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GALLIUM [ADVANCE RELEASE]

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Gallium

By Brian W. Jaskula

Domestic survey data and tables were prepared by Susan M. Weaver, statistical assistant.

Low-grade primary gallium is recovered globally as a byproduct of processing bauxite and zinc ores. No domestic low-grade primary gallium was recovered in 2016. Imports of gallium metal and gallium arsenide (GaAs) wafers plus domestically refined and recycled gallium continued to account for all U.S. gallium consumption (metal and gallium in GaAs). Metal imports were 63% lower than those in 2015 (table 4). The leading sources of imported gallium metal, in descending order, were China, Germany, France, and the United Kingdom. A significant portion of imports was thought to be low-grade gallium that was refined in the United States and shipped to other countries. Data on refined gallium exports, however, were not available. Doped GaAs wafer (a wafer with intentionally modified electrical properties) imports decreased by 53% from that of 2015—China was the leading source followed by Taiwan, Germany, and the Republic of Korea in descending order of quantity (table 5). Undoped GaAs wafer imports increased by 13% from that of 2015—Taiwan was the principal source. Almost all gallium consumed in the United States was for the production of GaAs and gallium nitride (GaN), which, along with imported wafers, were used in integrated circuits (ICs) and optoelectronic devices [laser diodes, light-emitting diodes (LEDs), photodetectors, and solar cells]. U.S. gallium consumption decreased by 39% from that in 2015 owing to a decline in gallium consumed for the production of analog ICs, laser diodes and LEDs, and photodetectors and solar cells (table 2), as well as a decrease in gallium metal and doped GaAs wafer imports.

In 2016, estimated world low-grade primary gallium production was 265 metric tons (t), a decrease of approximately 44% from estimated production of 473 t in 2015 (table 7, fig. 2). China, which accounted for 83% of global low-grade primary gallium capacity (table 6, fig. 1), was the leading producer. Germany, Japan, the Republic of Korea, Russia, and Ukraine were also significant producers. Kazakhstan, previously a significant producer of primary gallium, reported no production in 2016. The estimated worldwide compound annual growth rate (CAGR) of low-grade primary gallium production was 14% from 2006 through 2016 (fig. 2), owing primarily to China's large annual increases in production beginning in 2010. About 200 t of low-grade primary gallium was processed to high-grade refined gallium; the remaining low-grade primary gallium produced in 2016 was most likely stockpiled. High-grade primary refined gallium was produced in China, Japan, the United Kingdom, the United States, and possibly Slovakia. The worldwide CAGR of high-grade primary refined gallium production was 6% from 2006 through 2016. World high-grade secondary refined gallium production increased at a CAGR of 7%. World gallium consumption, which increased at a CAGR of 7% from 2006 through 2016, was estimated to have been 340 t in 2016 (fig. 2).

Production

No domestic production of low-grade primary gallium was reported in 2016 (table 1). Neo Performance Materials Inc. (Canada), previously Molycorp, Inc., recovered gallium from new scrap materials, predominantly those generated during the production of GaAs ingots and wafers. Neo's facility in Blanding, UT, had the capability to produce about 50 metric tons per year (t/yr) of high-grade gallium. The company purchased new scrap and low-grade primary gallium to refine into high-grade gallium. It also refined its customers' scrap into high-grade gallium. Neo's other gallium investments included an 80% interest in a gallium trichloride production facility in Quapaw, OK; a 50% interest in a primary gallium facility in Stade, Germany; a gallium recycling facility in Peterborough, Ontario, Canada; and an 80% interest in a new gallium trichloride production facility in the Hyeongok Industrial Zone in the Republic of Korea. Gallium trichloride is a precursor for many gallium compounds, including the organic gallium compounds used in epitaxial layering (Molycorp, Inc., 2015, p. 15, 47, 103).

Consumption

U.S. Consumption

Gallium consumption data were collected by the U.S. Geological Survey (USGS) from a voluntary survey of U.S. operations. In 2016, 74% of those canvassed responded to the gallium consumption survey. Data in tables 2 and 3 incorporated estimates for the nonrespondents to reflect full-industry coverage. Many of these estimates were based on company reports submitted to the U.S. Securities and Exchange Commission.

GaAs was used to manufacture ICs and optoelectronic devices. GaN principally was used to manufacture LEDs and laser diodes. ICs accounted for 69% of domestic gallium consumption, optoelectronic devices accounted for 30%, and research and development accounted for the remainder (table 2). Approximately 70% of the gallium consumed in the United States was contained in GaAs and GaN wafers. Gallium metal, trimethylgallium (TMG), and triethylgallium (TEG) used in the epitaxial layering process to fabricate epiwafers for the production of LEDs and ICs accounted for most of the remainder.

In 2016, U.S. gallium consumption was 18.1 t, a decrease of 39% from 29.7 t in 2015 owing to a decline in gallium consumed for the production of analog ICs (by 35%), laser diodes and LEDs (by 55%), and photodetectors and solar cells (by 16%), as well as a 63% decrease in gallium metal imports and a 53% decrease in doped GaAs wafer imports. U.S. gallium consumers opening new GaAs wafer production facilities in Asia to be closer to the Asian-dominated optoelectronics industry were thought to be a leading cause for the decrease in U.S. gallium consumption and gallium metal and wafer imports.

Global Consumption

Gallium Arsenide.—In 2016, GaAs technology continued to dominate the radio frequency (RF) compound semiconductor market, accounting for more than 80% of all revenue. Wireless and cellular applications, particularly sophisticated third-generation (3G) and fourth-generation (4G) smartphones, continued to drive the RF GaAs device market. The value of RF GaAs devices consumed worldwide increased by 9% to approximately $8.2 billion from $7.5 billion in 2015 (Higham, 2017; Strategy Analytics Inc., 2017).

Worldwide shipments of smartphones from device vendors in 2016 totaled more than 1.45 billion units, an increase of 0.7% from 1.44 billion units shipped in 2015. China, Europe, North America, and India were the principal regions and (or) countries of smartphone growth in 2016, with China accounting for 31% of smartphone sales, Europe accounting for 15% of sales, North America accounting for 12% of sales, and India accounting for 8% of sales. India, which has become one of the fastest growing smartphone markets in the world, was projected to overtake North America in sales by 2020 and account for 13% of the smartphone market (Scarsella and Stofega, 2016; Statista Inc., undated).

The value of worldwide GaAs wafers consumed increased by an estimated 12% in 2016, to $700 million from $624 million in 2015. Countries within the Asia-Pacific region (East Asia, Oceania, South Asia, and Southeast Asia) dominated the GaAs wafer market, with cellular, optoelectronics, and regional wireless manufacturers consuming about 60% of the GaAs wafers. The three largest GaAs wafer manufacturers in the world—WIN Semiconductors Corp. (Taiwan), Advanced Wireless Semiconductor Company (Taiwan), and Global Communication Semiconductors, LLC (Torrance, CA), in order of market share—have their wafer foundries established in Taiwan. Wireless and cellular manufacturers within North America consumed about 25% of GaAs wafers. Device manufacturers in Europe and the rest of the world consumed about 4% and 11%, respectively, of the remaining GaAs wafers (Technavio, 2016a, p. 21, 33–36).

Gallium Nitride.—Increased demand for opto semiconductors (LEDs and laser diodes) and power semiconductors (pure power devices and RF devices) provided significant growth for sales of advanced GaN-based products. In 2016, the estimated value of worldwide GaN device sales was $975 million, an increase of 12% from $871 million in 2015. GaN opto semiconductors accounted for approximately 64% of total sales, owing primarily to the widespread adoption of LEDs; GaN pure power and RF devices accounted for the remaining 36% of sales (Yole Développement, 2016a, p. 11; Grand View Research, 2017). Worldwide bulk GaN substrate production was estimated to be approximately 60,000 wafers (2-inch equivalent) for the year (Yole Développement, 2017a).

GaN RF device sales increased by an estimated 13% to approximately $340 million owing to an increase in wireless infrastructure applications, led primarily by widespread deployment of long-term evolution (LTE) base-station power amplifier networks in China. LTE is a standard for high-speed wireless communication for cellular telephones and data terminals. Defense use and wireless infrastructure were the two dominant applications for GaN RF devices. Satellite communication was also a significant application (Yole Développement, 2016a, p. 11, 15).

In 2016, GaN power device sales were valued at $14 million (Yole Développement, 2017b). GaN power devices operate at higher voltages, power densities, and switching frequencies, and offer greater power efficiency than existing GaAs and silicon devices. Increased demand from the military for enhanced battlefield performance stimulated demand for GaN power devices. The main application of GaN in the military was in discrete high electron mobility transistors (HEMT), which allow for high-frequency operations used in radar and electronic warfare systems (Transparency Market Research, 2015).

North America was a significant consumer of GaN devices in 2016, accounting for approximately 33% of GaN device sales, primarily owing to increasing investments by the aerospace and defense industries in research and development (Grand View Research, 2017). Prior to construction of the GaN devices, GaN substrates (where GaN is grown epitaxially on sapphire, silicon, or silicon carbide wafers or, to a lesser extent, on GaN wafers) were mostly produced and consumed in the Asia Pacific region. China, Japan, and the Republic of Korea accounted for more than 80% of world production. It was reported that the costs of the gallium material and fabrication were lower in China than elsewhere, and the country has attracted an increasing number of GaN substrate manufacturers (Semiconductor Today, 2015; Transparency Market Research, 2016).

Light-Emitting Diodes.—Gallium is a main component of many LEDs. Various gallium compounds, including GaAs, GaN, gallium phosphide, aluminum gallium indium phosphide, and gallium arsenide phosphide, produce variously colored light when exposed to an electric current. Worldwide LED consumption continued to increase in 2016. According to research and consulting firm Strategies Unlimited, shipments of LED lamps increased by approximately 33% from that of 2015, and the packaged LED market sales revenue was valued at about $15.5 billion (U.S. Department of Energy, 2017, p. 12, 14). LED prices in 2016, however, decreased by 25% from that of 2015. Significant LED capacity expansion began in 2011, brought about mostly by the creation of Government-subsidized LED companies in China. LED production has exceeded consumption since 2012, and prices for packaged LEDs have decreased continually since then (Wright, 2016, 2018).

The Asia-Pacific region was the leading consumer of LED material, followed by North America and Europe. The demand for LED material in the Asia-Pacific region was driven mainly by the large number of LED chip manufacturing facilities located in China, Japan, the Republic of Korea, and Taiwan. China had the largest LED industry in the world and accounted for 49% of LED chip production capacity (Chu, 2017).

In 2016, LEDs for general lighting applications remained the largest segment of the worldwide packaged LED market and, according to research and consulting firm Strategies Unlimited, accounted for 37% of LED sales. General lighting was forecast to continue to be the leading LED market segment by sales volume. LEDs for automotive and signage applications, each accounting for 14% of LED sales in 2016, were also forecast to increase substantially (U.S. Department of Energy, 2017, p. 13–14).

Packaged LEDs also accounted for the largest end use of all GaN devices. Key applications for GaN-based LEDs were computer monitors, notebook computers, tablet computers, televisions, and, increasingly, general lighting. In 2016, Technavio ranked the packaged GaN LED applications as general lighting, 46%; other lighting, 22%; televisions, 20%; digital signage, 8%; and cellular telephones, 4%. As of 2015, the Asia-Pacific region accounted for 76% of the consumption of all packaged GaN LEDs, whereas Europe consumed 14%, and North America consumed the remaining 10% (Technavio, 2016b, p. 17, 22).

As LED demand increased beginning in 2010, producers began expanding capacity for TMG, the metal-organic chemical used to fabricate the GaN epitaxial layer on LED epiwafers. When TMG and nitrogen gas are fed into the metal-organic chemical vapor deposition (MOCVD) reactor and heated, a GaN layer is formed on the epiwafer. TMG's purity and quality determine an LED's brightness and reliability. There were five major TMG producers worldwide: Akzo Nobel N.V. (Netherlands) manufactured TMG in Texas; Albemarle Corp. (Baton Rouge, LA) manufactured TMG in the Republic of Korea; the Dow Chemical Co. (Midland, MI) manufactured TMG in Massachusetts and the Republic of Korea; Jiangsu Nata Opto-electronic Material Co., Ltd. (China) manufactured TMG in Jiangsu Province, China; and SAFC Hitech (a subsidiary of Sigma Aldrich, St. Louis, MO) manufactured TMG in Taiwan and the United Kingdom (QYR Chemical and Materials Research Center, 2016, p. 22).

Solar Cells.—The solar cell market continued to be dominated by crystalline silicon solar cells, which accounted for 94% of the market (Fraunhofer Institute for Solar Energy Systems, ISE, 2018, p. 5). In 2008, industry experts had thought that copper-indium-gallium-selenide (CIGS) technology would eventually be able to compete with conventional silicon-based photovoltaic technology. CIGS technology, however, has been slow to enter the commercial market owing to a decline in prices of silicon-based solar cells, a complicated manufacturing process that has impeded commercial mass production of CIGS panels, and financial instability among many of the research-based startup CIGS companies. To keep CIGS technology competitive, CIGS manufacturers have decreased production costs, increased production capacities, improved module conversion efficiencies, and increased CIGS adoption in commercial rooftops. Several large corporations acquired select small startup companies and increased use of their production capacities. Japan's Solar Frontier K.K. was thought to be the only mass producer of CIGS solar cells. In June, scientists from Germany's Center for Solar Energy and Hydrogen Research—Baden-Württemberg (ZSW) announced they had achieved a record 22.6% efficiency for a CIGS solar cell in a laboratory setting (Semiconductor Today, 2016).

Prices

Since 2002, producer prices for gallium have not been quoted in trade journals. From U.S. Census Bureau data, the average annual value for imported low-grade (≤99.99%-pure) gallium in 2016 was estimated to be $125 per kilogram, about 34% less than that in 2015 (table 1). The estimated average annual import value for high-grade (≥99.9999%-pure) gallium increased by 118% to $690 per kilogram owing to higher than expected price per kilogram values from France, Germany, Japan, and the United Kingdom. Import data reported by the U.S. Census Bureau do not specify purity, and the estimated price distinction between gallium grades was based on the average customs value of the material and the country of origin.

According to Argus Media group – Argus Metals International, gallium prices also decreased in China during the first half of 2016. At the beginning of 2016, the low-grade gallium price in China was reported to be about $120 per kilogram, a decrease of 40% from that in January 2015. By July, the price had decreased to about $115 per kilogram. However, by December, owing to China's low-grade gallium production cuts begun earlier in the year, the price increased to about $150 per kilogram, a 30% increase from July.

Foreign Trade

In 2016, U.S. gallium metal imports were 63% less than those in 2015 (table 4), primarily owing to U.S.-based gallium consumers shifting a significant portion of their GaAs wafer production from the United States to Asia to be closer to the Asian-dominated optoelectronics industry, and also, perhaps, to import and consume less costly Asian-produced GaAs wafers. China (42%), Germany (34%), and France (16%) were the leading sources of imported gallium metal. Nonaggregated data of U.S. gallium exports were not available.

In addition to gallium metal, GaAs wafers were imported into the United States (table 5). Undoped GaAs wafer imports were 13% more than those in 2015, with Taiwan as the leading source, accounting for more than 99% of total imports. Doped GaAs wafer imports decreased by 53% from that of 2015, with China as the leading source, accounting for 55% of total imports. Taiwan (19%), Germany (9%), and the Republic of Korea (9%) were the other main sources of doped GaAs wafers. The data listed in table 5 may include some packaging material weight, and as a result, the quantities reported for 2016 may be higher than the actual total weight of imported wafers.

World Review

Imports of gallium into Japan and the United States, two leading consuming countries, and a gallium production estimate for China were initially used as the basis for estimating world gallium production. China reportedly decreased its production of low-grade primary gallium in 2016 by approximately 49% owing to a prolonged period of low prices (Asian Metal Inc., 2016; Sparks, 2016) and was estimated to account for 85% of worldwide production. Estimated worldwide low-grade primary gallium production was 265 t in 2016, a decrease of about 44% from that of 2015. Principal world producers were China, Germany, Japan, the Republic of Korea, Russia, and Ukraine. Hungary produced low-grade primary gallium in the past, but the status of current production is not clear. Germany ceased low-grade primary gallium production during the second quarter of 2016 owing to a prolonged period of low prices (Willing, 2016). Kazakhstan was believed to have ceased low-grade production in 2013. Production of high-grade primary refined gallium (sourced from current and stockpiled low-grade primary gallium) in 2016 was estimated to be 200 t, 25% less than low-grade primary production. China, Japan, Slovakia, the United Kingdom, and the United States refined high-grade gallium from low-grade primary material.

Worldwide gallium consumption was estimated to be about 340 t in 2016, an increase of 6% from that of 2015. Approximately 40% to 45% of total consumption was estimated to come from recycled material (Spicer, 2013). Therefore, about 190 t of high-grade primary refined gallium and 150 t of recycled gallium were estimated to have been consumed in 2016. Gallium was recycled from new scrap in Canada, China, Germany, Japan, Slovakia, the United Kingdom, and the United States. By 2020, Roskill Information Services Ltd. (2014) expected worldwide gallium consumption to increase to approximately 420 t.

Canada.—Orbite Technologies Inc. (formerly Orbite Aluminae Inc.) announced that commissioning and production rampup of its high-grade alumina plant in Cap-Chat, Quebec, was underway in the fourth quarter of 2016. A separation facility was to be built at the alumina plant to recover 4N (>99.9%- to ≤99.99%-pure) gallium and rare-earth elements (Orbite Aluminae Inc., 2012; Orbite Technologies Inc., 2017, p. 7).

China.—China produced 225 t of low-grade primary gallium in 2016 (Sparks, 2016) and consumed an estimated 90 t of gallium (Juncong, 2017, p. 8), approximately 26% of worldwide consumption. China's share of worldwide consumption was forecast to increase to 35% in 2020 owing to the rapid growth of the country's LED industry (Merchant Research & Consulting, Ltd., 2016). Approximately 95% of China's gallium was sourced from bauxite as a byproduct from its alumina production industry. The remaining 5% was sourced from the refining of lead and zinc ores (Juncong, 2017, p. 6).

China's low-grade primary gallium producers included Aluminum Corporation of China Ltd. (Beijing); Beijing JiYa Semiconductor Material Co., Ltd. (Beijing); East Hope Mianchi Gallium Industry Co., Ltd. (Shanghai); Shanxi Jiahua Tianhe Electronic Materials (Shanxi); Shanxi Zhaofeng Gallium Industry Co. (Shanxi); Xiaoyi Xingan Gallium Co., Ltd. (Guangxi); and Zhuhai Fangyuan Inc. (Guangdong) (Huy and Liedtke, 2016, p. 34). China's high-grade primary refined gallium producers included Beijing JiYa Semiconductor Material Co., Ltd.; 5N Plus Inc. (Shenzhen, Guangdong Province); Nanjing Jingmei Gallium (Nanjing, Jiangsu Province); and Zhuzhou Keneng New Material Co., Ltd. (Zhuzhou, Hunan Province) (Shen, 2015).

Japan.—Japan Oil, Gas and Metals National Corp. (JOGMEC) reported that Japan's gallium supply in 2016 totaled 160 t, a slight decrease from 162 t in 2015, with 54% of the gallium supply sourced from imports, 44% from recovered scrap, and 2% from low-grade primary gallium produced in Japan as a byproduct of zinc refining. Of Japan's 87 t of imported gallium, 64% came from China (Takashi Kamiki, Director, Planning Division and Stockpile Management Division, Rare Metals Stockpile Department, JOGMEC, written commun., July 5, 2017). The USGS estimated that Japan remained the leading gallium-consuming country and consumed 150 t of gallium in 2016, approximately 44% of worldwide consumption. Japan's share of worldwide consumption was forecast to decrease to 41% in 2020 owing to competition from China's LED industry (Compound Semiconductor, 2013). Production of GaN wafers was concentrated in Japan with more than 85% of the market held by three Japan-based companies: Mitsubishi Chemical Corp., Sciocs Co. Ltd., and Sumitomo Electric Industries (Yole Développement, 2017a).

Outlook

Smartphones are a fundamental structural shift in mobile communications, offering services not available on standard cellular telephones, such as internet access, video streaming, computer program applications ("apps"), and global positioning systems. Smartphones, which use up to 10 times the amount of GaAs-rich RF content than 2G cellular telephones, are expected to account for 77% of all worldwide handset sales by 2017 and 87% of all worldwide handset sales by 2021 (Scarsella and Stofega, 2017a, b). Installation of 3G and 4G mobile networks in India and the Republic of Korea is expected to further increase sales of smartphones. Additional increases in GaAs demand will also result from new Wi-Fi applications, such as point-to-point communications, smart meters, and tablet personal computer technologies. However, market research firm Strategy Analytics Inc. forecast that while RF compound semiconductor revenue will increase to more than $11 billion in 2021, GaAs devices will not be the primary reason for this revenue growth. A slowdown in the wireless segment is expected to allow for other RF compound semiconductor device technologies, including indium phosphide (InP), GaN, and silicon germanium (SiGe), to drive revenue growth (Higham and Anwar, 2017).

Yole Développement forecast that RF GaN device sales would increase by a CAGR of 14% between 2016 and 2022 owing to increased adoption of GaN technology in wireless infrastructure and defense applications, as well as implementation of new fifth-generation (5G) networks beginning around 2019. High-frequency RF applications over 3.5 gigahertz, including military radar and electronic warfare systems, commercial wireless telecommunications, and CATV applications, require the high voltage and high power capabilities of GaN devices. GaAs and silicon devices cannot operate at such high frequencies (Yole Développement, 2016b).

Owing to significant expansion of LED manufacturing capacity, Government incentives, and reduced prices, global LED sales are expected to increase by a CAGR of more than 18% between 2017 and 2021. General lighting is expected to remain the largest segment of the LED market, accounting for 77% by 2021. Sales within the Asia-Pacific region are projected to increase at a CAGR of 21% during the forecast period. The region is expected to remain the leading consumer of LED material owing to rapid construction in many Asian countries, Government incentives to encourage use of energy-efficient lighting, and the presence of the majority of the LED industry (Semiconductor Today, 2017).

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TABLE 1
SALIENT U.S. GALLIUM STATISTICS[1]

(Kilograms, unless otherwise specified)

	2012	2013	2014	2015	2016
Production, primary crude	--	--	--	--	--
Imports for consumption:					
Metal	58,200	35,400	53,900	28,600	10,500
Gallium arsenide wafers, gross weight	222,000	714,000	391,000	2,690,000	1,290,000
Consumption, reported	34,400	37,800	35,800	29,700	18,100
Price,[2] dollars per kilogram:					
Purity ≥ 99.9999%	529	502	363	317	690
Purity ≤ 99.99%	349	276	239	188	125

-- Zero.
[1]Table includes data available through April 12, 2018. Data are rounded to no more than three significant digits.
[2]Source: U.S. Census Bureau. Estimate based on average value of U.S. imports of gallium metal.

TABLE 2
U.S. CONSUMPTION OF CONTAINED GALLIUM, BY END USE[1, 2]

(Kilograms)

End use	2015	2016
Optoelectronic devices:		
Laser diodes and light-emitting diodes	11,400	5,140
Photodetectors and solar cells	391	329
Integrated circuits:		
Analog	16,000	10,400
Digital	1,720	2,110
Research and development	160	192
Total	29,700	18,100

[1]Table includes data available through April 12, 2018. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Includes gallium metal and gallium contained in compounds produced domestically.

TABLE 3
STOCKS, RECEIPTS, AND CONSUMPTION OF GALLIUM METAL, BY PURITY[1, 2]

(Kilograms)

Purity	Beginning stocks	Receipts	Consumption	Ending stocks
2015:				
97% to 99.9%	--	1	--	1
99.99% to 99.999%	2,910	-458 [3]	--	2,460
99.9999%	760	-190 [3]	32	538
99.99999% to 99.999999%	302	546	559	289
Total	3,980	-102 [3]	591	3,280
2016:				
97% to 99.9%	1	--	--	1
99.99% to 99.999%	2,460	-586 [3]	--	1,870
99.9999%	538	111	34	615
99.99999% to 99.999999%	289	457	514	232
Total	3,280	-18 [3]	548	2,720

-- Zero.
[1]Consumers only.
[2]Table includes data available through April 12, 2018. Data are rounded to no more than three significant digits; may not add to totals shown.
[3]Reshipments exceeded receipts.

TABLE 4
U.S. IMPORTS FOR CONSUMPTION OF UNWROUGHT GALLIUM AND GALLIUM POWDERS, BY COUNTRY OR LOCALITY[1]

Country or locality	2015 Quantity (kilograms)	2015 Value[2]	2016 Quantity (kilograms)	2016 Value[2]
Belgium	131	$223,000	--	--
China	9,330	1,850,000	4,410	$552,000
France	1,110	745,000	1,640	1,480,000
Germany	4,070	1,140,000	3,560	484,000
Hong Kong	24	4,080	--	--
Italy	--	--	60	24,100
Japan	180	97,900	131	70,500
Poland	--	--	1	9,000
Singapore	--	--	74	31,400
Ukraine	3,800	751,000	--	--
United Kingdom	9,980	2,310,000	676	260,000
Total	28,600	7,120,000	10,500	2,910,000

-- Zero.
[1]Table includes data available through April 12, 2018. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Customs value.

Source: U.S. Census Bureau.

TABLE 5
U.S. IMPORTS FOR CONSUMPTION OF
GALLIUM ARSENIDE WAFERS, BY COUNTRY OR LOCALITY[1]

Material and country or locality	2015 Quantity (kilograms)	2015 Value[2]	2016 Quantity (kilograms)	2016 Value[2]
Undoped:				
Austria	85	$30,700	77	$27,200
Canada	2,850	24,700	--	--
China	2,240	8,600	--	--
Germany	10	2,340	40	10,200
Japan	7,750	15,300	21	14,300
Taiwan	22,900	83,300	40,300	106,000
Other	28 r	17,800 r	8	30,100
Total	35,900	183,000	40,400	188,000
Doped:				
Austria	1,260	152,000	12	11,300
Belarus	9,010	1,810,000	9,400	1,850,000
Belgium	1,110	1,170,000	1,950	2,580,000
China	2,320,000	116,000,000	688,000	73,900,000
Denmark	241	131,000	166	86,200
Finland	6,280	4,520,000	6,620	4,820,000
France	4,860	5,270,000	4,330	3,530,000
Germany	69,000	14,600,000	116,000	16,700,000
Hong Kong	7,320	1,200,000	--	--
Israel	126	550,000	178	150,000
Italy	470	150,000	462	104,000
Japan	58,700	31,400,000	59,700	32,500,000
Korea, Republic of	6,350	1,410,000	110,000	9,040,000
Malaysia	778	132,000	1,950	321,000
Netherlands	160	34,000	39	54,400
Poland	205	268,000	526	323,000
Singapore	7,850	781,000	5,110	658,000
Taiwan	158,000	62,400,000	243,000	59,600,000
United Kingdom	1,320	2,310,000	5,860	1,930,000
Other	65 r	104,000 r	428	528,000
Total	2,660,000	245,000,000	1,250,000	209,000,000

[r]Revised. -- Zero.
[1]Table includes data available through April 12, 2018. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Customs value.

Source: U.S. Census Bureau.

TABLE 6
ESTIMATED WORLD ANNUAL LOW-GRADE
PRIMARY GALLIUM PRODUCTION CAPACITY, DECEMBER 31, 2016[1]

(Metric tons)

Country or locality	Capacity
China	600
Germany	40
Hungary	8
Japan	10
Kazakhstan	25
Korea, Republic of	16
Russia	10
Ukraine	15
Total	720

[1]Includes capacity at operating plants as well as at plants on standby basis. Data are rounded to no more than three significant digits; may not add to totals shown.

TABLE 7
GALLIUM: LOW-GRADE PRIMARY WORLD PRODUCTION, BY COUNTRY OR LOCALITY[1]

(Kilograms)

Country or locality	2012	2013	2014	2015	2016
China	300,000	300,000	450,000	444,000	225,000
Germany	30,000 e	38,000	16,000	11,000	16,000
Hungary	4,600 e	1,713	260 e	-- e	-- e
Japan	8,000	8,000	8,000	5,000	3,000
Kazakhstan	15,711	--	-- e	-- e	-- e
Korea, Republic of[e]	6,500	2,000	1,000	2,500	3,000
Russia[e]	10,000	6,000	1,000	1,000	9,000
Ukraine	11,000 e	13,000 e	13,000 e	9,400	9,000 e
Total	400,000	400,000	490,000	473,000	265,000

[e]Estimated. -- Zero.
[1]Includes data available through April 3, 2018. All data are reported unless otherwise noted. Totals and estimated data are rounded to no more than three significant digits; may not add to totals shown.

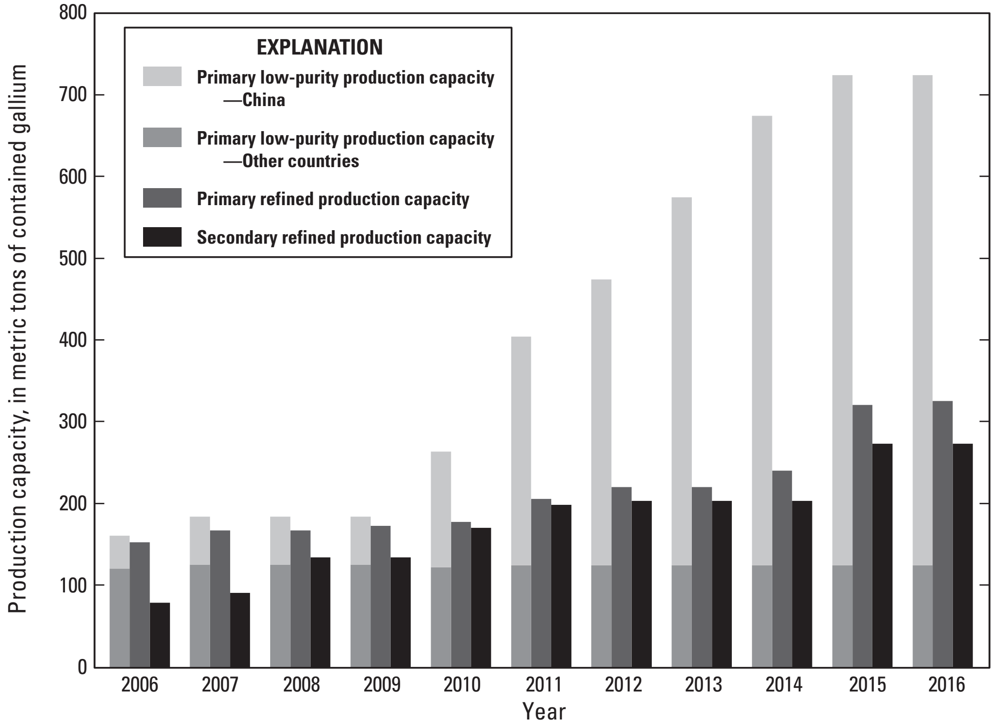

Figure 1. Estimated worldwide gallium production capacity from 2006 through 2016. Source: U.S. Geological Survey.

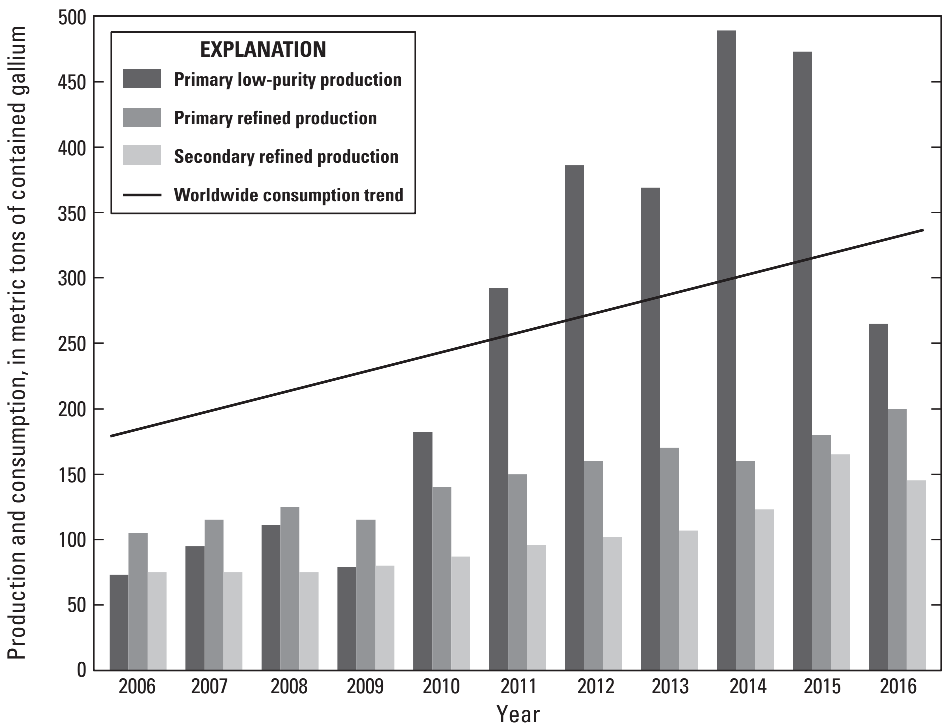

Figure 2. Estimated worldwide gallium production and consumption from 2006 through 2016. Source: U.S. Geological Survey.