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2018 Minerals Yearbook

GALLIUM [ADVANCE RELEASE]

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Gallium

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Low-purity primary gallium was recovered globally as a byproduct of processing bauxite and zinc ores. No domestic low-purity primary gallium was recovered in 2018. 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). The quantity of gallium metal imports was 58% higher, and the value was 45% higher than the revised amounts in 2017 (tables 1, 4). The leading sources of imported gallium metal and powders were, in descending order, China (including Hong Kong), Ukraine, the Republic of Korea, Germany, and Japan (table 4). A significant portion of imports was thought to be low-purity 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 45% from those of 2017. China was the leading source, followed by Taiwan, Japan, Germany, France, and the Republic of Korea in descending order of quantity (table 5). The U.S. Census Bureau ceased reporting undoped GaAs wafer imports in 2017. 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]. In 2018, U.S. gallium consumption decreased by 11% for production of analog and digital ICs and by 34% for production of laser diodes and LEDs. U.S. gallium consumed for production of photodetectors and solar cells increased by 31% in 2018 (table 2). Refined gallium metal consumption increased by 14% (table 3). These consumption figures, as well as the 58% increase in gallium metal imports and 45% decrease in doped GaAs wafer imports, suggest that a significant percentage of imported gallium metal was stockpiled rather than consumed in 2018 owing to anticipated higher tariffs on imports from China. The consumption figures also suggest that U.S. gallium consumers are relying more on metal imports to make GaAs substrates and epiwafers and less on GaAs wafer imports, as well as a continued migration of laser diode and LED production to the Asia and the Pacific region. About 98% of the gallium metal consumed in 2018 was at a purity level of 99.99999% to 99.999999% (table 3).

In 2018, estimated world low-purity primary gallium (99% to 99.99%) production was 413 metric tons (t), an increase of approximately 30% from estimated production of 317 t in 2017 (table 6). China, which accounted for 83% of global low-purity primary gallium capacity (fig. 1, table 7), produced 96% of the global low-purity primary gallium. Japan, the Republic of Korea, Russia, and Ukraine accounted for the remaining production. The estimated worldwide compound annual growth rate (CAGR) of low-purity primary gallium production was 14% from 2008 through 2018 (fig. 2), primarily owing to China's large annual increases in production beginning in 2010. About 205 t of low-purity primary gallium was processed to high-purity refined gallium (99.999% to 99.999999%); the remaining low-purity primary gallium produced in 2018 was most likely stockpiled. High-purity primary refined gallium was produced in China, Japan, the United States, and possibly Slovakia. The United Kingdom ceased production of high-purity primary refined gallium in 2018. The worldwide CAGR of high-purity primary refined gallium production was 5% from 2008 through 2018. World high-purity secondary refined gallium production increased at a CAGR of 8%. World gallium consumption, which increased at a CAGR of 6% from 2008 through 2018, was estimated to have been 370 t in 2018.

Production

No domestic production of low-purity primary gallium was reported in 2018. Neo Performance Materials Inc. (Canada) 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 capacity to produce about 50 metric tons per year (t/yr) of high-purity gallium. The company purchased new scrap and low-purity primary gallium to refine into high-purity gallium. It also refined its customers' scrap into high-purity gallium. Neo's other gallium facilities included a gallium trichloride production facility in Quapaw, OK (80% ownership); a gallium recycling facility in Peterborough, Ontario, Canada; and a gallium trichloride production facility in the Hyeongok Industrial Zone in the Republic of Korea (80% ownership). Gallium trichloride is a precursor for many gallium compounds, including the organic gallium compounds used in epitaxial layering (Neo Performance Materials Inc., 2019, p. 5, 8, 19, 20).

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 2018, of a total of 22 operations canvassed, 73% 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, gallium arsenide phosphide (GaAsP), and gallium phosphide (GaP) were used to manufacture ICs and optoelectronic devices. GaN principally was used to manufacture LEDs and laser diodes. ICs accounted for 73% of domestic gallium consumption, optoelectronic devices

accounted for 25%, and research and development accounted for the remainder (table 2). Approximately 80% of the gallium consumed in the United States was contained in GaAs, GaN, and GaP wafers. Gallium metal, trimethylgallium, and triethylgallium used in the epitaxial layering process to fabricate epiwafers for production of LEDs and ICs accounted for most of the remainder.

In 2018, U.S. gallium consumption was 15 t, a 16% decrease from 17.9 t in 2017 owing to a decline in gallium consumed for the production of analog and digital ICs, and laser diodes and LEDs, as well as a 45% decrease in doped GaAs wafer imports (tables 2, 5). Refined gallium metal consumption increased by 14% from that of 2017 (table 3). About 98% of the gallium metal consumed was at a purity level of 99.99999% to 99.999999%. 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 wafer imports.

Global Consumption

Gallium Arsenide.—Yole Développement (2018, p. 21, 267, 296) reported that global GaAs substrate consumption, by wafer volume, was approximately 2.06 million 6-inch equivalent units in 2018, an increase of 20% from 1.72 million units in 2017, owing mostly to a 34% increase in consumption by optoelectronics (that is, laser diode and LED) manufacturers. Consumption of GaAs substrates by radio frequency (RF) cellular, power, and wireless manufacturers also increased; however, its rate of increase slowed to 4% in 2018 to 715,300 6-inch equivalent units, from 683,690 units in 2017, owing to a gradual saturation of the smartphone market and the reduction in component size. Global GaAs epiwafer consumption, by wafer volume, was approximately 783,000 6-inch equivalent units in 2018, an increase of 10% from 714,000 units in 2017.

Wireless applications continued to drive the RF GaAs device market in 2018. The value of RF GaAs devices consumed worldwide was approximately $8.9 billion, a slight increase from $8.8 billion in 2017 (Strategy Analytics Inc., 2018, 2019).

Owing to market saturation, higher average selling prices, and longer upgrade cycles, worldwide shipments of smartphones from device vendors in 2018 decreased by 5% to 1.40 billion units from the revised 1.47 billion units shipped in 2017 (Scarsella and Stofega, 2018, 2019). China, Europe, North America, and India, in descending order, were the principal regions and (or) countries of smartphone growth in 2018, with China accounting for 28% of smartphone sales, Europe accounting for 14% of sales, North America accounting for 11% of sales, and India accounting for 10% 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 (Statista Inc., undated).

Gallium Nitride.—Increased demand for GaN pure power devices and RF devices provided significant growth for advanced GaN-based products. In 2018, the value of GaN power devices consumed worldwide was approximately $803 million, an increase of 32% from $609 million in 2017. The value of GaN RF devices consumed worldwide was approximately $452 million, an increase of 34% from $338 million in 2017 (Gaurav, 2019, p. 40, 45).

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 and the 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).

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. In 2018, defense and aerospace applications accounted for 31% of sales; information and communication applications, 27%; industrial and medical applications, 15%; consumer electronics applications, 12%; automotive applications, 10%; and other uses, 5% (Gaurav, 2019, p. 41).

RF GaN technology was originally developed for military use, and the technology is now used in cable television, communications base station transceivers, radar, and very-small-aperture-terminal (VSAT) satellite terminals among other end uses. In 2018, defense and aerospace applications accounted for 32% of sales; information and communication applications, 27%; industrial and medical applications, 16%; consumer electronics applications, 12%; automotive applications, 10%; and other uses, 3% (Gaurav, 2019, p. 46).

Laser Diodes and Light-Emitting Diodes.—Gallium is a main component of many laser diodes and LEDs. Various gallium compounds, including aluminum gallium indium phosphide, GaAs, GaAsP, GaN, and GaP, produce variously colored light when exposed to an electric current.

Yole Développement reported that laser diode applications are now driving growth in the GaAs wafer and epiwafer market more so than established GaAs RF applications owing primarily to Apple Inc.'s introduction of the iPhone X smartphone with three-dimensional (3D) sensing function in 2017. Using three GaAs-based vertical-cavity surface-emitting lasers (VCSELs) simultaneously, the iPhone X recognizes the smartphone owner's face and unlocks the phone. Global GaAs substrate consumption for laser diode applications was approximately 247,000 6-inch equivalent units in 2018, an increase of 41% from 175,000 units in 2017. Global GaAs epiwafer consumption for laser diode applications was approximately 67,500 6-inch equivalent units in 2018, an increase of 120% from 30,700 units in 2017. The introduction of the 3D sensing function using GaAs VCSELs has attracted much interest, and Yole expected multiple Android smartphone manufacturers and autonomous vehicle manufacturers to adopt this technology, further driving the GaAs wafer and epiwafer market (Yole Développement, 2018, p. 21, 169, 267, 296).

Worldwide LED consumption continued to increase in 2018 but at a lower rate than expected owing to the trade dispute between the United States and China and to LED oversupply.

According to TrendForce Corp., packaged LED market sales revenue was valued at $18.4 billion in 2018, an increase of 3.1% from the revised figure of $17.85 billion in 2017 (Chu, 2019). LED prices in 2018, however, decreased by 20% to 30% from those of 2017, which were already about 35% lower than those of 2015. Significant LED capacity expansion began in 2011, mostly brought about by the creation of Government-subsidized LED companies in China. The LED market has been in surplus since 2012, and prices for packaged LEDs have decreased continually since then (Wright, 2016, 2018; Semiconductor Today, 2018).

The Asia and the Pacific region was the leading consumer of LED material, followed by North America and Europe. The demand for LED material in the Asia and the Pacific region was driven mainly by the large number of LED chip manufacturing facilities in China, Japan, the Republic of Korea, and Taiwan. China had the largest LED industry in the world and accounted for about 54% of LED chip production capacity in 2017 (Chu, 2017).

LEDs also accounted for the leading end use of all GaN substrates (Transparency Market Research, 2019). Key applications for GaN-based LEDs were notebook computers, smartphones, tablet computers, televisions, and, increasingly, general lighting (Technavio, 2016, p. 17, 26).

As LED demand increased beginning in 2010, producers began expanding capacity for trimethylgallium (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 in 2018. 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 Inc. (a subsidiary of Sigma Aldrich Corp., St. Louis, MO) manufactured TMG in Taiwan and the United Kingdom (QYR Chemical and Materials Research Center, 2016, p. 22).

Prices

Since 2002, producer prices for gallium have not been quoted in trade journals. From U.S. Census Bureau data, the average unit value for imported low-purity gallium in 2018 was estimated to be $185 per kilogram, an increase of 49% from that in 2017 (table 1). The estimated average unit value for imported high-purity (≥99.999%-pure) gallium increased by 6% to $508 per kilogram. Import data reported by the U.S. Census Bureau do not specify purity, and the estimated price distinction between gallium purities was based on the average customs value of the material and the country of origin.

According to Asian Metal Ltd. (2018a, b, 2019a), the low-purity gallium price in China was about $160 per kilogram in January 2018. By June the price had increased to about $200 per kilogram. By December, the price had decreased to $150 per kilogram.

Foreign Trade

In 2018, United States gallium metal imports were 58% more than those in 2017 (table 1) owing to a 300% increase of imports from China (table 4) in anticipation of higher tariffs on imports from China in 2019. The additional gallium metal was most likely stockpiled. China, including Hong Kong (77%); Ukraine (8%); Germany (4%); the Republic of Korea (4%); and Japan (3%) were the leading sources of imported gallium metal. U.S. gallium export data were not available.

In addition to gallium metal, GaAs wafers were imported into the United States (table 5). Doped GaAs wafer imports decreased by 45% from those of 2017, with China as the leading source, accounting for 59% of imports. Taiwan (15%), Japan (8%), Germany (7%), and France (5%) 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 2018 may be higher than the actual total weight of imported wafers.

World Review

Reported gallium production figures for China and Japan, and imports of gallium into Japan and the United States, two leading consuming countries, were initially used as the basis for estimating world gallium production. China increased its production of low-purity primary gallium in 2018 by approximately 32% (Asian Metal Ltd., 2019b) and was estimated to account for 96% of worldwide low-purity primary gallium production. Estimated worldwide low-purity primary gallium production was 413 t in 2018 (table 6), an increase of about 30% from that of 2017. Principal world producers were China, Japan, the Republic of Korea, Russia, and Ukraine. Gallium also may have been recovered in Hungary. Production of high-purity primary refined gallium (sourced from current and stockpiled low-purity primary gallium) in 2018 was estimated to be 205 t, 50% less than low-purity primary production. China, Japan, the United States, and possibly Slovakia refined high-purity gallium from low-purity primary material. The United Kingdom ceased production of high-purity refined gallium in 2018 (5N Plus Inc., 2019, p. 7).

Worldwide gallium consumption was estimated to be about 370 t in 2018, an increase of 4% from that of 2017. Approximately 40% to 45% of total consumption was from recycled material (Spicer, 2013). Therefore, about 205 t of high-purity primary refined gallium and 165 t of recycled gallium were estimated to have been consumed in 2018. Gallium was recycled from new scrap in Canada, China, Germany, Japan, Slovakia, and the United States. The United Kingdom ceased recycling of gallium in 2018 (5N Plus Inc., 2019, p. 7). Roskill Information Services Ltd. (2014) expected that, by 2020, worldwide gallium consumption would increase to approximately 420 t.

China.—China produced a reported 397 t of low-purity primary gallium in 2018 (Asian Metal Ltd., 2019b) and consumed an estimated 115 t of gallium, approximately 31% 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 (Business Wire, Inc., 2016). Approximately 95% of China's gallium was sourced as a byproduct from bauxite during alumina production. The remaining 5% was sourced from the refining of lead and zinc ores (Juncong, 2017, p. 6).

China's major low-purity primary gallium producers included Aluminum Corp. of China Ltd. (Beijing); Beijing JiYa Semiconductor Material Co., Ltd. (Beijing Municipality); East Hope Mianchi Gallium Industry Co., Ltd. (Shanghai); Shanxi Jiahua Tianhe Electronic Materials (Shanxi Province); Shanxi Zhaofeng Gallium Industry Co. (Shanxi Province); Xiaoyi Xingan Gallium Co., Ltd. (Guangxi Province); and Zhuhai Fangyuan Inc. (Guangdong Province) (Huy and Liedtke, 2016, p. 34). China's high-purity primary refined gallium producers included Beijing JiYa Semiconductor Material Co., Ltd. (Beijing Municipality); 5N Plus Inc. (Shenzhen, Guangdong Province); Nanjing Jingmei Gallium Co., Ltd. (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 2018 totaled 174 t, a 6% increase from 165 t in 2017, with 57% of the gallium supply sourced from imports, 41% from recovered scrap, and 2% from low-purity primary gallium produced in Japan as a byproduct of zinc refining. Of Japan's 99.4 t of imported gallium, 75% came from China; Japan remained the leading gallium-consuming country and consumed 156 t of gallium in 2018, approximately 42% of worldwide consumption (Takashi Kamiki, Director, Planning Division and Stockpile Management Division, Rare Metals Stockpile Department, JOGMEC, written commun., November 1, 2019). Production of GaN wafers was concentrated in Japan with more than 85% of sales held by three Japan-based companies: Mitsubishi Chemical Corp., Sciocs Co. Ltd., and Sumitomo Electric Industries, Ltd., (Yole Développement, 2017).

Outlook

Gallium consumption is expected to increase as the use of GaN technology in defense applications and wireless infrastructure increases, as well as the implementation of new fifth generation (5G) networks globally. High-frequency RF applications over 3.5 gigahertz, including cable television applications, commercial wireless telecommunications, and military electronic warfare systems and radar, require the high voltage and high-power capabilities of GaN devices. GaAs and silicon devices cannot operate at such high frequencies. The consumption of GaAs wafers for laser diode applications is expected to increase, driven by devices with 3D sensing function.

Owing to significant expansion of LED manufacturing capacity, reduced prices, and government incentives, global LED sales are expected to increase by a CAGR of more than 16% between 2018 and 2022. General lighting is expected to remain the largest segment of the LED market, accounting for 77% by 2021, and the Asia and the Pacific region is expected to account for 52% of the market by 2022. The region is expected to remain the leading consumer of LED material owing to rapid development 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; Technavio, 2018).

Annual production of TMG was forecast to be 60 t on average from 2018 to 2020 and to increase to 64 t by 2022 (QYR Chemical and Materials Research Center, 2016, p. 91, 95).

References Cited

5N Plus Inc., 2019, Annual information form for the fiscal year ended December 31, 2018: Saint-Laurent, Montreal, Canada, 5N Plus Inc., February 26, 27 p. (Accessed May 6, 2019, at https://www.5nplus.com/files/15/Final%20AIF-Dec%202018_2019-02-26-19-36.pdf.)

Asian Metal Ltd., 2018a, Monthly gallium market report Jan 2018: Beijing, China, Asian Metal Ltd., February 5. (Accessed January 20, 2019, via http://www.asianmetal.com.)

Asian Metal Ltd., 2018b, Monthly gallium market report Jun 2018: Beijing, China, Asian Metal Ltd., July 10. (Accessed January 20, 2019, via http://www.asianmetal.com.)

Asian Metal Ltd., 2019a, Monthly gallium market report Dec 2018: Beijing, China, Asian Metal Ltd., January 10. (Accessed January 20, 2019, via http://www.asianmetal.com.)

Asian Metal Ltd., 2019b, Monthly gallium market report Jan 2019: Beijing, China, Asian Metal Ltd., February 14. (Accessed May 18, 2019, via http://www.asianmetal.com.)

Business Wire, Inc., 2016, Gallium demand to rise rapidly through 2020, states Merchant Research & Consulting in its report available at MarketPublishers.com: London, United Kingdom, Business Wire, Inc. press release, October 24. (Accessed October 25, 2016, at http://www.businesswire.com/news/home/20161024005618/en/Gallium-Demand-Rise-Rapidly-2020-States-Merchant.)

Chu, Roger, 2017, Chinese LED chip suppliers to represent 54% of global production capacity in 2017, says TrendForce: Taipei, Taiwan, TrendForce Corp. press release, October 24. (Accessed January 8, 2018, at https://press.trendforce.com/node/view/3002.html.)

Chu, Roger, 2019, China manufacturers raise capacity, causing general stagnation in revenue growth for top 10 LED packaging suppliers, says TrendForce: Taipei, Taiwan, TrendForce Corp. press release, April 23. (Accessed December 2, 2019, at https://press.trendforce.com/press/20190423-3234.html.)

Gaurav, S.G., 2019, Semiconductor devices for high temperature applications—Market opportunities: Wellesley, MA, BCC Research, LLC, May, 228 p.

Huy, Dieter, and Liedtke, Maren, 2016, Supply and demand of lithium and gallium: Hannover, Germany, Bundesanstalt für Geowissenschaften und Rohstoffe, May 1, 50 p. (Accessed October 12, 2016, at https://www.bgr.bund.de/EN/Themen/Min_rohstoffe/Downloads/studie_Li_Ga.pdf?__blob=publicationFile&v=4.)

Juncong, Feng, 2017, China's minor metals market and the supply and demand of gallium, selenium, and tellurium: Beijing, China, China Nonferrous Metals Industry Association, Gallium, Selenium, and Tellurium Branch presentation, April 26, 24 p.

Neo Performance Materials Inc., 2019, Annual information form for the year ended December 31, 2018: Toronto, Ontario, Canada, Neo Performance Materials Inc., March 10, 61 p. (Accessed May 26, 2019, at https://www.neomaterials.com/wp-content/uploads/2019/03/Neo_AIF_2018_AIF_FINAL.pdf.)

QYR Chemical and Materials Research Center, 2016, Global trimethylgallium (TMG) industry 2016 market research report: Beijing, China, QYR Chemical and Materials Research Center, November, 102 p.

Roskill Information Services Ltd., 2014, Roskill—Gallium market to benefit as GaN-based LED lighting comes of age: PRNewswire news release, May 12. (Accessed May 13, 2014, at http://www.prnewswire.com/news-releases/roskill-gallium-market-to-benefit-as-gan-based-led-lighting-comes-of-age-258928021.html.)

Scarsella, Anthony, and Stofega, William, 2018, Worldwide smartphone forecast update, 2018–2022—December 2018 [abs.]: Framingham, MA, IDC Research, Inc., December. (Accessed August 21, 2019, at https://www.idc.com/getdoc.jsp?containerId=US44522418.)

Scarsella, Anthony, and Stofega, William, 2019, Worldwide smartphone forecast update, 2019–2023 [abs.]: Framingham, MA, IDC Research, Inc., June. (Accessed August 21, 2019, at https://www.idc.com/getdoc.jsp?containerId=US45235019.)

Semiconductor Today, 2015, Demand for larger diameters to boost GaN substrate market from $2.2bn in 2014 to $4bn by 2020: Semiconductor Today, September 3. (Accessed January 20, 2016, at http://www.semiconductor-today.com/news_items/2015/sep/industryarc_030915.shtml.)
Semiconductor Today, 2017, LED market growing at 18% CAGR, boosted by demand for energy-efficient lighting: Semiconductor Today, September 8. (Accessed September 13, 2017, at http://www.semiconductor-today.com/news_items/2017/sep/technavio_080917.shtml.)
Semiconductor Today, 2018, LED market growth in 2018 revised from 11% to 4%: Semiconductor Today, September 25. (Accessed October 29, 2018, at http://www.semiconductor-today.com/news_items/2018/sep/ledinside_250918.shtml.)
Shen, Daisy, 2015, Chinese 6N gallium market flat, business slow: Metal-Pages, July 8. (Accessed September 17, 2015, via http://www.metal-pages.com/.)
Spicer, Andi, 2013, ESM13—Most specialty and minor metals lost in the copper recycling process–PPM: Metal-Pages, September 11. (Accessed September 11, 2013, via http://www.metal-pages.com/.)
Statista Inc., [undated], Market share of global smartphone shipments by region/country from 2015 to 2020: New York, NY, Statista Inc. (Accessed February 1, 2018, via https://www.statista.com/statistics/283325/market-share-smartphone-shipments/.)
Strategy Analytics Inc., 2018, RF GaAs device revenue reaches record levels in 2017: Boston, MA, Strategy Analytics Inc., April 2. (Accessed June 15, 2018, via https://www.strategyanalytics.com/access-services/components/advanced-semiconductors/reports/report-detail/rf-gaas-device-revenue-reaches-record-levels-in-2017.)
Strategy Analytics Inc., 2019, 2018 GaAs revenue snapshot: Boston, MA, Strategy Analytics Inc., March 11. (Accessed May 22, 2019, via https://www.strategyanalytics.com/access-services/components/advanced-semiconductors/reports/report-detail/2018-gaas-revenue-snapshot.)
Technavio, 2016, Global packaged GaN LED market, 2016–2020: Elmhurst, IL, Technavio, February, 42 p.
Technavio, 2018, Global LED market 2018–2022 to post a CAGR of 16%: Elmhurst, IL, Technavio press release, June 25. (Accessed December 5, 2018, at https://www.businesswire.com/news/home/20180625006042/en/Global-LED-Market-2018-2022-Post-CAGR-16.)
Transparency Market Research, 2016, GaN semiconductor devices market—Global industry analysis, size, share, growth, trends, and forecast 2016–2024: Albany, NY, Transparency Market Research press release, August 29. (Accessed October 20, 2016, at http://www.transparencymarketresearch.com/gallium-nitride.html.)
Transparency Market Research, 2019, GaN substrate market—Global industry analysis, size, share, growth, trends, and forecast 2019–2027: Albany, NY, Transparency Market Research press release, November 5. (Accessed December 21, 2019, at https://www.transparencymarketresearch.com/gan-substrate-market.html.)
Wright, Maury, 2016, Strategies Unlimited reports packaged LED revenue has been stymied by oversupply: LEDs Magazine, March 3. (Accessed June 21, 2016, at http://www.ledsmagazine.com/articles/2016/03/strategies-unlimited-reports-packaged-led-revenue-has-been-stymied-by-oversupply.html.)
Wright, Maury, 2018, Strategies in Light investor forum previews LED and SSL market data: LEDs Magazine, February 13. (Accessed February 14, 2018, at http://www.ledsmagazine.com/articles/2018/02/strategies-in-light-investor-forum-previews-led-and-ssl-market-data.html.)
Yole Développement, 2017, Bulk GaN—From technology to market: Lyon, France, Yole Développement press release, February 21. (Accessed March 23, 2017, at http://www.yole.fr/BulkGaN_Applications_Players.aspx.)
Yole Développement, 2018, GaAs wafer and epiwafer market, version 2018—RF, photonics, LED and PV: Lyon, France, Yole Développement, July, 316 p.

GENERAL SOURCES OF INFORMATION

U.S. Geological Survey Publications

Gallium. Ch. in Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply, Professional Paper 1802, 2017.
Gallium. Ch. in Mineral Commodity Summaries, annual.
Gallium (Ga). Ch. in Metal Prices in the United States Through 2010, Scientific Investigations Report 2012–5188, 2013.
Historical Statistics for Mineral and Material Commodities in the United States. Data Series 140.

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.
Gallium—Global Industry Markets & Outlook (8th ed.). Roskill Information Services Ltd., 2011.
Minor Metals in the CIS. Roskill Information Services Ltd., 1997.

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

(Kilograms, unless otherwise specified)

	2014	2015	2016	2017	2018
Production, primary crude	--	--	--	--	--
Imports for consumption:					
Metal	53,900	28,600	10,500	20,200 [r]	32,000
Gallium arsenide wafers (gross weight)[2]	391,000	2,690,000	1,290,000	804,000	446,000
Consumption, reported	35,800	29,700	18,100	17,900	15,000
Average value,[3] dollars per kilogram:					
Purity ≥99.9999%	363	317	690	477	508
Purity ≤99.99%	239	188	125	124	185

[r]Revised. -- Zero.
[1]Table includes data available through May 21, 2020. Data are rounded to no more than three significant digits.
[2]Data include imports of undoped and doped wafers from 2014 through 2016, but only doped wafers in 2017 and 2018.
[3]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	2017	2018
Optoelectronic devices:		
Laser diodes and light-emitting diodes	4,990	3,300
Photodetectors and solar cells	301	395
Integrated circuits:		
Analog	10,300	9,060
Digital	1,940	1,830
Research and development	370	425
Total	17,900	15,000

[1]Table includes data available through May 21, 2020. 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
2017:				
97% to 99.9%	1	1	2	--
99.99% to 99.999%	1,870	--	--	1,870
99.9999%	615	--	11	604
99.99999% to 99.999999%	232	631	493	370
Total	2,720	632	506	2,840
2018:				
97% to 99.9%	--	--	--	--
99.99% to 99.999%	1,870	--	--	1,870
99.9999%	604	2	11	595
99.99999% to 99.999999%	370	649	564	455
Total	2,840	651	575	2,920

-- Zero.
[1]Table includes data available through May 21, 2020. Data are rounded to no more than three significant digits; may not add to totals shown.
[2]Consumers only.

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

Country or locality	2017		2018	
	Quantity (kilograms)	Value[2]	Quantity (kilograms)	Value[2]
China	4,860	$686,000 r	19,300	$3,430,000
Denmark	28	12,000	--	--
Estonia	--	--	140	30,800
France	1,980	1,610,000	417	334,000
Germany	--	--	1,240	306,000
Hong Kong	2,000	270,000	5,400	1,250,000
Japan	540	263,000	1,070	390,000
Korea, Republic of	1,140 r	135,000 r	1,280	176,000
Russia	1,360	186,000	507	112,000
Singapore	525	223,000	--	--
South Africa	23	22,100	23	23,000
Ukraine	1,600	197,000	2,560	315,000
United Kingdom	6,180	809,000	50	10,600
Total	20,200 r	4,410,000 r	32,000	6,380,000

rRevised. -- Zero.
[1]Table includes data available through May 21, 2020. 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 DOPED GALLIUM ARSENIDE WAFERS, BY COUNTRY OR LOCALITY[1]

Country or locality	2017		2018	
	Quantity (kilograms)	Value[2]	Quantity (kilograms)	Value[2]
Australia	41	$26,700	--	--
Austria	7	5,140	12	$5,690
Belarus	8,840	1,980,000	1,030	238,000
Belgium	618	3,400,000	3,590	1,720,000
Canada	1	2,800	--	--
China	403,000	43,400,000	265,000	32,700,000
Denmark	--	--	389	286,000
Finland	3,790	3,190,000	5,410	5,440,000
France	36,100	31,600,000	22,900	28,200,000
Germany	55,000	18,500,000	32,700	23,600,000
Israel	9	40,000	12	62,800
Italy	1,420	686,000	474	152,000
Japan	67,000	26,800,000	35,400	29,700,000
Korea, Republic of	21,800	2,560,000	8,630	4,030,000
Malaysia	1,050	318,000	561	184,000
Netherlands	3	32,200	2	19,600
Poland	226	238,000	347	278,000
Singapore	1,140	301,000	756	408,000
Taiwan	202,000	67,600,000	65,200	84,000,000
United Kingdom	513	1,700,000	1,400	2,530,000
Other	821 r	450,000 r	1,580	972,000
Total	804,000	203,000,000	446,000	214,000,000

rRevised. -- Zero.
[1]Table includes data available through May 21, 2020. 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
GALLIUM: LOW-PURITY PRIMARY WORLD PRODUCTION, BY COUNTRY OR LOCALITY[1]

(Kilograms)

Country or locality	2014	2015	2016	2017	2018
China	450,000	444,000	225,000	300,000	397,000
Germany	16,000	11,000	16,000	--	--
Hungary[e]	260	--	--	--	--
Japan	8,000	5,000	3,000	3,000	3,000
Korea, Republic of[e]	1,000	2,500	3,000	3,000	3,000
Russia[e]	1,000	1,000	9,000	7,000	6,000
Ukraine	13,000 [e]	9,400	9,000 [e]	4,000 [e]	4,000 [e]
Total	489,000	473,000	265,000	317,000 [r, e]	413,000 [e]

[e]Estimated. [r]Revised. -- Zero.
[1]Table includes data available through July 22, 2019. 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.

TABLE 7
ESTIMATED WORLD ANNUAL LOW-PURITY PRIMARY GALLIUM PRODUCTION CAPACITY, DECEMBER 31, 2018[1, 2]

(Metric tons)

Country or locality	Capacity
China	600,000
Germany	40,000
Hungary	8,000
Japan	10,000
Kazakhstan	25,000
Korea, Republic of	16,000
Russia	10,000
Ukraine	15,000
Total	724,000

[1]Table includes data available through May 21, 2020. Data are rounded to no more than three significant digits.
[2]Includes capacity at operating plants as well as at plants on standby basis.

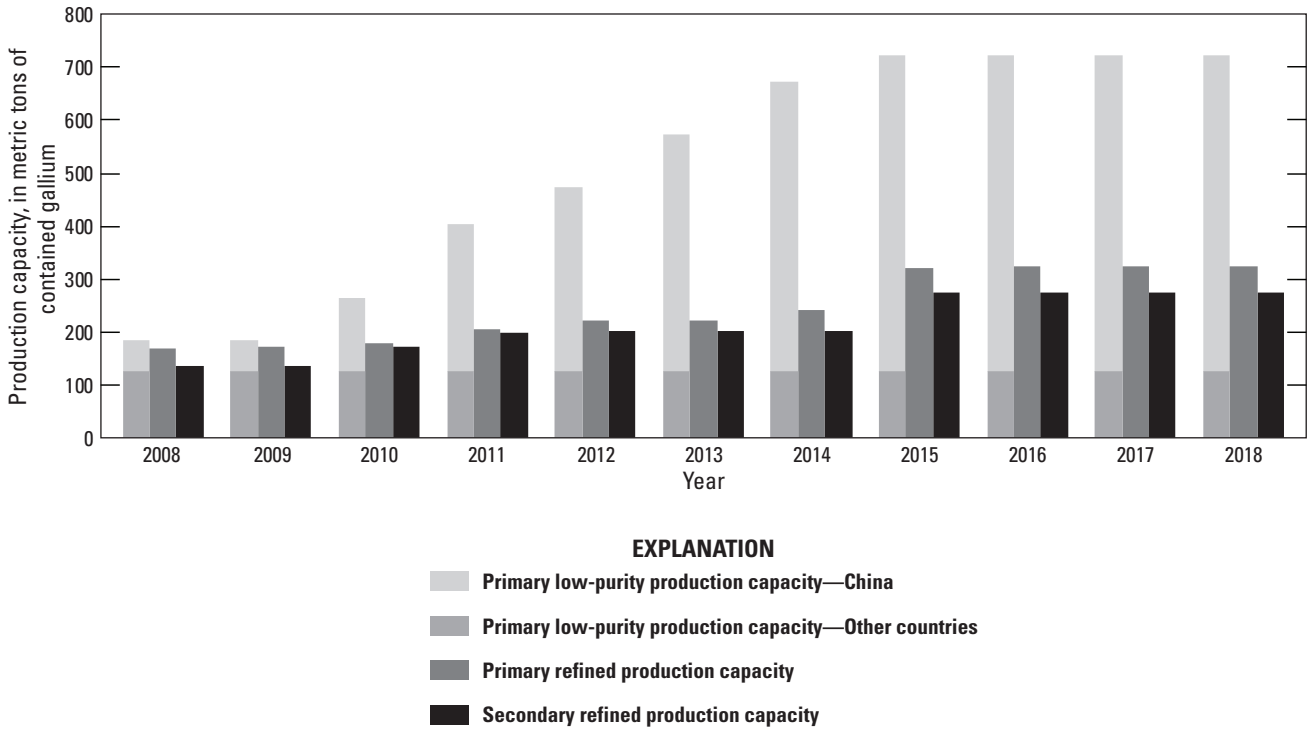

Figure 1. Estimated worldwide gallium production capacity from 2008 through 2018.

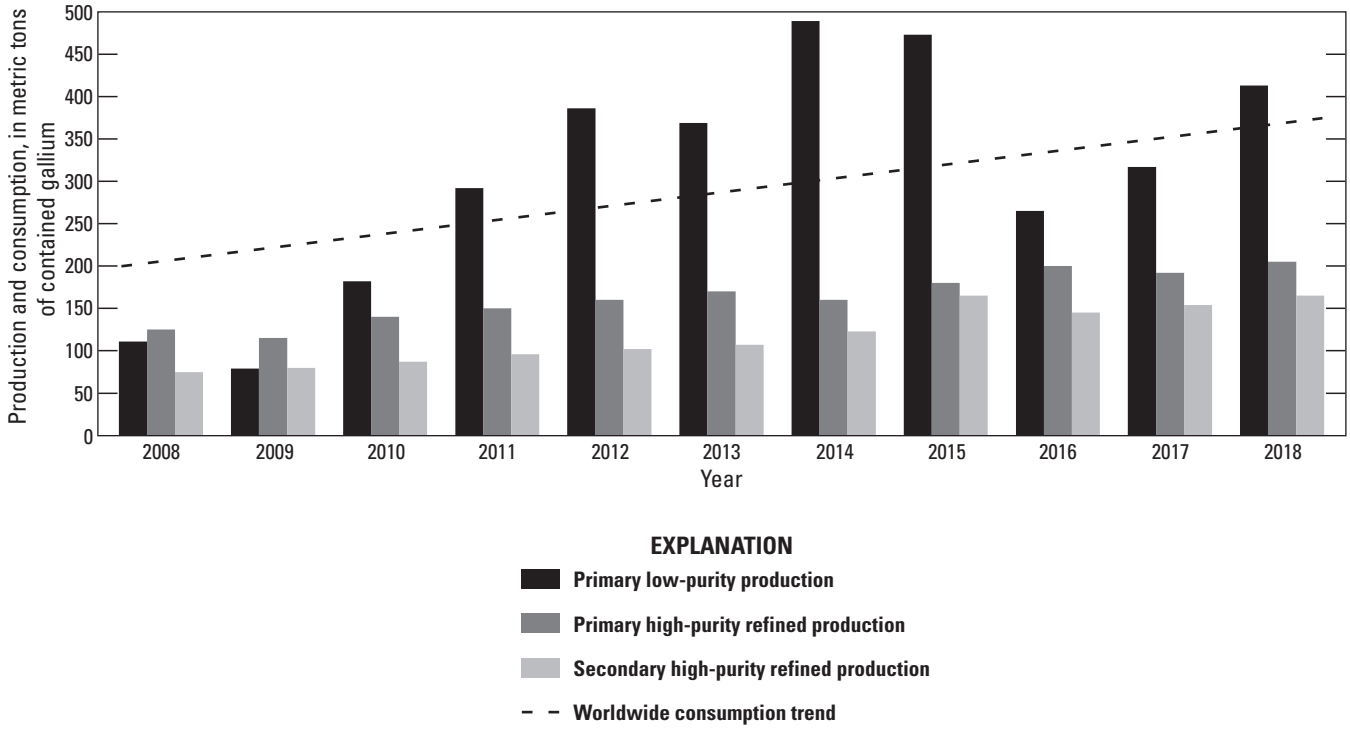

Figure 2. Estimated worldwide gallium production and consumption from 2008 through 2018.