GALLIUM

By Deborah A. Kramer

No primary gallium was produced in the United States in 1995. Although the country was one of the largest consumers of gallium in the world, its needs were met from imported material. France and Russia were the main sources for gallium imports. Almost all the gallium used in the United States was in the form of gallium arsenide (GaAs). Optoelectronic devices [light emitting diodes (LED's), laser diodes, photodetectors, and solar cells] were the primary end use for GaAs components, accounting for 87% of U.S. demand. Integrated circuit applications accounted for 11% of domestic demand, and the remainder was used for research and development. Most commercial research activities focused on developing blue LED's and laser diodes in commercial-scale quantities for a variety of potential applications.

Production

No production of primary gallium was reported in 1995. 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 scrap generated during the production of GaAs. Recapture Metals also upgraded gallium imported from Russia. *(See table 1.)*

Consumption

With 87% of total reported consumption, optoelectronic devices were the largest application for GaAs. Integrated circuits accounted for 11% of consumption, and research and development activities accounted for the remaining 2%. *(See tables 2 and 3.)*

Laser Communications Inc. developed a new laser docking-aid system that assists in the safe docking of large ships. The system determines vessel distance, angle of approach, and approach velocity of the ship, relative to the dock, allowing the ship to dock safely even in dense fog and heavy rain. The laser distance and velocity sensor is a pulsed GaAs semiconductor laser; radar sensors provide redundancy. Information is transmitted to the ship in real-time from shore-based personal computers.[1]

Gallium data are collected by the U.S. Geological Survey (USGS) from two voluntary surveys of U.S. operations. In 1995, there were 21 responses to the "Consumption of Gallium" survey, representing 80% of the total canvassed. Significant quantities of gallium are used by universities and Government research facilities, which are not canvassed by the USGS's survey. Data in tables 1, 2, and 3 representing gallium consumption were adjusted to reflect full industry coverage.

Prices

With the exception of 99.999999%-pure gallium, prices for domestically produced gallium metal increased in 1995. *(See table 4.)*

Foreign Trade

France (62%) and Russia (25%) were the principal sources of imported gallium. In addition to gallium metal, significant quantities of GaAs wafers were imported into the United States. A total of 283 kilograms of undoped GaAs wafers was imported in 1995, mostly from Japan. Japan (49%), Canada (35%) and the Republic of Korea (10%) were the main import sources for doped GaAs wafers, totaling 217,000 kilograms during the year. *(See table 5.)*

World Review

Crude gallium production was estimated to be about 61 metric tons in 1995. Principal world producers were Australia, Germany, and Russia. Rhône-Poulenc S.A. continued to feed its purification facility in France from stockpiled crude gallium produced earlier at its 50-ton-per-year plant in Australia and from gallium produced in Germany. France, Japan, and the United States were the main world gallium refiners.

Australia.—Rhône-Poulenc announced that it would reopen its 50-ton-per-year gallium recovery facility in Pinjarra, Western Australia, in 1996.[2]

Japan.—Gallium metal imports into Japan in 1995 were estimated to be 57 tons, nearly 50% more than the 1994 level of 39 tons. About 58% of the imports was high-purity gallium from France, Germany, and the United States. France, with 30 tons, was Japan's largest import source of high purity gallium. Crude gallium was imported from China, Hungary, Kazakstan, and Russia. Production of primary gallium was estimated to be 6 tons, at the same level since 1990.[3]

Yamanaka Hutech, the Japanese sales agent for Eagle-Picher, announced that it planned to start refining gallium in a joint venture with Eagle-Picher. Eagle-Picher will supply the gallium refining equipment and technology to the new firm, which will be called Yamanaka EP Corp. Plant feed material would be gallium slag generated in Japan, and the company planned to produce 99.9999%-pure gallium by autumn 1996.[4] *(See table 6.)*

Current Research and Technology

Astronauts on the space shuttle *Endeavour* tested the Wake Shield Facility for the second time in September. The facility is a stainless steel disk designed to generate an ultravacuum (10^{-11} torr) in its wake as it moves in low-Earth orbit. This type of vacuum allowed the growth of highly purified epitaxial films of GaAs and gallium aluminum arsenide. Two additional studies with the facility were scheduled for late 1996 and early 1998.[5]

Researchers continued to try to produce blue LED's and laser diodes in commercial-size quantities using gallium nitride (GaN). Blue LED's can be used in flat-panel displays and indicator lights, medical technology, and printing and data storage. Blue laser diodes, used in compact disk applications, could enable a 2-hour movie to be stored on a 5-inch-diameter disk. Potential commercial and defense applications could have a market of more than $100 million, according to some estimates.

EMCORE Corp. produced blue GaN LED's on production-scale equipment, capable of processing multiple 2- or 3-inch wafers per run. GaN was grown epitaxially on a sapphire substrate and had a room-temperature light emission of 400 nanometers.[6] The Advanced Research Projects Agency awarded a $4 million, 2-year contract to a consortium of U.S. firms and research institutions to develop blue LED's and laser diodes. The consortium, headed by SDL Inc., Hewlett-Packard Co., and Xerox Corp. will develop low-defect GaN semiconductor wafers.[7]

Researchers at Sandia National Laboratories reported a record 53% electrical-to-optical power conversion rate from an indium gallium arsenide (InGaAs) vertical-cavity, surface-emitting laser diode operating at 980 nanometers. Conventional edge-emitting lasers have an operating efficiency of about 40% at 1 milliwatt, the power at which the surface-emitting laser was operating. This power level is the level necessary for data communications, a key potential application for vertical-cavity, surface-emitting lasers. Other potential applications for the lasers are optical computing and laser printing.[8]

Personnel at AT&T Bell Laboratories demonstrated a practical method for integrating GaAs optoelectronics and silicon circuitry on a single device. This type of device is one step in developing high-capacity optical switches for information processing. The researchers started with silicon integrated circuits and put a large number of GaAs quantum well diodes on top on them. The optical diode can absorb light to generate electrical signals on the device, and changing the voltage applied to the diode controls the quantity of light transmitted, allowing the diode to emit a modulated light beam.[9]

Essential Research Inc. was awarded a Small Business Innovative Research grant to develop a solar-driven, thermophotovoltaic electric power generation system. (In solar thermophotovoltaic systems, sunlight heats the infrared emitter, which generates electricity.) With support from McDonnell Douglas Aerospace Corp., Essential Research will develop the emitters as well as InGaAs semiconductors to convert heat efficiently. The company planned to generate electricity at an efficiency greater than 30% with this system.

Outlook

Integrated Circuit Engineering Corp. estimated that the 1995 market for GaAs integrated circuits was $590 million and that by 2000, the total market would be $1.8 billion, a 23% cumulative annual growth rate. Most of the growth would occur in the analog sector of the market for commercial use in applications such as cellular telephones, pagers, and local networks.[10]

Development of commercial production methods for GaN-base blue LED's and laser diodes has the potential to increase the use of gallium. Although laboratory-scale fabrication has been successful, it will be some time until commercial-scale production of these devices becomes common.

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[1]Photonics Spectra. V. 29, No. 10. Oct. 1995, pp. 18, 20.
[2]Chemical Marketing Reporter. V. 249, No. 1, Jan. 1, 1996, p. 12.
[3]Roskill's Letter from Japan. No. 237, Jan. 1996, pp. 22-25.
[4]———. No. 233, Sept. 1995, p. 16.
[5]Chemical & Engineering News. V. 73, No. 39, Sept. 25, 1995, pp. 7-8.
[6]Lasers & Optronics. V. 13, No. 4, Apr. 1995, p. 6.
[7]Photonics Spectra. V. 29, No. 8, Aug. 1995, p. 50.
[8]————. V. 29, No. 3, Mar. 1995, p. 42.
[9]Science News. V. 147, No. 15, Apr. 15, 1995, p. 15.
[10]Korczynski, E. GaAs Chips Compete in a Comfortable Niche. Solid State Technol., v. 38, No. 11, Nov. 1995, pp. 58-60.

OTHER SOURCES OF INFORMATION

U.S. Geological Survey Publications

Gallium. Ch. in Mineral Commodity Summaries, annual.
Weeks, R. A. Gallium, Germanium, and Indium. Ch. in United States Mineral Resources, USGS Professional Paper 820, ed. by D. A. Brobst and W. P. Pratt, 1973, pp. 237-246.

Other Sources

Roskill Information Services Ltd. Gallium 1990, 5th ed.

TABLE 1
SALIENT U.S. GALLIUM STATISTICS 1/

(Kilograms unless otherwise specified)

	1991	1992	1993	1994	1995
Production e/	--	--	--	--	--
Imports for consumption	11,300	8,480	15,600	16,900	18,100
Consumption	11,200	10,600	11,300	15,500	16,900
Price per kilogram	$525	$425	$400	$395	$425

e/ Estimated.
1/ Data are rounded to three significant digits.

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

(Kilograms)

End use	1994	1995
Optoelectronic devices:		
Laser diodes and light-emitting diodes	9,240	13,700
Photodetectors and solar cells	840	1,120
Integrated circuits:		
Analog	2,760	1,610
Digital	2,370	355
Research and development	231	59
Other	115	94
Total	15,500	16,900

1/ Includes gallium metal and gallium compounds.
2/ Data are rounded to three significant digits; may not add to totals shown.

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

(Kilograms)

Purity	Beginning stocks	Receipts	Consumption	Ending stocks
1994:				
97.0% to 99.9%	3	--	1	2
99.99% to 99.999%	117	358	115	360
99.9999%	308	7,560	7,560	315
99.99999% to 99.999999%	568	7,770	7,870	459
Total	996	15,700	15,500	1,140
1995:				
97.0% to 99.9%	2	--	2	--
99.99% to 99.999%	360	589	92	857
99.9999%	315	11,400	11,100	532
99.99999% to 99.999999%	459	5,260	5,660	55
Total	1,140	17,200	16,900	1,440

1/ Consumers only.
2/ Data are rounded to three significant digits; may not add to totals shown.

TABLE 4
YEAREND GALLIUM PRICES

(Dollars per kilogram)

Gallium metal, 99.999999%-pure, 100-kilogram lots	$525
Gallium metal, 99.99999%-pure, 100-kilogram lots	425
Gallium metal, 99.9999%-pure, 100-kilogram lots	390
Gallium metal, 99.9999%-pure, imported	$380-425
Gallium oxide, 99.99%-pure, imported	275-350

Source: American Metal Market.

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

	1994		1995	
Country	Kilograms	Value	Kilograms	Value
Canada	--	--	837	$262,000
France	6,940	$1,960,000	11,300	3,040,000
Germany	1,830	428,000	--	--
Kazakstan	1,000	164,000	--	--
Russia	5,290	669,000	4,600	782,000
United Kingdom	634	51,500	114	21,200
Other	1,200	275,000	1,270	239,000
Total	16,900	3,550,000	18,100	4,350,000

1/ Data are rounded to three significant digits; may not add to totals shown.

Source: Bureau of the Census.

TABLE 6
WORLD ANNUAL PRIMARY GALLIUM
PRODUCTION CAPACITY, 1/ DECEMBER 31, 1995

(Metric tons)

Continent and country	Capacity
North America: United States 2/	3
Europe:	
France	20
Germany	20
Hungary	4
Slovakia	3
Former U.S.S.R. e/	30
Total	77
Asia:	
China	8
Japan	7
Total	15
Oceania: Australia 2/	50
World total	145

e/ Estimated.
1/ Includes capacity at operating plants as well as at plants on standby basis.
2/ Standby capacity as of Dec. 31, 1995.