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# CUBIC ZIRCONIA: AN UPDATE

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By Kurt Nassau

*Soon after it was first marketed in 1976, colorless cubic zirconia became the dominant diamond imitation, with current production of approximately 60 million carats per year. Although cubic zirconia was discovered as a natural mineral in 1937, crystals usable for faceting were first produced in 1969 and it was not until a practical skull-melting technique was developed in the USSR in 1972 that commercial production became feasible. This article reviews the skull-melting technique used to produce cubic zirconia and examines the current status of this diamond simulant with regard to quality, production, and market. The patent situation is discussed, as well as prospects for new diamond imitations and the recent surge of interest in colored cubic zirconia. Also included is an Appendix summarizing the technical and gemological data for cubic zirconia and its distinguishing characteristics.*

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## ABOUT THE AUTHOR

*Dr. Nassau is a research scientist residing in Bernardsville, NJ.*

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Cubic zirconia was discovered as a natural mineral in 1937, when two German mineralogists, von Stackelberg and Chudoba (1937), were examining a highly metamict zircon given to them by B. W. Anderson. The zircon contained some tiny crystals which they identified by X-ray diffraction as the cubic form of zirconium oxide (or zirconia), a compound known as baddeleyite when in the monoclinic form. So little did von Stackelberg and Chudoba think of this discovery that they did not even assign a name to the new mineral. As a result, it is known to this day by its scientific name, *cubic zirconia*, and the prefix *synthetic*, although proper, is not usually included.

This same material had already been used for many years as a ceramic composition for high-temperature industrial and scientific purposes; because of an exceptionally high melting point, "stabilized zirconia" ceramics can be used at temperatures up to 2540°C (4604°F) and are very resistant to most chemical substances. Such stabilized zirconia typically consists of 96% ZrO<sub>2</sub> (zirconia) and 4% CaO (lime), although MgO (magnesia) or Y<sub>2</sub>O<sub>3</sub> (yttria) also can be used in place of the CaO. Further discussion of the early work on this material is given in Nassau (1977).

Whenever the powder or ceramic form of a substance has interesting properties, scientists usually attempt to grow large crystals; this permits a more precise study of a broader range of properties and often leads to additional uses. In the case of cubic zirconia, crystal growth proved most difficult in view of the material's exceptionally high melting point. Pure ZrO<sub>2</sub> melts at about 2750°C (4982°F), but at a somewhat lower temperature when stabilizers are added. Flux growth was tried (Nassau, 1977, 1980a), but it produced either monoclinic baddeleyite or a tetragonal form. On heating, the former is transformed from monoclinic to tetragonal at about 1100°C (2012°F), and from tetragonal to cubic at about 2000°C (3632°F). Un-



*Figure 1. A large skull-melting apparatus being operated by George Bramhall. Courtesy of the Ceres Corp., Waltham, MA.*

fortunately, these changes reverse on cooling and the starting material forms once again. The addition of stabilizers such as  $\text{CaO}$ ,  $\text{MgO}$ , or  $\text{Y}_2\text{O}_3$  prevents these transformations on cooling: cubic zirconia then remains the stable form down to room temperature. Details of the different forms of zirconia are given in the Appendix.

Crystals of cubic zirconia in a usable size were finally reported in 1969 by Roulin, Vitter, and Déportes of France. They used a difficult form

of melting the material without a crucible to obtain crystals more than 15 mm (0.6 inch) long, of composition 87.5%  $\text{ZrO}_2$ , 12.5%  $\text{Y}_2\text{O}_3$ . Only a few properties of the crystals appear to have been measured at that time, however, and the potential remained unrecognized. A somewhat modified and greatly enlarged form of this apparatus was used by Aleksandrov, Osiko, Prokhorov, and Tatarintsev at the Lebedev Physical Institute of the USSR Academy of Sciences in Moscow (1973).

Their technique, called "skull melting," is described in detail in the next section. Crystals one inch (2.5 cm) and larger in diameter can be grown with a modern embodiment of this arrangement (fig. 1) without excessive difficulty. The impetus for this work had been the hope—unfulfilled—of finding improved materials for laser or opto-electronic uses, but measurements of the crystals showed a material that was hard, colorless, and with optical properties that approximate the brilliance and fire of diamond better than any previous diamond imitation.

With its introduction into the gem trade late in 1976, cubic zirconia as a diamond imitation immediately created a huge demand as well as considerable anxiety. As with the introduction of every diamond imitation before it (Nassau, 1980a), some jewelers who did not know how to recognize the new material were unable to protect themselves. Nevertheless, examination techniques have now been adapted to readily distinguish cubic zirconia from diamond, and new instruments have appeared to assist the gemologist-jeweler in this task, as outlined in the Appendix.

As with YAG (yttrium aluminum garnet), which was overproduced and peaked about 1972 (Nassau, 1980a), we are now seeing a rapid rise in the production of cubic zirconia accompanied by a rapid fall in the price. This supply-and-demand movement, together with the recent introduction of colored forms of cubic zirconia and the curious patent situation, is also discussed in the following sections.

#### THE SKULL-MELTING TECHNIQUE FOR GROWING CUBIC ZIRCONIA

The technique of crystal growth by solidification from the melt in a container is one of the easiest and least costly ways of obtaining large crystals. When, however, a material has as high a melting point and is as reactive as cubic zirconia, no container can be found to hold the melt, and a "self-contained melt," "cold crucible," or "autocrucible" arrangement must be used. The technique described here was patented by Joseph F. Wenckus and coworkers (1977), now one of the major manufacturers of cubic zirconia as the Ceres Corporation, Waltham, MA.

The apparatus shown in figures 2 and 3 consists of a cup-like arrangement made up of a circle of copper fingers, water-cooled by complicated in-

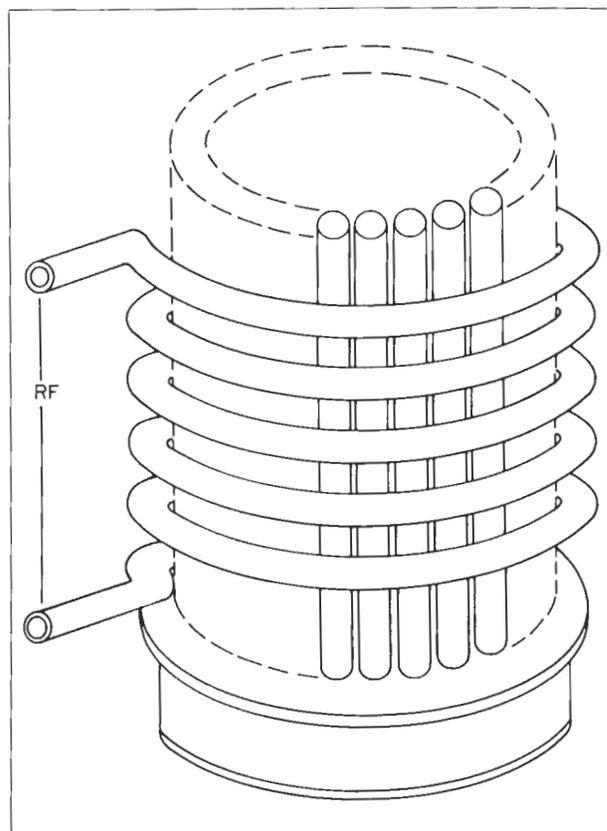


Figure 2. Schematic of one form of skull-melting apparatus; only some of the fingers are shown.



Figure 3. The split halves of a small skull-melting apparatus.

ternal plumbing. There are small gaps between the fingers. Surrounding this apparatus is a water-cooled copper coil activated by a radio-frequency generator, typically operated at a frequency of 4 MHz and at power levels as high as 100 kW.

The small gaps between the metal fingers enable the radio-frequency energy to pass into the cup, which is initially filled with zirconia powder mixed with the required stabilizer. The powder is an electrical insulator at room temperature; it will not begin to heat until after the addition of some pieces of zirconium metal, which are then rapidly heated by the radio-frequency field. As the zirconia adjacent to the zirconium metal heats up, it also begins to conduct electricity and melts in a matter of minutes. The zirconium metal reacts with the oxygen in the air to produce more zirconia.

All the zirconia soon melts, except for a relatively thin sintered shell or skin that remains solid because it is cooled and prevented from melting by contact with the water-cooled fingers. In this way the molten zirconia is contained within a jacket of its own powder, which also prevents contamination from the metal. More zirconia, again containing the required stabilizer, is added to the molten material to fill the skull to the desired level. A porous crust forms over the top of the melt, as shown in section A of figure 4, and helps to reduce heat loss. The contents are kept molten for some hours to ensure uniformity, as well as to permit the vaporization of some impurities. The cup is then lowered very slowly out of the heating coil, typically over a 12-hour period. Useful crystal growth begins at the bottom of the melt. As can be seen in section B of figure 4, crystals nucleate and form parallel columns near the bottom and grow upwards. They continue to grow until the whole melt has solidified, as in section C, whereupon the power is shut off.

The growth process under way is shown in figure 1, and half of a "skull"—the solidified crystals with the surrounding crust—is shown in figure 5. A "dopant," a purposely added impurity, had been used to produce yellow cubic zirconia in this growth run. Light tapping will separate the crystal columns, which appear as in figure 6. Annealing, typically at 1400°C (2552°F), in air or in oxygen may be used at times to remove residual strain to remove any discoloration resulting from a slight oxygen loss, or to adjust the valence states of impurities.

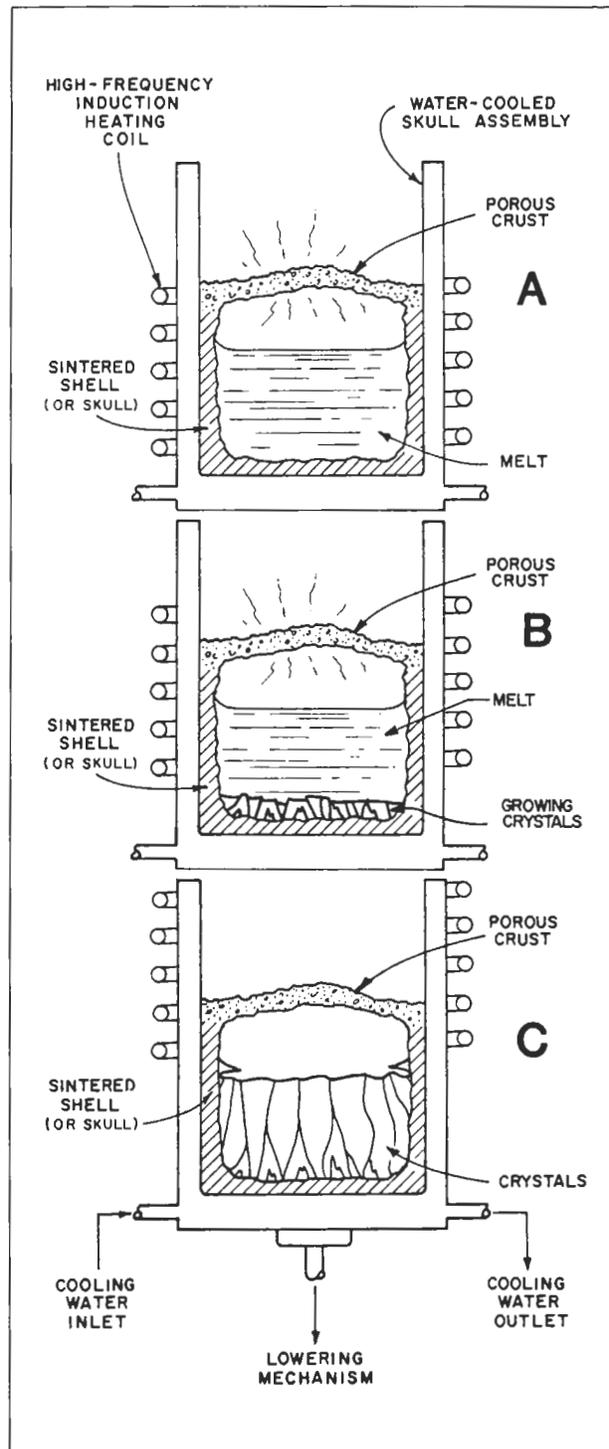


Figure 4. The process of solidification during skull-melting crystal growth. A = formation of a porous crust over the top of the melt, B = early growth of parallel columns of crystal nucleate, and C = final stage, with the entire melt solidified by the crystal growth.



Figure 5. Half of a large skull of yellow cubic zirconia crystals grown using the technique described in figure 4. Courtesy of the Ceres Corp., Waltham, MA.

At first, a skull 3 inches (7.5 cm) in diameter was considered the state of the art for cubic zirconia crystals, but today skulls 12 inches (30 cm) in diameter and weighing 150 lbs. (68 kg), such as the one shown in part in figure 5, are produced. These yield about 100 lbs. (45.5 kg or 227,000 carats) of usable rough. Individual crystals are well over one inch (2.5 cm) wide and several inches long; stones several hundred carats in weight have been faceted. The economy of large-scale production is significant, although the rather high cost of the high-purity starting material is not much affected by such a scale-up.

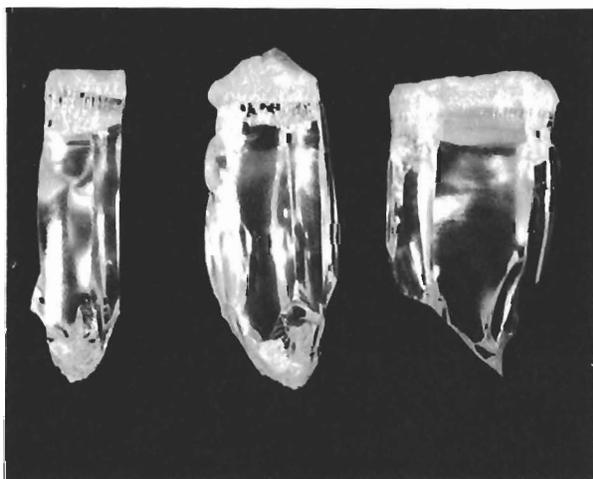


Figure 6. Columnar crystals of cubic zirconia one inch (2.5 cm) across.

### THE CURRENT STATUS OF COLORLESS CUBIC ZIRCONIA

Starting from a small amount in 1976, within just four years production has grown to an estimated 13 tons (12,000 kg or 60 million carats) of cubic zirconia per year at the end of 1980. Corresponding to the figures for rough material, the annual production of faceted material is estimated at about 3 tons (2700 kg or 13.5 million carats) per year. During this same time period, the wholesale price per faceted carat has fallen from an initial US \$40 or more to US \$4 or less, varying of course with the quality of the material and the faceting, as well as with size, shape, and quantity.

It is interesting to compare the production data for cubic zirconia with the data for synthetics previously used as diamond imitations, as shown in table 1. Annual production of cubic zirconia has already well surpassed the YAG peak of 1972 which, it must be remembered, represented overproduction, was more than the market could absorb, and resulted in the discontinuation of production by a number of manufacturers. A reasonable guess would be that the equivalent stage for cubic zirconia is close at hand. A factor that may prevent this from happening is the apparent opening up in recent months of the European market, where previous diamond imitations never achieved significant popularity.

Many jewelry retailers at first showed a strong resistance to handling cubic zirconia, but experience has now demonstrated that the simulant has had no significant effect on diamond sales, occupying instead a separate niche in the jeweler's range of goods. The available data for 1977 permitted an estimate of the retail value of all diamond imitations sold in the United States of about \$20 million, compared to about \$2000 million for diamonds (Nassau, 1980a). Although by now the sales figure for diamond imitations has grown significantly, so has the figure for diamonds, and the 1% ratio of diamond-imitation sales to diamond sales has probably increased only a little.

Major manufacturers of cubic zirconia in the U.S. include the Ceres Corporation of Waltham, MA (marketing through MSB Industries of New York City); ICT Corporation of Shelby, MI; Singh Industries of Randolph, NJ; the Lambda/Airtron Division of Litton Systems of Morris Plains, NJ; and Commercial Crystal Laboratories of South Amboy, NJ. Outside the U.S. there is production

**TABLE 1.** The historical sequence of synthetics used as diamond imitations.

Synthetic	Year of initial use	Peak annual production of rough (in carats)	Year of peak
Sapphire	After 1905	?	?
Spinel	About 1920	?	?
Rutile	1948	750,000	1955
Strontium titanate	1955	1,500,000	1968
YAG	1968	40,000,000 <sup>a</sup>	1972 <sup>a</sup>
GGG	1975	Small	1976
Cubic zirconia	1976	60,000,000 <sup>b</sup>	1980–1981 <sup>b</sup>

<sup>a</sup>Premature peak due to overproduction.

<sup>b</sup>May still be increasing.

in Moscow, USSR (marketed in the U.S. through Clayhill Resources of New York City); at V. Djévahirdjian S.A. of Monthey, Switzerland (at first erroneously reported as using flux-growth [Nassau, 1976]); as well as recent production in Taiwan and undoubtedly elsewhere. The rough material is faceted all over the world, but until recently almost all has been used in the U.S. Despite the great improvement of cubic zirconia over YAG (in brilliance) and over strontium titanate (in hardness), both of these other simulants continue to be manufactured and sold, albeit on a considerably smaller scale.

Claims are sometimes made that one manufacturer's cubic zirconia is better than another's, for example, in respect to turning dark in normal use. Although some bad batches were undoubtedly produced in the early days, currently there is no significant difference in the behavior of the high-grade material produced by the various manufacturers. Similarly, inclusions are virtually absent in top-grade material.

Names used for marketing cubic zirconia include:

CZ	Diamonique III
Cerene	Diamonite or
Cubic Z	Diamondite
Cubic Zirconia	Djevalite
Cubic Zirconia II	Fianite
Cubic Zirconium	Phianite or
Cubic Zirconium	Phyanite
Oxide or Dioxide	Shelby
Diamon-Z	Singh Kohinoor
Diamond-QU	Zirconia
Diamonair II	Zirconium
Diamonesque	Zirconium Yttrium
Diconia	Oxide

Some of these names are registered trademarks, others are not. It is important to note that, by themselves, *zirconium* and *cubic zirconium* are misnomers, since they would refer to zirconium metal! Also, some sellers are using the ending “—Z” with other terms, possibly to imply cubic zirconia when this may not, in fact, be the material at hand.

The stabilizer used in cubic zirconia is usually  $Y_2O_3$ , although CaO has also been used. The phase diagrams indicate that up to 65 weight percent  $Y_2O_3$  or up to 14 weight percent CaO could be used in cubic zirconia. Too much stabilizer results in a softer and less brilliant product, however, and amounts much smaller than those indicated in the phase diagrams are used for the commercial product, as described in the Appendix.

Now that large crystals of cubic zirconia are readily available at a relatively low cost, scientists are once again studying the material for possible technological uses, thus coming full circle to the original purpose for growing the crystals!

Cubic hafnia—hafnium oxide ( $HfO_2$ ) stabilized with  $Y_2O_3$ —has also been described in the cubic zirconia patents. This has about the same refractive index as cubic zirconia, but with an even higher specific gravity. Since hafnia is much more expensive than zirconia, cubic hafnia is not likely to be used as a diamond imitation.

#### THE CUBIC ZIRCONIA PATENTS

In December 1972, the USSR group of V. I. Aleksandrov and coworkers applied for patents in the U.S. and other countries, the relevant claim being cubic zirconia stabilized with 10% to 30% yttrium oxide. British patent 1,373,888 was published on November 13, 1974, and German patent

2,261,851 appeared on July 11, 1974. The U.S. patent application was abandoned and then refiled in March 1977, was again abandoned and then refiled in January 1978; it issued on May 8, 1979, as U.S. patent 4,153,469.

Meanwhile, additional patents had been applied for in January 1975, leading to British patent 1,491,362, published on November 9, 1975, and German patent 2,501,800, published on July 22, 1976. The relevant claim in these patents was cubic zirconia stabilized with 5% to 10% yttrium oxide. Such a claim may also have been involved in one of the U.S. refilings; if so, it was apparently not allowed. It should be noted that the items being patented are the chemical composition of cubic zirconia crystals, not the growth technique.

After the issuance of the U.S. patent in 1979, some retailers hesitated to purchase domestically produced material. At least one U.S. producer (the Ceres Corp.) guaranteed its customers that it would defend them in any suits that might arise from this patent. A suit based on this patent has, in fact, been filed; as of this writing it is still undecided. It should be noted that most cubic zirconia produced in the U.S. is believed to be made with somewhat less than the 10% minimum claimed in the patent. Even if this argument were rejected, there is the fact that the patent contains no mention of the cubic zirconia stabilized with 12.5%  $Y_2O_3$  reported in 1969 (Roulin et al.) and shown in large crystal form in a French film made at that time; this would seem to imply that a court test of the validity of the patent might well result in an invalidation.

### COLORED CUBIC ZIRCONIA

Aleksandrov and coworkers gave details on the manufacture of colored cubic zirconia in their 1972 patent application. Until recently, however, most manufacturers have concentrated on keeping color out of their crystals, since even trace amounts of impurities such as iron can produce a yellow hue, undesirable in a diamond imitation. Some experimentation persisted, though, particularly to find good ruby red and emerald green colors, neither of which seems to have been achieved thus far. Along the way, significant amounts of yellow and other colored material accumulated. Some was faceted by amateurs for the fun of it and was found to be very attractive.

A major breakthrough in the market for colored cubic zirconia was apparent at the 1979 Tuc-

son (Arizona) Gem and Mineral Show, where all available colored cubic zirconia rough was quickly bought up by amateur as well as professional cutters. The attractiveness of the colors lies in their coupling with a high refractive index and dispersion, and can be seen to some extent in figure 7. The optical constants of most colored gemstones—ruby, sapphire, emerald, amethyst, citrine, topaz, etc.—have relatively low values, and their attractiveness resides predominantly in the color. With colored cubic zirconia, however, there is considerable brilliance, or "life," in addition to the color; this liveliness can be transmitted only poorly in even the best photograph.

A listing of the colors produced by specific dopants (purposely added impurities) is given in table 2, and the dopant compounds used to produce desired colors appear in table 3. The nature of the color can change with the concentration of the dopant as well as with its oxidation state, and combinations of dopants are used to obtain desired shades. Just some of the colors produced by one manufacturer are shown in figures 7 and 8. The manner in which allochromatic transition metal impurities produce colors is described elsewhere (Nassau, 1974–75, 1980a, and 1980b).

The most frequently used colors at present are (1) the amethyst to lavender to lilac range, (2) the yellow (canary) to orange to reddish-brown range, and (3) pink. Colored cubic zirconia produces faceted stones that are much more "lively" than the analogous amethyst or purple sapphire for the first color group and citrine, padparadsha sapphire, imperial topaz, or garnet for the second. Prices for colored rough are somewhat higher than for the colorless. At present, these colored stones seem to be used primarily for fad-type medium-priced fashion jewelry. The quantity of colored cubic zirconia produced is still quite small but is increasing rapidly and may soon represent a significant portion of the market. Attractive intense greens, blues, and reds have not been produced thus far.

Were it not for the relative rarity of colored diamonds and the fact that most people are not familiar with them, these colored cubic zirconias would provide excellent imitations for naturally occurring canary, pink, blue, and green diamond. Jewelers should indeed be aware that, with the correct shade and intensity of color, these cubic zirconias could easily be mistaken for colored diamonds.



Figure 7. Faceted cubic zirconias; the largest is 9 mm across. Courtesy of the Ceres Corp., Waltham, MA, and MSB Industries, New York, NY.

**TABLE 2.** Colors produced by specific dopants added to cubic zirconia.<sup>a</sup>

Dopant	Symbol	Color
Cerium	Ce	Yellow-orange-red
Chromium	Cr	Olive
Cobalt	Co	Lilac
Copper	Cu	Yellow
Erbium	Er	Pink
Europium	Eu	Pink
Holmium	Ho	Pink
Iron	Fe	Yellow
Manganese	Mn	Brown-violet
Neodymium	Nd	Lilac
Nickel	Ni	Yellow-brown
Praseodymium	Pr	Amber
Thulium	Tm	Green
Titanium	Ti	Yellow-brown
Vanadium	V	Green

<sup>a</sup>Typically at the few tenths of a percent level; the color achieved may depend on the oxidation state of the dopant.

**TABLE 3.** Dopants used in cubic zirconia to give desired colors.

Color range	Dopants used
Yellow-orange-red	CeO <sub>2</sub> , Ce <sub>2</sub> O <sub>3</sub>
Yellow-amber-brown	CuO, Fe <sub>2</sub> O <sub>3</sub> , NiO, Pr <sub>2</sub> O <sub>3</sub> , TiO <sub>2</sub>
Pink	Er <sub>2</sub> O <sub>3</sub> , Eu <sub>2</sub> O <sub>3</sub> , Ho <sub>2</sub> O <sub>3</sub>
Green-olive	Cr <sub>2</sub> O <sub>3</sub> , Tm <sub>2</sub> O <sub>3</sub> , V <sub>2</sub> O <sub>3</sub>
Lilac-violet	Co <sub>2</sub> O <sub>3</sub> , MnO <sub>2</sub> , Nd <sub>2</sub> O <sub>3</sub>

### PROSPECTS FOR THE FUTURE

In chapter 1 and the epilogue of my book (Nassau, 1980a), there is an extensive discussion of the sources of new synthetics as well as of the way in which these sources have been changing over the years. Today, only the most difficult of the syntheses have not yet been achieved and, as crystal growth techniques have become ever more sophisticated, the search for new crystals has become more costly and time consuming.



Figure 8. Colored cubic zirconia rough; the largest piece is 2.5 inches (6.5 cm) long. Courtesy of the Ceres Corp., Waltham, MA.

It is, therefore, hardly a coincidence that the most recent diamond imitations—YAG, GGG (gadolinium gallium garnet), and cubic zirconia—all originated as spin-offs from technological research. The use of YAG as a laser material is well known, GGG was developed as a substrate for magnetic bubble memories, and cubic zirconia was studied as a possible laser or opto-electronic material. Is it then likely that this source will produce another material that might provide a diamond imitation that is superior to cubic zirconia?

I believe the answer to this question is *yes*, but a qualified *yes*. Although such a material will undoubtedly appear sooner or later, it must be realized that technological research for new materials has slowed significantly. In part, this is because present needs have been largely filled and the areas left to be explored are becoming smaller; in part, it is because existing materials are being studied intensively so as to utilize their poten-

tials more fully. So it may not be all that soon that a potential successor to cubic zirconia will arrive.

Further qualifications arise from two factors. First, the optical constants of cubic zirconia are sufficiently close to diamond in a material of adequate hardness and wearability that a large improvement cannot be expected. This was hardly true of any of the previous diamond imitations. Second, the cost involved in developing and marketing a new synthetic or imitation is never small and, given the existence of a highly satisfactory material in the marketplace, may not be justifiable in terms of the potential returns. (One may note the difficulty synthetic flux-grown rubies have had in achieving market penetration in competition with the Verneuil-grown product; they recently came close to success by posing as natural rubies with forged GIA certificates!) All in all, it would seem that cubic zirconia is likely to be with us for quite some time.

## APPENDIX: TECHNICAL AND GEMOLOGICAL DATA AND IDENTIFICATION

**Composition.** Typically zirconia (zirconium [di]oxide,  $ZrO_2$ ) containing about 10 mol. percent yttria (yttrium oxide,  $Y_2O_3$ ) or 15 mol. percent lime (calcium oxide,  $CaO$ ). Zirconia can exist in several polymorphic structures, as listed in table 4.

**Structure.** Same as that of fluorite,  $CaF_2$ , with Zr in place of Ca and O in place of F. This structure, shown in figure 9, consists of a simple cubic arrangement of oxygens with every other cube occupied by a Zr. Each O is surrounded by four Zr, each Zr by eight O. When  $ZrO_2$  is stabilized with either  $Y_2O_3$  or  $CaO$ , there are fewer than two oxygens per metal atom, and some oxygens are missing: one O for every two Y or one O for every Ca, as is implied in the typical formulations  $Zr_{0.90}Y_{0.10}O_{1.95}$  and  $Zr_{0.85}Ca_{0.15}O_{1.85}$ . Some Zr and some dopants may have only seven or six O around them instead of the usual eight; this changes the crystal field and, accordingly, the color (Nassau, 1974-75, 1980a, 1980b).

**Crystal Symmetry.** Cubic; class,  $4/m\bar{3}2/m$ ; space group,  $Fm\bar{3}m$ .

**Optical Properties.** Refractive index, 2.15 to 2.18; no birefringence, singly refracting; dispersion, 0.058 to 0.066.

**Mechanical Properties.** Hardness, 8.0 to 8.5 (a slight anisotropy in hardness appears to be present; this is possible even in the cubic system and also occurs in diamond); specific gravity, 5.6 to 6.0; no cleavage; conchoidal to uneven fracture; somewhat brittle; good wearability.

**Inclusions.** Small particles (Nassau, 1976, 1977, and 1980a; Liddicoat and Koivula, 1978), gas bubbles (Nassau, 1976), and a curious striated appearance (Nassau, 1976, 1977, and 1980a) can sometimes be seen but are absent in good-quality material.

**Effect of Exposure to Ultraviolet and Other Irradiations.** Variable fluorescence, may be completely absent; often turns brown, depending on quality, nature, and length of irradiation. Good-quality material will again fade to colorless when placed in sunlight for a few hours and will not darken in sunlight, that is, "solarize."

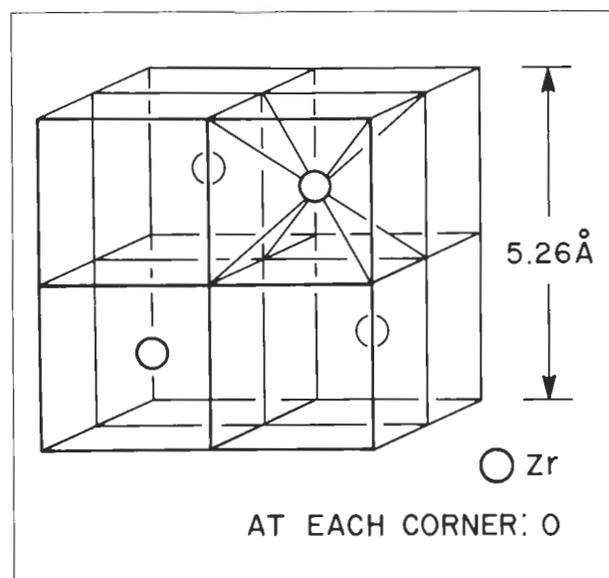


Figure 9. The crystal structure of cubic zirconia.

TABLE 4. The polymorphs of zirconium oxide.

Structure	Temperature range (°C) <sup>a</sup>	Unit cell parameters (Å)	Specific gravity
Monoclinic $P2_1/c$	Up to 1100	$a = 5.15$ , $b = 5.21$ $c = 5.31$ , $\beta = 99^\circ 23'$	5.83
Tetragonal $P4_2/nmc$	1100 to 2000	$a = 3.64$ , $c = 5.27$	5.86
Hexagonal (?)	About 1900	$a = 3.60$ , $c = 5.90$ (5.88)	6.13
Cubic <sup>b</sup> $Fm\bar{3}m$	2300 to 2750	$a = 5.26$	5.64
Cubic <sup>c</sup> $Fm\bar{3}m$	Up to melting	$a = 5.12$	6.00
Cubic <sup>d</sup> $Fm\bar{3}m$	Up to melting	$a = 5.12$ to $5.16$	5.60 to 6.00

<sup>a</sup>The exact temperatures depend on the impurities present and the amounts thereof.

<sup>b</sup>The unstabilized high-temperature form of pure  $ZrO_2$ .

<sup>c</sup>The natural stabilized material of von Stackelberg and Chudoba (1937).

<sup>d</sup>The synthetic stabilized material.

**Distinction from Diamond.** Several articles in this journal have dealt with various aspects of this problem (Liddicoat and Koivula, 1978; Nassau, 1978–79a, 1978–79b, 1981; Nassau and Schonhorn, 1977–78; Shaw, 1978). The distinction is obvious to the trained, aware eye. In a loose stone, the high specific gravity is readily apparent. Flatness of faces and sharpness of edges are not foolproof criteria, and girdles apparently showing “naturals” have been observed on cubic zirconia (Liddicoat and Koivula, 1978; Nassau, 1978–79b). The uniquely high thermal conductivity of diamond provides an unambiguous identification of diamond when a well-compensated instrument such as the Ceres Diamond Probe (Nassau, 1978–79a) is used, but some care is required with a simpler instrument such as the pocket-sized Ceres Czeckmate. A comprehensive test of such instruments, including the GEM Diamond Master is under way (Nassau, to be published). The breath test is a zero-cost version of the thermal conductivity test but requires comparison stones (Nassau,

1978–79b). Although there are some limitations, one of the many reflectivity meters should give a clear distinction (Liddicoat and Koivula, 1978; Nassau, 1978–79b). Finally, the wetting contact angle (Nassau and Schonhorn, 1978–79) provides a distinction when the GEM Diamond Pen or one of a number of other pens is used (see Shaw, 1978, for a discussion of the GEM Diamond Pen, and Nassau, 1978–79b, for a discussion of that and other pens), but surface coatings may have to be removed. As always, the gemologist must guard against the possibility of a doublet.

**Size, Weight, and Shape.** Proportions and cutting techniques have been discussed (Kerr, 1979). A graph for the rapid conversion of size to weight and to the equivalent diamond weight has also been given (Nassau, 1979 and 1980a). It should be noted that cubic zirconia stones may be sold by size, by weight, or by equivalent diamond weight (the last is not always so specified).

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