



# 2011 Minerals Yearbook

---

## GALLIUM

---

# GALLIUM

By Brian W. Jaskula

**Domestic survey data and tables were prepared by Maria Arguelles, statistical assistant.**

In 2011, no domestic production of primary gallium was reported, and imports of gallium metal and gallium arsenide (GaAs) wafer continued to account for most of the U.S. gallium consumption. Metal imports were 45% higher than those in 2010, with Germany, the United Kingdom, China, and Singapore, in descending order of imports by gallium content, as the leading sources of imported gallium. Undoped GaAs wafer imports were 37% higher than those in 2010—Germany, Japan, and Taiwan were the principal sources. Doped GaAs wafer imports were 29% higher than those in 2010—Germany and Japan were the principal sources. Almost all gallium consumed in the United States was in the form of GaAs and gallium nitride (GaN) and was used in integrated circuits (ICs) and optoelectronic devices [laser diodes, light-emitting diodes (LEDs), photodetectors, and solar cells]. Gallium consumption increased by 5% from that in 2010. In 2011, gallium consumed in the United States was less than the gallium imported because a large portion of the U.S. imports was estimated to be low-purity material that was refined in the United States and shipped to other countries.

In 2011, estimated world crude gallium production was 292 metric tons (t). Principal producers were China, Germany, Kazakhstan, the Republic of Korea, Russia, and Ukraine. Plants in Hungary and Japan also recovered gallium. Refined gallium production was estimated to be about 378 t, which may inadvertently include some refined new scrap. Refined gallium was produced in China, Japan, the United Kingdom, and the United States.

## Legislation and Government Programs

TriQuint Semiconductor, Inc. (Hillsboro, OR) began work on phase 2 of the Defense Advanced Research Projects Agency (DARPA) multiyear Nitride Electronic NeXt-Generation Technology (NEXT) program. The NEXT program was established to create digital GaN circuits for defense and aerospace applications. Phase I concentrated on fabricating very-high-frequency devices and meeting defined yield metrics. Phase 2 was to concentrate on process development in the pursuit of increased yields while doubling the current operating frequency of 200 gigahertz up to 400 gigahertz. The devices developed under the NEXT program were expected ramp-up applications for lower voltage GaN-based products, which achieve power densities four times higher than GaAs devices (Compound Semiconductor, 2012c).

Northrop Grumman Corp. (Linthicum, MD) was awarded a 3-year, \$8.9 million contract by DARPA to develop a more efficient radio frequency (RF) transmitter technology. Northrop was to research GaN Class E power amplifiers, RF wideband contour modulation, and sub-banded switching supply modulation, and to develop RF power amplifier designs

that could result in highly efficient RF transmitters without an increase in size. The new technology could create more powerful electronic systems for a wide variety of applications (Compound Semiconductor, 2011b).

The U.S. Department of Energy (DOE) announced a \$57 million award to The College of Nanoscale Science and Engineering at the State University of New York at Albany as part of its SunShot Advanced PV Manufacturing Partnerships Program. The DOE's SunShot initiative would attempt to reduce the total costs of photovoltaic solar energy systems by about 75%, and thereby allow copper-indium-gallium diselenide (CIGS) solar technology to be cost competitive with other forms of energy by the end of the decade (AZoCleantech.com, 2011).

## Production

No domestic production of primary gallium was reported in 2011 (table 1). Recapture Metals Ltd. [a subsidiary of Neo Material Technologies, Inc. (Toronto, Ontario, Canada)] recovered gallium from scrap materials, predominantly those generated during the production of GaAs. Recapture Metals' facilities have the capability to produce about 50 metric tons per year (t/yr) of high-purity gallium. The company recovered gallium from its customers' scrap on a fee basis and purchased scrap and low-purity gallium for processing into high-purity material.

In 2011, Neo Material Technologies acquired an 80% interest in gallium trichloride manufacturer Gallium Compounds, LLC (Quapaw, OK), and planned to expand Gallium Compounds' gallium trichloride manufacturing technology into the Republic of Korea. Gallium trichloride is a precursor for many gallium compounds, including the organic gallium compounds used in epitaxial growth (Semiconductor Today, 2011c).

## Consumption

Gallium consumption data were collected by the U.S. Geological Survey from a voluntary survey of U.S. operations. In 2011, there were 11 respondents to the gallium consumption survey, representing 65% of the total canvassed. Data in tables 2 and 3 were adjusted by incorporating estimates to reflect full industry coverage. Many of these estimates were based on company 2011 10-K reports submitted to the U.S. Securities and Exchange Commission.

More than 99% of the gallium consumed in the United States was in the form of GaAs or GaN. GaAs was used to manufacture optoelectronic devices (laser diodes, LEDs, photodetectors, and solar cells) and ICs. ICs accounted for 71% of domestic consumption and optoelectronic devices accounted for 29% (table 2). GaN principally was used to manufacture LEDs and laser diodes.

In 2011, U.S. consumption of gallium for use in ICs increased by 7% from that in 2010 owing to the growth of GaAs-rich “smartphones” (cellular telephones with advanced personal computer-like functionality) and other wireless communication devices. Gallium use in LEDs and laser diodes only increased slightly from 2010 owing to reduced demand for LED-backlit televisions, as well as manufacturing efficiencies that required fewer LEDs per television. Gallium supplied to the photodetector and solar cell industry increased by 15% from that of 2010, but was still 17% lower than that of 2009 owing to a complicated manufacturing process that had impeded commercial mass production of CIGS panels. Decreased prices of silicon-based solar cells also slowed demand for the more expensive CIGS technology.

**Gallium Arsenide.**—The value of worldwide GaAs device consumption increased to \$5.2 billion in 2011, a 6% increase from \$4.9 billion in 2010. The GaAs device market slowed considerably during the second half of 2011 owing to lower demand for RF circuits, and wired and wireless networks. Developments in cellular telephone technology, particularly sophisticated third-generation (3G) and fourth-generation (4G) smartphones, continued to drive the GaAs device industry. Fourth-generation smartphones use up to 10 times the amount of GaAs that a standard cellular telephone does. In 2011, smartphone market sales increased by 68% compared with sales in 2010. Smartphone market sales in 2010 were also 68% higher than those of 2009. The proportion of smartphones shipped worldwide increased to 32% of total handset shipments in 2011 from 22% in 2010 (Higham and Anwar, 2012; IQE plc, 2012, p. 8; Stevenson, 2012).

To meet increasing GaAs wafer demand, TriQuint Semiconductor Inc. opened a 6-inch GaAs wafer production facility in Texas in 2011, which contributed to a 40% overall increase in the company’s GaAs wafer production capacity from that of 2010 (TriQuint Semiconductor Inc., 2012, p. 28).

**Gallium Nitride.**—Increased demand for GaN device applications, namely laser diodes, power electronics, and RF electronics, provided significant growth opportunities for advanced GaN-based products. GaN power transistors operate at higher voltages and with a higher power density than current GaAs devices. GaN power transistors and amplifiers have enabled microwave designers to reduce heat sink requirements and part counts, leading to smaller systems with higher performance and greater efficiency. The key drivers of this emerging GaN-based technology have been military and defense applications, but the technology also was being used in automotive, industrial, medical, and other consumer applications.

The value of worldwide GaN power and RF electronics consumption was estimated to be approximately \$60 million in 2011. Military applications accounted for 90% of the market, and commercial satellite communication and cable television applications accounted for 9%. Commercial power electronics applications accounted for the remaining 1% (Higham, 2012).

The value of worldwide GaN LED consumption decreased to \$8 billion in 2011, a 6% decrease from \$8.5 billion in 2010. Owing to a combination of slower than expected growth in LED-based backlighting, significant LED capacity expansions,

and enhanced light guide technologies that required fewer LED units per television, GaN LED supply increased nearly three times faster than consumption in 2011, which resulted in reduced LED factory utilization levels and decreased LED prices. The LED supply surplus increased to 45% in 2011 from 7% in 2010 (IMS Research Ltd., 2012a).

In a joint partnership, Sumitomo Electric Industries Ltd. (Tokyo, Japan) and Soitec (Bernin, France) initiated pilot production of 4- and 6-inch-diameter engineered GaN substrates. The substrates were created by transferring ultrathin GaN layers from a single GaN wafer to produce multiple engineered GaN substrates, and were to be used in LEDs for the lighting market and power-efficient controllers for the electric vehicle and energy markets (Soitec, 2012).

**Light-Emitting Diodes.**—The worldwide high-brightness (HB) LED market increased to \$12.5 billion in 2011, an 11% increase from \$11.3 billion in 2010. Owing to the significant LED capacity expansion in 2011 and the resulting LED surplus, prices for HB-LEDs decreased. The lower prices, however, proved beneficial to the HB-LED lighting sector, where LED consumption increased by 44% from that of 2010 and helped offset the decline in LED revenue of the backlighting sector. Commercial and industrial lighting were the largest areas of growth. Research and consulting firm Strategies Unlimited reported that mobile display applications (such as cellular telephones, computer notebooks and tablets, eBooks, and MP3 players) were the largest HB-LED market segment in 2011, with a 27% share. The television and monitor LED-based backlighting segment was 24% of the overall HB-LED market. Additional HB-LED market segments in 2011 included general lighting, signage, and automotive, with respective market shares of 15%, 11%, and 9%. Various smaller market segments comprised the remaining 14% of the overall HB-LED market (LEDs Magazine, 2012; Whitaker, 2012).

Japan and the Republic of Korea supplied 30% and 26%, respectively, of the 2011 worldwide HB-LED market. Additionally, the United States and Europe supplied 19% of the market, Taiwan supplied 19%, and China supplied 6%. China’s HB-LED market share tripled from 2% in 2010 owing to the large investments it made in its domestic solid-state lighting industry (Whitaker, 2012).

LED firms continued expanding their manufacturing capacities in 2011. Semiconductor Equipment and Materials International (SEMI) of San Jose, CA, indicated that 29 new LED fabrication plants came online in 2011, to reach a total of 142 plants in operation worldwide. LED manufacturing equipment spending in 2011 increased by 36% from that of 2010, and 2011’s worldwide LED manufacturing capacity was estimated to be 1.6 million (4-inch-equivalent) wafers per month. Taiwan’s LED fabrication plants accounted for 28% of global capacity, followed by Japan (22%), China (21%), the Republic of Korea (19%), the Americas (6%), Southeast Asia (3%), and Europe and the Mideast (1%) (Peters, 2012; Semiconductor Equipment and Materials International, 2012).

During 2010 and the first half of 2011, the worldwide market for metal-organic chemical vapor deposition (MOCVD) reactors, which were used to make GaN LEDs, experienced the largest investment cycle in its history owing to demand for

LED-backlit televisions, subsidies by the Chinese Government, and anticipation for the LED general lighting market. By yearend 2011, however, LED production capacity was substantially more than demand, and MOCVD utilization rates decreased to about 50% of capacity, resulting in a significant reduction of new orders for equipment. Shipments of MOCVD reactors decreased to 654 units in 2011, 15% lower than the 771 units shipped in 2010. Consulting firm IMS Research Ltd. forecast MOCVD reactor shipments to decrease by an additional 48% in 2012. Aixtron AG (Herzogenrath, Germany) and Veeco Instruments Inc. (Plainview, NY) were the leading MOCVD manufacturers, representing 96% of the market in 2011 (Semiconductor Today, 2012d; Yole Développement, 2012).

As HB-LED demand increased throughout 2010 and the first half of 2011, materials suppliers began adding more capacity for trimethylgallium (TMG), a metal-organic chemical used in the fabrication of epiwafers. When TMG and nitrogen gas are fed into the MOCVD reactor and heated, a GaN layer is formed on the epiwafer. TMG's purity and quality determine an LED's brightness and reliability (Seok-hyeon, 2010). In the United States, AkzoNobel N.V. (Amersfoort, Netherlands) doubled TMG production capacity at its plant in LaPorte, TX. The company announced plans to build a new TMG production plant with total capacity of more than 100 t/yr—approximately three times the size of its existing TMG plant (Semiconductor Today, 2011a). Albermarle Corp. (Baton Rouge, LA) continued the construction of its TMG and triethylgallium (TEG) production facility in the Republic of Korea (Semiconductor Today, 2012a). SAFC Hitech, a subsidiary of Sigma-Aldrich Co. LLC (St. Louis, MO), began the expansion of its TMG and TEG production facility in Kaohsiung, Taiwan (Sigma-Aldrich Co. LLC, 2012).

**Solar Cells.**—Sustained high energy prices continued to spark interest in solar energy. In 2011, the solar cell market continued to be dominated by crystalline silicon solar cells, which account for approximately 90% of the market. However, a lightweight, flexible, durable, and low-cost thin-film photovoltaic technology—CIGS—has entered the printed solar cell market. CIGS modules can be directly integrated into building materials, consumer electronics for portable power, space applications, or configured as stand-alone modules for large-scale terrestrial deployment. Industry experts thought CIGS 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 and a complicated manufacturing process that has impeded commercial mass production of CIGS panels. These two factors resulted in a large oversupply of CIGS modules that caused prices in 2011 to decrease by 20% (Compound Semiconductor, 2011c). World production of CIGS solar cells increased to 813 megawatts (MW) in 2011, a 91% increase from 426 MW produced in 2010 (Roskill's Letters from Japan, 2012b).

Nevertheless, consulting firm Lux Research, Inc., (Boston, MA) reported that in 2011 CIGS manufacturers trimmed production costs, increased production capacities, improved module conversion efficiencies, and increased CIGS adoption in commercial rooftops. Strategic partnerships by the strongest

companies and overall consolidation of the industry were considered key in keeping CIGS technology viable and competitive (Lux Research, Inc., 2012).

## Prices

Since 2002, producer prices for gallium have not been quoted in trade journals. Data in table 4 represent the average customs value of gallium imported into the United States. Reports in Metal-Pages indicated the volatile state of gallium prices during 2011. At the beginning of the year, the low-grade gallium price was reported to be about \$635 per kilogram owing to the rapid growth of China's LED industry that began in 2010, and tightness of worldwide gallium supply as end users restocked inventories depleted since the beginning of the global economic slowdown. By June, the price had increased to about \$950 per kilogram as tightness in the gallium market continued. By December, the price had decreased to about \$520 per kilogram as the market for LED backlighting in televisions did not increase as forecast and newly expanded primary gallium capacity in China greatly exceeded demand.

From U.S. Census Bureau import data, the annual average value for low-grade (99.99%-pure) gallium was estimated to be \$374 per kilogram, about 22% higher than that in 2010. For high-grade (>99.99%-pure) gallium, the annual average estimated value increased to \$688 per kilogram, about 15% higher than that in 2010. Import data reported by the U.S. Census Bureau do not specify purity, so the values listed in table 4 were estimated based on the average value of the material imported and the country of origin.

## Foreign Trade

In 2011, U.S. gallium imports were 45% higher than those in 2010 (table 5). Germany (41%), United Kingdom (32%), China (10%), and Singapore (7%) were the leading sources of imported gallium.

In addition to gallium metal, GaAs wafers were imported into the United States (table 6). In 2011, 86,500 kilograms (kg) of undoped GaAs wafers and 215,000 kg of doped GaAs wafers were imported. Imports of undoped GaAs wafers were 37% higher than those in 2010, while imports of doped GaAs wafers were 29% higher than those in 2010. The data listed in table 6 may include some packaging material and, as a result, quantities may be higher than the actual total weight of imported wafers.

## World Review

Imports of gallium into Japan and the United States, the two leading consuming countries, were used as the basis for estimating world gallium production. In addition, Metal Bulletin provided an updated Chinese gallium production estimate, expanding the estimate of China's production considerably owing to the substantial capacity increases of Chinese gallium operations. Estimated worldwide crude gallium production was 292 t in 2011. Principal world producers were China, Germany, Kazakhstan, the Republic of Korea, Russia, and Ukraine. Gallium also was recovered in Hungary and Japan. Refined gallium production was estimated to be about 378 t, which may

inadvertently include some recycled new scrap. China, Japan, the United Kingdom, and the United States refined gallium.

Roskill Information Services estimated worldwide gallium consumption to be 218 t in 2011. Neo Material Technologies estimated that 50% of gallium consumed worldwide came from recycled sources (Seeley, 2011; Roskill's Letters from Japan, 2012a). Gallium was recycled from new scrap in Canada, Germany, Japan, the United Kingdom, and the United States.

**Canada.**—In 2011, minor metals refiner 5N Plus Inc. (Montreal, Quebec) acquired Belgium-based MCP Group SA. MCP operated a primary gallium facility in Germany and gallium refineries in China and the United Kingdom (5N Plus Inc., 2011b). 5N Plus also signed a memorandum of understanding with Rio Tinto Alcan to potentially recover primary gallium from Rio Tinto's Vaudreuil alumina facility in Quebec (Metal Bulletin, 2011). Additionally, 5N Plus announced that it would construct a gallium chemicals plant in the Republic of Korea in partnership with primary gallium producer Golden Harvest Investments Ltd. (Hong Kong, China). The South Korean facility would produce gallium chemicals for the LED market and was expected to be operational by 2012 (5N Plus Inc., 2011a).

Orbite Aluminae Inc. (Montreal, Quebec) (formerly known as Exploration Orbite V.S.P.A. Inc.) completed construction of a pilot plant to recover alumina from aluminous clays near Grande-Vallee, Quebec, and planned to construct a smelter-grade alumina refinery that would be commissioned by 2013. In addition to alumina, the refinery would also recover gallium and other rare metals and rare-earth elements (Orbite Aluminae Inc., 2011).

**China.**—Throughout 2010 and 2011, China invested substantially in its LED manufacturing infrastructure, which was valued at \$5.8 billion in 2011, an increase of 23% from \$4.7 billion in 2010. Subsidies from local governments were instrumental in helping ramp up LED production capacity. China became the world's leading consumer of LED lighting and the leading producer of liquid crystal display (LCD) televisions, a percentage of which were LED backlit. The country was reported to have produced 200 t of primary gallium in 2011, and doubled its primary gallium manufacturing capacity to 280 t in 2011 from 141 t in 2010. China accounted for 76% of the 654 MOCVD reactors shipped worldwide in 2011. The Chinese Government also implemented a widespread street-lighting program that was expected to create strong domestic demand for LED-based lighting (Semiconductor Today, 2011b; IMS Research Ltd., 2012b; Metal Bulletin, 2012).

China's primary gallium producers were Aluminum Corporation of China, Ltd.; Beijing JiYa Semiconductor Material Co., Ltd.; China Crystal Technologies, Ltd.; East Hope Mianchi Gallium Industry Co.; and Zhuhai Fangyuan (Roskill Information Services, Ltd., 2011, p. 21–26).

**Germany.**—Global Solar Energy, Inc. (Tuscon, AZ) commissioned a CIGS manufacturing facility in Berlin-Adleshof, Germany, with a production capacity of 35 MW (Global Solar Energy, Inc., 2011). In Lower Saxony, Germany, GP Joule GmbH (Reußenköge, Germany) constructed what is thought to be the world's leading solar powerplant using CIGS technology. The plant had a total capacity of 20.8 MW,

and would supply electricity to approximately 6,000 households (GP Joule GmbH, 2011). Avancis GmbH & Co. KG (Torgau, Germany) opened its second CIGS manufacturing facility in Torgau, Germany, with a production capacity of 100 MW. The second facility increased Avancis' total CIGS production capacity to 120 MW (Avancis GmbH & Co. KG, 2011).

**Japan.**—The Japan Oil, Gas, and Metals National Corp. (JOGMEC) estimated that Japan consumed 114 t of gallium in 2011, with the LED market accounting for 42% of consumption (Kita Yoshiyuki, Director, Rare Metals Stockpile Department, Japan Oil, Gas, and Metals National Corp., written commun., February 29, 2012). Following the 2011 earthquakes and tsunami that devastated northeast Japan, several Japanese compound semiconductor-related manufacturing plants were destroyed, which reduced Japanese production of GaAs substrates. Sumitomo Chemical Co. Ltd. announced that it would double the GaAs epiwafer production capacity of its Chiba Works facility in Sodegaura (Sumitomo Chemical Co. Ltd., 2011; Compound Semiconductor, 2012a).

In 2011, Solar Frontier K.K. (Tokyo, Japan) established the world's first gigawatt-scale CIGS manufacturing facility in Miyazaki, Japan, with an annual capacity of 900 MW. Combined with Solar Frontier's already existing CIGS plants, the new facility increased the company's total annual CIGS production capacity to approximately 1 gigawatt (Solar Frontier K.K., 2011).

**Korea, Republic of.**—In 2011, the Government initiated a LED lighting program as part of its national energy-saving strategy. The program aimed to achieve a 100% adoption rate for LED lighting in the South Korean public sector and a 60% adoption rate for all lighting applications nationwide by 2020 (Compound Semiconductor, 2011a). Neo Material Technologies began construction of its gallium trichloride production facility in the Hyeongok Industrial Zone, which was regarded as the center of the country's LED industry. Commercial production at the facility was expected to commence by the third quarter of 2012 (Neo Material Technologies, Inc., 2011).

## Outlook

According to IQE, smartphones represented a fundamental structural shift in mobile communications. Increased use of smartphones, which use up to 10 times the amount of GaAs-rich RF content than standard cellular telephones, was expected to account for 43% of all handset sales by 2014 (IQE plc, 2012, p. 8). Installation of 3G and 4G mobile networks in India and the Republic of Korea was expected to increase sales of smartphones further. Additional increases in GaAs demand will also result from new applications for wireless fidelity (WiFi), such as point-to-point communications, smart meters, and tablet personal computer technologies. Market research firm Yole Développement predicted that the GaAs substrate market would increase at a compound annual growth rate of nearly 11%, increasing to \$650 million by 2017 owing primarily to the rise in GaAs content in handsets and increased penetration of LEDs in general lighting and automotive applications (Semiconductor Today, 2012c).

Yole Développement reported that emerging companies in the GaN power device market were expected to transition from

qualification to production ramp up in 2013, and the increased GaN device capacity would enable the market to expand rapidly. It was thought the GaN power device market could reach \$1 billion in revenue by 2019 if GaN power devices were qualified in the electric vehicle/hybrid electric vehicle sector. Yole Développement also indicated that some LED manufacturers considered manufacturing GaN power electronics as a means of diversifying their excess LED fabrication capacity (Keller, 2012).

Strategy Analytics forecast the overall GaN device market was to increase at a compound annual average growth rate of nearly 29%, to reach \$178 million in 2015. The U.S. defense industry would continue to be the major customer of GaN devices. The percentage of total GaN revenue derived from military applications, however, would decrease from 98% in 2010 to 67% in 2015, as GaN's efficiency, power dissipation, and operating temperature advantages are used in commercial market applications (Compound Semiconductor, 2012b).

Yole Développement forecast that LED revenue would reach \$11.4 billion in 2012 and peak to \$17.1 billion by 2018. Owing to the lower adoption of LED television backlighting in 2011, excess LED capacity, and the reduction of LED prices, the LED industry was expected to begin migrating to general lighting applications in 2012. By 2014, general lighting applications were anticipated to account for more than 50% of the LED market. Yole Développement indicated, however, that LED prices must decrease by at least a factor of 10 from those of 2011 if LEDs are to successfully compete against lower cost technologies in the general lighting market (Compound Semiconductor, 2012d).

Industry analyst firm NanoMarkets, LC forecast that the CIGS market could reach \$4.4 billion by 2017 provided that CIGS manufacturers adopt new strategies to protect themselves from declining crystalline silicon solar panel prices. NanoMarkets expected CIGS manufacturers to continue reducing prices via increases in production volume and manufacturing efficiencies, as well as aggressive recycling strategies (Semiconductor Today, 2012b).

## References Cited

- 5N Plus Inc., 2011a, 5N Plus expands Asian activities: Montreal, Quebec, Canada, 5N Plus Inc. press release, November 7, 2 p. (Accessed November 20, 2011, at [http://www.5nplus.com/uploads/En\\_JV\\_Press\\_release.pdf](http://www.5nplus.com/uploads/En_JV_Press_release.pdf).)
- 5N Plus Inc., 2011b, 5N Plus Inc. completes the acquisition of MCP Group SA and a \$125 million equity financing: Montreal, Quebec, Canada, 5N Plus Inc. press release, April 11, 3 p. (Accessed April 25, 2011, at [http://www.5nplus.com/uploads/Press\\_Release\\_Closing.pdf](http://www.5nplus.com/uploads/Press_Release_Closing.pdf).)
- Avancis GmbH & Co. KG, 2011, Avancis increases production capacity by a factor of six: Torgau, Germany, Avancis GmbH & Co. KG press release, December 16. (Accessed April 20, 2012, at <http://www.avancis.de/en/press/press-releases/view/meldung/avancis-startet-neue-fertigung-und-versechsfacht-produktionskapazitaet/>.)
- AZoCleantech.com, 2011, US DOE awards \$57m to fund advanced solar project: AZoCleantech.com, April 11. (Accessed April 12, 2011, at <http://www.azocleantech.com/news.aspx?newsID=14804>.)
- Compound Semiconductor, 2011a, China aims for LED global domination by 2015: Watford, United Kingdom, Compound Semiconductor, August 2. (Accessed August 25, 2011, at <http://www.compoundsemiconductor.net/csc/news-details.php?cat=news&id=19733854>.)
- Compound Semiconductor, 2011b, Northrop bags \$8.9 million for GaN microscale power conversion: Watford, United Kingdom, Compound Semiconductor, December 2. (Accessed December 9, 2011, at <http://www.compoundsemiconductor.net/csc/news-details.php?cat=news&id=19734320>.)
- Compound Semiconductor, 2011c, No surprise with CIGS startup Solyndra shutdown: Watford, United Kingdom, Compound Semiconductor, September 1. (Accessed September 2, 2011, at <http://www.compoundsemiconductor.net/csc/news-details.php?cat=news&id=19733965>.)
- Compound Semiconductor, 2012a, GaAs back on track with expanding RF wafer market: Watford, United Kingdom, Compound Semiconductor, April 20. (Accessed April 25, 2012, at <http://www.compoundsemiconductor.net/csc/news-details.php?cat=news&id=19734899>.)
- Compound Semiconductor, 2012b, GaN gaining traction in commercial applications: Watford, United Kingdom, Compound Semiconductor, January 4. (Accessed January 6, 2012, at <http://www.compoundsemiconductor.net/csc/news-details.php?cat=news&id=19734432>.)
- Compound Semiconductor, 2012c, TriQuint advances into next generation GaN products: Watford, United Kingdom, Compound Semiconductor, January 11. (Accessed January 16, 2012, at <http://www.compoundsemiconductor.net/csc/news-details.php?cat=news&id=19734454>.)
- Compound Semiconductor, 2012d, Yole claims that LED prices must plummet for lighting success: Watford, United Kingdom, Compound Semiconductor, August 8. (Accessed August 10, 2012, at <http://www.compoundsemiconductor.net/csc/news-details.php?cat=news&id=19735330>.)
- Global Solar Energy, Inc., 2011, Berlin-Adlershof—Operation starts at new solar module factory: Tucson, AZ, Global Solar Energy, Inc. press release, September 6. (Accessed October 10, 2011, at <http://www.globalsolar.com/company/media/berlin-adlershof-operation-starts-at-new-solar-module-factory/>.)
- GP Joule GmbH, 2011, Solarpark Ammerland—Lower Saxony's largest ground-based PV installation to go online after only four months of construction: Reußenköge, Germany, GP Joule GmbH press release, October 29. (Accessed November 15, 2011, at <http://www.gp-joule.de/en/news/detail/article/solarpark-ammerland/>.)
- Higham, Eric, 2012, Future RF market opportunities for GaN: International Microwave Symposium, Montreal, Quebec, Canada, June 17–22, 2012, presentation, 12 p.
- Higham, Eric, and Anwar, Asif, 2012, GaAs industry overview and forecast, 2010–2015: CS MANTECH Conference 2012, Boston, MA, April 23–26, 2012, presentation, [unpaginated].
- IMS Research Ltd., 2012a, IMS Research expects 2011 packaged GaN LED revenues to decline 6% to \$8 billion on weakness in backlighting—LED growth expected from 2012–2015 as lighting accelerates: Wellingborough, United Kingdom, IMS Research Ltd. press release, January 17. (Accessed January 30, 2012, at [http://imsresearch.com/news-events/press-template.php?pr\\_id=2541&from=all\\_pr](http://imsresearch.com/news-events/press-template.php?pr_id=2541&from=all_pr).)
- IMS Research Ltd., 2012b, MOCVD sales to hit bottom in first half of 2012: Wellingborough, United Kingdom, IMS Research Ltd. press release, March 27. (Accessed April 5, 2012, at [http://imsresearch.com/press-release/MOCVD\\_Sales\\_To\\_Hit\\_Bottom\\_In\\_First\\_Half\\_of\\_2012&from=all\\_pr](http://imsresearch.com/press-release/MOCVD_Sales_To_Hit_Bottom_In_First_Half_of_2012&from=all_pr).)
- IQE plc, 2012, Annual report & financial statements 2011: St. Mellons, United Kingdom, IQE plc, 58 p.
- Keller, John, 2012, GaN power electronics device market growing from \$10 million this year to \$1 billion by 2019: Tulsa, OK, Military & Aerospace Electronics, March 8. (Accessed March 8, 2012, at <http://www.militaryaerospace.com/articles/2012/03/gan-power-electronics-market-forecast.html>.)
- LEDs Magazine, 2012, LED lighting experienced strong growth surge in 2011: Cedar Park, TX, LEDs Magazine, February 7. (Accessed February 17, 2012, at <http://www.ledsmagazine.com/news/9/2/9>.)
- Lux Research Inc., 2012, CIGS solar market to nearly double to \$2.35 billion and 2.3 gigawatts in 2015: Boston, MA, Lux Research Inc. press release, January 24. (Accessed February 2, 2012, at [http://www.luxresearchinc.com/images/stories/brochures/Press\\_Releases/RELEASE\\_Solar\\_Components\\_1\\_24\\_12a.pdf](http://www.luxresearchinc.com/images/stories/brochures/Press_Releases/RELEASE_Solar_Components_1_24_12a.pdf).)
- Metal Bulletin, 2011, 5N Plus eyes gallium recovery jv with Rio Tinto Alcan: Metal Bulletin, October 18. (Accessed October 20, 2011, via <http://www.metalbulletin.com>.)
- Metal Bulletin, 2012, Chinese gallium market may be heading for chronic stagnation: Metal Bulletin, February 29. (Accessed March 5, 2012, via <http://www.metalbulletin.com>.)
- Neo Material Technologies, Inc., 2011, Neo Material Technologies expands its gallium business: Toronto, Ontario, Canada, Neo Material Technologies, Inc. press release, August 30. (Accessed September 1, 2011, at <http://>)

- www.newswire.ca/en/story/832915/neo-material-technologies-expands-its-gallium-business.)
- Orbite Aluminae Inc., 2011, Orbite releases positive preliminary economic assessment: Montreal, Quebec, Canada, Orbite Aluminae Inc. news release, November 29, 8 p. (Accessed July 19, 2012, at [http://www.orbitealuminae.com/media/upload/news/Press\\_release\\_Orbite\\_PEA\\_final.pdf](http://www.orbitealuminae.com/media/upload/news/Press_release_Orbite_PEA_final.pdf).)
- Peters, Laura, 2012, LED manufacturers reduce cost with automation, larger wafers, new materials: Cedar Park, TX, LEDs Magazine, March 30. (Accessed June 7, 2012, at <http://www.ledsmagazine.com/features/9/3/3>.)
- Roskill Information Services, Ltd., 2011, Gallium—Global industry markets & outlook (8th ed.): London, United Kingdom, Roskill Information Services, Ltd., 108 p.
- Roskill's Letters from Japan, 2012a, Gallium—7% growth forecast for 2012: London, United Kingdom, Roskill's Letters from Japan, no. 430, June, p. 3.
- Roskill's Letters from Japan, 2012b, Table 3—World production of solar cells by type, 2008–2011 (MW): London, United Kingdom, Roskill's Letters from Japan, no. 431, July, p. 19.
- Seeley, Larry, 2011, Primary and secondary production: Technology Metals for Energy & Security 2011, Washington DC, March 22–23, 2011, presentation, [unpaginated].
- Semiconductor Equipment and Materials International, 2012, LED fab equipment spending to decline 18% in 2012: San Jose, CA, Semiconductor Equipment and Materials International press release, January 4. (Accessed February 1, 2012, at <http://www.semi.org/en/node/40246?id=highlights>.)
- Semiconductor Today, 2011a, AkzoNobel building two new LED precursor plants: Cheltenham, United Kingdom, Semiconductor Today, June 24. (Accessed June 28, 2011, at [http://www.semiconductor-today.com/news\\_items/2011/JUNE/AKZONOBEL\\_240611.html](http://www.semiconductor-today.com/news_items/2011/JUNE/AKZONOBEL_240611.html).)
- Semiconductor Today, 2011b, China's LED industry to grow 23% to \$5.8bn in 2011: Cheltenham, United Kingdom, Semiconductor Today, August 22. (Accessed August 30, 2011, at [http://www.semiconductor-today.com/news\\_items/2011/AUG/IHS\\_220811.html](http://www.semiconductor-today.com/news_items/2011/AUG/IHS_220811.html).)
- Semiconductor Today, 2011c, Neo Material acquires 80% stake in Gallium Compounds: Cheltenham, United Kingdom, Semiconductor Today, August 31. (Accessed September 4, 2011, at [http://www.semiconductor-today.com/news\\_items/2011/AUG/NEOMATERIAL\\_310811.html](http://www.semiconductor-today.com/news_items/2011/AUG/NEOMATERIAL_310811.html).)
- Semiconductor Today, 2012a, Albarle expanding Korea facility to electronic-grade metal organics: Cheltenham, United Kingdom, Semiconductor Today, August 7. (Accessed August 9, 2012, at [http://www.semiconductor-today.com/news\\_items/2012/AUG/ALBEMARLE\\_070812.html](http://www.semiconductor-today.com/news_items/2012/AUG/ALBEMARLE_070812.html).)
- Semiconductor Today, 2012b, CIGS PV panel market to grow rapidly to \$4.4bn by 2017: Cheltenham, United Kingdom, Semiconductor Today, February 6. (Accessed February 6, 2012, at [http://www.semiconductor-today.com/news\\_items/2012/FEB/NANOMARKETS\\_060212.html](http://www.semiconductor-today.com/news_items/2012/FEB/NANOMARKETS_060212.html).)
- Semiconductor Today, 2012c, GaAs wafer market to exceed \$650m by 2017: Cheltenham, United Kingdom, Semiconductor Today, April 17. (Accessed April 23, 2012, at [http://www.semiconductor-today.com/news\\_items/2012/APRIL/YOLE\\_170412.html](http://www.semiconductor-today.com/news_items/2012/APRIL/YOLE_170412.html).)
- Semiconductor Today, 2012d, MOCVD system shipments for GaN LEDs to fall 48% to 342 in 2012: Cheltenham, United Kingdom, Semiconductor Today, March 26. (Accessed March 28, 2012, at [http://www.semiconductor-today.com/news\\_items/2012/MAR/IMS\\_260312.html](http://www.semiconductor-today.com/news_items/2012/MAR/IMS_260312.html).)
- Seok-hyeon, Ahn, 2010, LED TMG shock looming large: etnews.com, April 11. (Accessed August 30, 2011, at <http://english.etnews.com/news/detail.html?id=201011040009>.)
- Sigma-Aldrich Co. LLC, 2012, SAFC Hitech opens new Taiwan facility to enhance global capacity for high-brightness LED precursor manufacturing: St. Louis, MO, Sigma-Aldrich Co. LLC press release, March 15. (Accessed April 1, 2012, at <http://www.safcglobal.com/safc-global/en-us/home/press-releases/2012-press-releases/new-taiwan-facility.html>.)
- Solar Frontier K.K., 2011, Japan's largest solar panel factory reaches full commercial operations, announces Solar Frontier: Tokyo, Japan, Solar Frontier K.K. press release, July 29. (Accessed August 25, 2011, at <http://www.solar-frontier.com/end/news/2011/C002132.html>.)
- Soitec, 2012, Soitec and Sumitomo Electric announce major milestone in strategic joint development of engineered gallium nitride substrates: Bernin, France, Soitec press release, January 24. (Accessed April 8, 2012, at <http://www.soitec.com/en/news/press-releases/soitec-and-sumitomo-electric-announce-major-milestone-in-strategic-joint-development-of-engineered-gallium-nitride-substrates-891/>.)
- Stevenson, Richard, 2012, Shifting landscapes in the GaAs industry: Watford, United Kingdom, Compound Semiconductor, July 11. (Accessed July 26, 2011, at <http://www.compoundsemiconductor.net/csc/features-details.php?cat=features&id=19735234>.)
- Sumitomo Chemical Co. Ltd., 2011, Sumitomo Chemical to strengthen compound semiconductor materials business: Tokyo, Japan, Sumitomo Chemical Co. Ltd. press release, October 7, 2 p. (Accessed January 5, 2012, at <http://www.sumitomo-chem.co.jp/english/newsreleases/docs/20111007e.pdf>.)
- TriQuint Semiconductor, Inc., 2012, Annual report 2011: Hillsboro, OR, TriQuint Semiconductor, Inc., 105 p.
- Whitaker, Tim, 2012, LED market grew almost 10% in 2011, with 44% growth in lighting: Cedar Park, TX, LEDs Magazine, February 7. (Accessed February 17, 2012, at <http://www.ledsmagazine.com/news/9/2/6>.)
- Yole Développement, 2012, A US \$6.1 billion opportunity through the end of the decade: Lyon, France, Yole Développement press release, April 17, 3 p. (Accessed April 28, 2012, at [http://www.yole.fr/iso\\_upload/News/2012/Press\\_20Release\\_20III-V\\_20Epitaxy\\_YOLE\\_20DEVELOPPEMENT\\_April\\_202012.pdf](http://www.yole.fr/iso_upload/News/2012/Press_20Release_20III-V_20Epitaxy_YOLE_20DEVELOPPEMENT_April_202012.pdf).)

## GENERAL SOURCES OF INFORMATION

### U.S. Geological Survey Publications

- Gallium. Ch. in Mineral Commodity Summaries, annual.
- Gallium, Germanium, and Indium. Ch. in United States Mineral Resources, Professional Paper 820, 1973.
- 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.
- Mining Journal.
- Minor Metals in the CIS. Roskill Information Services Ltd., 1997.

TABLE 1  
SALIENT U.S. GALLIUM STATISTICS<sup>1</sup>

(Kilograms unless otherwise specified)

	2007	2008	2009	2010	2011
Production	--	--	--	--	--
Imports for consumption	37,100	41,100	35,900	59,200	85,700
Consumption	25,100	28,700	24,900	33,500	35,300
Price <sup>2</sup> dollars per kilogram	530	579	449	600	688

-- Zero.

<sup>1</sup>Data are rounded to no more than three significant digits.

<sup>2</sup>Estimate based on average value of U.S. imports of high-purity gallium.

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

(Kilograms)

End use	2010	2011
Optoelectronic devices:		
Laser diodes and light-emitting diodes	9,390	9,500
Photodetectors and solar cells	612	705
Integrated circuits:		
Analog	21,200	22,900
Digital	2,100	2,050
Research and development	235	123
Other	--	--
Total	33,500	35,300

-- Zero.

<sup>1</sup>Data are rounded to no more than three significant digits; may not add to totals shown.

<sup>2</sup>Includes gallium metal and gallium compounds.

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

(Kilograms)

Purity	Beginning stocks	Receipts	Consumption	Ending stocks
2010:				
99.99% to 99.999%	3,240	624	--	3,870
99.9999%	740	500	280	960
99.99999% to 99.999999%	118	501	475	144
Total	4,100	1,630	755	4,970
2011:				
99.99% to 99.999%	3,870	1,290	7	5,150
99.9999%	960	679	301	1,340
99.99999% to 99.999999%	144	842	619	367
Total	4,970	2,810	927	6,850

-- Zero.

<sup>1</sup>Consumers only.

<sup>2</sup>Data are rounded to no more than three significant digits; may not add to totals shown.

TABLE 4  
ESTIMATED AVERAGE GALLIUM PRICES

(Dollars per kilogram)

Gallium metal	2010	2011
Purity $\geq$ 99.9999%; average value of U.S. imports	600	688
Purity $\leq$ 99.99%; average value of U.S. imports	307	374

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

Country	2010		2011	
	Quantity (kilograms)	Value <sup>2</sup>	Quantity (kilograms)	Value <sup>2</sup>
Canada	4,170	\$1,480,000	--	--
China	12,200	3,960,000	8,890	\$6,540,000
France	601	378,000	1,290	667,000
Germany	14,400	3,760,000	35,200	13,000,000
Hungary	--	--	268	152,000
Japan	649	409,000	1,250	844,000
Korea, Republic of	--	--	1,420	900,000
Netherlands	1,400	745,000	3,100	1,720,000
Russia	1,000	395,000	701	607,000
Singapore	530	218,000	6,050	2,880,000
Ukraine	3,810	1,360,000	149	123,000
United Kingdom	20,500	6,450,000	27,300	16,200,000
Other	3 <sup>r</sup>	3,540 <sup>r</sup>	--	--
Total	59,200	19,200,000	85,700	43,700,000

<sup>r</sup>Revised. -- Zero.

<sup>1</sup>Data are rounded to no more than three significant digits; may not add to totals shown.

<sup>2</sup>Customs value.

Source: U.S. Census Bureau.

TABLE 6  
U.S. IMPORTS FOR CONSUMPTION OF  
GALLIUM ARSENIDE WAFERS, BY COUNTRY<sup>1</sup>

Material and country	2010		2011	
	Quantity (kilograms)	Value <sup>2</sup>	Quantity (kilograms)	Value <sup>2</sup>
<b>Undoped:</b>				
Austria	34	\$22,500	26	\$18,800
Canada	19,500	1,720,000	2,910	23,600
China	--	--	558	178,000
Germany	103	12,700	11,200	131,000
India	9,030	12,000	--	--
Japan	1	5,400	12,300	41,700
Taiwan	2,140	128,000	59,400	304,000
United Kingdom	32,200	55,700	25	2,360
Other	109 <sup>r</sup>	38,300 <sup>r</sup>	25	4,730
Total	63,200	1,990,000	86,500	704,000
<b>Doped:</b>				
Belarus	34	5,460	9,030	1,980,000
China	14,100	21,200,000	15,100	22,100,000
Czech Republic	1,460	1,350,000	1,190	1,230,000
Finland	4,180	2,440,000	6,490	4,400,000
France	7,050	7,220,000	2,290	3,670,000
Germany	30,500	25,700,000	56,000	31,600,000
Japan	72,100	84,800,000	84,000	96,900,000
Korea, Republic of	1,100	787,000	1,830	697,000
Norway	30	63,700	2,250	738,000
Poland	1,230	691,000	700	644,000
Singapore	8,800	12,900,000	6,560	10,700,000
Taiwan	20,300	28,500,000	17,300	45,700,000
United Kingdom	2,950	1,750,000	9,280	3,250,000
Other	2,140 <sup>r</sup>	1,800,000 <sup>r</sup>	2,600	1,880,000
Total	166,000	189,000,000	215,000	225,000,000

<sup>r</sup>Revised. -- Zero.

<sup>1</sup>Data are rounded to no more than three significant digits; may not add to totals shown.

<sup>2</sup>Customs value.

Source: U.S. Census Bureau.

TABLE 7  
ESTIMATED WORLD ANNUAL PRIMARY GALLIUM  
PRODUCTION CAPACITY, DECEMBER 31, 2011<sup>1</sup>

(Metric tons)

Country	Capacity
China	280
Germany	40
Hungary	8
Japan	10
Kazakhstan	25
Korea, Republic of	16
Russia	10
Ukraine	15
Total	404

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