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USGS Mineral Resources Program

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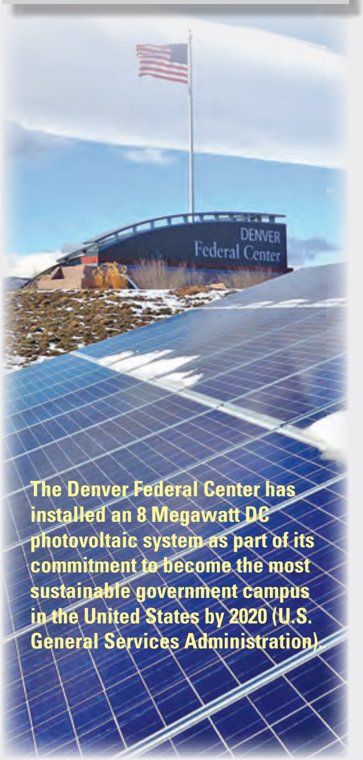
Germanium—Giving Microelectronics an Efficiency Boost

As part of a broad mission to conduct research and provide information on nonfuel mineral resources, the U.S. Geological Survey (USGS) supports science to understand

- *How and where germanium resources form and concentrate in the Earth's crust*
- *How germanium resources interact with the environment to affect human and ecosystem health*
- *Trends in the supply and demand for germanium in domestic and international markets*
- *Where future germanium resources might be found*

Why is this information important? Read on to learn about germanium and the important role it plays in the national economy, in national security, and in the lives of Americans every day.



The Denver Federal Center has installed an 8 Megawatt DC photovoltaic system as part of its commitment to become the most sustainable government campus in the United States by 2020 (U.S. General Services Administration).

Germanium is a rare element but is present in trace quantities in most rock types because of its affinity for iron- and organic-bearing materials. The average germanium content of the Earth is about 14 parts per million (ppm), but the majority of germanium resides within the Earth's core (37 ppm) while the Earth's crust contains only about 1.5 ppm. Germanium does not occur as a native metal in nature, but about 30 different germanium minerals are known to exist. In refined form, it is grayish-white and metallic in appearance. Germanium is a semiconducting metalloid with electrical properties between those of a metal and an insulator.

Germanium was discovered in the late 1800s within silver ore at a mine near Freiberg, Germany. The German chemist who described the element, Clemens Winkler, named it germanium, after his native country. More than half a century elapsed before its first commercial use after World War II, when Karl Lark-Horovitz from Purdue University discovered its properties as a semiconductor. Today germanium is commonly used in commercial, industrial, and military applications.

Germanium is an essentially nontoxic element, with the exception of only a few compounds. However, if dissolved concentrations in drinking water are as high as one or more parts per million chronic diseases may occur.

How Do We Use Germanium?

During germanium refinement processes, different germanium compounds and metals are extracted that are designed for a wide variety of specific applications. The major use of germanium worldwide is for fiber-optic systems, whereby germanium is added to the pure silica glass core of fiber-optic cables to increase their refractive index, minimizing signal loss over long distances.

Fiber-optic technology is a cutting edge method of sending and receiving information long distances using transmitted light. Photograph from EnerTech Systems, Inc.

The leading domestic use of germanium is for the production of infrared optical lenses and windows. Infrared imaging devices are used extensively by the military and law enforcement agencies for surveillance, reconnaissance, and target acquisition applications. Infrared optical devices improve a soldier's ability to effectively operate weapon systems in harsh conditions, and they are increasingly used in remotely operated unmanned weapons and aircraft. Infrared optical devices are also used for border patrol and by emergency response teams for conducting search-and-rescue operations.

High-purity, single-crystal germanium blocks are sliced into wafers and polished to form substrates for use in electronics and solar electric applications. Germanium substrates are used to form the base layer in multijunction solar cells, the highest-efficiency solar cells available as of 2014. These solar cells are the preferred type for use in space-based solar power applications because of their high energy-conversion efficiency and strength at minimal size, and they have great potential for increased use in terrestrial-based photovoltaic installations. Germanium substrates are also used in high-brightness light-emitting diodes (LED) for backlighting liquid-crystal display (LCD) televisions and in vehicle head and taillights.

Powdered compounds of germanium are used to catalyze the polymerization of polyethylene terephthalate (PET) resin, which is commonly used to manufacture polyester textiles and clear plastic bottles. Less common uses of germanium include gamma and X-ray detectors, medical applications such as chemotherapy, and metallurgy.

Where Does Germanium Come From?

Germanium is a trace metal found in a variety of magmatic and sedimentary ore deposit types worldwide, including seafloor volcanogenic massive sulfide (VMS), porphyry copper (±molybdenum, ±tin), epithermal, sedimentary exhalative massive sulfide (SEDEX), sedimentary basin Mississippi Valley-type (MVT) deposits, and carbonate-hosted Kipushi-type (KPT) zinc-lead-copper deposits. Germanium is primarily recovered as a byproduct from zinc, silver, lead, and copper ores from these deposits, but world-wide production is dominantly from the zinc ore mineral, sphalerite (zinc sulfide). Because metallurgical operations are commonly fed by concentrates from multiple deposits and diverse locations, it is difficult to track germanium production to specific deposits. It has been estimated that less than 5 percent of the germanium contained in zinc concentrates is recovered.

Germanium-rich coal and lignite deposits have attracted both researchers and industry, and may become more important sources of germanium in the future. Coal ashes containing up to 1.1 percent germanium were identified in 1933 by V.M. Goldschmidt from the Durham Coalfield, United Kingdom. The process to recover germanium from coal ash collected from flue dusts at power stations was developed in the 1950s; however, germanium recovery dropped when coal gas was subsequently replaced by natural gas. Currently, 30 to 50 percent of primary germanium production is from lignite deposits in China, Russia, and Uzbekistan. As of 2013, the largest known germanium-rich coal deposit is located in the Yimin coal field in Inner Mongolia, with an estimated 4,000 tonnes of germanium resources.

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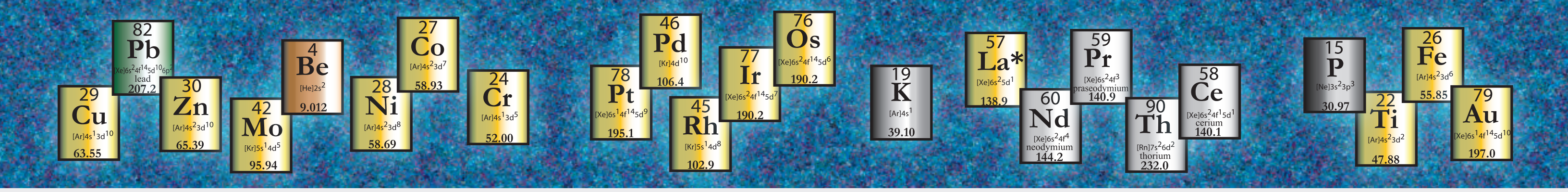

Worldwide Supply of and Demand for Germanium

Polycrystalline block of germanium with uneven cleaved surfaces. Photograph by Jurii, Wikimedia Commons—Creative Commons Attribution–Share Alike 3.0 Unported.

Global resources and reserves of germanium are difficult to estimate because germanium is a byproduct commodity, coming from a wide variety of deposit types. Trace metal concentration data in many deposits are not readily available or are of poor quality, making reserve calculations problematic. Nevertheless, in 2013 the combined U.S. germanium reserves and resources were estimated to total about 450 tonnes, whereas those in China and the Russian Federation were estimated to be about 3,800 tonnes and 4,000 tonnes, respectively. Results from continued exploration suggest that additional reserves of germanium-rich coals are about 5,600 tonnes in Inner Mongolia and 6,000 to 7,000 tonnes in the Russian Far East.

Worldwide production of germanium has increased dramatically over the last decade; however, production levels are highly volatile and the market is relatively opaque. In 2012, the world's total production of germanium was estimated to be 128 tonnes. This comprised germanium recovered from zinc concentrates, fly ash from coal burning, and recycled material produced in China (70 percent), Russia (4 percent), the United States (2 percent), and other countries including Canada, Spain, India, Finland, and Australia. Outside of China, the major germanium producer is Teck Metals Ltd. (Canada), with a reported production of 40 tonnes germanium in 2007. Their production includes local and imported zinc concentrations, some of which comes from the Red Dog mine in Alaska, one of the United States' germanium-rich zinc mines.

Various companies, several of which are based in the United States, produce specialized germanium-based technologies including semiconductor production equipment, materials for lighting display applications and wireless and fiber-optic communications, and a wide variety of industrial materials and recycling services.

Did you know... ***Germanium-rich coal seams are interbedded with siliceous rocks including siliceous limestones***

How Do We Ensure Adequate Supplies of Germanium for the Future?

Red Dog Mine, located in northwest Alaska, is one of the worlds' largest producers of zinc concentrate from which germanium is recovered as a byproduct. Photograph from NANA Regional Corporation, Inc.

The extensive use of germanium for military and commercial applications has made it a critical material in the United States and the rest of the world. Silicon can be a less-expensive substitute for germanium in certain high-frequency electronic, light-emitting diode, and infrared applications, but commonly at the expense of performance. There are few adequate substitutes for germanium in defense and law enforcement applications.

Future sources of germanium supplies will likely continue to be germanium-bearing residues from the processing of zinc ores, coal ash, and from recycling. In recent years, exploration for new zinc deposits and expansions of known zinc mines have been maintained at a high level. Although information about germanium grades of discovered zinc deposits are typically not reported, it is possible that some could contain germanium concentrations high enough to be extracted from residues during the smelting and refining stages of the zinc ore. Deposits similar to the Kipushi ores in Africa are possible rich sources of germanium; however, given their remoteness, exploration and development has been minimal. Germanium-bearing coal and flue dusts compose the most important germanium resource by volume, but production from this source will depend on technological improvements and an increase in germanium prices.

Recycling will remain a major global source of germanium in the future. Because of its low abundance in most finished products, little germanium is recovered from post-consumer scrap. However, new scrap generated during the manufacture of fiber-optic cables, infrared optics, and substrates is typically reclaimed at high rates and fed back into the production process. In 2006, a recycling rate of 70 to 80 percent was obtained for fiber-optic production in the United States.

Did you know... ***Future demand for germanium is likely to be driven by fiber-optic cable production, and is estimated to increase eight-fold from 2006 to 2030***

For More Information

- On production and consumption of germanium: http://minerals.usgs.gov/minerals/pubs/commodity/germanium/
- On germanium recycling in the United States: http://pubs.er.usgs.gov/publication/cir1196V/
- On historical statistics for germanium in the United States: http://minerals.usgs.gov/minerals/pubs/historical-statistics/

The USGS Mineral Resources Program is the principal Federal provider of research and information on germanium and other nonfuel mineral resources.

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