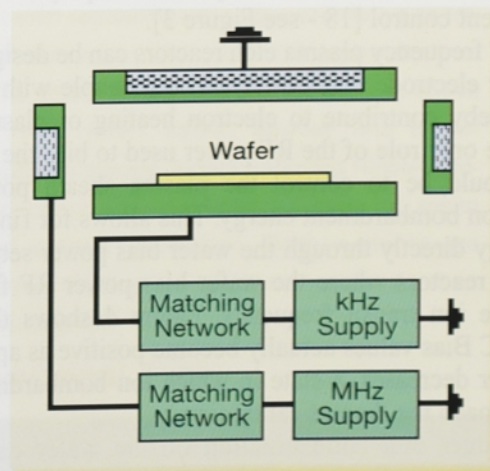


Figure 3. RF configuration of the dual frequency HRe- reactor in the Tegal models 6510/6520 [After reference 18].

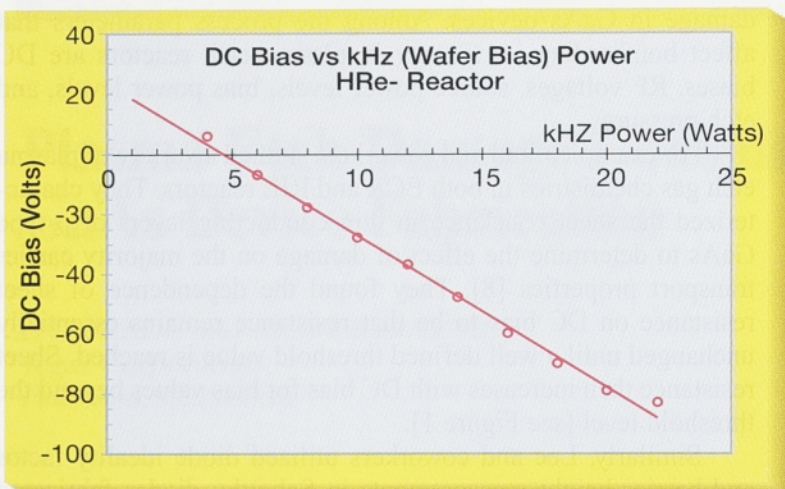


Figure 4. DC bias and ion energy control in the HRe-. At low wafer bias power levels the DC bias approaches the plasma potential.

short exposures to high etch rate processes may be preferable to long exposures to low etch rate processes.

Reactor Design for Damage-Free Etching

The best approach to eliminating damage in plasma etch tools is to incorporate from the outset specific reactor configurations and process controls that prevent both surface and bulk material damage during plasma etch.

The paramount objective for the design, development and optimization of plasma reactors for GaAs device etching is the ability to establish (and then utilize) rigorous independent control of ion energy from ion (and reactive species) flux. This can be achieved by a combination of careful attention to the electric fields produced in plasma reactors, and through the use of dedicated RF power supplies with different frequencies for the plasma source excitation and wafer electrode bias power. Judicious selection of the two RF frequencies employed enhances the independent control [18 - see Figure 3].

Dual frequency plasma etch reactors can be designed so that the wafer electrode bias power will not couple with the plasma (and thereby contribute to electron heating or plasma production). The only role of the RF power used to bias the wafer electrode should be to control the plasma sheath potential, and thereby ion bombardment energy. This allows for fine control of ion energy directly through the wafer bias power setting, particularly in reactors where the wafer bias power RF frequency is below the ion transit frequency. Figure 4 shows the example where DC Bias values actually become positive as applied wafer bias power decreases, a state in which ion bombardment energy will approach the theoretical minimum.

Residues and contamination on the wafer can originate from either the reactor inner surfaces or from the wafer itself. It is important that all plasma-wetted surfaces be either inert or be made from innocuous materials in order to avoid residues and contamination that originate from the reactor walls. Added

benefits are obtained if both the DC and RF electric fields in the plasma reactor are controlled to eliminate sputtering of the reactor walls.

Conclusions

The plasma etch damage mechanisms that have been observed in GaAs devices result in two kinds of damage: surface damage, and damage to the bulk material. Ion bombardment energy is the critical factor controlling plasma etch damage in GaAs devices. Among the process parameters that affect bombarding ion energy are DC bias, RF voltage, source power level, bias power level, and operating pressure. Dual frequency plasma reactors operating with low frequency wafer bias power can be run at DC Bias levels close to zero volts, where ion bombardment energies are quite low. Knowing the basic contributions ion energy, ion flux, and contamination have to GaAs device damage, etch tool manufacturers can incorporate from the outset specific plasma reactor design configurations and controls that facilitate avoiding residues, contamination, and physical and electrical damage during the processing of GaAs-based devices.

Acknowledgment

The authors are indebted to Robert Ditizio and Steve DeOrnellas for useful discussions.

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A Flexible Approach to the Challenges of Through-Wafer Via Etching

MICHELLE M. BOURKE, DAVID J. THOMAS,
CONSTANTINE FRAGOS and KEVIN POWELL

*Trikon Technologies Ltd.,
Newport, United Kingdom**

As the worldwide compound semiconductor market continues to grow the majority of component suppliers are experiencing increasing demand for their products. This rise is seen in all areas including the analog, digital and optoelectronics markets and results from the explosive growth of both wireless and optoelectronic communications. The mobile hand set market increased by 40% during 1999 and this trend is projected to continue, driven by subscription rates and the provision of emerging services. In the optoelectronics market, the demand can be attributed directly to the upsurge in Internet access.

To accommodate this demand most compound semiconductor fabs are increasing their capacity. For GaAs components, this has necessitated a change from 4-inch to 6-inch substrates, while for InP components the wafer size has increased from 3 to 4 inches. When making this change many companies have had to address their equipment choice and existing facilities. Many compound semiconductor fabs now resemble those previously only seen in mainstream silicon and the wafer volumes required are such that the approach to the manufacturing process must now be more rigorous.

In the fabrication of heterojunction bipolar transistors (HBTs), a common component in the mobile handset, many

manufacturers are looking to reduce device cycle times and shrink critical dimensions for the future. One of the main areas that takes a considerable length of time, and is most costly in real estate terms on a wafer, is the backside via process. Figure 1 is a cross section of an HBT.

The backside via process takes place near the end of the production cycle, once the front face processing is complete. To make the through-wafer contact the substrates are typically ground or polished from a full thickness of around 600 μm to around 100 μm . Prior to thinning, the wafers are mounted on a carrier using an adhesive wax as they become more fragile during this process. Sapphire has become the industry standard carrier material.

High-Density Plasmas

Historically via etches have been carried out in reactive ion etch (RIE) systems and etch rates of $\sim 5 \mu\text{m}/\text{min}$ have been reported. Although such an etch rate is desirable, the profile cannot be controlled without the introduction of a polymer-forming gas. Freon 12 has been extensively used to passivate the sidewall and produce a more anisotropic etch profile. However, this gas has the disadvantage of compromising the etch rate.

Recent environmental restrictions concerning Freon 12 have meant that alternative processes need to be addressed. High density plasmas have become prevalent throughout the silicon microelectronics industry and are finding their way into compound semiconductor fabs.

There are many types of high-density plasma. Trikon Technologies Omega® 201 inductively coupled plasma (ICP) system relies upon a high density plasma (10^{11} – 10^{12} ions/ cm^3) operating typically in the 3–30 mTorr pressure range. The system is shown in Figure 2.

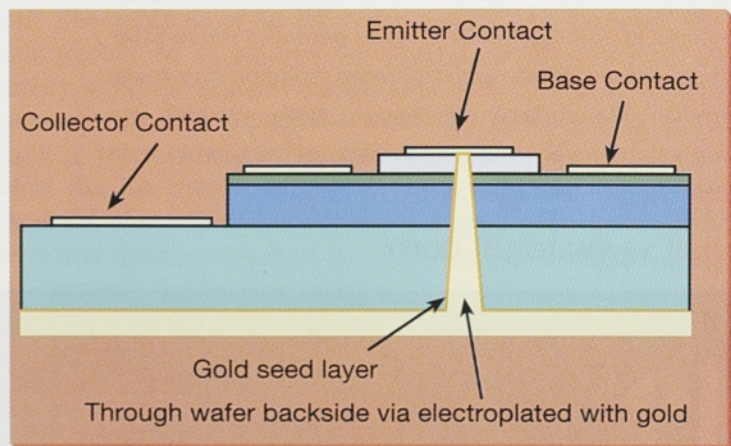


Figure 1. Schematic cross-section of an HBT, showing the location of the backside via.

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United Kingdom. TEL: +44 (0)1633 414000, FAX: +44 (0)1633 414141,

WEB: www.trikon.com.

The plasma is formed by inductively coupling RF at 13.56 MHz through a ceramic chamber wall. By varying the RF bias to the electro-static chuck (ESC), the degree of ion bombardment at the wafer surface can be varied.

Wafer temperature control is critical for backside via processing due to the relatively low melting point of the wax that holds the wafer onto the carrier. Trikon use an ESC with ~10 Torr of helium back pressure for temperature control. The thick capacitive design of the ESC allows it to clamp the wafer through the sapphire carrier without the need to metallize the carrier [1]. This reduces the number of process steps required in the manufacturing process. Unlike mechanical clamps, an ESC completely eliminates any mechanical contact to the front of the carrier. This leads to improved particle performance and a higher overall tool availability.

Anisotropic Vias

The drive towards smaller devices means that the backside via shape and size must change. Hence there is a move away from vias with an isotropic shape to more anisotropic profiles. A disadvantage of anisotropic vias however is that they are known to be more difficult to metal seed and electroplate. Therefore it is important that via processes are easily adaptable so that they can meet current needs but also show extendibility for the future.

The flexibility of the Omega® 201 means that it can generate via profiles ranging from isotropic to anisotropic in the same chamber by managing the process parameters. A simple chlorine (Cl_2) chemistry is used and the mode of operation (RIE or ICP) varied. Reactive ion etching in the ICP tool is achieved using bias power alone. Unlike other systems the via profile achievable is not dependant on the profile of the photoresist prior to etching.

Figure 3 shows a variety of via profiles. It begins with an isotropic via and concludes with an anisotropic result. To gen-

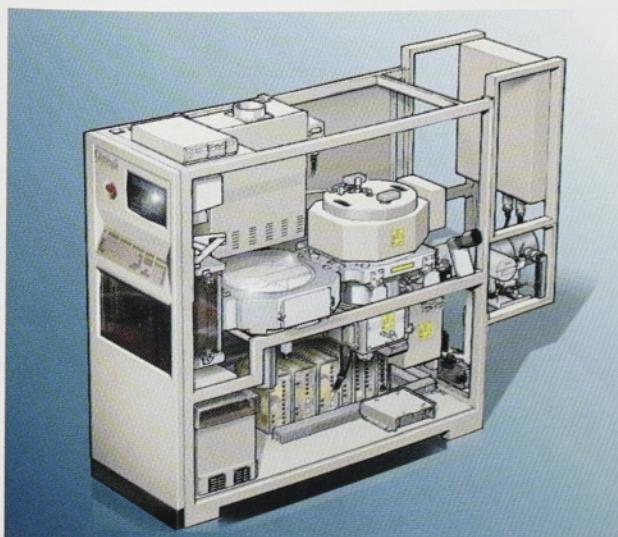


Figure 2. Omega® 201 ICP system, manufactured by Trikon Technologies.

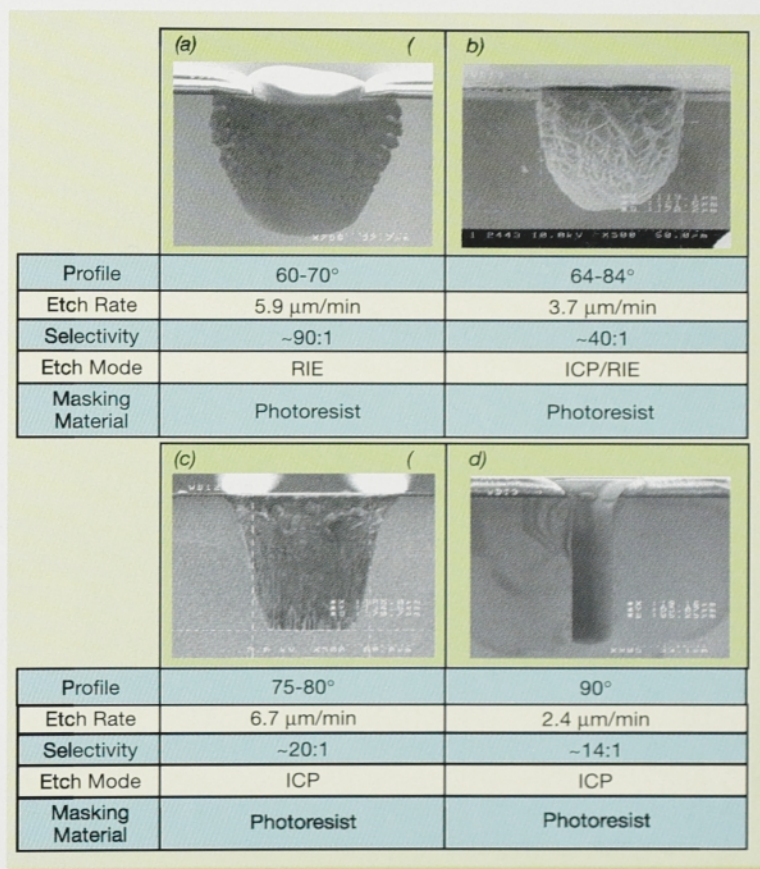


Figure 3. Summary of various GaAs backside via results, ranging from an isotropic etch (a) in the RIE mode, to an anisotropic profile with 90° sidewalls (d) in the ICP mode.

erate an isotropic profile [see Figure 3a] the system is run in RIE mode and at a relatively high pressure, typically ~80 mTorr. By combining RIE and ICP it is possible to generate a vertical sidewall with a rounded bottom section [Figure 3b]. In ICP mode alone the profile can easily be varied from 75-90° [Figure 3c & d]. The anisotropic process is typically run at a relatively low pressure of ~7 mTorr.

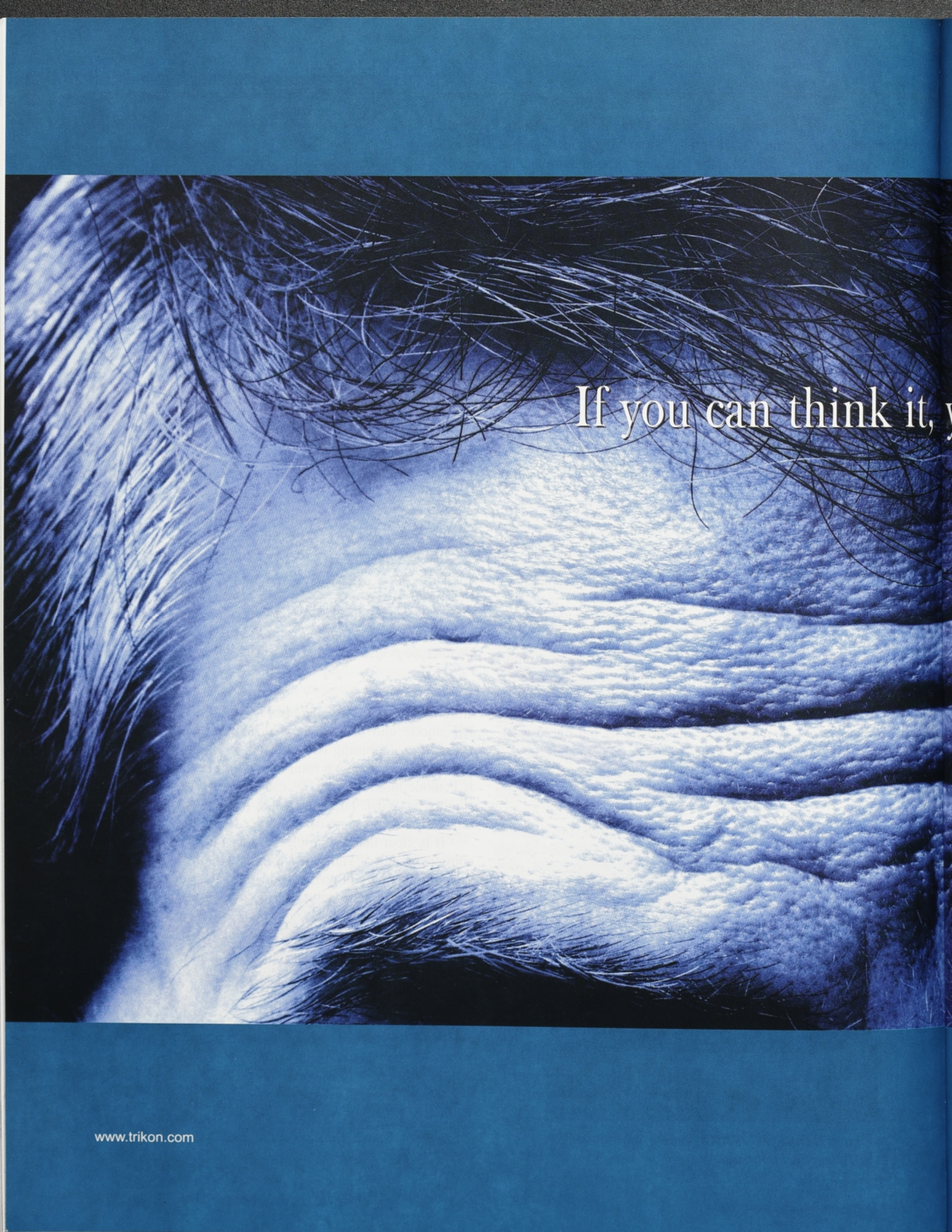
It is clear that by simply varying the process parameters a complete range of via shapes are available from a single plasma system. The range of profiles and etch rates address those issues facing design and manufacturing engineers today and show extendibility to the future.

A versatile approach such as this greatly simplifies the production cycle for devices that require backside vias, and helps to reduce the manufacturing cost for today's compound semiconductor manufacturers.

Acknowledgments

Trikon Technologies would like to thank Nortel Networks and Sanders, a Lockheed Martin Company for their permission to publish SEM pictures.

[1] D. Tossell et al., Proc. GaAs Mantech 2000, p. 79



If you can think it, y



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TECHNOLOGIES

HBT Transistors Reach the 100 GHz Barrier

IEEE Bipolar/BiCMOS Circuits and Technology Meeting (BCTM)

September 25–26, 2000

Minneapolis, MN, USA

PHILLIP B. ESPINASSE*

At the dawn of a new millenium, Bipolar/BiCMOS technology is soaring. The high frequency performance of these devices make them quite adequate for the highly competitive GHz communications market in 10 and 40 Gb/s long haul and LAN fiber-optic systems and mm-wave link applications. 10 Gb/s optical fiber technologies are well established but the 10 Gb/s long-haul market is currently experiencing growth. The early technology mostly incorporated III-V designs, but Si/SiGe bipolar ICs are starting to dominate, having attained higher speeds and lower manufacturing costs. Multimode fibers, short-wavelength vertical-cavity lasers and Si bipolars amongst others are contributing to the emerging market for 10 Gb/s Ethernet products.

Future 40–160 Gb/s fiber-optic systems, and wireless microwave and mm-wave radio links, are fueling research for devices in the race towards THz bandwidths. These high-frequency applications require electronics at 100 GHz and beyond. Today's state of the art III-V HBTs easily reach 300 GHz F_{max} while Si/SiGe HBTs have surprisingly crossed the 100 GHz barrier (100 GHz F_{max} for planar structures, 180 GHz F_{max} for mesa structures) [see Figure 1]. The realization of 100 GHz electronics and beyond appears

to be mainly an economic issue, where III-V high speed optoelectronic mm-wave ICs are expensive but offer a tremendous amount of bandwidth. Integration of analog, digital and MMIC design is crucial for the increasing demand of microwave mixed-signal ICs and 100 GHz logic applications.

Optimization of Silicon Device Structures

As keynote speaker at the recent BCTM conference, Mark Rodwell of the University of California at Santa Barbara (UCSB) explained that differences between compound semiconductor and silicon technology can be attributed to a cultural effect. III-V materials have long been academia's brainchild, where the focus has been on material and transport physics at the expense of device design optimization. In contrast, the Si research community has been very closely tied to circuit design and is very focused on scaling, resulting in impressive Si/SiGe HBT circuit speeds.

Strong efforts in extrinsic parasitic reductions have driven the optimization of Si device structures. The general goal has been to maximize the cut-off frequency (F_t) of the device by minimizing both the emitter-base and collector-base depletion layer capacitances as well as the forward transit time.

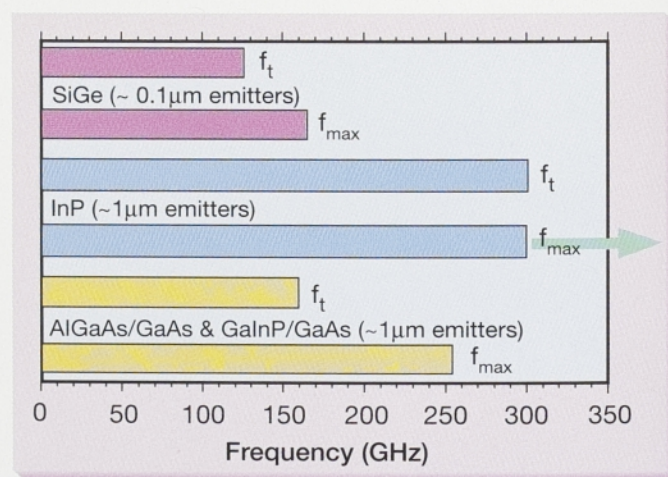


Figure 1. State-of-the-art HBT performance in 2000: Cut-off (F_t) and maximum oscillation (F_{max}) frequencies.

The most effective way to reduce these extrinsic parasitics has been to employ self-aligned single-polysilicon or double-polysilicon advanced structures (polysilicon emitter, polysilicon extrinsic base contact etc) that possess small parasitic capacitances. As for the forward transit time, its key component, the base transit time, is effectively diminished by reducing the intrinsic base width at the expense of intrinsic base resistance and Early voltage (V_A). Improved isolation techniques such as shallow (STI) and deep (DTI) trench isolations have also helped in minimizing collector-substrate capacitances by cutting straight through the NPN subcollector area.

The successful combination of these individual techniques have resulted in very fast and reliable Si/SiGe devices.

*Phillip Espinasse is a science & technology columnist for Photonics Online and a process development engineer at PolarFab, a mixed-signal IC foundry based in Bloomington, MN, involved in the development and manufacturing of c-BiCMOS ICs.

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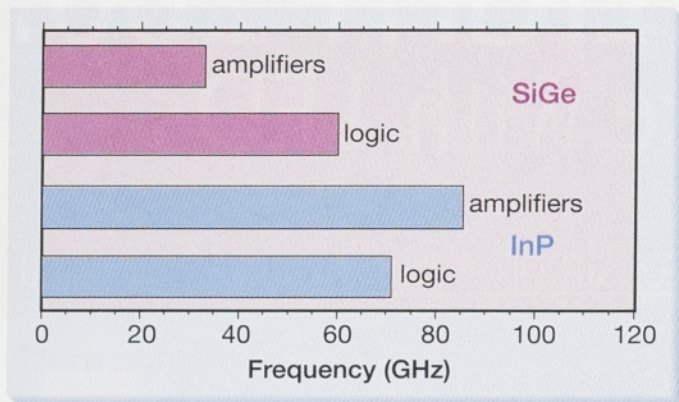


Figure 2. State-of-the-art HBT performance in 2000: Small-scale circuits.

Although these devices have significantly poorer material parameters than their III-V counterparts, they are much better scaled in size, have greatly reduced extrinsic parasitics and operate at much higher current densities.

SiGe vs. InP

In addition to these improvements, other strong features of Si bipolars are their low emitter widths ($0.1 \mu\text{m}$) and large emitter current densities on the order of $10 \text{ mA}/\mu\text{m}^2$. SiGe small-scale logic circuits are comparable to InP logic circuits despite lower cut-off frequencies [see Figure 2]. This is mostly due to a higher current density (SiGe has $10^6 \text{ A}/\text{cm}^2$ current density vs. $10^5 \text{ A}/\text{cm}^2$ for InGaAs) and better emitter contacts (SiGe has $5\times$ better emitter ohmic contact resistivity). Reduction in parasitic capacitance attained through area scaling and use of self-alignment structures has allowed SiGe-based logic to effectively compete with III-V logic. However, because amplifier technology relies on gain as its principal figure of merit, which is predominantly dependent on material parameter and properties, III-V amplifiers have outperformed SiGe amplifiers in terms of frequency performance.

Sub-Micron Scaling

Furthermore, it is necessary to aggressively pursue sub-micron scaling of III-V HBTs for 50–100 GHz analog and digital IC applications. Scaling is key in obtaining the fast transistors required for today's emerging HBT applications. Future developments of III-V HBTs should include vertical and lateral scaling to increase cut-off (F_t) and maximum oscillation (F_{max}) frequency performance respectively, as well as addressing high emitter current densities and reductions of emitter extrinsic parasitics.

Substantial efforts are currently underway to address the collector width scaling in III-Vs through various techniques:

- Heavily doping the base with carbon ($10^{20}/\text{cm}^3$)
- Performing a substrate transfer through a flip-chip process and lithographically defining the collector under the base, which allows for narrower collectors.
- Undercutting the collector through wet etching.

Transferred-Substrate HBTs

Transferred-substrate HBTs permit lateral scaling of HBT technology. The flip chip process allows for narrower collectors, and in turn promotes large increases in bandwidth through decreased base resistance and collector capacitance. Sub-micron collector and emitter scaling alone would yield maximum oscillation frequencies (F_{max}) on the order of 700 GHz. As devices maximizing both F_{max} and F_t are required, it is important to note that a laterally scalable device allows F_{max} to be retained when F_t is improved by vertical scaling. Rodwell's UCSB group is currently working on realizing transistors with a projected performance of 500 GHz F_t and 1500 GHz F_{max} by pursuing a deep sub-micron transferred-substrate regrown-base HBT [see Figure 3].

Wiring Considerations

Successful achievement of logic clock rates on the order of 100 GHz imposes stringent guidelines on the type of wiring environment that can be used. Top surface wiring for 10–100 GHz ICs requires more attention, especially in aspects of IC and package design and modeling. These high frequency ICs will favor microstrip lines and ground-planes for signal integrity. Also, in order to maintain very high clock rates, these transistor ICs will be tightly spaced so as to minimize wiring delays and thus will require extraordinary heatsinking capability to deal with the high power densities, possibly approaching $1 \text{ kW}/\text{cm}^2$.

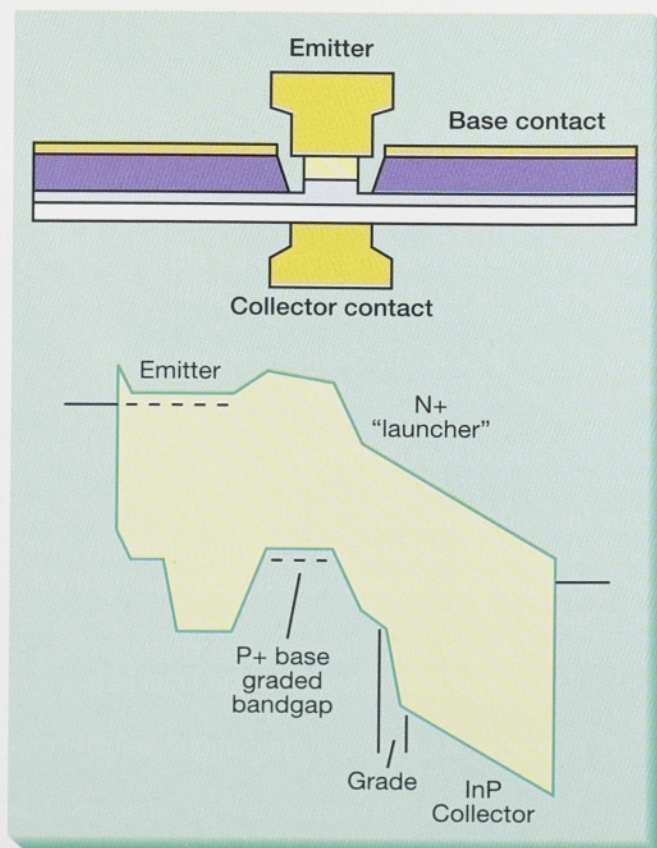


Figure 3. Cross-section and bandgap structure for a transferred-substrate HBT.

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For more information visit the conference web site at <http://www.knt-ec.com/IPRM01/> or use the link in the "Calendar" section of www.compoundsemiconductor.net



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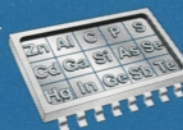
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The 2001 Conference will host a wide range of sessions, invited papers, exhibits, and special activities. Keynote addresses in areas of cell phone technology as well as the history and future of GaAs manufacturing from renowned manufacturers are actively being explored.



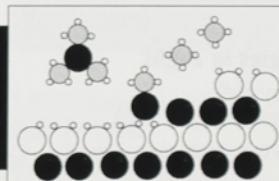
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OIDA Roadmap on Solid State Lighting

Industry Workshop at Photonics West
January 24
San Jose, CA, USA
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European Workshop on MBE (Euro-MBE 2001)

February 4-7
Hinterzarten, Black Forest, Germany
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Strategies in Light

February 8-9
Burlingame, CA, USA
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High Temperature Electronic Materials, Devices and Sensors

February 11-16
San Diego, CA, USA
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March



Key Conference on Compound Semiconductors

March 4-6
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<http://www.keyconference.com/>

Int'l School on Crystal Growth of Materials for Energy Production and Energy-saving Applications

March 5-10
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Yokosuka, Japan
<http://www.ilcc.com/TSMMW/index.html>

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Optical Fiber Communication Conference (OFC)

March 18-23
Anaheim, CA, USA
<http://www.osa.org/>

Workshop on Doping Issues in Wide Bandgap Semiconductors

March 21-23
University of Exeter, UK
Abstract Deadline: February 28, 2001
<http://newton.ex.ac.uk/wide-gap2001/>

Microscopy of Semiconducting Materials

March 25-29
Oxford, UK
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April

Int'l Conference on Mid-Infrared Optoelectronics Materials and Devices (MIOMD)

April 2-3
Montpellier, France
<http://www.univ-montp2.fr/~miomd>

MRS Spring Meeting

April 16-20
San Francisco, CA, USA
<http://www.mrs.org/meetings/spring2001/>

IEEE Int'l Reliability Physics Symposium

April 30-May 3
Disneyworld, FL, USA
<http://www.iprs.org/>

May

CLEO/QELS 2001 Conference on Lasers and Electro-Optics Quantum Electronics and Laser Science Conference

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Baltimore, MD, USA
http://www.osa.org/mtg_conf/CLEO/

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European Workshop on MOVPE (EW-MOVPE IX)

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<http://www.newi.ac.uk/conferences/ew-movpe/>

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Chiba, Japan
<http://www.bcasj.or.jp/cpr2001>

Electronic Materials Conference (EMC)

June 27–29
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July–August

Int'l Conference on Integrated Optics and Optical Fiber Communication (IOOC) Optoelectronics and Communications Conference (OECC)

July 1–5
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Fourth Int'l Conference on Nitride Semiconductors (ICNS-4)

July 16–20
Denver, CO, USA
Abstract Deadline: March 15
<http://www.mrs.org/meetings/icns4/>

International Symposium on Optical Science and Technology (SPIE Annual Meeting)

July 29–August 3
San Diego, California, USA

Int'l Conf. Crystal Growth-13 with Vapor Growth and Epitaxy-11

July 30–August 4
Kyoto, Japan
Abstract Deadline: January 15, 2001
<http://iccg.gakushuin.ac.jp/>

Crystal Growth & Epitaxy (ACCGE-13)

August 12–16
Abstract Deadline: March 15
<http://www.crystalgrowth.org/conferences/acgge-13/>

Opto Taiwan 2001

August 16–19
Taipei, Taiwan
<http://www.pida.org.tw/show>

Sept–Oct

Int'l Conf. on II-VI Compounds

September 9–14
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<http://www.ii-vi2001.uni-bremen.de/>

GAAS 2001 European Microwave Conference European Conf. on Wireless Technology

September 24–28
London, UK
Abstract Deadline: March 16
<http://www.eumw.com/>

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September 30–October 4
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<http://www.medicongress.com/ECOC2001>

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Email: Rod_Beresford@brown.edu

GaAs IC Symposium

October 21–24
Baltimore, MA, USA
<http://www.gaasic.org/>

Int'l Conf. on Silicon Carbide and Related Materials

October 28–November 2
Tsukuba, Japan
Abstract Deadline: June 1
<http://www.icscr2001.gr.jp/>

Nov–Dec

LEOS Annual Meeting (LEOS 2001)

November 12–15
San Diego, CA, USA
<http://www.ieee.org/organizations/society/leos>

MRS Fall Meeting

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Wall Street vs. The Real World

MARIE MEYER

One of the worst things about writing a reoccurring column is the need to own up to mistakes made in previous issues. So as I scan the Portfolio table and see that, on average, the share prices are down more than 50% from their historic highs, I am forced to recall what I wrote in our April issue. Compound semiconductor stocks might seem overvalued, I said, but then again it is also possible that they deserved their high valuations, given that most of them were important suppliers to the communications industry. To quote myself, "since compound semiconductors are the fastest growing segment of this fast growing area [communications], it can certainly be argued that the leaders in this field deserve their very high valuations." Even then the possibility of a major stock market correction was looming on the horizon, which prompted me to add that even if there was a downturn, the most likely impact would be a "flight to quality", wherein investors would be more discriminating about their selections, as opposed to just throwing money at every company that had a compound semiconductor-related story to tell.

Apparently I was wrong on both counts. As far as valuations are concerned, every company but one has lost at least a third of its market cap, and most are down by half or more. The one exception is Alcatel Optronics, which just went public a few months ago and therefore missed the height of the bull market. And as far as selectivity is concerned, in a rout like this it is hard to say that some companies are holding up better than others just because they have lost 40% of their value while others have lost 60% or more.

Although I may have been wrong, I remain unrepentant. Communications will remain the hottest business sector for the foreseeable future. People will continue to buy cell phones and find new uses for wireless technology. And even though the "dot-coms" have seemingly all turned into "dot-bombs", Internet use will continue to grow at high double-digit rates, making a rapidly expanding market for fiber optic components. As a result, as noted elsewhere in this issue, the outlook for compound semiconductors in 2001 is

extremely good [see page 7]. Perhaps, in retrospect, we didn't deserve the heights that we hit in late 1999/early 2000. Chalk that up to "irrational exuberance". But we don't deserve the current lows, either.

As one analyst recently told me, "I really cannot understand how investors who loved JDSU at \$154 a share won't touch it now that it is around \$75 a share, when very little in their fundamentals has changed." Which brings to mind an adage: don't confuse what happens on Wall Street with what goes on in the real world.

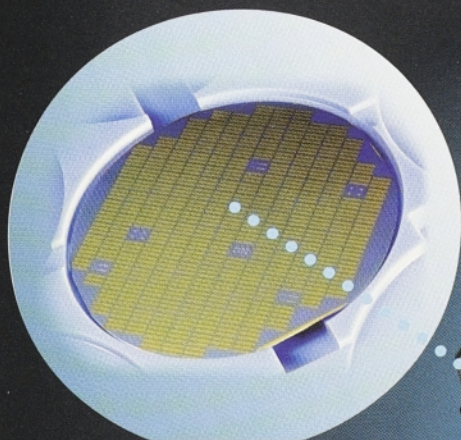
Company	Symbol	Closing Price Dec 8	52 Week Low - High	Market Cap*	P/E Ratio**
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Anadigics	ANAD	19 13/16	15 3/4 - 112 1/8	592.6M	22
Celeritek	CLTK	47 3/4	6 7/8 - 85 1/4	565.5M	N/A
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Endwave	ENWV	3 3/8	2 1/2 - 20 5/8	109.8M	N/A
RF Microdevices	RFMD	35 31/32	12 1/16 - 92 1/4	5.835B	101
Stanford Microdevices	SMDI	32 1/8	13 3/4 - 60 1/4	846.5M	N/A
TriQuint	TQNT	58 15/16	21 - 67 3/4	4.626B	76
Vitesse	VTSS	60 15/16	35 5/8 - 115 11/16	10.945B	87
Opto Companies					
Agilent	A	59 1/2	38 1/16 - 162	27B	33
Alcatel Optronics	ALAO	58 7/8	47 - 71 3/4	971.4M	48
Coherent	COHR	35 7/8	24 7/16 - 107 3/8	969.0M	13
Cree	CREE	75 5/16	55 1/2 - 202	2.689B	61
JDS Uniphase	JDSU	74 15/64	49 7/8 - 153 3/8	71.379B	N/A
SDL	SDLI	269 1/2	77 1/8 - 460 1/2	23.560B	229
Uniroyal Tech.	UTCI	7 11/16	6 7/8 - 36 7/16	200.2M	N/A
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Kopin	KOPN	15 3/8	9 1/2 - 49 7/8	975.2M	85
Tegal	TGAL	2 5/8	1 9/16 - 13 1/2	32.8M	N/A
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Aixtron	AIX	125	69.3 - 175.5	3.925B	205
Filtronics	FTC	6.65	5.39 - 38	507.88M	N/A
IQE	IQE	4.08	4.08 - 12.83	664.88M	267
Picogiga	PICO NM	28.5	7.25 - 36.50	184M	77
Riber	RIBER	19.5	9 - 38.5	377M	N/A

*Market Capitalization = # shares × current share price

** Price/Earnings Ratio = (income for last 4 quarters ÷ # shares) ÷ current share price

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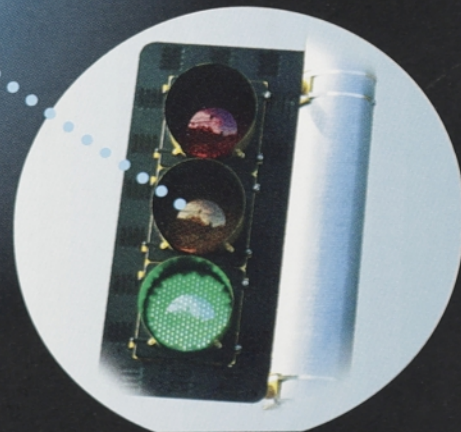
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* PSINet Stadium Video Display by SACO Smartvision, Inc.

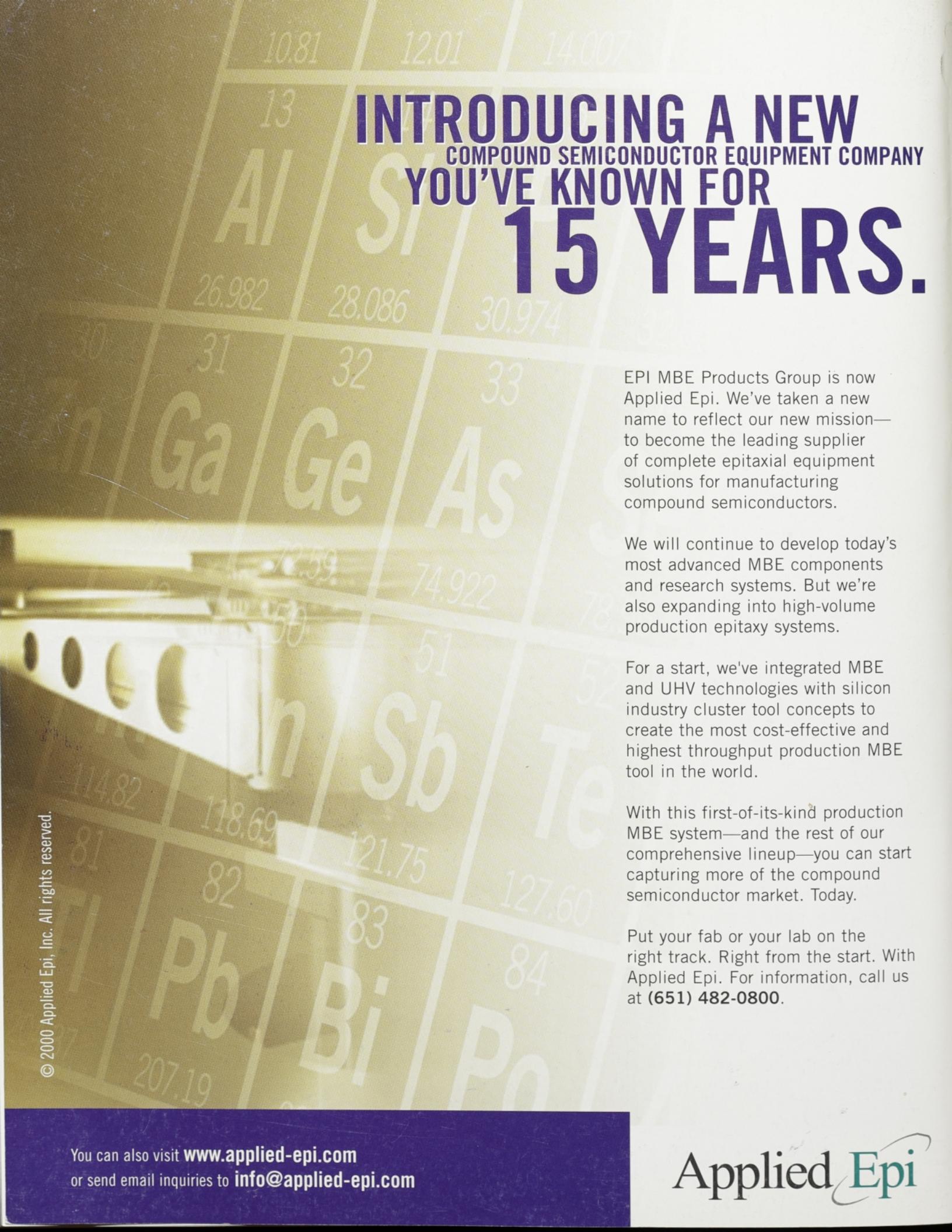
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