# GEMOLOGICAL PROPERTIES OF NEAR-COLORLESS SYNTHETIC DIAMONDS

By James E. Shigley, Thomas M. Moses, Ilene Reinitz, Shane Elen, Shane F. McClure, and Emmanuel Fritsch

*Examination of 51 colorless to near-colorless synthetic diamonds from all known sources of production confirms that they can be distinguished from similar-appearing natural diamonds on the basis of their gemological properties. Although some may contain opaque mtallic inclusions, the most distinctive feature of near-colorless synthetic diamonds is their luminescence to ultraviolet radiation and to an electron beam (cathodoluminescence). In particular, almost all fluoresce yellow or yellow-green to short-wave UV and, when the ultraviolet lamp is turned off, they continue to phosphorese for 60 seconds or more. These distinctive reactions to ultraviolet radiation are very useful in identification, because many diamonds can be checked at one time.*

ABOUT THE AUTHOR

*Dr. Shigley is director of GIA Research, Carlsbad, California; Mr. Moses is vice president of Identification Services, and Dr. Reinitz is a research scientist, at the GIA Gem Trade Laboratory, New York; Mr. Elen is a research associate in GIA Research, Carlsbad; and Mr. McClure is supervisor of Identification Services in the GIA Gem Trade Laboratory, at the Gemological Laboratory, Physics Department, University of Nantes, France.*

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The past few years have witnessed the entry into the trade of synthetic diamonds (mainly yellow) from various research institutes in Russia and elsewhere (Shigley et al., 1993a; Scarratt et al., 1994). In 1993, however, Thomas Chatham, of Chatham Created Gemstones, made the first of several public announcements of his intention to market Russian-grown synthetic diamonds, including "colorless" ones, for jewelry purposes ("Chatham to sell 'created' diamonds," 1993; Nassau, 1993). So far, however, there are only a few documented cases of faceted "colorless" synthetic diamonds in the jewelry trade. In 1996, a near-colorless 0.16 ct round-brilliant-cut synthetic diamond was submitted to the GIA Gem Trade Laboratory in New York by a local diamond dealer, and was quickly identified by laboratory staff. Nevertheless, gem-testing laboratories, individual diamond dealers, and jewelers need to prepare for the appearance of small amounts of this material in the market, possibly represented as natural stones.

A brief description of the distinctive features of colorless to near-colorless synthetic diamonds was provided in a chart and article by Shigley et al. (1995). However, the information in that chart was based on the examination of only 22 near-colorless synthetic diamonds, the total data base at the time the chart was prepared. The present article expands on that description by presenting detailed information on these 22 synthetic diamonds plus 29 examined since then (see, e.g., figure 1), for a total of 51 colorless to near-colorless synthetic diamonds tested by GIA researchers from 1984 through 1996 (see the list in table 1). All known manufacturers are represented.

## BACKGROUND

In 1971, Robert Crowningshield published the first gemological description of the faceting-quality synthetic

*Figure 1. These near-colorless synthetic diamonds (0.41 to 0.91 ct) were fashioned from crystals grown for experimental purposes at the De Beers Diamond Research Laboratory in Johannesburg, South Africa. Examination of these and many other near-colorless synthetic diamonds, representing all known methods of production, has revealed several distinctive gemological properties that allow then identification by standard gem-testing methods.*

diamonds that had been grown by General Electric (G.E.) scientists. Among the samples he examined were two faceted synthetic diamonds that were nearly colorless (0.305 ct and 0.260 ct; "J" and "G" color grades, respectively).

Although a number of diamond simulants (such as strontium titanate, yttrium aluminum garnet [YAG], and synthetic spinel) were available in the jewelry trade at that time (Nassau, 1980; Hobbs, 1981), these could be easily and readily distinguished from diamond on the basis of their thermal conductivity and other gemological features. In contrast, the possibility of faceted "colorless" synthetic diamonds entering the gem market caused great concern among diamond dealers at both wholesale and retail levels. If these synthetics could not be identified readily and practically with simple gem-testing equipment (since thermal conductivity meters would read the same for both natural and synthetic diamond), they could undermine consumer confidence in natural gem diamonds.

Following the article by Crowningshield (1971) and an update on the G.E. synthetics by Koivula and Fryer (1984), we know of only a few other gemological articles that mention "colorless" synthetic diamonds. In the early 1990s, we reported on two experimental, isotopically pure carbon-12, diamond crystals (1.04 and 0.91 ct) grown at General Electric Superabrasives (Anthony et al., 1990; Shigley et al., 1993b). Shigley et al. (1992) described a 5.09 ct synthetic diamond crystal produced by Sumitomo researchers that was yellow and blue at the outer portions, and colorless in the center. Rooney et al. (1993) described a small, experimental, boron-doped, near-colorless (slightly gray) De Beers synthetic diamond that weighed 0.049 ct. In their Fall 1996 Gems *&* Gemology article, Welbourn et al. describe two diamond-verification instruments developed by De Beers scientists, the DiamondSure™ and the DiamondView™. The DiamondSure, which is based largely on a spectral feature inherent to most near-colorless type la natural diamonds, but not their colorless to near-colorless synthetic counterparts, will refer near-colorless synthetic diamonds for further tests. However, the Diamond View uses the pattern of ultraviolet fluorescence, which is very different for natural as compared to synthetic diamonds, as the basis for separating both near-colorless and colored diamonds.

## MATERIALS AND METHODS

**Synthetic Diamonds Examined.** Table 1 lists the 51 near-colorless synthetic diamond samples seen by GIA researchers from 1984 to the present and some of our observations: 11 from General Electric, three produced by Sumitomo Electric Industries, six Russian synthetic diamonds (the research facility where they were produced has not been identified by the distributor, Chatham Created Gems), 22 manufactured by De Beers researchers in South Africa, eight of unidentified manufacture (loaned by Starcorp Inc., of Goleta, California), and the 0.16 ct round brilliant mentioned above, which was submitted to the GIA Gem Trade Laboratory by a client in the trade. Most of these 51 samples (specifically, the G.E., Sumitomo, and De Beers

TABLE 1. Properties of near-colorless synthetic diamonds examined by GIA. 1984–1996.

| Ref. no. | Discription | Color grade[a] | Date of study | Mfr.[d] | Ultraviloet luminescence[e] | | Cathodo-Inclusions | Inclusions | Attraction to a magnet | Electrical conductivity (intensity) | Other features |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Short-wave UV fluorescence | Phosphorescence (duration) | | | | | |
| 10210 | 0.30 ct round brilliant | n.t.[b] | 1984 | G.E. | Weak yellow | Yellowish white | n.t. | n.t | n.t. | n.t. | |
| 10211 | 0.31 ct crystal | n.a.[c] | 1984 | G.E. | Yellow | Yes (color not reported) | n.t. | n.t. | n.t. | n.t. | |
| 20121 | 0.20 ct crystal | na. | 1986 | G.E. | Moderate yellowish white | Strong blue, persistent[f] | n.t. | Opaque metallic flux | n.t | n.t | |
| 20226 | 0.50 ct crystal | n.a. | 1986 | Sumitomo | Moderate yellow | Strong yellow, persistent | Strong green-blue; blue phosphorescence | Opaque metallic flux | n.t. | Yes (variable) | |
| 20805 | 0.75 ct crystal | n.a. | 1988 | G.E. | Moderate yellow, zoned | Strong yellow, persistent | Strong blue, zoned; blue phosphorescence | Opaque metallic flux | n.t. | Yes | Blue electrolumines cence |
| 20808 | 0.39 ct round brilliant | J-K | 1988 | G.E. | Moderate yellow, zoned | Moderate yellow, persistent | Strong blue, zoned | Opague metallic flux | n.t. | Yes (weak) | |
| 781 | 0.91 ct crystal | n.a. | 1991 | G.E. | Weak orange-yellow | Moderate green-yellow, persistent | Strong blue, zoned | Clouds of gray platelets | Yes | n.d.[g] | Yellow luminescence to X-rays |
| 782 | 1.04 ct crystal | n.a. | 1991 | G.E. | Weak orange-yellow | Moderate green-yellow, persistent | Moderate yellow-green, zoned | Triangular platelets and opaque metallic flux | n.d. | n.d. | Yellow luminescence to X-rays |
| 21282 | 0.78 ct round brilliant | F-G | 1991 | G.E. | Moderate green-yellow, zoned | Moderate green-yellow, persistent | n.t. | Opaque metallic flux | Yes | Yes (variable) | Blue electroluminescence |
| 21283 | 0.29 ct oval brilliant | H | 1991 | G.E. | Moderate green-yellow, zoned | Moderate green-yellow, persistent | n.t. | Pinpoint | Yes | Yes (variable) | Blue electroluminescence |
| 21399 | 0.05 ct round brilliant | K | 1991 | De Beers | Strong yellow, zoned | Strong yellow, persistent | Strong yellow, zoned | Opaque metallic flux | n.d. | n.d. | Faint yellow and blue color zones |
| 21620 | 0.16 ct crystal | n.a. | 1993 | De Beers | Moderate green-yellow | Moderate yellow, persistent | Yellow-green, zoned | Triangular platelets and opaque metallic flux | n.d. | Yes (variable) | Faint blue color zone |
| 21621 | 0.15 ct crystal | n.a. | 1993 | De Beers | Moderate green-yellow | Moderate yellow, persistent | Yellow-green, zoned | Pinpoint attraction | Weak | n.d. | |
| 21622 | 0.15 ct crystal | n.a. | 1993 | De Beers | Moderate green-yellow | Moderate yellow, persistent | Yellow-green, zoned | Opague metallic flux | Moderate attraction | n.d. | |
| 21705 | 1.25 ct crystal | n.a. | 1994 | Sumitomo | Moderate orange-yellow, zoned | Orange-yellow | Weak blue, zoned | Opaque metallic flux | Moderate attraction | Yes (variable) | Zoned: blue and red electroluminescence, with blue phospho rescence; orange thermoluminescence; weak orange fluores cence to long-wave UV |
| 21706 | 0.23 ct crystal | n.a. | 1994 | Sumitomo | Weak green, zoned | Greenish blue, persistent | Strong blue | Opaque metallic flux | n.d. | n.d. | |
| 21617 | 0.19 ct crystal | n.a. | 1994 | De Beers | Moderate greenish yellow, zoned | Moderate yellow, persistent | Yellow-green, zoned | Opaque metallic flux | Weak attraction | Yes (variable) | Faint blue and yellow color zones |
| 21619 | 0.17 ct crystal | n.a. | 1994 | De Beers | Moderate greenish yellow, zoned | Moderate yellow, persistent | Yellow-green, zoned | Opaque metallic flux | Weak attraction | Yes (variable) | Faint blue and yellow color zones |
| 21618 | 0.22 ct crystal | n.a. | 1994 | De Beers | Moderate greenish yellow, zoned | Moderate yellow, persistent | Yellow-green, zoned | Pinpoint | n.d. | Yes (variable) | Faint blue and yellow color zones |
| 21686 | 0.42 ct crystal | n.a. | 1994 | Unidentified Russian co. (Chatham) | Very weak yellow | Weak yellow, persistent | n.t. | Opaque metallic flux | n.d. | Yes (variable) | |
| 30089 | 0.11 ct crystal | n.a. | 1995 | Unidentified Russian co. (Chatham) | Weak yellow | Moderate yellow, persistent | n.t. | Opaque metallic flux | Yes | Yes (variable) | |
| 30099 | 0.01 ct round brilliant | I | 1996 | Unknown (Starcorp) | Inert | Inert | n.t. | None visible | Too small to test | Too small to test | |
| 30094 | 0.09 ct trill iant | I | 1996 | Unknown (Starcorp) | Weak yellow, zoned | Weak yellow, persistent | n.t. | Opaque metallic flux | Yes | n.d. | |
| 30091 | 0.11 ct rectangle | K | 1996 | Unknown (Starcorp) | Weak yellow, zoned | Weak yellow, persistent | n.t. | Opaque metallic flux | Yes | Yes (variable) | Blue electroluminesc ence, zoned, withblue phosphorescence |
| 30096 | 0.22 ct crystal | n.a. | 1996 | Unknown (Starcorp) | Moderate yellow | Moderate green-blue, persistent | n.t. | Opaque metallic flux | Yes | Yes (variable) | Blue electrolumines cence, zoned, with blue phosphores cence; fluoresced weak yellow to long-wave UV |
| 30092 | 0.07 rectangle | I | 1996 | Unknown (Starcorp) | Weak yellow, zoned | Strong yellow, persistent | n.t. | Opaque metallic flux | Yes | Yes (variable) | Blue electrolumines cence, zoned, with blue phosphores cence |
| 30095 | 0.25 ct crystal | n.a. | 1996 | Unknown (Starcorp) | Weak yellow, zoned | Strong yellow, persistent | n.t. | Opaque metallic flux | n.d | Yes (variable) | Blue electrolumines cence, zoned, with blue phosphores cence |

| Ref. no. | Discription | Color grade[a] | Date of study | Mfr.[d] | Ultraviloet luminescence[e] | | Cathodo-Inclusions | Inclusions | Attraction to a magnet | Electrical conductivity (intensity) | Other features |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Short-wave UV fluorescence | Phosphorescence (duration) | | | | | |
| 30098 | 0.02 ct round brilliant | H | 1996 | Unknown (Starcorp) | Weak yellow | Strong yellow, persistent | n.t. | None visible | Too small to test | Too small to test | |
| 30097 | 0.02 ct round brilliant | H | 1996 | Unknown (Starcorp) | Weak yellow | Strong yellow, persistent | n.t. | None visible | Too small to test | Too small to test | |
| 30103 | 0.41 ct round brilliant | G | 1996 | De Beers | Weak yellow-green, zoned | Strong green-yellow | Strong blue | Opaque metallic flux | n.d. | n.d. | Blue thermolumines cence |
| 30102 | 0.52 ct round brilliant | I | 1996 | De Beers | Weak yellow-green, zoned | Strong green-yellow | Strong blue | Opaque metallic flux, with a reddish appearance | Moderate attraction | n.d. | Blue thermolumines cence |
| 35018 | 0.16 ct round brilliant | F to G | 1996 | Unknown | Weak yellow-green | Weak green changing to blue | Moderate blue, zoned | None visible | n.d. | n.d. | |
| 35017 | 0.72 ct round brilliant | H to J | 1996 | G.E. | Moderate yellow | Strong yellow-green | n.t. | Pinpoint | n.d. | nd | |
| 30100 | 0.61 ct round brilliant | H | 1996 | De Beers | Weak yellow, zoned | Strong green-yellow | Strong blue, zoned | Blue, triangular platelets | n.d. | n.d. | Blue thermolumines cence |
| 30101 | 0.91 ct round brilliant | I | 1996 | De Beers | Weak yellow, zoned | Strong green-yellow | Strong blue | Opaque metallic flux | n.d. | n.d. | Blue thermolumines cence |
| 21966 | 0.56 ct round brilliant | H | 1996 | De Beers | Moderate yellow-green, zoned | Moderate yellow-green | n.t. | Platelet, pinpoint, and opaque metallic flux | Moderate attraction | n.d. | |
| 21965 | 0.58 ct round brilliant | I | 1996 | De Beers | Moderate yellow-green, zoned | Moderate yellow-green | n.t. | Triangular platelets | Weak attraction | n.d. | |
| 21962 | 0.37 ct round brilliant | H | 1996 | De Beers | Moderate yellow-green, zoned | Moderate yellow-green | n.t. | Platelet, pinpoint, and opaque metallic flux | n.d. | n.d. | |
| 21961 | 0.26 ct round brilliant | H | 1996 | De Beers | Moderate yellow-green, zoned | Moderate yellow-green | n.t. | Pinpoint and opaque metallic flux | n.d. | n.d. | |
| 21960 | 0.37 ct round brilliant | H | 1996 | De Beers | Moderate yellow-green, zoned | Moderate yellow-green | n.t. | Pinpoint and opaque metallic flux | n.d. | n.d. | |
| 21959 | 0.32 ct round brilliant | H | 1996 | De Beers | Moderate yellow-green, zoned | Moderate yellow-green | n.t. | Platelet, pinpoint, and opaque metallic flux | n.d. | n.d. | |
| 21970 | 0.42 ct round brilliant | H | 1996 | De Beers | Moderate yellow-green, zoned | Moderate yellow-green | n.t. | Pinpoint and opaque metallic flux | Weak attraction | n.d. | |
| 21969 | 0.67 ct round brilliant | I | 1996 | De Beers | Moderate yellow-green, zoned | Moderate yellow-green | n.t. | Pinpoint and opaque metallic flux | Strong attraction | n.d. | |
| 21967 | 0.57 ct round brilliant | H | 1996 | De Beers | Moderate yellow-green, zoned | Moderate yellow-green | n.t. | Platelet, pinpoint, and opaque metallic flux | n.d. | n.d. | |
| 21956 | 0.36 ct round brilliant | H | 1996 | De Beers | Moderate yellow-green, zoned | Moderate yellow-green | n.t. | Pinpoint and opaque metallic flux | n.d | nd | |
| 30105 | 0.51 ct crystal | n.a. | 1996 | Unidentified Russian co. (Chatham) | Very weak orange | Weak yellow | n.t. | Opaque metallic flux | Yes | Yes | |
| 30106 | 0.50 ct crystal | n.a. | 1996 | Unidentified Russian co. (Chatham) | Strong yellow | Strong yellow, persistent | n.a. | Opaque metallic flux | Yes | Yes | |
| 30107 | 0.41 ct crystal | n.a. | 1996 | Unidentified) Russian co. (Chatham) | Strong yellow | Strong yellow, persistent | n.t. | Opaque metallic flux | Yes | Yes | |
| 30108 | 0.42 ct crystal | n.a. | 1996 | Unidentified) Russian co. (Chatham) | Very weak orange | Weak yellow | n.t. | Opaque metallic flux | Yes | Yes | |
| 30109 | round brilliant | n.a. | 1996 | G.E. | Moderate yellow-green | Very strong green | n.t. | Pinpoint | n.t. | n.a. | |
| 22007 | 0.27 ct round brilliant | n.t. | 1996 | De Beers | Moderate yellow-green, zoned | Moderate yellow-green | n.t | Opaque metallic flux | n.d. | n.d. | |

*[a]Color grades are for discussion purposes only. GIA-GTL does not grade synthetic diamonds. No grades are given for unfashioned samples.*

*[b]n.t. = Not tested.*

*[c]n.a. = Not applicable.*

*[d]GE. = General Electric Company: Sumitomo = Sumitomo Electric Industries; De Beers = De Beers Diamond Research Laboratory.*

*[e]All but two samples were inert to long-wave UV. The two samples that fluoresced to long-wave UV were ret. nos. 21705 (weak orange, zoned) and 30096 (weak yellow).*

*[f] Persistent=Phosphorescence that lasted 15 seconds or longer.*

*[g]n.d. = Tested but no reaction detected.*

synthetic diamonds) represent experimental, rather than commercial, products. Color-grade equivalents on most of the faceted samples were determined by the staff of the GIA Gem Trade Laboratory, using standard grading procedures, for research purposes only. (GIA GTL does not provide color or clarity grading services for synthetic diamonds.)

A large portion of this sample consists of the 15 faceted near-colorless experimental synthetic diamonds, produced by De Beers scientists during 1995, that were loaned to GIA for examination in the spring of 1996 (see, again, figure 1 here and also figure 1 in Welbourn et al., 1996, which illustrates similar material). The largest of these samples weighed 0.91 ct, and the color grades of this group all fell within the "G" to "I" range.

In May 1994, Thomas Chatham loaned GIA Research a 0.42 ct near-colorless synthetic diamond crystal that he reported was of Russian origin (for a photo and brief description of this crystal, see Koivula and Kammerling, 1994, pp. 123–124). Two years later, in May 1996, Mr. Chatham also made available to us about 100 small (as large as 0.7 ct, but most weighing 0.25 ct or less) near-colorless synthetic diamond crystals from Russia, which he later offered for sale at the 1996 JCK jewelry show in Las Vegas. Although these crystals appeared colorless, for the most part they were distorted in shape, contained numerous metal inclusions, and were very small; as such, they were not well-suited for jewelry. Because we had very little time to examine these samples, we selected only four of the larger crystals for testing.

The majority of the samples we examined for this study would be considered near-colorless on the GIA color-grading scale.

**Characterization Techniques.** To observe the color, relative intensity (described as *none, very weak, weak, moderate, strong,* and *very strong*), and distribution pattern, if any, of the ultraviolet fluorescence in all of the samples, we used a long-wave (366 nm) and short-wave (254 nm) GIA Gem Instruments UV lamp unit in a darkened room with contrast-control glasses. When the UV lamp was turned off, a notation was made of the color, relative intensity, and duration (by means of an electronic timer) of any phosphorescence emitted by each sample. Whenever possible, we took photos of these UV luminescence reactions to help illustrate the diagnostic value of these features. Some of the samples acquired in 1996 were examined with the De Beers Diamond View, which was loaned to GIA in September 1996. Fluorescence images captured with the Diamond View were stored electronically.

Relative transparency to ultraviolet radiation was observed in all samples examined since 1991 by placing the sample between the short-wave UV lamp and a piece of synthetic scheelite (a material that luminesces blue to short-wave UV). The extent of the UV transparency could then be estimated by judging the relative intensity of the scheelite's fluorescence.

We looked for luminescence to an electron beam (cathodoluminescence) in 21 samples with a Nuclide ELM-2B luminoscope (currently manufactured by Premier American Technologies, Bellefonte, Pennsylvania), again noting the color and distribution pattern, if any. Photographs of all the types of luminescence were captured whenever possible.

We used a binocular gemological microscope to examine all but the two earliest G.E. samples for inclusions and other features. (A Nikon SMZ-U photomicroscope was used to prepare photomicrographs of distinctive visual features for those samples seen since spring 1995.)

Magnetism (caused by the presence of transition metal inclusions, such as iron) has been shown to be a valuable test for recognizing some synthetic diamonds (Koivula and Fryer, 1984; Shigley et al., 1986, 1987, 1993a,- Hodgkinson, 1995). We judged magnetic attraction (none, weak, moderate, or strong) for 41 samples by observing the amount of movement or rotation when a rare-earth iron magnet (as suggested by H. Oates and W. Hanneman,-see Hodgkinson, 1995) was brought close to a synthetic diamond that had been suspended in air by means of a thin plastic thread. (We did not use this specific test on the early G.E. samples or those that were too small to be suspended from the thread.)

Forty-four samples were tested for electrical conductivity with a standard gemological conductometer. We also looked for visible luminescence produced by an electrical current (electroluminescence) in these 44 samples. We used a darkened room with the sample placed between the metal probes of the conductometer.

In five of the samples examined in 1996, we detected some interesting thermoluminescence by placing the synthetic diamond in hot water (about 140°F/60°C) after exposure to the ultraviolet lamp. Again, a subjective visual judgment was made of the emitted color.

We used either a Beck prism or a Discan digital-scanning diffraction-grating spectroscope to observe the optical absorption spectra of all of our samples. Pye-Unicam 8800 and Hitachi U-4001 spectrophotometers were also used to record visible-range absorption spectra over the wavelength range 250–850 nm (with the sample held at liquid-nitrogen temperatures in an evacuated chamber) for 25 samples. A Nicolet 60SX Fourier-transform infrared spectrometer was used to record room-temperature infrared absorption spectra over the wavelength range 400–25000 $cm^{-1}$ for 24 samples.

## RESULTS

We determined that all of these synthetic diamond samples were type Ha on the basis of a combination of their infrared absorption spectra and their greater transparency to ultraviolet radiation. As table 1 indicates, some of these were electrically conductive or had a faint yellow or faint blue component to their color. In those samples for which we had infrared spectra, we typically saw evidence of boron- and/or nitrogen-related absorption features.

**Characteristics of the Crystals.** As with other synthetic diamond crystals (Shigley et al., 1986, 1987, 1993a), all of the near-colorless crystals in this study had a very distinct shape that consisted of a portion of a cuboctahedron with a flat base. Octahedral {111} and cube {100} faces were most common in both abundance and surface area (size) on these synthetic diamond crystals, but smaller dodecahedral {110} and trapezohedral {113}—and, occasionally, {115}—faces were also seen. In general, these crystals had relatively flat faces, with sharp edges and corners between adjacent faces (figure 2). The flat base was not a true crystal face but a growth surface, where the tiny seed crystal was located (figure 3).

The evidence of extensive mechanical abrasion or chemical etching that is seen on many natural (octahedral) diamond crystals was absent on our synthetic samples. Nevertheless, many of these synthetic diamond crystals had interesting surface markings that, if retained after faceting, might be of diagnostic value. Such diagnostic markings include dendritic or striated patterns (figures 2 and 4). However, features that appear identical to the well-known trigons seen on natural diamond crystals may also be found on some synthetic diamonds (figure 5), so it is important not to conclude that a diamond is natural based on the presence of these triangular markings.

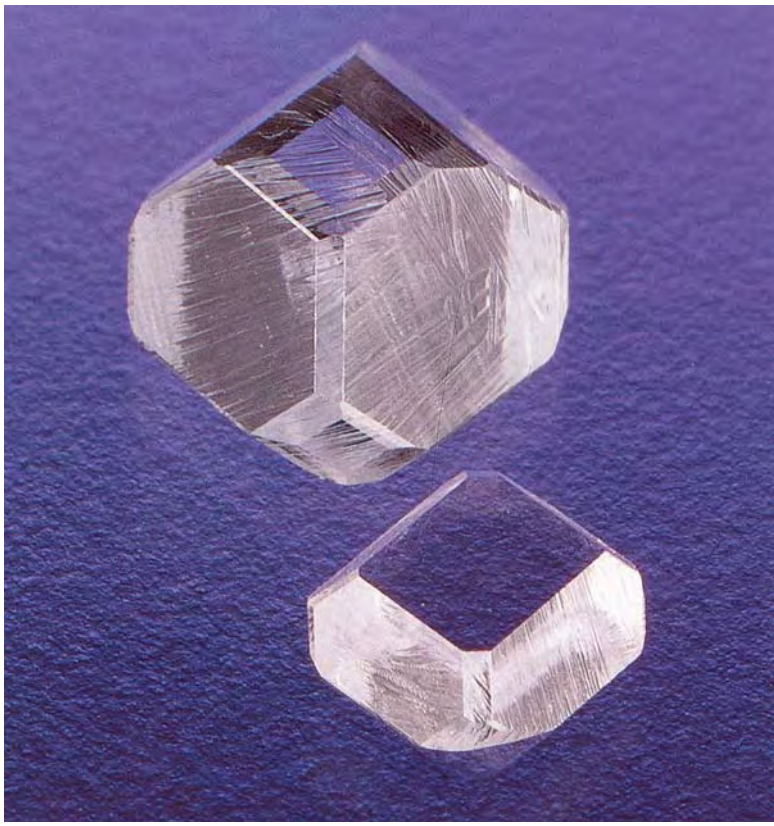


*Figure 2. The cuboctahedral form exhibited by these two experimental Sumitomo synthetic diamond crystals (0.23 and 1.25 ct; reference nos. 21706 and 21705, respectively) is typical of synthetic diamonds from all known manufacturers. The 1.25 ct crystal shows the larger octahedral faces and smaller cube, dodecahedral, and trapezohedral faces that are characteristic of this material. Note also the striations covering the surface, which are not seen in natural diamonds. Photo © GIA and Tino Hammid.*

**Ultraviolet Fluorescence and Phosphorescence.** All but two samples showed no fluorescence to long-wave UV radiation. No response to either long- or short-wave UV was observed in sample no. 30099. However, all other samples did fluoresce yellow to orange-yellow or yellow-green to short-wave UV (see, e.g., figure 6). The intensity of this reaction varied from very weak to moderate. Because the very weak short-wave fluorescence observed in some of these synthetic diamonds could be mistaken for no fluorescence reaction, care must be taken

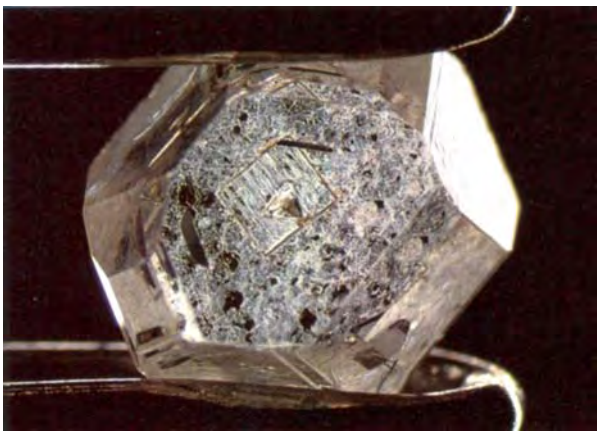


*Figure 3. The flat base of this 0.22 ct Starcorp synthetic diamond crystal (reference no. 30096) shows the square imprint of the seed from which the crystal grew. Photomicrograph by Shane Elen; magnified 5×.*

in making these observations. This is why fluorescence should be tested in a *completely darkened room,* and only when one's eyes have had time to adjust to those viewing conditions (at least several minutes).

In many of our study samples, the short-wave UV fluorescence was unevenly distributed, with certain internal growth sectors (sometimes in the form of a black, cross-shaped pattern; again, see figure 6) exhibiting no fluorescence. An example of the UV fluorescence pattern obtained with the new De Beers DiamondView instrument is shown in figure 7 (see also Welbourn et al., 1996). Note that the color of the UV fluorescence as seen with the DiamondView is different from that seen with a standard UV lamp unit. In either case, it is the fluorescence pattern that is of greatest diagnostic importance.

In addition, when the UV lamp was turned off, most of our study samples continued to phosphoresce a weak to strong yellow, yellow-green, or blue for 15–60 seconds or longer. In some cases, this phosphorescence was so intense that the glowing synthetic diamond could be seen from a distance of several feet in a darkened room.

**Cathodoluminescence.** Of the samples tested, 19 (representing all sources of production) exhibited blue (figure 8), yellow, or green-yellow Cathodoluminescence. This was unevenly distributed in a pattern (again, often cross-shaped) that differs from those patterns seen in a natural diamond.

**Magnification.** When viewed with a binocular gemological microscope, the study samples revealed a few distinctive features. Most prominent were fluxmetal inclusions, which usually appeared opaque in transmitted light and metallic in reflected light. The flux inclusions were usually elongate with rounded edges, and could be seen singly or in small groups,-some had a dendritic appearance (figure 9). The elongate metallic inclusions were present in most of the samples (see table 1). In general, however, they

*Figure 4. Magnification (12×) reveals the distinctive striation pattern on this Sumitomo synthetic diamond crystal (reference no. 21706). Photomicrograph by John I. Koivula.*

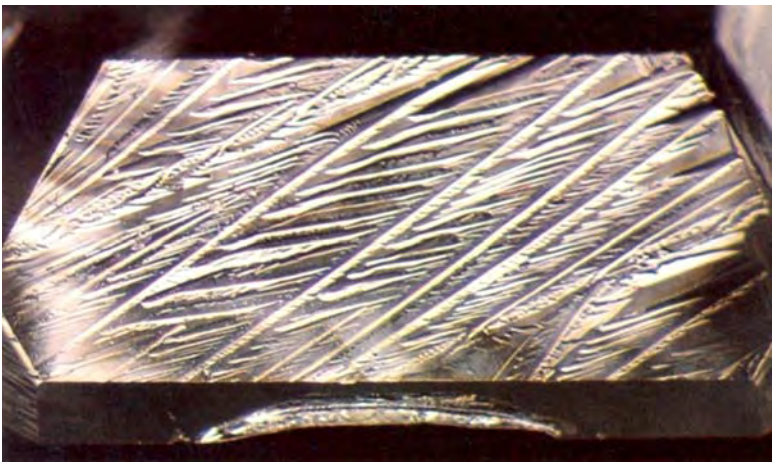
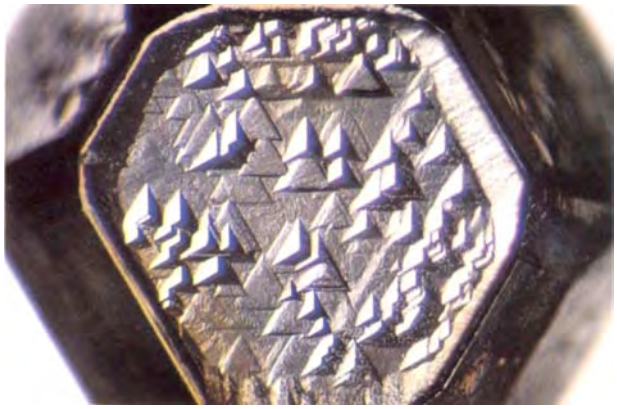


*Figure 5. The triangular, pyramid-like markings on an octahedral crystal face of this near-colorless De Beers synthetic diamond (reference no. 21618) strongly resemble the trigons seen on natural diamonds. Photomicrograph by John Koivula; magnified 10 ×.*



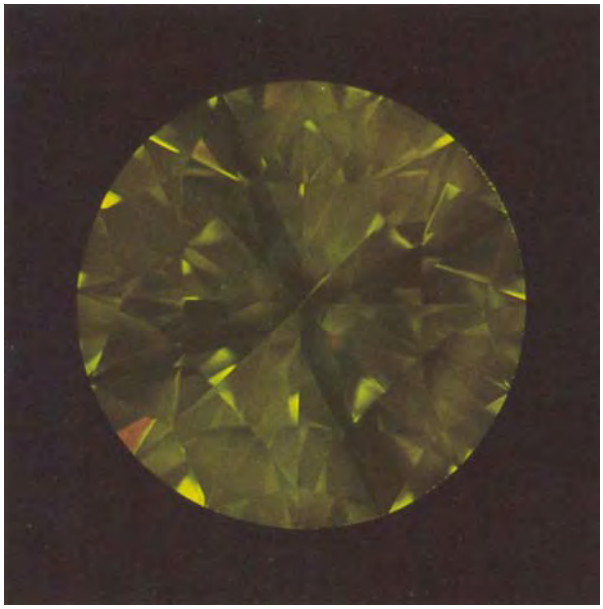


*Figure 6. This 0.91 ct De Beers synthetic diamond (reference no. 30101) displays the zoned fluorescence to short-wave UV that is commonly seen in synthetic diamonds. The black, cross-shaped areas where there is no fluorescence correspond to internal growth sectors that lack the impurities responsible for the UV fluorescence emitted by the other growth sectors. Photo by Shane Elen.*

seemed to be more numerous in the Russian synthetic diamonds. In some cases, the synthetic diamond was attracted by a magnet because of these metallic inclusions. In approximately onethird of our samples, we saw tiny pinpoint inclusions that probably also were metallic flux.

In eight of the De Beers synthetic diamonds, we saw groups of thin, translucent, oriented, triangular inclusions of uncertain identity (figure 10). These inclusions, often associated with weak strain (anomalous birefringence), were translucent and blue in transmitted or polarized light (figure 11, left), and less translucent and reddish brown in reflected light (figure 11, right). These triangular inclusions often were apparent only in certain orientations of the sample (with respect to the direction of the light source); otherwise, they were nearly transparent and could easily go unnoticed during observation with a gemological microscope. Close inspection of these features revealed surface details similar to the large tetrahedral stacking faults observed using X-ray topography (as illustrated in Field, 1979, p. 442).

We did not see intersecting graining patterns in any of the samples; these patterns are an important identification feature in colored synthetic diamonds (Shigley et al., 1995). Even the most strong-

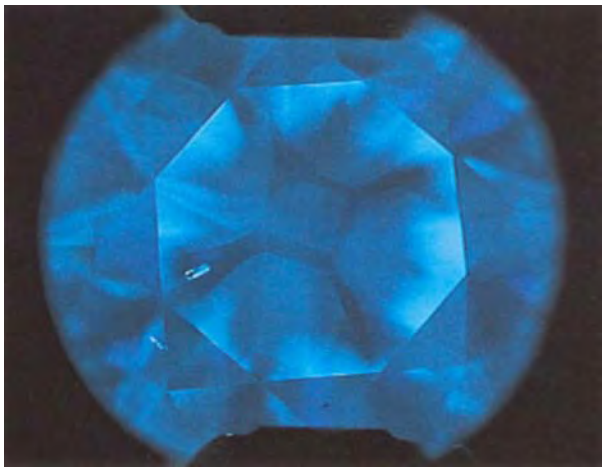


*Figure 7. The uneven pattern of fluorescence typical of synthetic diamonds-here, in a cross shape-is readily apparent in this reference photo taken with the De Beers DiamondView verification instrument. Note that because two very different excitation sources are used, the color of fluorescence as seen with the DiamondView is very different from that seen with a standard UV unit (e.g., figure 6). Photo by Shane Elen.*

colored sample (no. 30095) exhibited no obvious internal color zoning. (In several instances, though, a very faint color zone was seen with magnification; table 1.)

*Figure 8. Like fluorescence, cathodoluminescence in near-colorless synthetic diamonds is also typically uneven and very different from the patterns seen in natural diamonds. A faint cross shape is visible in this 0.61 ct near-colorless De Beers synthetic diamond (reference no. 30100). Photo by Shane Elen.*

*Figure 9. An unusual dendritic inclusion accompanies the elongate inclusions in this 1.25 ct Sumitomo synthetic diamond crystal (reference no. 21705). Photomicrograph by John I. Koivula; transmitted light, magnified 20×.*

**Birefringence.** When observed between crossed polarizing filters with the microscope, the synthetic diamonds typically displayed weak anomalous birefringence ("strain"; see, e.g., figure 6 in Shigley et al., 1993b, p. 194), as was the case for many of the colored synthetic diamonds we examined. This weak "strain" is indicated by low-order interference colors (typically just black, gray, or white, and frequently in a cross-shaped pattern).

**Magnetism.** About one-half of the study samples exhibited some attraction to a magnet. Samples with more metallic inclusions seemed to display a stronger attraction.

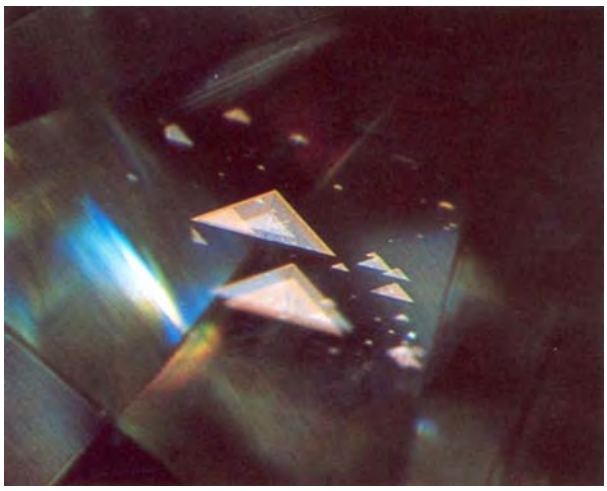
**Electrical Conductivity.** In 20 of the 45 samples tested, we noted some electrical conductivity with a strength that varied depending on the point on the sample that we tested with the conductometer probes. For the crystals, this electrical conductivity could be seen to vary depending on which pair of crystal faces were selected for testing with the probes (although it was not possible to determine exactly which faces were conductive because of their small size and the difficulty of ensuring that we were touching just one face with the probe).

**Electroluminescence.** Of the samples that showed some electrical conductivity, six also displayed aninteresting blue luminescence (usually sporadic and weak) when the sample was touched with the conductometer probes (figure 12). To our observers, this luminescence did not appear to be emitted by the entire sample. Rather, it appeared to be localized, and to extend between the points on the sample touched by the two probes (somewhat like a flash of lightning). Because this reaction is similar to that seen in many natural diamonds, this test usually is not useful to identify the synthetic stones. However, one Sumitomo crystal displayed both *blue* and *red* electroluminescence, depending on where it was touched with the probes; when the probes were removed, the diamond continued to phosphoresce blue for several seconds.

As was the case with electrical conductivity, we could not relate the visible electroluminescence in the unfashioned samples to the particular crystal faces being touched by the conductometer probes (although the impurities causing the conductivity were presumed to be distributed unevenly between the internal growth sectors of the synthetic diamond).

**Thermoluminescence.** When immersed in hot water after exposure to UV radiation, all five samples tested were seen to emit luminescence (which continued briefly when the still-warm sample was removed from the water). Four emitted blue and one (reference no. 21705) emitted orange. We have not observed this reaction in natural diamonds.

*Figure 10. Groups of tiny, translucent, oriented, triangular inclusions of uncertain identity can be seen in this 0.61 ct De Beers synthetic diamond (research no. 30100). Photomicrograph by Shane Eleri; unpolarized reflected light, magnified 15×.*



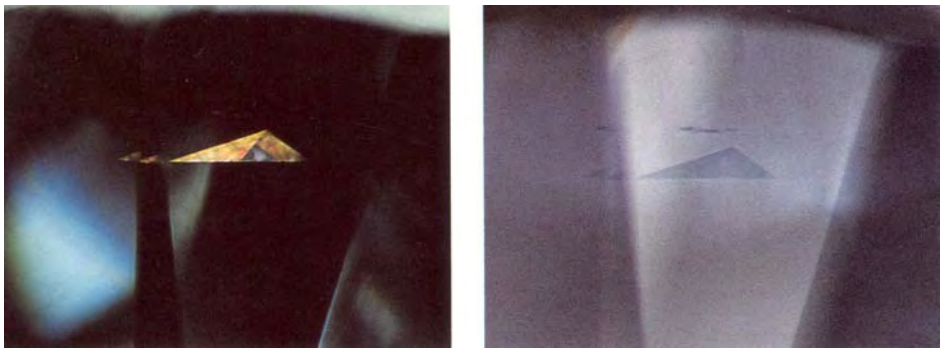
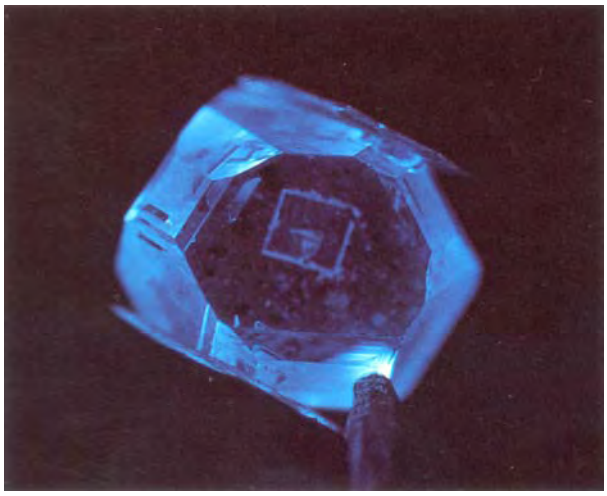


*Figure 11. In polarized transmitted light (left), the triangular growth features appeared translucent blue and often had localized strain. In unpolarized reflected light (right), they appeared less translucent and reddish brown. Sample no. 21967 (De Beers); photomicrographs by Shane Elen, magnified 12.5×.*

**Absorption Spectrum.** The vast majority of the synthetic diamonds in this study did not reveal any significant absorption bands with either the spectrophotometer or the handheld spectroscope. (Although a well-defined band at 270 nm has been identified in near-colorless synthetic diamonds [C. Welbourn, pers. comm., 1997], it was not resolvable with our instruments.) However, the two G.E. synthetic near-colorless diamonds we examined in 1984 displayed a very weak band at about 732 nm in the spectra recorded with the Pye-Unicam spectrophotometer (a feature discussed by Lawson and Kanda, 1993). Since we have not seen this band in synthetic diamonds produced more recently, we do not consider it to be significant.

Although the infrared spectra allowed us to establish that all of our samples were type IIa diamonds (and, as mentioned earlier, that some had weak boron- and/or nitrogen-related absorption features), they contained no features by which we could separate a natural type IIa diamond from a synthetic type IIa stone.

*Figuie 12. Blue electroluminescence was emitted by some of the samples when they were touched with the conductometer probes. Sample no. 30096 (Starcorp); photomicrograph by Shane Elen, magnified 2.5×.*



## DISCUSSION

Natural near-colorless diamonds are usually type Ia; those that contain little or no nitrogen are referred to as type IIa (for a brief discussion of diamond types, see Box A in Fritsch and Scarratt, 1992, pp. 38–39). The synthetic diamonds described here are all type IIa, although some have a small type lib or type IaB component. To date, we have not seen a type la near-colorless gem synthetic diamond; nor, to our knowledge, has one ever been reported. Near-colorless type IIa diamonds have a greater degree of transparency from the blue end of the visible spectrum into the near-ultraviolet region than do near-colorless type la diamonds.

In addition, type IIa diamonds do not display the nitrogen-related sharp absorption peaks in their absorption spectra ("Cape lines," with the strongest peak at 415 nm and additional peaks between 415 and 478 nm) that are seen in type la diamonds. This is the principal behind the new De Beers DiamondSure instrument (Welbourn et al., 1996). Once it is established that the diamond in question is a type IIa, other tests such as UV fluorescence or cathodoluminescence can be used to determine whether it is natural or synthetic.

Natural diamond crystals are typically in the shape of an octahedron or dodecahedron, where growth has taken place outward in all directions from a central core to give an equant crystal (see figure 7 in Welbourn et al., 1996 p. 163). Many natural diamond crystals have rounded surfaces that are due to chemical dissolution (etching) of the diamonds while they were still in the Earth, or to mechanical abrasion during transport from the host rock in a stream or river. Synthetic diamonds have a very different crystal morphology (again, see figure 5 in the

article by Welbourn et al., 1996, p. 162). Unlike natural diamonds, growth only takes place outward and upward from the seed location at the flat base.

In his description of the early G.E. synthetic diamonds, Crowningshield (1971) reported that the two near-colorless samples had an unusual reaction to ultraviolet radiation. They did not fluoresce to long-wave UV, but did fluoresce to short-wave UV, with a yellow color that continued, in his words, "for a long time" even after the UV lamp had been turned off (phosphorescence). He mentioned how different this reaction was to that of natural near-colorless diamonds, and how observation of both fluorescence and phosphorescence to short-wave UV would be imperative for synthetic diamond verification. Thus, at this early date, he established what has become a practical means by which synthetic diamonds can be recognized by the gemologist.

Observations of the fluorescent and phosphorescent reactions to UV radiation among our study samples confirm Crowningshield's results. Specifically, strong short-wave UV fluorescence (relative to long-wave UV) and, in some cases, phosphorescence are very distinctive of synthetic diamonds (Shigley et al., 1995). Almost all the near-colorless synthetic diamonds we have examined to date exhibited these phenomena. Weak or absent long-wave UV fluorescence, and the presence of stronger short-wave UV fluorescence and phosphorescence, do not immediately prove that a "colorless" diamond is a synthetic. However, any diamond that displays these reactions should be considered suspect and should be examined by other gem-testing methods. The typical form of zoned fluorescence seen in synthetic diamonds is not found in natural diamonds. When present, fluorescence in a natural near-colorless diamond is typically blue (rarely, it is yellow) to both long- and short-wave UV radiation, with the reaction almost always being more intense to long-wave UV.

Cathodoluminescence is an important additional means of identifying a diamond as being synthetic, since the pattern of luminescence from the different internal growth sectors is even more visible with this technique than with conventional observation of UV fluorescence (Ponahlo, 1992; Shigley et al., 1995). This equipment has become more standard at gem-testing laboratories, although the availability of the new De Beers DiamondView may make the need for cathodoluminescence instrumentation less-critical.

Strong magnetism in a diamond suggests that it is synthetic. However, because some synthetic diamonds (including a number examined during this study) contain few if any metallic inclusions, magnetism is not an effective test for all stones.

Our latest findings, reported here, support previous indications that the most diagnostic gemological features for distinguishing near-colorless type Ha synthetic diamonds (so far, from any source) are still those summarized by Shigley et al. (1995):

- The cuboctahedral crystal shape, and the possibil ity of striations and other unusual patterns on the surfaces of the crystal faces.
- Metallic inclusions, which seem to be relatively abundant in the near-colorless Russian-grown synthetic diamonds we have examined so far.
- Attraction of the synthetic diamond to a magnet.
- The short-wave ultraviolet fluorescence and phosphorescence.
- The greater UV transparency, which is indicative of a type IIa diamond (most natural near-color diamonds are type la).
- Weak or absent anomalous birefringence ("strain").
- Electrical conductivity.

In contrast to the situation with colored synthetic diamonds, our near-colorless synthetic samples lacked color zoning, graining patterns, and, in most cases, distinctive absorption bands in the visible and infrared spectra. Thus, these features are of little if any diagnostic value for the separation of natural from synthetic near-colorless diamonds.

## CONCLUSION

A few polished synthetic diamonds have been seen in the jewelry industry, but we know of only one confirmed instance of a near-colorless sample of unknown origin appearing in the trade without being represented as synthetic (the 0.16 ct round brilliant mentioned earlier). Because of technical challenges and the high cost of production, we question the likelihood that fashioned near-colorless synthetic diamonds over 25 points will enter the jewelry industry in commercial quantities. In our opinion, the greatest possibility is the availability of near-colorless melee, because at these small sizes synthetic diamonds can be grown relatively fast and efficiently.

The group of near-colorless type IIa synthetic diamonds described in this article is the largest known to have been examined by standard and advanced gem-testing techniques for the express purpose of establishing practical identification criteria. The most useful identification clues for synthetic diamond crystals are the crystal shape and surface features. For a polished stone, key identification features include metallic inclusions and the related possibility of attraction to a magnet, the possibility of electrical conductivity, and the characteristic short-wave UV fluorescence and phosphorescence. These gemological properties appear to be diagnostic of near-colorless type IIa synthetic diamonds, and are very different from near-colorless natural type la and type IIa diamonds.

Diamond dealers, jewelers, and gemologists must be prepared to handle the identification of jewelry-quality near-colorless synthetic diamonds if they become more widely available. Testing will require a more careful gemological examination of near-colorless diamonds. The synthetic nature of a diamond must be disclosed at the time of sale or appraisal. The GIA Gem Trade Laboratory will continue its policy of issuing only identification reports, reports, on synthetic diamonds.

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