QUARTZ CRYSTAL

By Ronald F. Balazik

Electronic-grade quartz crystal is single-crystal silica which has properties that make it uniquely useful for accurate frequency controls, timers, and filters in electronic circuits. These devices are utilized for a wide variety of electronic applications in communications equipment, computers, aerospace hardware, instruments for military/commercial uses (e.g., altimeters and navigational aids), and consumer goods (e.g., clocks, television receivers, and games/toys). Such uses generate practically all of the demand for electronic-grade quartz crystal. A lesser amount of optical-grade quartz crystal is used as windows and lenses in specialized devices including some lasers.

Natural quartz crystal primarily was used in electronic and optical applications until 1971, when it was surpassed by cultured quartz crystal. The use of natural quartz crystal for carvings and other gemstone applications continued; quartz crystal for such applications are covered in an annual Gemstones Mineral Industry Survey published by the U.S. Geological Survey (USGS).

Legislation and Government Programs

The strategic value of quartz crystal was demonstrated more than 50 years ago when it gained wide use as an essential component of military communication systems during World War II. After the war, natural electronic-grade quartz crystal was officially designated as a strategic and critical material for stockpiling by the Federal Government. Cultured quartz crystal, which eventually supplanted natural crystal in nearly all applications, was not commercially available when acquisition of the latter for a national stockpile began.

As of December 31, 1995, the National Defense Stockpile (NDS) contained 236,513 pounds of natural quartz crystal with a reported market value of more than $1 million. The stockpile has 11 weight classes for natural quartz crystal ranging from 200 grams to more than 10,000 grams. However, the stockpiled crystals primarily are in the larger weight classes. The larger pieces are suitable as seed crystals for cultured quartz crystal production. In addition, much of the stockpiled crystals could be of interest to the specimen and gemstone industry. Little, if any, of the stockpiled material is likely to be utilized in the same applications as cultured quartz crystal.

As cultured quartz crystal displaced natural quartz crystal in most applications, the Federal Government continued to assess its stockpile goals for the latter material. In a May 1995 report to Congress on NDS requirements, the Department of Defense recommended a reduced stockpile goal of 15,520 pounds for natural quartz crystal. This quantity was the amount of individual crystals in the NDS inventory that weighed 10 kilograms or more and could be used as seed material to generate cultured quartz crystal. Brazil traditionally has been the source of such large natural crystals, but changes in mining operations have reduced its production to a very small output. Due to the significance of seed crystal and the lack of alternative sources, the Department of Defense has recommended that quartz crystal should remain as one of the few stockpiled materials to retain a "critical and strategic" designation. However, sales of quartz crystal in the smaller stockpile weight classes were planned for Fiscal Year 1996, which began on October 1, 1995.

Production

The USGS collects domestic production data for quartz crystal through a survey of the domestic industry. In 1995, the industry consisted of four cultured quartz crystal producers and one company that mined feed material, called lascas, for producing cultured crystal. All five producers responded to the industry survey, representing 100% of the lascas and cultured quartz crystal output shown in table 1.

Coleman Quartz Inc., Jessieville, AR, is the only domestic company known to supply lascas for producing cultured quartz crystal. Coleman mined only during the summer months, but processed lascas throughout the year. After mining, crushing, and sizing by Coleman, lascas was transported to the company's processing plant where operators rinsed it in oxalic acid and then in deionized water to remove external contaminants. Finally, hand sorting, drying, and examination on a light table completed the necessary processing. The material was then shipped to cultured quartz crystal producers in 45-kilogram (100-pound) bags within 20,000-kilogram lots.

The following four U.S. companies produced cultured quartz crystal during 1995: Sawyer Research Products Inc. of Eastlake, OH; Thermo Dynamics Corp. of Merriam, KS; Motorola Inc. of Chicago, IL; and P. R. Hoffman Material Processing Co. of Carlisle, PA. Sawyer and Thermo Dynamics produced crystal bars for domestic and foreign firms in the crystal device fabrication industry. Motorola produced quartz crystal for both internal consumption and domestic device fabricators. P. R. Hoffman reported external sales.

The aforementioned companies produced cultured quartz crystal using a hydrothermal process in large pressure vessels, known as autoclaves. Seed crystals (very thin crystals cut to exact dimensions) were mounted on racks and suspended in the upper growth region of the vessel. Lascas was loaded in an open-mesh wire basket that was placed in the bottom of the autoclave.

A solution of sodium hydroxide or sodium carbonate (the mineralizer), with additives such as lithium salts and deionized or distilled water was used to fill the vessel from 75% to 85% of its volume. The bottom half of the growing vessel was heated to temperatures averaging between 350 °C to 400 °C; the temperature of the top portion was maintained at 5 °C to 50 °C less, depending on the mineralizer used. At these temperatures, the solution expands and creates an internal pressure in the vessel between 10,000 and 30,000 pounds per square inch. Under these conditions the lascas dissolves to create a solution saturated with silica. Through convection, the saturated solution transports dissolved silica to the cooler upper half of the vessel where it becomes supersaturated, and the excess dissolved quartz deposits on the seed crystals in the top half of the autoclave. The process continues until the growing crystals reach their desired size. The process normally take 30 to 60 days for a 1-inch thick bar and longer for other types of crystal; at least one producer has made runs of about 180 days. The cultured crystals can be custom grown with specific properties.

The processing of quartz crystal for various end uses is the same whether natural or cultured seed crystal is used. However, producers must avoid seed crystals with defects that would pass on to new generations of cultured crystal. Natural quartz crystal is preferred as seed material to ensure that genetic defects will not be repeated in the succeeding generations.

Once produced, cultured crystals are examined for physical defects before cutting. They are then cut, usually with diamond or slurry saws, along a predetermined crystallographic plane to a thickness slightly larger than that desired. Each wafer is inspected and diced into blanks of the desired dimensions. The blanks then progress through a series of lapping stages until they reach the final thickness; electrodes are attached and the crystals are mounted in suitable holders. The final assembly, called a quartz crystal unit, is ready for insertion into an electronic circuit.

Consumption

The USGS collected 1995 domestic consumption data for quartz crystal through a survey of 27 U.S. firms in 11 States that fabricate quartz crystal devices. These companies represented virtually all of domestic consumption. Eighteen companies responded to the survey.

Quartz crystal is used in piezoelectric and optical applications. The piezoelectric effect is achieved when a suitable electrical signal applied to a quartz wafer makes the wafer vibrate mechanically throughout the bulk of the material at a characteristic natural resonance frequency. Quartz resonators are uniquely suitable for military, aerospace, and commercial bandpass filter applications that require very high selectivity or in oscillator applications that require very high stability. In addition, for many applications requiring only moderate stability, a quartz resonator offers a unique combination of high performance, small size, and low cost. Quartz resonators also are used for many less demanding applications such as providing timing signals for electronic circuits in industrial, automotive, and consumer products.

Cultured quartz is used almost exclusively by the crystal device industry because of cost advantages. For resonator applications, raw quartz must be cut into thin wafers oriented precisely with the raw material crystal axes. The uniformity and convenience of cultured quartz have made its use almost universal. Unlike cultured quartz, natural electronic-grade quartz requires special orientation, cutting, grading, and sizing to produce a quartz wafer. As a result, most device manufacturers that cut natural quartz in the past have discontinued its use. One of the remaining uses of natural electronic-grade material is in pressure transducers used in deep wells.

The quartz wafer must be cut too thinly for practical use at very high frequencies (above 100 megahertz). Quartz crystal structures that use surface vibrations, in which the frequency is determined by electrode dimensions rather than wafer thickness, have become more important at these higher frequencies. These structures are called surface acoustical wave (SAW) devices.

Most optical applications use quartz in the fused form as silica glass. Relatively small quantities of cultured quartz crystal are used directly for special optical considerations. Quartz crystal also has uses involving normally polarized laser beams; quartz retardation plates (especially quartz wave plates), Brewster windows and prisms, birefringent filters, and tuning elements are utilized in laser optics.

Prices

The average value of as-grown cultured quartz was $60 per kilogram in 1995. The average value of lumbered quartz, as-grown quartz that has been processed by sawing and grinding, was about $300 per kilogram. (Also note market value cited above for natural quartz crystal in the NDS.)

Foreign Trade

The U.S. Department of Commerce, which is the major government source of U.S. trade data, does not provide specific import or export statistics on lascas. Some lascas reportedly was imported from Africa (probably Namibia) and Brazil in 1995. Imports and exports of all electronic-grade quartz crystal are shown in table 1.

World Review

Cultured quartz crystal production is concentrated in China, Japan, Russia and the United States with several companies producing crystal in each country. Smaller production capacity exists in Belgium, Brazil, Bulgaria, France, Germany, South Africa, and the United Kingdom. Details concerning quartz operations in China, nations that formerly comprised the U.S.S.R., and Eastern European countries is unavailable. However, it is known that those in Russia have significant capacity to produce synthetic quartz.

Outlook

Demand for quartz crystal devices should continue to grow and, consequently, quartz crystal production should remain strong well into the future. Growth of the consumer electronics market (e.g., personal computers, electronic games, and cellular telephones) particularly in the United States, will continue to promote domestic production. The growing global electronics market may require additional production capacity worldwide.

OTHER SOURCES OF INFORMATION

U.S. Geological Survey Publication

Quartz Crystal, Chapter in Mineral Commodity Summaries, annual.

Other Sources

Electronic News, weekly.
Electronics, biweekly.
Electronic Component News, monthly.
A Stockpile Primer (U.S. Department of Defense, Directorate of Strategic Materials Management; August 1995).
1995 Report to the Congress on National Defense Stockpile Requirements (U.S. Department of Defense; May 1995).

TABLE 1
SALIENT U.S. ELECTRONIC- AND OPTICAL-GRADE QUARTZ CRYSTAL STATISTICS 1/

(Thousand kilograms and thousand dollars)

	1991	1992	1993	1994	1995
Production:					
Mine	454	778	454	544	435
Cultured	441	407	394	294	360
Exports (cultured):					
Quantity	53	15	24	38	35
Value	$2,620	$1,280	$2,260	$6,110	$10,900
Imports (cultured):					
Quantity	3	6	8	19	47
Value	$418	$1,130	$2,250	$5,950	$10,800
Consumption	394 r/	398 r/	378 r/	275 r/	370 e/

e/ Estimated. r/ Revised.

1/ Data are rounded to three significant digits.