GALLIUM

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Gallium demand in the United States was satisfied by imports, primarily high-purity material from France and low-purity material from Kazakhstan and Russia. More than 95% of gallium consumed in the United States was in the form of gallium arsenide (GaAs). Analog integrated circuits (IC's) were the largest application for gallium, with optoelectronic devices [mostly laser diodes and light-emitting diodes (LED's)] as the second largest end use. Several U.S. firms are increasing their capacities to produce GaAs wafers for wireless communications applications; this is projected to be the largest growth area for gallium-base devices.

World production of virgin gallium was estimated to be 75 metric tons (t); demand for this material was centered in Japan, the United States, and Western Europe. Significant quantities of new scrap were recycled and supplemented supplies, particularly in Japan.

Production

No domestic production of primary gallium was reported in 1999 (table 1). Eagle-Picher Industries Inc. recovered and refined gallium from domestic and imported sources at its plant in Quapaw, OK. Recapture Metals Inc., Blanding, UT, recovered gallium from scrap materials, predominantly that generated during the production of GaAs. Recapture Metals' facilities have the capability to process about 17 metric tons per year (t/yr) of high-purity gallium. The company recovered gallium from its customers' scrap on a fee basis and purchased scrap and low-purity gallium for processing into high-purity material.

Consumption

More than 95% of the gallium consumed in the United States was in the form of GaAs. GaAs was manufactured into optoelectronic devices (LED's, laser diodes, photodetectors, and solar cells) and IC's. Analog IC's were the largest end-use application for gallium, with 52% of total consumption. Optoelectronic devices accounted for 42% of domestic consumption, and the remaining 6% was used in digital IC's, research and development, and other applications (tables 2-3).

Gallium consumption data are collected by the U.S. Geological Survey from one voluntary survey of U.S. operations. In 1999 there were 10 responses to the "Consumption of Gallium" survey, representing 53% of the total canvassed. Because of the poor response rate, data in tables 2 and 3 were adjusted by incorporating estimates to reflect full industry coverage.

Nichia Chemical Industries Ltd. of Japan began shipping commercial samples of its indium gallium nitride blue-violet laser diodes in February. These new laser diodes will enable denser digital video disk data storage. The new lasers that operate at a wavelength of 400 nanometers can store about 12 gigabits per side, and the red laser diodes that they would replace that operate at 650 nanometers, can store about 4.7 gigabits per side. Other potential applications for the laser diodes include laser printers, medical equipment, and digital video recorders (Photonics Spectra, 1999).

In addition to the blue and blue-violet laser diodes, U.S. and Japanese firms are developing blue and blue-violet LED's based on gallium nitride (GaN). Blue is the last color in the visible spectrum to be developed, and successful commercial production of these devices could lead to white LED's, which would compete with light bulbs in many applications. In June, EMCORE Corp. and the GE Lighting Div. of General Electric Co. (GE) formed a joint venture firm called GELcore LLC to produce white and high-brightness colored LED's. The company planned to introduce its first products in the second half of 1999 (GELcore, June 1999, GE Lighting and EMCORE Corporation complete formation of new company, GELcore LLC, to design and market solid state lighting products, accessed April 10, 2000, at URL http://gelcore.com/announce/june_3.html).

Kopin Corp. announced that it would double its manufacturing capacity for GaAs heterojunction bipolar transistor (HBT) wafers during 1999 and 2000. This is the company's second major expansion in 2 years. Kopin cited the acceptance of the HBT's in the power amplifier section of digital phone handsets as the principal driver behind the capacity expansion. The high-performance HBT's eliminate the need for many of the support circuits required by other technologies, so they provide a simpler, lower cost circuit (GaAsNet, January 7, 1999, Kopin to double device wafer manufacturing capacity, accessed February 22, 1999, at URL http://www.gaasnet.com/news/kopin_070199). In April, Kopin announced a third major expansion increase with the purchase of two additional multiwafer metal-organic chemical vapor deposition (MOCVD) reactors from the German firm AIXTRON AG; Kopin had ordered two reactors when it announced its initial expansion. By 2000, the company's total production capacity for HBT wafers will be 100,000 4-inch wafers and 50,000 6-inch wafers per year (GaAsNet, April 16, 1999, Kopin announces third major expansion of manufacturing capacity for GaAs HBT device wafer products, accessed April 16, 1999, at URL http://www.gaasnet.com/news/kopin_160499.html). The company began shipping HBT's from its new 6-inch wafer facility in December.

Epitaxial Products International Ltd., Cardiff, Wales, United Kingdom, and Quantum Epitaxial Designs Inc., Bethlehem, PA, merged in May to form a new company, International Quantum Epitaxy (IQE) (IQE plc in the United Kingdom and IQE Inc. in the United States). The new company combines the original firms' expertise in MOCVD and molecular beam epitaxy (MBE) and creates the world's largest supplier for epitaxial products and services. IQE completed an expansion in Wales that increases the facility's total manufacturing area to 3,700 square meters, capable of housing 16 MOCVD reactors, and the Pennsylvania facility received an MBE reactor in mid-1999 that increased its production capacity (GaAsNet, May 6, 1999, EPI and QED merge to create the world's leading 'pure play' merchant epiwafer supplier, accessed May 14, 1999, at URL http://www.gaasnet.com/news/epimbe_060599.html). In December, IQE reported that it had ordered six additional multiwafer MBE reactors that can process multiple 6-inch wafers per run as well as having the capability to process multiple 4-inch wafers more cost effectively than current systems (GaAsNet, December 10, 1999, IQE places orders for up to eight new multiwafer MBE production systems, accessed December 15, 1999, at URL http://www.gaasnet/com/news/qed_1299.html).

RF Micro Devices Inc. completed a 4,500-square-meter expansion of its MBE facility in Greensboro, NC, in June and broke ground on a new 12,000-square-meter facility in July. The new facility is expected to begin production of HBT wafers by December 2000. After the first phase is completed, production capacity will be 50,000 4-inch wafers per year, and phase two, scheduled for completion by late 2001, is expected to bring the total production capacity to 210,000 4-inch wafers per year. This is about four times RF Micro Devices' current production capacity. Increased demand in the wireless communications market is cited as the principal reason for expansion (RF Micro Devices Inc., September 9, 1999, RF Micro Devices breaks ground on new gallium arsenide HBT fabrication facility, accessed April 3, 2000, via URL http://www.rfmd.com).

TriQuint Semiconductor Inc. announced that it would increase the clean-room space at its Hillsboro, OR, GaAs facility by the second quarter of 2000. The new space, which will increase the company's clean-room facilities by about 35%, initially will be used to expand production of 4-inch wafers and will be eventually converted to 6-inch wafer production. The expansion was in response to increase demand for TriQuint's products in the telecommunications sector (GaAsNet, November 14, 1999, TriQuint Semiconductor announces expansion of Oregon wafer fabrication facility, accessed November 17, 1999, at URL http://www.gaasnet.com/news/triquint_1411199.html).

Alpha Industries Inc. completed the first phase of an expansion at its Woburn, MA, facility in September. When the expansion is finished, it will quadruple the company's total capacity for GaAs integrated circuits, which are primarily for use in wireless handsets. Alpha Industries is accelerating its timetable for the second phase of the expansion because growth in consumption for its products has been greater than originally anticipated. The second phase, which will involve installation of additional equipment, is scheduled to be completed by summer 2000 (GaAsNet, September 12, 1999, Alpha Industries completes major GaAs fab expansion, accessed September 13, 1999, at URL http://www.gaasnet.com/news/alpha_120999.html).

With the increased world demand for gallium-base devices in wireless communications applications and the switch from 4-inch to 6-inch manufacturing capabilities, equipment manufacturers also are expanding their facilities. AIXTRON is expanding its manufacturing facilities because of growing demand for its equipment. During 1999, Kopin ordered 6 of the company's MOCVD systems, and IQE ordered up to 10 reactors for installation at its facility in Wales, with 2 for delivery in 1999 and the remainder to be installed over a 3-year period. VG Semicon Ltd. (a subsidiary of Thermo Optek Corp.) received orders from RF Micro Devices and IQE for several of its MBE systems. RIBER SA, a manufacturer of MBE systems, also sold multiple systems to companies in France, Taiwan, and the United States and initiated an expansion in October 1999 to increase production and testing capacity for its MBE equipment.

Spire Corp. sold its optoelectronics business to Chicago-based Methode Electronics Inc. in December for about $13 million. With the sale of this section of its business, which includes its MOCVD capabilities, Spire plans to concentrate on its solar and biomedical businesses. Methode plans to operate the former Spire business under a subsidiary called Bandwidth Semiconductor LLC and focus on very high data transmission rates using light (Spire Corp., December 30, 1999, Spire Corporation completes sale of optoelectronics assets for approximately $13 million in cash, accessed May 23, 2000, via http://www.spirecorp.com/corpnews.htm; Methode Electronics Inc., 2000, Report for the third quarter 2000, accessed May 23, 2000, via http://www.methode.com/financial/).

ANADIGICS Inc. announced that it successfully fabricated the first indium gallium phosphide (InGaP) HBT on 6-inch wafers. This was part of the company's effort to develop advanced HBT's for cellular and personal communications systems handsets. According to ANADIGICS, the InGaP HBT's are more compatible with the GaAs substrate and exhibit greater temperature stability than traditional gallium aluminum arsenide HBT's (GaAsNet, October 7, 1999, ANADIGICS announces internal InGaP HBT process capability, accessed October 19, 1999, at URL http://www.gaasnet.com/news/ anadigics_071099.html).

EMCORE signed a long-term agreement with Japan's Sumitomo Electric Industries Ltd. to develop and produce InGaP epitaxial wafers for HBT devices. The new devices will be produced at EMCORE's facility in New Jersey and marketed in Japan for digital wireless and cellular applications (GaAsNet, May 19, 1999, Sumitomo Electric and EMCORE sign long term agreement to manufacture InGaP epi material for HBT devices, accessed June 30, 1999, at URL http://www.gaasnet.com/news/ emcore_190599.html).

Prices

In 1999, producer-quoted prices for high-purity gallium increased from those at yearend 1998 (table 4). At midyear, press reports indicated that the prices for gallium were about $500 per kilogram for high purity (99.9999% pure) and $420 to $440 per kilogram for crude (99.99% pure) (Roskill's Letter from Japan, 1999).

Foreign Trade

U.S. gallium imports dropped by about 8% in 1999 (table 5).

France (32%), Kazakhstan (31%), Germany (10%), and Russia (10%) were the principal sources of imported gallium. In addition to gallium metal, GaAs wafers were imported into the United States. In 1999, 21,400 kilograms (kg) of undoped GaAs wafers was imported, mostly from Japan (97%). The Republic of Korea (27%), Taiwan (20%), Japan (18%), and Malaysia (16%) were the main import sources for doped GaAs wafers, totaling 311,000 kg during the year, an increase of more than 200% from the level in 1998. Quantities of GaAs wafers reported by the Bureau of the Census may include the weight of the packaging material and thus may be overstated.

World Review

Estimated crude gallium production was 75 t in 1999. Principal world producers were Australia, Germany, Kazakhstan, and Russia. China, Hungary, Japan, Slovakia, and Ukraine also recovered gallium. Refined gallium production was estimated to be about 60 t. France was the largest producer of refined gallium using stockpiled crude gallium from Australia and from gallium produced in Germany as feed material. Japan and the United States also refined gallium. Gallium was recycled from new scrap in Germany, Japan, the United Kingdom, and the United States.

World demand for gallium was forecast to be 167 t in 1999 by Dowa Mining Co.; this figure includes significant quantities of recycled gallium scrap. Regional demand was estimated to be as follows: Japan, 109 t; the United States, 40 t; Europe, 11 t; and other countries, 7 t (Roskill's Letter from Japan, 1999).

France.—The U.S. firm GEO Specialty Chemicals Inc. acquired Rhodia Inc.'s (a subsidiary of Rhône-Poulenc S.A.) gallium facilities in France and Germany in September. The facilities included a 20-t/yr production facility in Stade, Germany, and a 20-t/yr purification plant in Salindres, France, plus offices in Paris. The deal did not include Rhodia's 50-t/yr gallium extraction facility in Australia (Metal Bulletin, 1999).

Japan.—Gallium supply in Japan in 1999 was estimated to be 118 t, a 17% decline from the 1998 level, and demand was estimated to be 109 t in 1999, an 8% decline from that in 1998. The drop in supply was attributed to a decrease in imports; from 74 t in 1998 to 49 t in 1999. Most of this decline was because of a significant drop in imports from Kazakhstan, which had been unusually high in 1997 and 1998 owing to shipments from stockpiled materials, rather than virgin production (Roskill's Letter from Japan, 1999).

Hitachi Cable Ltd. announced that it would expand its GaAs wafer manufacturing facilities in Tagasako at its new 1,250-square-meter facility that was completed in August. Increased demands for GaAs substrates grown by the Horizontal Bridgeman method and liquid-phase epitaxy for the LED and laser diode market and those grown by liquid-encapsulated Czochralski (LEC) and MOCVD for the cellular telephone market were cited as the reason for the expansion. Hitachi Cable plans to increase production of MOCVD wafers from 8,000 4-inch wafers per month to 12,000 wafers per month while increasing their diameter to 5 and 6 inches. Also the company plans to increase the diameter of its LEC substrates to 5 and 6 inches and increase the quantity produced from 20,000 to between 25,000 and 30,000 per month. Completion of the expansion was scheduled for November 2000 (GaAsNet, October 10, 1999, Hitachi Cable announces further expansion of GaAs crystal growth & epiwafer capabilities, accessed October 19, 1999, at URL http://www.gaasnet.com/news/hitachic_10101999.html).

United Kingdom.—Wafer Technology Ltd. expanded its vertical gradient freeze GaAs products to include 3-inch-diameter wafers; the largest wafers that had been produced by this technology were 2-inch diameter. The new wafers can be used for laser, LED, and electronics applications. Vertical gradient freeze technology is used for producing low-dislocation-density GaAs crystals. Chunks of polycrystalline GaAs, produced by horizontal synthesis, are placed in a crucible with a seed crystal of the required orientation. The crucible is then placed vertically in a furnace, and a temperature gradient is moved up the length of the crystal (away from the seed). Single crystal growth propagates from the seed crystal and, because the crystal forms in the shape of the crucible, diameter control of the ingot is relatively simple. The single-crystal ingot then can be sliced into wafers (GaAsNet, June 21, 1999, Wafer Technology expands VGF product range with 3-inch GaAs wafers, accessed June 30, 1999, at URL http://www.gaasnet.com/news/wafertech_0699.html).

Current Research and Technology

Under the National Institute of Standards and Technology's Advanced Technology Program, researchers at GE plan to develop a low-cost method to produce high-quality bulk GaN. Cooperating with personnel at Sanders Co. and Cornell University, the researchers propose to produce GaN by growing the material in a high-pressure, high-temperature apparatus similar to that used to make synthetic diamonds (National Institute of Standards and Technology, October 1999, Bulk GaN and homoepitaxial device manufacturing, accessed November 18, 1999, at URL http://www.atp.nist.gov/www/comps/briefs/ 99012069.htm).

A research team from North Carolina State University, Honeywell Technology Center, and the Department of Defense Night Vision Laboratory reported the first successful demonstration of a digital camera based on an array of GaN-gallium aluminum nitride photodiodes. The camera is designed to detect radiation only in the 320- to 365-nanometer region of the ultraviolet spectrum. When fully developed, this type of camera may be used in detecting biological agents and missile and shellfire and in studies of astronomical objects (Brown, J.D. and others, 1999, Visible-blind UV digital camera based on a 32 x 32 array of GaN/AlGaN p-i-n photodiodes: MRS Internet Journal Nitride Semiconductor Research, v. 4, accessed October 19, 1999, via http://nsr.mij.mrs.org/).

Spire Corp. received a 2-year, $750,000 contract from the U.S. Air Force to continue development of high-frequency transistors for military and commercial communications systems. Spire will use its proprietary MOCVD process to produce HBT's using a gallium arsenide nitride base region doped with carbon grown on GaAs wafers (GaAsNet, September 12, 1999, Spire Corporation to develop next-generation transistors for communications under Air Force contract, accessed September 13, 1999, at http://www.gaasnet.com/news/spire_120999.html). The company also received a

$600,000 contract from the National Aeronautics and Space Administration to develop high-speed photodetectors to be used in fiber-optics communications systems. The new detectors, to be produced from indium gallium arsenide (InGaAs) and aluminum gallium antimonide using MOCVD, will have as their goal a reduced noise level, as compared to that generated by current photodetectors. Reduced noise will lead to longer distances between repeaters and lower data error rate, ultimately resulting in improved reliability and lower cost (GaAsNet, October 26, 1999, Spire Corporation to develop advanced photodiodes for optical fiber communications systems under NASA contract, accessed October 26, 1999, at URL http://www.gaasnet.com/news.spire_26101999.html).

Cree Research Inc. received research contracts from the Office of Naval Research and the Air Force Research Laboratories to develop wide bandgap microwave and power switching devices. These devices will be used in advanced radar systems that require high power levels that are not possible with current technology using GaAs or silicon. Cree Research will develop chips made from silicon carbide and GaN for the advanced radar for airborne radar and space-based military systems. The total contract award for this research was $3.5 million (GaAsNet, September 23, 1999, Cree Research receives government GaN contract, accessed October 1, 1999, at URL http://www.gaasnet.com/news/cree_230999.html).

Scientists at Bell Laboratories demonstrated the first laser diode that can simultaneously emit light at multiple, widely separated wavelengths. The new laser diode is a version of a quantum cascade laser diode consisting of regions of aluminum indium arsenide, 4 atomic layers thick, alternating with InGaAs, 18 atomic layers thick. Through this design, the wavelengths of light emitted are determined through the thickness of the materials rather than entirely by chemical composition. An electric current injected into the device causes electrons to cascade through 25 stages of the material, emitting light at 2 or 3 wavelengths in each stage. The wavelengths can be tuned by adjusting the temperature of the laser. Potential applications for the new laser diode include pollution monitoring, noninvasive early detection of diseases, and monitoring performance of automobile catalytic converters (Comello, 1999).

Outlook

Strategies Unlimited estimated that the market for visible LED's would grow from a 1998 level of $1.9 billion to $3.16 billion by 2003, an average annual growth rate of 10.4%. Much of this growth will result from steady gains in traditional, low-brightness applications, which represent 77% of the total world LED market. These applications primarily consist of electronic displays and indicator lights, and conventional LED's are expected to grow by about 7.1% per year to 2003 to reach a total of $2.09 billion. High-brightness LED's, which are used in automotive applications, aircraft runway indicators, and other illuminated signs that need to be seen in the daylight, are expected to grow at a rate of about 34% annually to 2003. By 2003, conventional LED's will have 66% of the total market, and high-brightness LED's will have 34% (Dixon, Richard, 1999, The market for visible LEDs: Compound Semiconductor, v. 5, no. 3, April, available via URL http://www.compoundsemi conductor.net/archives/).

Although the development of white LED's promises to open new applications, technological hurdles to their widespread use in general illumination applications are not expected to be overcome in the next 5 years. Some industry analysts predict that this market is 10 to 20 years away. In order for these devices to be used in high-volume applications, improvements in efficiency and reductions in costs are needed, larger areas LED's must be able to be manufactured, and shorter wavelength (ultraviolet) devices will be required (Compound Semiconductor, 1999, White light LEDs in the spotlight: Compound Semiconductor, v. 5, no. 1, January-February, available via URL http://www.compoundsemiconductor.net/archives/).

The wireless communications market represents one of the largest growth markets for gallium-base devices as is evidenced by the number of companies increasing production capacity for these devices. Strategies Unlimited predicts that the worldwide market for radio frequency semiconductor devices in cellular telephones will grow to $7.7 billion by 2004 from $3.9 billion in 1999. GaAs components comprised 33% of the market in 1999. Annual handset demand is projected to increase to 600 million units in 2004 from 240 million in 1999. New services such as instant messaging, internet access, and wireless data will underlie the growth in handsets, and this will provide additional opportunities for GaAs devices (Compound Semiconductor, December 20, 1999, RF semiconductor market in cellular telephones to reach $7.7 billion in 2004, accessed April 6, 2000, at URL http://www.compoundsemiconductor.net/Beta/PressReleases/PR12209902.htm).

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[1] Prior to January 1996, published by the U.S. Bureau of Mines.

TABLE 1
SALIENT U.S. GALLIUM STATISTICS 1/

(Kilograms, unless otherwise specified)

	1995	1996	1997	1998	1999
Production	--	--	--	--	--
Imports for consumption	18,100	30,000	19,100	26,300	24,100
Consumption	16,900	21,900	23,600	26,900	29,800
Price per kilogram	$425	$425	$595	$595	$640

-- Zero.

1/ Data are rounded to no more than three significant digits.

TABLE 2
U.S. CONSUMPTION OF GALLIUM, BY END USE 1/ 2/

(Kilograms)

End use	1998	1999
Optoelectronic devices:		
Laser diodes and light-emitting diodes	10,300	12,500
Photodetectors and solar cells	1,710	712
Integrated circuits:		
Analog	14,000	15,300
Digital	844	686
Research and development	46	572
Other	57	60
Total	26,900	29,800

1/ Data are rounded to no more than three significant digits; may not add to totals shown.

2/ Includes gallium metal and gallium compounds.

TABLE 3
STOCKS, RECEIPTS, AND CONSUMPTION OF GALLIUM, BY GRADE 1/ 2/

(Kilograms)

Purity	Beginning stocks	Receipts	Consumption	Ending stocks
1998:				
99.99% to 99.999%	834	159	103	890
99.9999%	181	11,900	12,000	108
99.99999% to 99.999999%	1,000	14,800	14,800	1,000
Total	2,020	26,900	26,900	2,000
1999:				
99.99% to 99.999%	890	399	632	657
99.9999%	108	13,600	13,200	485
99.99999% to 99.999999%	1,000	16,000	16,000	1,000
Total	2,000	29,900	29,800	2,140

1/ Consumers only.

2/ Data are rounded to no more than three significant digits; may not add to totals shown.

TABLE 4
YEAREND GALLIUM PRICES

(Dollars per kilogram)

	1998	1999
Gallium metal, 99.99999%-pure, 100-kilogram lots	595	640
Gallium metal, 99.9999%-pure, 100-kilogram lots	550	595
Gallium metal, 99.9999%-pure, imported	380-425	380-425
Gallium oxide, 99.99%-pure, imported	275-350	275-350

Source: American Metal Market.

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF GALLIUM (UNWROUGHT, WASTE AND SCRAP), BY COUNTRY 1/

(Kilograms)

Country	1998 Quantity	1998 Value	1999 Quantity	1999 Value
China	600	$248,000	99	$37,100
France	8,560	4,050,000	7,750	3,200,000
Germany	751	149,000	2,490	1,240,000
Hungary	894	233,000	1,760	491,000
Japan	1,140	510,000	354	286,000
Kazakhstan	6,020	2,580,000	7,330	3,350,000
Russia	6,100	2,230,000	2,470	1,060,000
United Kingdom	1,070	441,000	1,240	532,000
Other	1,150	225,000	575	175,000
Total	26,300	10,700,000	24,100	10,400,000

1/ Data are rounded to no more than three significant digits; may not add to totals shown.

Source: Bureau of the Census.

TABLE 6
ESTIMATED WORLD ANNUAL PRIMARY GALLIUM PRODUCTION CAPACITY, DECEMBER 31, 1999 1/

(Metric tons)

Continent and country	Capacity
North America: United States 2/	3
Europe:	
France	20
Germany	20
Hungary	4
Kazakhstan	20
Slovakia	3
Russia	15
Ukraine	3
Total	85
Asia:	
China	8
Japan	7
Total	15
Oceania: Australia 2/	50
World total	153

1/ Includes capacity at operating plants as well as at plants on standby basis.

2/ Standby capacity as of December 31, 1999.