

# GALLIUM

By Deborah A. Kramer

The United States relied on imports of gallium to supply its domestic demand. France continued to be the largest supplier of gallium to the U.S. market. Most gallium was used to manufacture gallium arsenide (GaAs), which in turn, was used to produce optoelectronic devices and integrated circuits for commercial and military applications. Demand for gallium increased significantly in 1996, and domestic GaAs producers responded by increasing capacity to produce GaAs wafers. In addition to increasing capacity, some of the new facilities being constructed will be able to produce larger wafers, thereby reducing production costs.

## Production

No production of primary gallium was reported in 1996. (See 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 scrap generated during the production of GaAs. Recapture Metals' facilities have the capability of processing about 15 metric tons of high-purity gallium per year. The company recovers gallium from its customers' scrap on a fee basis and purchases scrap and low-purity gallium for processing to high-purity material.

## Consumption

Optoelectronic devices continued to be the largest end use for gallium, with 59% of total consumption. Integrated circuits accounted for 40%, and the remaining 1% was used in research and development and other applications. (See tables 2 and 3.) The large increase in reported consumption of gallium in analog devices resulted from an adjustment in reporting by several firms.

Gallium data are collected by the U.S. Geological Survey from two voluntary surveys of U.S. operations. In 1996, there were 16 responses to the "Consumption of Gallium" survey, representing 70% of the total canvassed. Significant quantities of gallium are used by universities and Government research facilities, which are not canvassed by the survey. In tables 1 through 3, data representing gallium consumption were adjusted to reflect full-industry coverage.

In March, M/A-COM Inc. produced a 22-kilogram, 100-millimeter-diameter single-crystalline structure GaAs ingot. The ingot was grown by the high-pressure, liquid-encapsulated Czochralski method using its proprietary large-melt process. This is one of the largest GaAs crystals grown commercially, and 400 wafers can be produced from an ingot this size. The

ingot was remarkable because it was produced from a 24-kilogram melt. This type of increase in manufacturing efficiency has the potential to reduce costs to the customer (M/A-COM Inc., 1996).

Increased demand for GaAs resulted in several U.S. firms deciding to increase production capacity. TriQuint Semiconductor Inc. is constructing a new GaAs manufacturing facility and headquarters in Hillsboro, OR. The project, which is scheduled to be completed by March 1997, will include a 36,000-square-foot GaAs wafer fabrication unit incorporating 16,000 square feet of Class 100 clean room. TriQuint manufactures GaAs integrated circuits principally for analog applications in wireless telecommunications and computer systems (DPR Construction Inc., 1996). TriQuint also introduced two new manufacturing processes for its GaAs foundry customers. The principal advantages of the two new processes are a higher level of integrations (i.e., more components per wafer) and higher power throughput, up to 3 watts. Depending on the number of wafers purchased, costs for wafer processing by the new methods range from \$2,800 to \$5,200 per wafer (TriQuint Semiconductor Inc., 1996).

Anadigics Inc. also was constructing a new GaAs manufacturing facility near its Warren, NJ, headquarters. The expansion, which will renovate a vacant building, will have a new 10,000-square-foot clean room to process 4-inch wafers. This will nearly double Anadigics' GaAs wafer production capacity when the new capacity becomes operational in the fourth quarter of 1997. Although the equipment purchased for the facility will produce 4-inch wafers, it will be upgradable to process 6-inch wafers (Anadigics Inc., 1996).

In October, Vitesse Semiconductor Corp. began construction of a new GaAs integrated circuit manufacturing facility in Colorado Springs, CO. The new facility will be the first 6-inch GaAs very-large-scale integration production facility in the world and will have 100,000 square feet of manufacturing space. Total cost of the plant is estimated to be \$75 million and will create 140 new jobs. Completion is scheduled for 1998. This is Vitesse's second GaAs manufacturing facility; the company operates a plant in Camarillo, CA (Vitesse Semiconductor Corp., 1996).

TRW Inc. installed a new multiwafer molecular beam epitaxy machine that can double the company's GaAs integrated circuit production capacity. The new machine can process either five 3-inch or three 4-inch GaAs wafers at one time, and the processing time for the five 3-inch wafers is the same as that for one 3-inch wafer on conventional equipment. Although the new equipment can produce epitaxial material for high-electron-mobility transistors and heterojunction bipolar transistors

(HBT's), TRW is using the machine primarily to produce HBT's because of the high demand for HBT's in commercial wireless communication systems (TRW Inc., 1996).

Because the aluminum component of some laser diodes can oxidize in rising temperatures, attacking and degrading the laser cavity, scientists have developed aluminum-free laser diodes. Northwestern University granted an exclusive licence to Semiconductor Laser International Corp. (SLI), Endicott, NY, to develop, manufacture, and market aluminum-free semiconductor lasers. The manufacturing technique, developed at Northwestern, replaces aluminum with phosphorous or indium. Northwestern claims that the ion replacement will improve performance and increase power levels, leading to longer lived lasers. SLI expects to have the new lasers on the market in 1997 (Tatterson, 1996).

In Finland, researchers also have developed a method to produce aluminum-free laser diodes by substituting gallium indium arsenide phosphide (GaInAsP) for gallium aluminum arsenide (GaAlAs). The laser contains a layer of gallium indium arsenide between two layers of GaInAsP, and Tutcore, a commercial spin-off of the University of Tampere, claims that the laser can operate at twice the power output of conventional lasers with no loss of reliability (Walko, 1996).

Lidatek LLC, Mukilteo, WA, is marketing a line of consumer devices that the company claims operate as countermeasures to police laser speed guns. A silicon photodiode receiver detects incoming infrared light at a wavelength of about 900 nanometers, which then activates a GaAs laser diode that emits light at 904 nanometers, effectively jamming the laser radar gun (Photonics Spectra, 1996a).

## Prices

Producer-quoted prices for gallium in 1996 did not change from those at yearend 1995. (See table 4.) By yearend 1996, traders reported that 99.9999%-pure gallium metal was being traded in the high \$300's per kilogram, and 99.99%-pure gallium was in the low \$300's per kilogram (Metal Bulletin, 1997).

## Foreign Trade

U.S. gallium imports increased significantly in 1996. France (54%), Canada (20%), and Russia (11%) were the principal sources of imported gallium. (See table 5.) In addition to gallium metal, significant quantities of GaAs wafers were imported into the United States. A total of 4,940 kilograms of undoped GaAs wafers was imported in 1996, mostly from Japan. Japan (68%) and Canada (12%) were the main import sources for doped GaAs wafers, totaling 141,000 kilograms during the year.

## World Review

Estimated crude gallium production was 55 tons in 1996; this was about a 10% decline from estimated production in 1995.

Most of the decrease in production was from Russia and Kazakstan. Principal world producers were Australia, Germany, and Russia. Rhône-Poulenc S.A. continued to feed its purification facility in France from crude gallium produced 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. (See table 6.)

Estimated imports of gallium to Japan in 1996 were 41.7 tons, with France as the largest import source. Total gallium imports to Japan decreased significantly from the 1995 level of 58.3 tons, with the largest decrease in imports from France and Russia. The decline in imports from France was attributed to a rise in prices, and the decrease in imports from Russia was because of a decline in stocks (Roskill's Letter from Japan, 1997).

In early 1996, Dow Mining Co. Ltd. began construction of a new plant to process rare-metal scrap, including gallium. The company plans to extract gallium, tantalum, and germanium dioxide from used semiconductors at the plant near Dow's zinc smelter in Iijima. Dow already operates a gallium purification plant in Hachioji and a gallium recycling plant near Kosaka. When the new plant became operational in April, Dow's total gallium recycling capacity doubled to 10 tons per year (Metal Bulletin, 1996).

## Current Research and Technology

Commercial development of blue lasers diodes based on gallium nitride (GaN) continue to fuel most research and development activities. The Japanese firm Nichia Kagaku Kogyo K.K. reportedly operated at blue-purple laser diode at room temperature; at 410 nanometers, the company claims the laser has the world's shortest wavelength for a semiconductor. The laser is made mostly of GaN, with some other materials that the company did not disclose. Potential applications for the new laser are in digital video disk players and compact disk players. If the laser can be used in compact disk players, then it could increase the recording density by four times over current technology (Photonics Spectra, 1996b). Toshiba Corp. also reported operating a GaN blue-purple laser at 417 nanometers at room temperature.

Scientists at the National Research Council of Canada produced a quantum dot laser that emits visible light. Until this development, quantum dot lasers only emitted light in the infrared region of the spectrum. The scientists sandwiched indium aluminum arsenide between two layers of GaAlAs in clusters of about 20 nanometers in diameter to create the quantum dot laser. One of the difficulties that must be addressed before commercial applications of these type of devices is the ability to grow a large number of the quantum dots and to assure that their sizes do not fluctuate by more than 10%; in a device this small, 10% corresponds to a difference of about 20 atoms (Wu, 1996).

Solarex reported a new record for solar efficiency with a copper indium gallium diselenide (CuInGaSe<sub>2</sub>) thin film. The record, which was confirmed by the National Renewable Energy

Laboratory, was 13% conversion efficiency. Solarex claimed that the combination of high efficiency and low cost places the CuInGaSe<sub>2</sub> material as a leading candidate for photovoltaic devices for bulk power generation (Troy, 1996).

## Outlook

Gallium demand is expected to continue to grow in the United States, particularly for telecommunications applications. New GaAs production capacity being installed has the potential to enable production of GaAs devices at lower cost than by using current technology. A reduction in production costs will help to fuel the increase in demand. With an increase in demand, larger quantities of GaAs scrap will be generated, and this scrap most likely will be reprocessed and help to meet a portion of the demand. Although GaAs demand is expected to increase over the next few years, primary gallium demand will increase at a slightly slower rate.

In a report released by Strategies Unlimited, Mountain View, CA, the world market for short wavelength laser diodes in nontelecommunications applications was forecast to grow by 20% per year until 2000—from an estimated \$486 million in 1995 to \$1,238 million by 2000. This increase in demand will be driven by new digital video disk uses and high-speed CD-ROM uses. In addition, the study predicts that the blue-green laser diode, which is the focus of aggressive research, should appear in high-density storage applications by 2000 (Lasers & Optronics, 1996).

## References Cited

- Anadigics Inc., 1996, Anadigics' new wafer fabrication plant: Anadigics Inc. press release, July 23, 1996. (Accessed May 19, 1997, on the World Wide Web at URL [http://www.anadigics.com/press/clean\\_room.html](http://www.anadigics.com/press/clean_room.html))
- DPR Construction Inc., 1996, DPR Construction selected to build Triquint Semiconductor headquarters and wafer fab: DPR Construction Inc. press release, June 10, 1996. (Accessed January 14, 1997, on the World Wide Web at URL <http://www.dprinc.com/pr061096.html>)
- Lasers & Optronics, 1996, Laser diode market to zoom: Lasers & Optronics, v. 15, no. 12, p. 6.
- M/A-COM Inc., 1996, M/A-COM announces 24kg 100mm HPLEC semi-insulating GaAs process: M/A-COM Inc. (Accessed September 27, 1996, on the World Wide Web at URL <http://www.macom-gaaswafers.com/mamma.html>)
- Metal Bulletin, 1996, Dowa to construct rare metal scrap plant: Metal Bulletin, no. 8045, January 15, p. 13.
- 1997, Germanium to soften, gallium looks up: Metal Bulletin, no. 8145, January 16, p. 9.
- Photonics Spectra, 1996a, Beating police laser radar at its own game: Photonics Spectra, v. 30, no. 10, p. 198.
- 1996b, Nichia claims room-temperature blue-purple diode laser: Photonics Spectra, v. 30, no. 1, p. 27.
- Roskill's Letter from Japan, 1997, Gallium—Divergence in pricing policies: Roskill's Letter from Japan, no. 249, p. 9.
- Tatterson, K.G., 1996, Laser firm gets university license for marketing Al-free laser diodes: Photonics Spectra, v. 30, no. 12, p. 55-56.
- TriQuint Semiconductor Inc., 1996, TriQuint Semiconductor offers new process to its gallium arsenide foundry customers: TriQuint press release, June 18, 1996. (Accessed on January 14, 1997, on the World Wide Web at URL [http://www.triquint.com/Financial/Media/Press/pr\\_960618.htm](http://www.triquint.com/Financial/Media/Press/pr_960618.htm))
- Troy, C.T., 1996, Solar thin-film record claimed: Photonics Spectra, v. 30, no. 1, p. 40.
- TRW Inc., 1996, TRW installs high-volume chip making equipment, doubles capacity for producing commercial gallium arsenide integrated circuits: Businesswire, November 19, 1996. (Accessed on January 14, 1997, on the World Wide Web at URL <http://www.businesswire.com/trw/bw11196/233854.htm>)
- Vitesse Semiconductor Corp., 1996, Vitesse Semiconductor to break ground for new gallium arsenide wafer fab in Colorado Springs: Vitesse Semiconductor Inc. press release, October 28, 1996. (Accessed January 14, 1997, on the World Wide Web at URL <http://www.vitesse.com/news/1028.html>)
- Walko, John, 1996, Finns get aluminum out of laser diodes: Photonics Spectra, v. 30, no. 7, p. 40.
- Wu, C., 1996, Drawing a bead on quantum dot lasers: Science News, v. 150 no. 21, November 23, p. 327.

## SOURCES OF INFORMATION

### U.S. Geological Survey Publications

- Gallium. Ch. in Mineral Commodity Summaries, annual.<sup>1</sup>
- Gallium, Germanium, and Indium. Ch. in United States mineral resources, U.S. Geological Survey Professional Paper 820, 1973.

### Other

- Gallium. Ch. in Mineral Facts and Problems, U.S. Bureau of Mines Bulletin 675, 1985.
- Gallium and gallium arsenide: supply, technology, and uses. U.S. Bureau of Mines Information Circular 9208, 1988.
- Roskill Information Services Ltd. Gallium 1990, 5th ed.

<sup>1</sup>Prior to January 1996, published by the U.S. Bureau of Mines.

TABLE 1  
SALIENT U.S. GALLIUM STATISTICS 1/

(Kilograms unless otherwise specified)

	1992	1993	1994	1995	1996
Production	--	--	--	--	--
Imports for consumption	8,480	15,600	16,900	18,100	30,000
Consumption	10,600	11,300	15,500	16,900	21,900
Price per kilogram	\$425	\$400	\$395	\$425	\$425

1/ Data are rounded to three significant digits.

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

(Kilograms)

End use	1995	1996
Optoelectronic devices:		
Laser diodes and light-emitting diodes	13,700	11,600
Photodetectors and solar cells	1,120	1,280
Integrated circuits:		
Analog	1,610	8,200
Digital	355	623
Research and development	59	184
Other	94	38
Total	16,900	21,900

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

2/ Includes gallium metal and gallium compounds.

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

(Kilograms)

Purity	Beginning stocks	Receipts	Consumption	Ending stocks
1995:				
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	1,130	17,200	16,900	1,440
1996:				
99.99% to 99.999%	857	39	462	434
99.9999%	532	8,970	9,080	422
99.99999% to 99.999999%	55	13,300	12,300	1,020
Total	1,440	22,300	21,900	1,880

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, 99.99999%-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

(Kilograms)

Country	1995		1996	
	Quantity	Value	Quantity	Value
Canada	837	\$262,000	5,900	\$1,590,000
France	11,300	3,040,000	16,300	5,360,000
Hungary	370	60,200	493	128,000
Japan	260	77,400	1,310	164,000
Netherlands	--	--	1,500	578,000
Russia	4,600	782,000	3,360	1,240,000
United Kingdom	114	21,200	25	13,500
Other	635 r/	101,000 r/	1,120	364,000
Total	18,100	4,350,000	30,000	9,440,000

r/ Revised.

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, 1996

(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	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, 1996.