

GALLIUM

By Deborah A. Kramer

No gallium production was reported in the United States in 1994. The U.S. gallium demand was supplied primarily by imports. France, Russia, and Germany, in declining order, were the principal import sources, representing 83% of the total. Approximately 65% of the U.S. gallium demand was for optoelectronic devices [light-emitting diodes (LED's), laser diodes, photodetectors, and solar cells], and 33% was consumed for integrated circuits. The remainder was used in research and development and other applications. Gallium arsenide (GaAs) manufacturers are beginning to commercialize some of the products originally made for defense applications, and significant strides in the development of a brighter blue LED, based on gallium nitride (GaN) could expand the applications for gallium.

Production

No production of primary gallium was reported in 1994. Eagle-Picher Industries Inc. recovered and refined gallium from both 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

Gallium consumption increased significantly in 1994. Although the total quantity of gallium used in optoelectronic devices increased, its percentage of total consumption remained the same. The bulk of the increase in demand was in integrated circuits.

Night-vision goggle manufacturer ITT Corp. reportedly granted Bausch & Lomb exclusive marketing and distribution rights to sell the goggles into the sports market. This marketing effort is part of ITT's strategy to commercialize its military technology. ITT already markets night-vision goggles to the law enforcement and marine markets. To reduce costs for the products, ITT is trying to improve the manufacturing technique used to produce the GaAs microchannel plates that guide and amplify photons.¹

McDonnell Douglas Corp. reportedly will transition its Improved Mast Mounted Sight Systems Processor, used primarily on the U.S. Army's OH-58D helicopter, to production status in mid-1996. The processor is based on GaAs integrated circuits and is one of the fastest programmable digital signal processors on the market, according to the company.² (See tables 2 and 3.)

Gallium data are collected from two voluntary surveys of U.S. operations. In 1994, there were 17 responses to the "Consumption of Gallium" survey, representing 68% of the total canvassed. Significant quantities of gallium are used by universities and Government research facilities, which are not canvassed by the Bureau's survey. Data in tables 1, 2, and 3 representing gallium consumption were adjusted to reflect full industry coverage.

Prices

Early in 1994, prices for gallium were reported to be about \$130 to \$170 per kilogram for 99.99%-pure to 99.9999%-pure gallium from China and Russia, and U.S. prices were about \$300 per kilogram for high-grade gallium. Quoted yearend prices for gallium metal declined by \$5 per kilogram for 99.9999%-pure and 99.99999%-pure material in 1994. Eagle-Picher reported that it had lowered prices because of competitive world pressure on prices and less costly raw materials. (See table 4.)

Foreign Trade

France, Russia, and Germany were the principal sources of imported gallium, accounting for 41%, 31%, and 11% of total imports, respectively. In addition to metallic gallium, the United States also imported significant quantities of GaAs wafers. In 1994, 1,190 undoped GaAs wafers were imported, primarily from Sweden (47%) and Japan (46%). Japan and Canada were the major sources of doped GaAs wafers, with 61% and 26%, respectively, of the total of 183,000 wafers. (See table 5.)

World Review

Crude gallium production was estimated to be about 51,000 kilograms in 1994. Principal

world producers were Australia, Germany, and Russia. More than 15,000 kilograms of gallium were imported into Japan and the United States from Russia in 1994. Some of this material was thought to have been from stockpiles maintained in Russia. Rhône-Poulenc S.A. continued to feed its purification facility in France from stockpiled crude gallium produced earlier at its 50,000-kilogram-per-year plant in Australia and from gallium produced in Germany.

Germany.—In April, Rhône-Poulenc announced that it would acquire Ingal International Gallium GmbH. Ingal operated a gallium extraction plant in Stade and a gallium refining plant in Schwandorf. Rhône-Poulenc planned to close the Schwandorf plant, but continue to operate the Stade facility. Gallium refining operations would be moved to Rhône-Poulenc's current refining facility in Salindres, France.³

Japan.—Gallium imports into Japan in 1994 were estimated to be nearly 42 metric tons, about double the 1993 level. France supplied about one-half of the gallium imports, with a purity level of 99.9999% to 99.99999%. Russia, with 24% of the total imports, was the second largest source, but the purity level was only 99.99% and required further refining in Japan.⁴ Demand for compound semiconductor materials in Japan continued to increase because of higher consumption of LED's for mobile telephones in Japan and for consumer electronics in China and other Asian countries. Total Japanese shipments for GaAs and gallium phosphide (GaP) in 1994 were ¥30 billion, and increase of 21% from 1993 shipments.⁵ (See table 6.)

Current Research and Technology

Scientists at Harvard University reportedly fabricated a new type of transistor based on GaAs and a new insulator, gallium sulfide (GaS). This research is part of an effort to find an insulator for GaAs that essentially has the same properties that a silica insulator has for silicon. The Harvard group produced a new phase of GaS with a cubic structure that matches that of GaAs by decomposing [(tert-butyl)GaS]₄ at 400° C and depositing the GaS by metal-organic chemical vapor deposition. A simple prototype GaAs device

was created that performed better than a traditional GaAs field-effect transistor, but not as well as a silicon-base transistor. The research represents a first step in increasing the applications for GaAs devices.⁶

University and Government scientists continued to develop methods to improve the economics and technology of producing GaAs and other compound semiconducting materials. Researchers at Sandia National Laboratories developed a new optics-based monitoring system to control growth rates in molecular beam epitaxy (MBE). The technique has the potential to increase yields up to 50% by increasing accuracy and reproducibility.⁷ At the National Institute of Standards, scientists were looking for commercial companies to license a laser photoionization technology that can simultaneously measure multiple substances being deposited during MBE.⁸ Physicists at Nippon Telegraph & Telephone Corp. announced they had developed a method of controlling a semiconductor material so that it grows orderly rows of boxlike structures, called quantum dots. The quantum dots currently could be adapted as amplifiers for semiconductor lasers and could replace conventional etching techniques to produce a variety of minuscule electronic components.⁹

Brown University scientists were developing a method to grow GaN on silicon substrates by chemical vapor deposition and MBE. Aluminum gallium nitride, one of the compounds that could be produced by this method, would cover a spectral range for which there are few solid-state light sources. This compound, which emits blue light, would enable the development of full-color, solid-state displays when combined with existing red and green sources.¹⁰

The goal of a collaboration between Xerox, Honeywell Inc., and Sandia National Laboratories was to develop prototype indium gallium aluminum phosphide vertical cavity surface-emitting laser arrays that could operate at room temperature in a continuous mode. The 2-year project, funded for \$3.1 million through the Advanced Projects Research Agency, would yield components that could become practical for low-cost networks based on plastic fiber and for the next generation of high-performance laser printers.¹¹

AT&T Bell Laboratories announced the development of a new semiconductor laser design called a quantum cascade laser. The aluminum indium arsenide/gallium indium arsenide structure can be tailored to emit light at any frequency in the mid- to far-infrared range, which is not easily accessible with other laser diodes. In addition, the new structure is less temperature sensitive and produces an

intrinsically narrower line width than conventional lasers. Potential applications for the new device are in chemical sensing applications and monitoring of gas emissions.¹²

Several organizations continued to develop LED's made principally from GaN that emit blue light. Japan's Nichia Chemical Industries Ltd. reported that it began commercial manufacture of a GaN LED that emits blue light at brightness of 1,000 millicandelas; most of the current blue LED's made from silicon carbide have a brightness of about 10 millicandelas.¹³ At Boston University, researchers developed a new method for making GaN LED's that can be easily scaled up and uses MBE rather than metal organic chemical vapor deposition to produce the devices. Blue LED's are expected to be used for optical storage, color copiers, printers, and facsimile machines.¹⁴

Epitax Optoelectronic Devices Inc. reportedly produced an indium gallium arsenide detector array for use on an environmental research satellite mission. The detector array will be part of a focal plane array used to detect trace atmospheric gases. The satellite, sponsored by German and Dutch space agencies, is scheduled to be launched in 1998.¹⁵

Outlook

According to a study sponsored by Allied Business Intelligence, demand for military GaAs-base monolithic microwave integrated circuits is expected to grow at an annual rate of 9% over the next 5 years, in terms of dollar value. Electronic warfare devices, with 23% of the total, was the largest military use of these GaAs devices. Radar, 20%; communications equipment, 19%; navigation, 18%; and ordnance and weapons, 10% were the other military uses.¹⁶

Overall gallium demand should increase slightly as devices originally manufactured for military applications become commercialized. In addition, work to develop a blue LED based on GaN should expand the market for gallium throughout the world.

¹Chinnock, C. Night-Vision Goggles Go Dual Use. *Military & Aerospace Electron.*, v. 5, No. 11, Oct. 1994, pp. 1, 14.

²Military & Aerospace Electronics. McDonnell Douglas Gets Funding For IMSP Production. V. 5, No. 9, Aug. 1994, p. 9.

³Platt's Metals Week. V. 65, No. 16, Apr. 18, 1994, p. 3.

⁴Roskill's Letter From Japan. No. 226, Feb. 1995, p. 2.

⁵_____. No. 225, Jan. 1995, pp. 23-24.

⁶Dagani, R. New Transistor Class is Based on GaS, GaAs. *Chem. & Eng. News*, v. 72, No. 12,

Mar. 21, 1994, p. 8.

⁷*Lasers & Optronics*. V. 13, No. 4, Apr. 1994, p. 6.

⁸Photonics Spectra. Laser Ionization Aids Molecular Beam Epitaxy. V. 28, No. 5, May 1994, p. 50.

⁹Hamilton, D. P. Chips "Grown" in Lab May Be Possible in Future, Japan Team's Test Suggests. *Wall St. J.*, v. 223, No. 93, May 12, 1994, p. B3.

¹⁰Beresford, R. Growing GaN by Plasma-Assisted Molecular-Beam Epitaxy. *J. Met.*, v. 46, No. 3, Mar. 1994, pp. 54-58.

¹¹Photonics Spectra. Red VCSEL Program Targets Information Applications. V. 28, No. 5, May 1994, pp. 33-34.

¹²Chemical & Engineering News. New Semiconductor Laser Developed at Bell Labs. V. 72, No. 17, Apr. 25, 1994, pp. 7-8.

¹³Photonics Spectra. Blue Gets Brighter. V. 28, No. 2, Feb. 1994, pp. 30, 32.

¹⁴_____. BU Researcher Develops Blue LED. V. 29, No. 1, Jan. 1995, p. 28.

¹⁵Military & Aerospace Electronics. InGaAs Focal Plane Array Set For IR Space Mission. V. 5, No. 13, Dec. 1994, p. 10.

¹⁶Military & Aerospace Electronics. Strong Growth Forecast in Military MMICs. V. 5, No. 13, Dec. 1994, p. 30.

OTHER SOURCES OF INFORMATION

U.S. Bureau of Mines Publication

Gallium. Ch. in *Mineral Commodity Summaries*, annual.

Other Sources

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

TABLE 1
SALIENT U.S. GALLIUM STATISTICS 1/

(Kilograms unless otherwise specified)

	1990	1991	1992	1993	1994
Production e/	--	--	--	--	--
Imports for consumption	9,890	11,300	8,480	15,600	16,900
Consumption	9,860	11,200	10,600	11,300	15,500
Price per kilogram	\$525	\$525	\$425	\$400	\$395

e/ Estimated.

1/ Previously published and 1994 data are rounded by the U.S. Bureau of Mines to three significant digits.

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

(Kilograms)

End use	1993	1994
Optoelectronic devices:		
Laser diodes and light-emitting diodes	6,470	9,240
Photodetectors and solar cells	890	840
Integrated circuits:		
Analog	2,420	2,760
Digital	325	2,370
Research and development	405	231
Other	834	115
Total	11,300	15,500

1/ Includes gallium metal and gallium compounds.

2/ Previously published and 1994 data are rounded by the U.S. Bureau of Mines 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
1993:				
97.0% to 99.9%	15	7	19	3
99.99% to 99.999%	11	106 r/	--	117 r/
99.9999%	397	6,270	6,360	308
99.99999% 3/	304	5,240 r/	4,970	568 r/
Total	727	11,600 r/	11,300	996 r/
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% 3/	568	7,770	7,870	459
Total	996	15,700	15,500	1,140

r/ Revised.

1/ Consumers only.

2/ Previously published and 1994 data are rounded by the U.S. Bureau of Mines to three significant digits; may not add to totals shown.

3/ Includes 99.999999% -pure gallium.

TABLE 4
YEAREND GALLIUM PRICES

(Dollars per kilogram)

Gallium metal, 99.99999%-pure, 100-kilogram lots	\$525
Gallium metal, 99.99999%-pure, 100-kilogram lots	395
Gallium metal, 99.9999%-pure, 100-kilogram lots	325
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

Country	1993		1994	
	Kilograms	Value	Kilograms	Value
France	5,630	\$1,750,000	6,940	\$1,960,000
Germany	4,190	1,150,000	1,830	428,000
Hungary	2,030	392,000	--	--
Kazakhstan	--	--	1,000	164,000
United Kingdom	434	83,300	634	51,500
Other	3,300	754,000	6,480	943,000
Total	15,600	4,130,000	16,900	3,550,000

1/ Previously published and 1994 data are rounded by the U.S. Bureau of Mines 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, 1994

(Metric tons)

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

e/ Estimated.

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

2/ Standby capacity as of Dec. 31, 1994.