Synthetic moissanite: A new man-made jewel

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Synthetic moissanite (silicon carbide, SiC) is a new man-made gemstone material developed and marketed by Charles and Colvard, Ltd., (formerly C3 Inc.) of Morrisville, USA. It provides exceptionally attractive and durable jewels, being second in hardness to diamond but not having diamond's pronounced cleavage. Synthetic moissanite can also serve as a diamond substitute, having properties overall closer to those of diamond than any other simulant: refractive indices 2.648 and 2.691 (diamond – 2.417), dispersion 0.104 (0.044), birefringence 0.043 (0), hardness 9–1/4 (10), specific gravity 3.22 (3.52). Thermal probes, in wide use for distinguishing diamond from all other simulants, usually give a 'diamond' reaction when testing synthetic moissanite. Diagnostics to the trained gemmologist for distinction from diamond are the birefringence, characteristic inclusions and subtle surface details.

1. Introduction

Crystal growth yielding the man-made equivalent of a suitable for use in jewellery was first achieved in 1920 when A. V. L. Verneuil of France produced synthetic ruby by a melting approach, using a hydrogen–oxygen torch[1]. The terms 'synthetic', 'man-made', or 'created' when preceding the name of a natural gemstone imply the exact laboratory-produced equivalent, having the same chemical composition, crystal structure and colour-causing impurities or structures; therefore the physical properties and appearance are also the same. Over the years, there has been a series of additional synthetic gemstone materials, the best known being cubic zirconia, widely used as a diamond imitation since 1976 (ref. 1).

A material long known to have great potential for gemstone use is silicon carbide, SiC. This substance is known as carborundum when used in ceramic form as an abrasive, first prepared by E. G. Acheson in the 1890s (ref. 2). It is also known as moissanite, its mineral name, after Ferdinand Frederick Henri Moissan[3], the French Nobel Prize winner (Figure 1), who identified crystals of SiC in the Canyon Diablo (Arizona, USA) meteorite in 1920 (ref. 4). It occurs in nature only as tiny green to black crystals and intensive research over almost a century yielded at best only thin randomly-oriented platelets. In a book published in 1980, the present author wrote[1]: 'Silicon carbide (SiC) presents a special case, since it has shown so much promise for so long . . . . During the manufacture of silicon carbide for abrasive use, some flat centimeter-size single crystal plates have been occasionally obtained . . . (these) range in colour from black via green to pale tan, and up to one half carat gemstones have been faceted. These synthetic moissanites are quite attractive and might provide a superb diamond imitation if they could only be made completely colourless. Despite many decades of intense effort by scientists using a variety of different approaches, it has not been possible to control either the colour, or even the crystal growth itself precisely enough to make single crystals suitable for either technological or gemmological use'.

Only recently has the controlled growth of large crystals, both coloured and near-colourless synthetic moissanites, been achieved at Cree Research Inc. of Durham, NC, USA[5,6], so that material that is colourless to the naked eye finally became available for gemmological use.

The technological importance of SiC was demonstrated by a series of international conferences starting in 1959 (ref. 7). Only at the sixth conference in 1969 (ref. 8) were there 'epoch-making results in the history of the subject . . . . For SiC these include . . .'.

This article summarizes the background for and characteristics of synthetic moissanite, a new attractive and durable man-made jewel that can also serve as the most

Figure 1. Ferdinand Frederick Henri Moissan, the discoverer of elemental fluorine (received the Nobel Prize in 1906), the carbon arc furnace and moissanite in the Canyon Diablo (Arizona) meteorite[3].

convincing diamond substitute to date (see Figure 2). A summary of gemmological data and identification techniques is also given; detailed gemmological examinations[9,10] and additional background material[10] have been published. While moissanite does exist in nature, both terrestrially and in meteorites, it does not occur in pieces large enough to be faceted.

2. Structure and growth of moissanite

Considerable confusion resulted when early investigators found a variety of different structures for moissanite, including those having cubic (C), hexagonal (H), and rhombohedral (R) symmetries. This complexity is explained by the existence of *polytypes* variations in the crystal structure that can depend on growth conditions[10,11]. Such polytypes can occur in any material consisting of stacked identical hexagonal layers, based on variations in the stacking sequence; properties generally change only a little. More than 150 polytypes are known in the case of SiC, all of which are properly designated as moissanite. Note that carbon also occurs in two polytypes: cubic diamond and hexagonal lonsdaleite.

The synthetic material described here is the moissanite-6H form of o-silicon carbide or SiC : 6H which has a stacking sequence consisting of repetitions of the six-layer ABCACB unit shown in Figure 3. The only other moissanite polytype that can be grown in large crystals is the 4H form[6], which has the stacking sequence ABCB . . . . The cubic 3C polytype, silicon carbide, with the stacking sequence ABC . . . might be interesting if it could be grown in bulk; its inherent deep yellow colour would prevent its use as a diamond imitation, but not as a unique synthetic jewel.

The Acheson process[2] for the production of carborundum abrasives is used industrially on a huge scale[11–16]. Carbon in the form of petroleum coke or anthracite coal is mixed with sand and a little sawdust and salt. An electric current is passed through a central graphite rod surrounded by the mixture to heat it internally to a maximum temperature of 2700°C (4892°F), producing the simple reaction:

$$SiO_2 + 3C \rightarrow SiC + 2CO.$$

Batch sizes range up to 125 tons[11]. A bulldozer is used to break up the reacted mass (Figure 4), which is then crushed to yield an abrasive powder. This may then be pressed or cemented into products such as sharpening stones, grinding wheels and the like. About half of the production is used for abrasives and about half in the metallurgical industry to de-oxidize and modify molten

Figure 2. Twelve near-colourless synthetic moissanite jewels; the largest is 6.73 ct, 12.5 mm and would be graded as M, SI1 on the GIA scale. Material courtesy of Charles and Colvard. Photo by Robert Weldon.

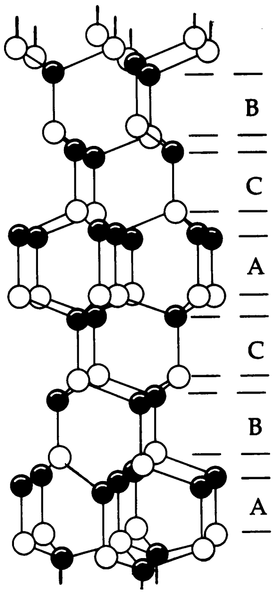

Figure 3. Structure of the 6H form of o-silicon carbide; a single repeating unit is shown.

Figure 4. A cluster of black carborundum platelets (synthetic moissanite) produced by the Acheson process[2] for abrasives use.

iron and steel. Minor uses include high temperature and/or chemically-resistant structural items such as turbine blades, as well as crucibles and heating elements for furnaces operating up to 1600°C (2912°F).

Single crystals occasionally occur among clusters (Figure 4) in sizes up to 1 cm across and a few millimetres in thickness, ranging in colour from black to green to tan, from which stones up to about 1/2 carat have been cut occasionally.

Several techniques for growing crystals of synthetic moissanite have been studied for almost a century[7,11–17]. Of these only a seeded sublimation process, derived from the Lely[17] approach, has proved viable for the controlled growth of large single crystal boules of moissanite. The Lely process uses sublimation, where SiC is vapourized and then condensed without ever passing through the liquid state. In his original work, Lely[17] used a cylinder made of lumps of SiC containing a hollow cavity. This was heated in a sealed graphite crucible to 2500°C (4532°F), when crystals grew inside the cavity. Many modifications have been tried out to control purity and polytypes, particularly the use of a thin porous graphite tube to line the cavity, as well as carefully controlled atmosphere and temperature gradients. The lining tube controls the rate of sublimation, with crystals growing on its inside. The work of Tairov and coworkers in Russia provided significant advances[18].

The final break-through in the control of the Lely process came at Cree Research with the patent[5] of Davis *et al.*, where controlled growth of a specific polytype occurs on a seed crystal. One configuration described in this patent is shown in a simplified form in Figure 5. As indicated by the arrows, SiC vapour from the feed powder passes through the porous graphite tube to feed the growing crystal boule. Because of proprietary considerations, details of the actual growth process have not been released by Cree Research, who own the rights to this patent and who manufacture the crystals.

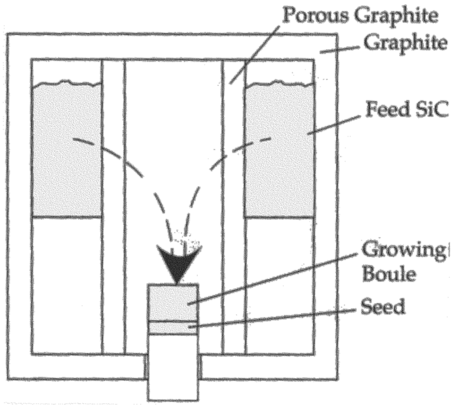

Figure 5. Growth configuration described in the patent of Davis *et al.*[5] for the controlled growth of single crystal moissanite.

This patent, initially filed in 1987, reports the growth of a 12 mm diameter, 6 mm thick moissanite-6*H* crystal during a six hour growth period. One of many recent publications by Cree Research[8] on various aspects of moissanite growth and applications to the electronics industry mentions 50 mm diameter boules in 1994 (ref. 19). Crystals three inches (7.5 cm) in diameter are under development and a magnificent faceted round jewel 4.75 cm (1–7/8 inch) in diameter weighing 310 ct (62 gm) has recently been cut.

Yellow to green synthetic moissanite is easily obtained when traces of atmospheric nitrogen enter the lattice; in diamond, nitrogen impurities also cause the same colours. A blue colour is produced by the addition of aluminum. A technique for obtaining near-colourless synthetic moissanite by compensating impurities is described in a patent by Carter *et al.*[6].

3. Gemmological considerations

The major gemmological constants of synthetic moissanite are compared with those of diamond and cubic zirconia in Table 1. More details and other properties have been published elsewhere[9,10].

As has always happened with any new synthetic gemstone material, there has been considerable concern in the jewellery trade. Particularly problematic are properties of synthetic moissanite so close to those of diamond that it usually passes as ‘diamond’ under test by thermal probe instruments, by the ‘red-through’ effect, and by several other conventional tests used to distinguish diamond from its simulants.

While Charles and Colvard, the manufacturer and marketer of faceted synthetic moissanites, is positioning it as a new attractive and durable synthetic jewel, the colourless material is also widely perceived as a diamond substi-

Table 1. Some properties of diamond, moissanite and cubic zirconia

Material	Mohs hardness	Toughness	Refractive index	Dispersion	Birefringence	Specific gravity
Diamond	10	*	2.427	0.044	None	3.52
Moissanite	9.25	Excellent	2.67#	0.104	0.043	3.22
Cubic zirconia@	8.5	Good	2.16	0.060	None	5.80

*Good in cleavage direction, otherwise exceptional.

#Average of the two birefringence values, 2.648 and 2.691.

@All values can vary somewhat, depending on the nature and concentration of stabilizer.

tute. With regard to the latter, it is now 24 years since cubic zirconia was first seen in the trade as a diamond imitation in 1976 (ref. 1). This is probably the longest unchallenged reign of any synthetic diamond simulant.

All previous synthetic diamond imitations[1] have significant deficiencies. As examples, synthetic spinel, colourless sapphire and yttrium aluminum garnet are much less brilliant; synthetic rutile and strontium titanate are much too soft; gadolinium gallium garnet and cubic zirconia have very high specific gravities, and the last of these is somewhat brittle. By contrast as seen in Table 1, the synthetic moissanite has refractive index a little higher than that of diamond, significantly higher dispersion (but not as excessive as 0.190 of strontium titanate), specific gravity near that of diamond and hardness second only to that of diamond.

The hardness of synthetic moissanite of 9–1/4 on the Mohs scale, where diamond is 10 and corundum (ruby, sapphire) is 9, can be misleading because of the nonlinearity at the top of the Moh's scale as seen in Figure 6, in fact, synthetic moissanite cannot be polished by conventional techniques. Synthetic moissanite is actually tougher than diamond because it has no strong cleavage as does diamond. There is a strong (0001) parting in the heavily twinned Acheson platelets (previously misinterpreted as a strong cleavage), but only a weak basal cleavage in single crystal moissanite[9]. The thermal properties are so close to those of diamond, that all thermal probe testers tried gave a 'diamond' reaction for synthetic moissanite[9].

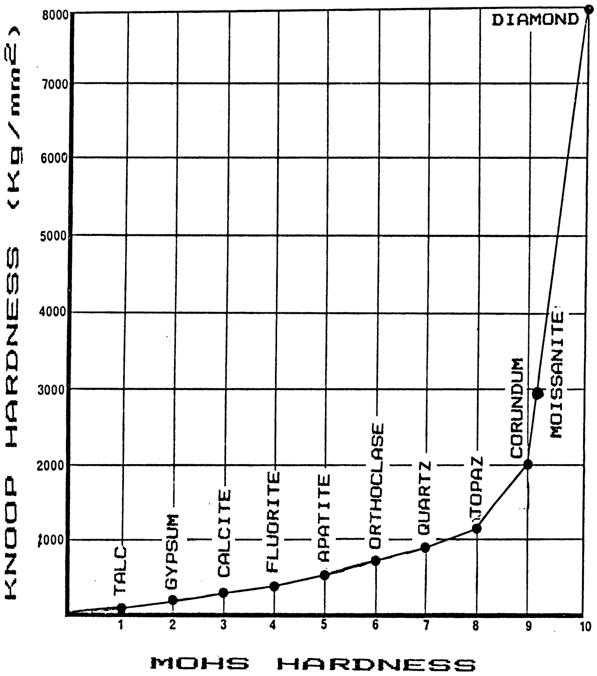

Figure 6. Comparison of the Moh's (scratch) and Knoop (indentation) hardness scales; the latter better illustrates the hardness relationship among the hardest gemstone materials.

A drawback of synthetic moissanite is the presence of a significant birefringence of 0.043; this is much less than the huge 0.330 of synthetic rutile, once used as a diamond imitation. Birefringence produces an apparent doubling of facet junctions, resulting in a 'fuzzy' appearance. However this effect is minimal in practice because all synthetic moissanite jewels are faceted with the optic axis perpendicular to the table facet. As a result, doubling of facets is absent when looking squarely into the top of a stone at the culet region. Doubling is an excellent identification criterion, seen when focusing deeper at reflections in the pavilion facets as in Figure 7 or when looking into a stone at an angle.

Colours of marketed synthetic moissanite jewels range from J to M on the GIA diamond scale, some with greyish, greenish, yellowish or brownish hues. Under ordinary illumination, especially when set in jewellery, these colours usually appear to be better than their equivalent diamond grades. This difference has two origins. The first is particularly noted in greyish stones, which lack the expected yellow of the cape series. The second derives from the higher dispersion, the fire from which appears to create a 'whiter' impression. Marketing of synthetic moissanite jewels by Charles and Colvard began in 1998 with prices in the 5–10% range of the average retail price of comparable diamonds.

White sub-parallel needles near-perpendicular to the table facet as in Figure 8 are often seen under magnification, as well as pinpoint inclusions, sometimes arranged in clouds. Polishing lines are all in one direction, providing valid distinction from diamond, where the variability of hardness with orientation forces the polisher to constantly adjust direction. Facet junctions may be somewhat rounded compared to those of diamond.

The spectroscope shows no lines, but there is an absorption below about 425 nm, which could be confused

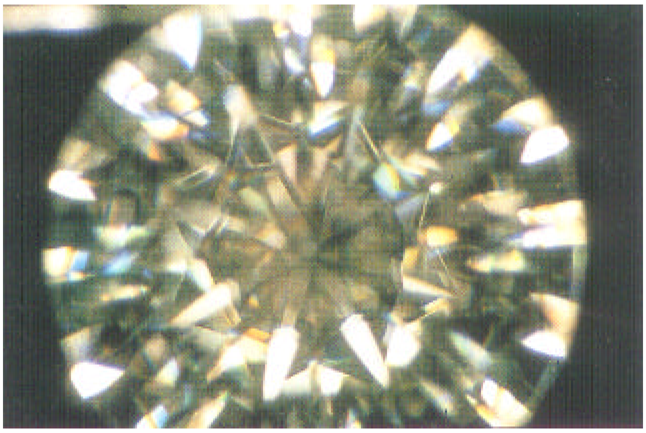

Figure 7. Doubling of the table and crown facets in a synthetic moissanite jewel derived from the birefringence, seen by reflection; other facet junctions remain single, because the view is down the *c*-axis (17 ×). Photo by James McClure, courtesy of GIA.

with the ‘Cape’ line seen at 415 nm in yellowish diamonds[9]. This absorption is used in the ‘Colourless Moissanite/Diamond Tester Model 590’, shown in Figure 9, developed by Charles and Colvard for distinction from diamond, intended to be used only after a thermal tester has given a ‘diamond’ indication.

Infrared, ultraviolet and Raman spectra are characteristic and different from those of diamond[9]. The short-wave and long-wave UV fluorescence is inert (usually) to moderate orange and uniform if present, the X-ray luminescence is inert (usually) to moderate yellow, and the X-ray transparency is medium opaque[9].

Reflectometers give a higher reflectivity than that of diamond, but great care must be taken, since these instruments may give variable responses with doublets and with dirty or poorly polished surfaces. In addition, a surface film of silica produced by heating in air can give any reflectivity, including that of diamond, even down to zero[20].

The stability of moissanite to heat is better than that of diamond: in air to 1700°C (3092°F), in vaccum to 2000°C, to most chemicals to well over 1000°C, except to fluorine, chlorine, molten alkalis and some molten metals[12]. There is excellent resistance to *in situ* soldering of broken prongs and all usual jewellery procedures such as setting, repairing and cleaning; it is even possible to cast gold jewellery with stones in place as in Figure 10.

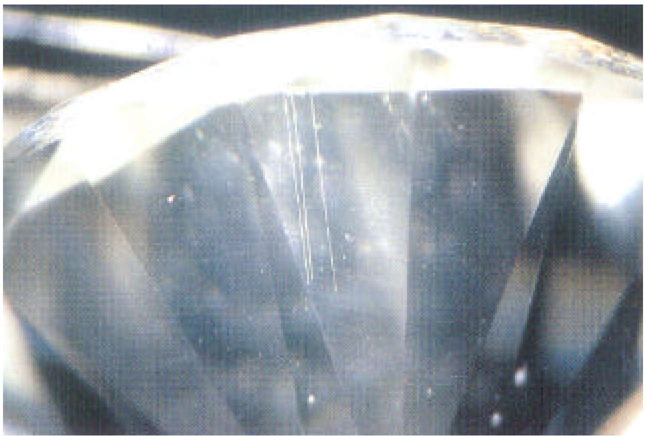

Figure 8. Needles and scattered pinpoint inclusions frequently seen in synthetic moissanite (20 ×). Photo by John Koivula, courtesy of GIA.

4. Distinguishing synthetic moissanite from diamond

To the trained eye, the distinction between synthetic moissanite and diamond should present no problems. Under magnification, the double refraction as in Figure 7 is diagnostic. It must be emphasized that visual examination looking squarely down at the table can be misleading, since jewels are faceted with the optic axis perpendicular to the table.

A thermal tester will give a positive ‘diamond’ response for both diamond and moissanite, distinguishing these two materials from all other gemstones; the Model 590 tester described above (see Figure 9), can then be used for a definitive identification of diamond or moissanite.

Strong indications are sub-parallel needles near-perpendicular to the table facet as in Figure 8, unidirectional polishing lines, and somewhat rounded facet junctions. Reflectometers can give positive identification, but see the qualifications given above. Both the near ultraviolet and X-ray opacities could also be used as distinguishing criteria.

For loose stones, the specific gravity can provide a convenient distinction from diamond: moissanite float but diamond, cubic zirconia and all the other currently-used diamond imitation sink in methylene iodide (specific gravity 3.32); note that care and adequate ventillation are required with this toxic material.

Figure 9. The Colourless Moissanite/Diamond Tester Model 590 of Charles and Colvard, designed to distinguish between diamond and synthetic moissanite only after a stone is given a ‘diamond’ reaction by a thermal probe. Photo by Maha DeMaggio, courtesy of GIA.

Figure 10. A 14 kt gold ring containing pale green synthetic moissanite jewels that were mounted in wax and then cast in place. Photo by Maha DeMaggio, courtesy of GIA.

5. Summary

Synthetic moissanite provides reasonably priced attractive and durable new jewels. At present it can be grown in green, yellow, blue and near-colourless forms, the last of these providing a believable diamond substitute that is closer in appearance and heft to diamond than any other gemstone material. Compared to diamond, it has more dispersion but about the same brillance, a higher refractive index, a slightly lower specific gravity. It is closer in hardness to diamond than any other gemstone material known to man, but does have a significant birefringence.

A positive distinction from diamond is most conveniently obtained in one of three ways:

(a) By examination under magnification for birefringence (Figure 7), inclusions (Figure 8), polishing marks and facet edges; (b) By the use of a thermal tester followed by the Tester 590 (Figure 9); (c) For loose stones by flotation in methylene iodide.

While there have already been a number of misidentifications usually based on blind reliance on thermal testers, knowledge of the characteristics of this new synthetic gemstone material should readily prevent such occurrences.

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