CUTTING DIFFRACTION GRATINGS TO IMPROVE DISPERSION ("FIRE") IN DIAMONDS

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A new microlithography process developed to create high-resolution diffraction grating patterns on portions of certain facets can improve the dispersion of light and thus the amount of "fire" in a diamond. These Nanocut plasma-etched diamonds can be identified with magnification by the presence of small, unpolished-appearing areas on the facets where the grating pattern has been created. Round brilliant–cut diamonds displaying such patterns will be classified by the GIA Laboratory as modified round brilliants; as such, they will receive color and clarity grades, but not a cut grade.

For nearly 450 years, the diamond trade has sought to define the factors that characterize the most attractive polished diamonds. While the color and clarity intrinsic to the diamond have long been important in this regard, by focusing on proportions the merchant is able to *create* a superior visual appearance (see review in Gilbertson, 2007). When Henry Morse introduced new measurement tools in the 1870s and '80s, cutters were able to achieve more precise angles and proportions—and produce more attractive diamonds (Kunz, 1888; Leviticus, 1908). One could see "a mediocre diamond transformed into a snapping, blazing gem, full of fire, simply by being recut with a proper regard for the accuracy of the facets" ("The diamond cutting industry in America," 1894, p. 54). Today, the appearance of "fire" in a diamond—the visual manifestation of its dispersion—is considered one of the essential criteria by which the stone's overall appearance is judged (e.g., figure 1).

Quantitatively, *dispersion* is a measure of the angular separation of refracted light of different wavelengths (specifically, blue light at 430.8 nm and red light at 686.7 nm) within a given material. Diamond has a fairly strong dispersion value of 0.044. White light entering a polished diamond from most angles refracts and separates into its distinct component colors. Although the initial expansion of colors is very slight (typically less than 0.5°), the angular spread of light rays of various wavelengths widens with each facet interaction and continues to do so as the rays travel farther from the point of refraction. In other words, the more times a light ray reflects within a diamond, the greater the separation of the spectral colors—and the more obvious the appearance of fire—will be. Fire in a gemstone is best defined as "the visible extent of light dispersed into spectral colors" (Reinitz et al., 2001). In a polished diamond, this is seen as flares or flashes of color that appear and disappear as the diamond, the observer, or the light source moves.

See end of article for About the Authors and Acknowledgments.
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Figure 1. The appearance of fire in a diamond has traditionally been one of the key elements in assesing the quality of its overall appearance. These Nanocut plasma-etched diamonds (0.41–0.46 ct) have diffraction gratings etched into small portions of their pavilions to enhance fire. Photo by Robert Weldon.

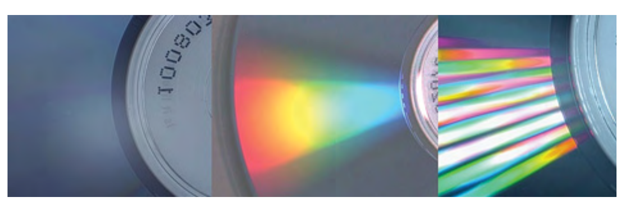
Ordinarily, a faceted diamond has a specific arrangement of flat facets, and light travels within it in ways familiar to diamond cutters. However, the standard faceting process is not the only way white light can be separated into its component colors. Another method is with a diffraction grating, familiar to gemologists as part of a handheld spectroscope. Joseph von Fraunhofer constructed the first diffraction grating in 1820 by tautly extending fine, parallel metal wires between two threaded rods. Fraunhofer used this device to observe emission lines in sunlight (Fraunhofer, 1899). A beam of white light incident on a diffraction grating will separate into component wavelengths based on the angle of incidence, with each beam traveling in a slightly different direction (Bragg, 1913). Because of their light-dispersive properties, diffraction gratings are used in monochromators (to produce monochromatic light) and spectrometers (to measure the properties of light at specific wavelengths; Jenkins, 1976). The extent of spectral colors diffracted from such a grating also depends on the type of incident light source (figure 2).

This article describes recent work performed by a research team at the California Institute of Technology in Pasadena, California, to influence the path of light return in a diamond—and thus enhance the perceived fire—by patterning small areas of its facet surfaces with a high-resolution diffraction grating using a proprietary, patent-pending method that combines microlithography and plasma etching (again, see figure 1). For the remainder of this article, the process will be referred to as "plasma etching." The resulting gems are marketed by Rockoco Inc. (www.rockocoinc.com) as Nanocut plasma-etched diamonds.

MATERIALS AND METHODS

To understand the effect of a diffraction grating on diamond without the influence of facets at various angles and proportions, we first etched a series of grating patterns that radiated from a common center on the polished surface of a flat diamond crystal (figure 3). Micrometer-scale diffraction gratings were then applied to all or part of the pavilion or crown facets of 42 polished diamonds: 41 round brilliant cuts and one octagonal step cut (e.g., table 1; full data for all the diamonds are given in the *G&G* Data Depository at www.gia.edu/gandg. The pavilions of

Figure 2. Under diffused lighting (left), the diffraction grating formed by lines on the surface of a compact disc (6,250 lines per centimeter) very faintly separates white light into spectral colors. Under spot lighting (center), the same grating separates a single spot light source into distinct spectral colors, like those in a rainbow. Under an array of spot lighting (right), it separates multiple spot light sources into a myriad of distinct spectral colors. Composite photo by A. Gilbertson.



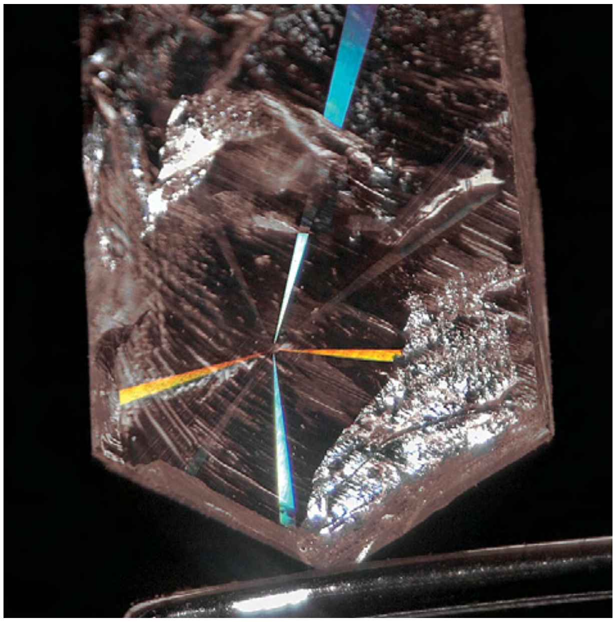


Figure 3. A radiating pattern of diffraction gratings was placed on the flat polished surface of a tabular diamond crystal. As shown here, they diffract the incident spot (fiber-optic) lighting into spectral colors. Photo by John Koivula.

the first five diamonds (0.04–0.08 ct) were covered entirely with diffraction gratings consisting of 1,000 lines per centimeter. Next, six different styles (A–F in figure 4)—each representing a different placement of a grating pattern at 5,000 lines per centimeter—were plasma etched on round-brilliant samples 6 through 41. For visual comparison, the authors used four round brilliant–cut diamonds that did not have grating patterns (RD01, RD04, RD11, and RD78), all of which were previously used in GIA's cut-grade research (see, e.g., Moses et al., 2004).

The 36 study diamonds with patterns A through F were assessed by the authors and others. These diamonds weighed between 0.37 and 0.71 ct, with color grades in the E–I range and most clarity grades ranging from VS to SI (one was I_1). We chose this size range because researchers involved in GIA's 2004 cut study found that such diamonds could be comfortably compared against each other for cut evaluation; additionally, the cut study found that observers were able to assess overall cut appearance regardless of differences in bodycolor (Moses et al., 2004). Although these observations were not a controlled study, we found the results helpful in refining our approach.

Bob Lynn, a jeweler aware of this new process, had a 2.30 ct diamond in his inventory plasma etched with pattern C and allowed us to examine it before and after the etching process. To determine if placement of a diffraction grating could improve the apparent fire in colored and/or step-cut diamonds, we also had a variation of pattern C etched onto an octagonal step-cut fancy brown diamond.

The Process. *Microlithography* is a process by which a temporary coating (called a *resist*) is deposited onto a substrate, exposed to light or an electron beam, and developed (i.e., with a solvent that selectively removes the resist) to define small patterns within the resist layer. The pattern is transferred onto the substrate by etching or by depositing another material. Microlithography is commonly used in the semiconductor industry for manufacturing integrated circuits.

TABLE 1. Plasma-etched and conventionally cut diamonds used for the visual comparison tests in this study.

Sample number	GIA cut grade[a]	Pattern style	Weight (ct)	Clarity	Color	Table %	Crown angle	Pavilion angle	Star length	Lower half %	Girdle minimum length %	Girdle maximum	Girdle %	Culet size	Polish	Symmetry
32	VG	B	0.47	SI_1	F/G	56	36.5	40.6	55	75	Thin	Medium	2.5	Very small	EX	EX
33	G	C	0.45	VS	H/I	59	30.5	40.4	50	75	Thin	Thin	2.0	None	EX	VG
37	VG	C	0.71	VS_2/ SI_1	F/G	57	36.5	41.4	50	80	Medium	Medium	3.0	Very small	VG	VG
RD01	EX	None	0.61	VS_1	E	54	34.5	40.6	55	80	Thin	Medium	3.0	None	VG	VG
RD04	VG	None	0.70	VVS_2	E	59	36.0	42.0	55	75	Slightly thick	Thick	4.5	None	VG	G
RD11	G	None	0.71	VS_2	D	58	37.0	42.2	45	85	Medium	Slightly thick	4.0	None	VG	G
RD78	EX	None	0.73	VS_1	J	58	35.0	41.0	55	80	Medium	Slightly thick	4.0	None	VG	VG

[a]*Equivalent GIA cut grades are used for the plasma-etched diamonds, based on proportions, polish, and symmetry. In practice, plasma-etched diamonds do not receive GIA cut grades. Abbreviations: EX = Excellent, VG = Very Good, and G = Good.*

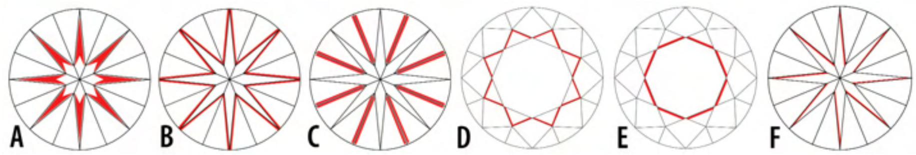


Figure 4. Six diffraction grating pattern styles were developed in the course of this study. The placement of the gratings on specific areas of the pavilion or crown facets is shown here in red.

NEED TO KNOW

- A new process combining microlithography with plasma etching creates microscopic diffraction gratings on selected facets of a diamond.
- Properly applied, these diffraction gratings can increase the apparent fire in spot and mixed lighting.
- The best results were obtained by applying the gratings to areas of pavilion facets that would otherwise appear dark face-up.
- Nanocut plasma-etched diamonds will not receive cut grades from GIA.

Plasma etching is the process of eroding material from the surface of a solid by bombarding it with particles of ionized gas. Unlike chemical-etching processes, plasma etching allows anisotropic removal (i.e., preferentially along one direction), where the pattern depth is controlled entirely by the processing time. Oxygen plasma etching is commonly used to prepare samples prior to examination by electron microscopy, and pure carbon can be removed at rates well over 100 nm per minute. This method has been refined to the point where it can create structures smaller than the wavelength of visible light (as small as 100 nm).

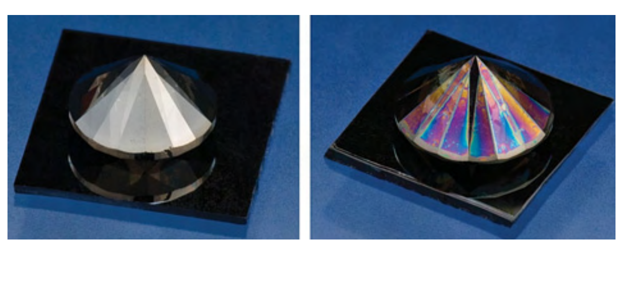
Steps in Creating a Diffraction Grating on a Polished Diamond. First, the diamond must be carefully cleaned by soaking it in a solvent and then boiling it in sulfuric acid. Next, the diamond is centered table-down on a silicon wafer and held in place using a polymer adhesive. A proprietary coating material, the resist, is placed on the diamond. The stone is spun at a high speed to coat the pavilion uniformly, and then heated to bake the resist onto the surface (figure 5).

Once coated with the resist, the diamond is placed in a vacuum chamber (figure 6) and precisely aligned so that the grating can be located in the exact pattern and position required. After the selected pattern (see the computer screen on the left of figure 7) is centered, an electron beam is directed across the surface within the pattern outline. The beam changes the chemical composition of the resist (Wells et al., 1965; Wolf et al., 1970), so that a chemical developer can be used to dissolve only the altered portions and expose the area where the lines of the grating will be etched. This leaves a residual etch mask of the pattern, with the resist covering the remainder of the pavilion surface (figure 8).

The diamond is then placed in a second closed chamber for plasma etching (Pan, 1994). Oxygen gas is introduced into the chamber, where the oxygen molecules are ionized by an electromagnetic field and react with the exposed areas of the diamond to form carbon dioxide gas. This etching process takes only a few seconds, and the grating pattern is created on the portion of the diamond not covered by the resist (figure 9). After etching, the diamond is placed in an acid bath to remove the residual resist.

Currently, the entire process takes five hours per diamond. Scanning the electron beam is the most time-consuming step, since considerable alignment is necessary to stabilize the beam and center the diamond, and the high-vacuum chamber must be cycled each time it is opened. However, the actual scanning time is only a few minutes. Likewise, the plasma etching is performed in a vacuum system that has lengthy pump-cycle times, uses gas lines that need to be purged before and after etching, and requires peri-

Figure 5. After cleaning, a diamond (here, ~0.5 ct) is first cemented onto a silicon wafer and coated with a resist (left). After the resist has been baked on the facet surfaces, the coated diamond is ready for further processing (right). Photos by Robert Weldon.



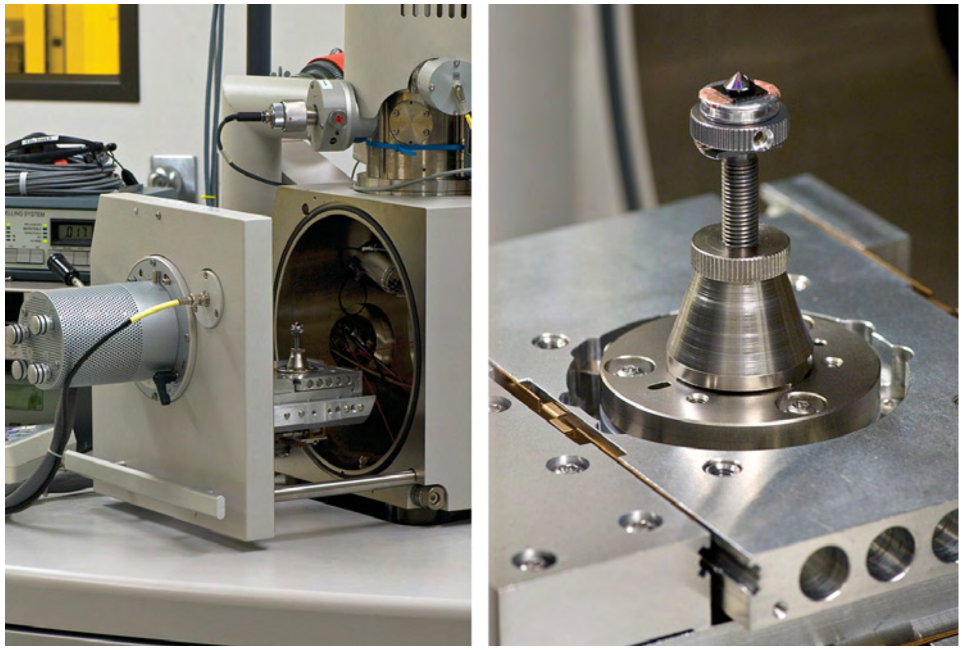
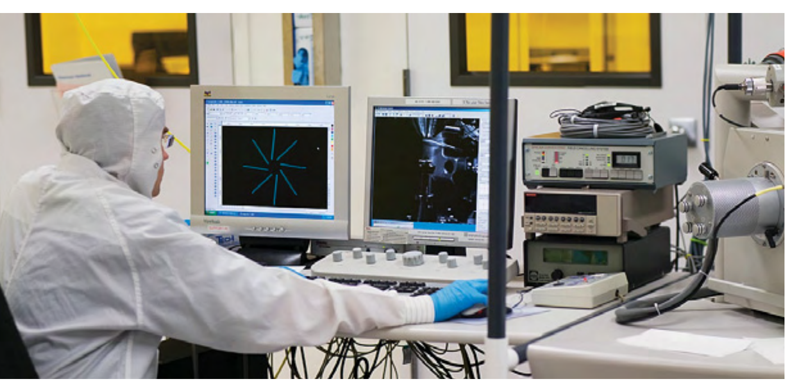


Figure 6. The coated diamond is placed inside a chamber (left) where an electron beam etches a pattern into the resist. The diamond is carefully aligned on the stage of the chamber (right). Photos by Robert Weldon.

odic chamber cleaning. The complete scanning and etching processes each take about 90 minutes.

A diffraction grating can be applied to facets on diamonds of any size or shape. During this study, several refinements were made to the fabrication process to improve the appearance of light dispersion (e.g., changing the number of etched lines in the grating and the targeted portion of the pavilion, and tuning the plasma to minimize the roughness of etched areas). While the goal of this study was to produce faceted diamonds with more fire, further modifications could make it possible to produce other optical effects. Although similar gratings can also be applied to other polished gems, the method described here is most suitable for carbon-based materials, especially diamond due to its relatively pure chemical composition.

Figure 7. The operator oversees the careful patterning of the electron beam on the diamond. The computer monitor on the right enables the operator to view and control the alignment, and the one on the left shows the pattern to be etched. The sample chamber is at the far right. Photo by Robert Weldon.



Visual Comparison Tests. Our ultimate goal was to determine if there was a diffraction grating pattern that could be placed on diamonds of commercial cut quality (such as GIA Good or Very Good cut grades) that would improve their appearance in spot or mixed lighting environments. After evaluating the results from the first five stones (plasma etched over their entire pavilions at 1,000 lines per centimeter), we had a group of 26 diamonds of various proportions (diamonds 6–31; again, see the *G&G* Data Depository) etched with a grating of 5,000 lines per centimeter using pattern A in figure 4. This enabled us to see how diffraction gratings affected face-up appearance across a broad range of proportions. We carefully looked at these plasma-etched diamonds in the diffused, spot, and mixed lighting of the DiamondDock (as described in King et al., 2008), comparing them to the four conventionally cut diamonds. The DiamondDock's spot lighting was set at approximately half power for the mixed lighting and spot lighting observations; the intensity of spot lighting can vary within mixed lighting environments. We used the same gray stone trays as in the 2004 cut study, and observation distances varied by user (from approximately 10 to 20 in. [25–50 cm]).

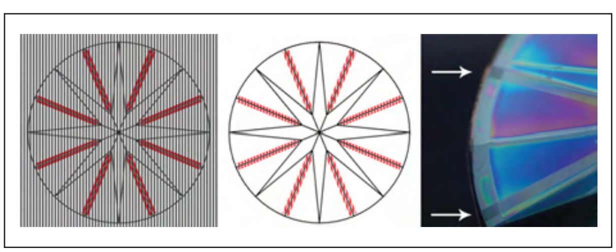
On the basis of these observations, we modified the original pattern A (again, at 5,000 lines per centimeter) and applied various modifications to a further set of diamonds (nos. 31–40) to achieve a better balance of fire and overall appearance, resulting in a total of five additional grating patterns (again, see figure 4). We made further comparisons to the conventionally cut diamonds in terms of overall appearance in different lighting environments, and also asked random observers who were *not* experienced in assessing overall diamond appearance (referred to here as outside observers) to make similar observations.

For example, we asked 10 outside observers to look at a set of seven diamonds: four conventionally cut (RD01, RD04, RD11, and RD78; cut grades Excellent, Very Good, Good, and Excellent) and three with diffraction gratings (nos. 32, 33, and 37; cut grades Very Good, Good, and Very Good; again, see table 1). We then asked the observers to rank their top three visual preferences in each of the same three lighting environments, with 1 as best. The four diamonds that were not selected were each given an average ranking of 5.5 (the average of 4, 5, 6, and 7). As noted above, our experience during GIA's cut study was that variations in size (such as 0.40–0.90 ct), color (D to beyond L), and clarity (SI or better) did not influence visual judgment of cut quality. The observers' occasional comments about overall appearance also provided useful information.

One important question we hoped to answer was whether a diamond that had been cut-graded as Very Good (no. 37) could be improved by the plasma-etching process, so that it would equal or exceed the appearance of a conventional diamond with an Excellent cut grade (RD01). To this end, we carefully compared these two diamonds in the DiamondDock in each of the three lighting conditions. Both diamonds were placed in light gray trays (like those used in the 2004 cut study) that could be held at a comfortable distance and moved as necessary. A different group of observers (again, without experience in assessing overall diamond appearance) were asked to indicate which diamond they preferred.

Other Tests. To test the durability of the plasma-etching process, we placed several diamonds with diffraction gratings together with other diamonds in a ball mill and tumbled them for one week. We then examined their surfaces with a scanning electron microscope (SEM) to detect signs of damage. We also weighed sample no. 42 before and after plasma etching to determine if there was any detectable weight loss.

Figure 8. The resist covers the entire pavilion surface. The electron beam emitter moves in parallel lines (black, left) above the diamond, and as it moves, the electron beam traces these lines onto the diamond surface within the area of the selected pattern outline (red). The chemical composition of the resist is altered by the electron beam only in the pattern areas. Those areas are chemically dissolved, and the underlying portions of the facets are left exposed to allow a small amount of diamond to be removed by plasma etching (center). The photo on the right shows a diamond after the electron beam has left a pattern on the resist. Arrows indicate the altered portion of the resist. Photo by Robert Weldon.



RESULTS

Experiments to Enhance Fire. We first wanted to see if fire could be improved with the application of a diffraction grating pattern on all or part of certain facet surfaces. Under spot lighting, the tabular dia-

Figure 9. This SEM image shows the parallel etched lines of the diffraction grating on a diamond surface. Image by B. Gudlewski.

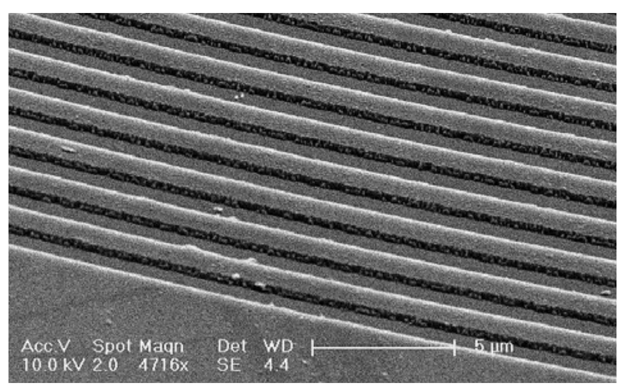


Figure 10. The grating pattern covers the entire pavilion of this 0.07 ct diamond. Modifying all the facet surfaces caused a reduction in overall brightness under diffused light (left). When examined with spot lighting (right), the diamond has an opalescent appearance and appears to be dirty or oily. Photos by Robert Weldon.

mond crystal we started with displayed fire from the radiating features (again, see figure 3). This was best seen from less than 10 in. (25 cm) away; it was not as dramatic at greater distances. Even with the extreme case of a tabular piece of diamond, however, a diffraction grating could generate attractive patterns of light dispersion.

The five diamonds (nos. 1–5) with a diffraction grating over their entire pavilions showed a modest improvement in fire, but the overall appearance was not pleasing. Modifying the entire pavilion with a grating pattern significantly diminished both the overall return of white light and the light-dark contrast pattern between adjacent facets, producing a somewhat dull, opalescent appearance, even with spot lighting (figure 10).

Although the 26 diamonds that received pattern A (nos. 6–31; again, see the *G&G* Data Depository) showed marked improvement in fire and overall appearance compared to the previous test pattern, the result was still not satisfactory (figure 11). We observed that the diamonds were brighter than those in the initial group, but they were still duller than conventionally cut diamonds. We subsequently determined that this was due to placement of the diffraction patterns on facets that normally would have been seen as bright.

Figure 11. The grating patterns on the pavilion of this diamond (at 10×) cover too much of the areas that normally reflect white light. This experimental pattern (A in figure 4) improved fire, but the overall appearance of the diamond was not as bright, and the contrast pattern was greatly diminished. Note that even though the diffraction grating creates spectral colors (inset at 30×), the individual lines of the grating pattern cannot be seen, and areas that have been etched could be mistaken for unpolished or poorly polished facets. Composite photo by Robison McMurtry.

The experiments with modified grating patterns yielded what the authors observed to be the optimal pattern: C, used on samples 33 and 37. Pattern C was designed to brighten the face-up appearance by placing the diffraction grating on areas of the pavilion that would otherwise appear slightly dark when the stone was viewed face-up (figure 12). Typically, the strong reflection of white light from the larger facet surfaces leads to a preferred face-up appearance (e.g., figure 13). By placing a small grating pattern on facets that did not interrupt the large areas of white-light return (a problem discovered with the first group of 26), we found that fire could be improved in areas that are usually darker under both spot and certain mixed lighting conditions without diminishing the brightness of the stone (figure 14).

Figure 12. The virtual image on the left illustrates a diamond's pattern of dark and light areas when viewed in a mixed environment of diffused and slight spot lighting. The virtual image in the center and the diagram on the right show (red) the portions of the pavilion surface that were etched with a diffraction grating for pattern C, the optimal result. Modifying these areas on the pavilion results in the removal of some of the darker regions of the diamond's face-up pattern, which are then replaced with areas that display spectral colors. Photo by Robison McMurtry.

Comparison Tests. For the first comparison test, which assessed overall appearance, we observed that the four conventionally cut diamonds had the

Figure 13. This 2.30 ct diamond originally had a GIA cut grade of Excellent, as shown here in diffused light (top left) and spot lighting (top right). In both environments, there is little fire. After processing with pattern C, it looks much the same in diffused light (bottom left) but has a more dynamic face-up appearance in spot lighting (bottom right). Courtesy of Bob Lynn, Lynn's Jewelry Studio, Ventura, Calif.; photos by Robert Weldon.

best appearance in diffused lighting. In mixed lighting, however, the diamonds with pattern C looked bright and well balanced, but more fiery, with a better overall appearance. While pattern B (no. 32) did not improve a diamond as much as C, the stone was still attractive. As figure 15 indicates, all three of these Nanocut plasma-etched diamonds performed better and were more fiery than the conventionally cut diamonds in spot lighting. The first group of outside observers agreed with our assessments. Although based on a small sample of diamonds, these results indicate that creating small grating patterns can significantly enhance appearance in spot lighting, and may even improve overall appearance in mixed lighting.

For the question regarding the potential for plasma etching to improve the appearance of a diamond the equivalent of one cut grade, as expected plasma-etched no. 37 (Very Good) was less attractive than conventionally cut RD01 (Excellent) in diffused lighting, but it looked much better than RD01 in spot lighting. In mixed lighting, we felt these were about the same (an improvement for no. 37 from before it was etched). When the second group of outside observers looked at the two stones in the DiamondDock, they agreed with our findings: 8 of the 10 preferred RD01 in diffused light, but 9 of the 10 preferred no. 37 in spot lighting, with no real preference in mixed lighting. In both mixed and spot lighting, outside observers noted an increase in fire.

Durability of the Diffraction Gratings. During the course of this study, we found that the most effective placement of the diffraction grating was on the pavilion, which has a relatively low risk of damage in the course of normal jewelry wear. Nevertheless, examination with the SEM revealed that tumbling did not damage the narrow grooves of the grating; nor did we see any alteration in the diamonds' appearance.

Figure 14. These two diamonds of similar proportions, one cut conventionally (RD01, left) and the other with pattern C (no. 32, right), are shown in three lighting environments: diffused (top), mixed (center), and spot lighting (bottom). When spot lighting is substantial, careful placement of the diffraction grating can improve the appearance of certain diamonds by making them more fiery. Photos by Robert Weldon.

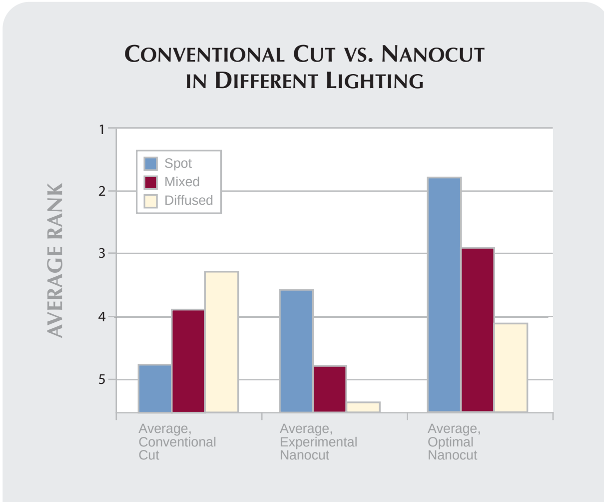


Figure 15. When a group of outside observers compared a set of four conventionally cut diamonds to three diamonds with diffraction gratings on their pavilions in a DiamondDock, they ranked the conventionally cut diamonds highest in diffused light, but the plasma-etched diamonds (nos. 32, 33, and 37) highest in spot lighting. They all noted an increase in fire seen in spot and mixed lighting.

The diffraction gratings can best be removed by repolishing the diamond (but this will also result in some weight loss).

Weight Loss. We predicted that the weight loss from plasma etching would be less than 0.001%. While we did not weigh all the diamonds before and after plasma etching, we did weigh the fancy brown octagonal cut (no. 42) with a modified pattern C diffraction grating. It went from 0.71325 ct to 0.71324 ct, a negligible difference that falls within normal measurement error.

DISCUSSION

Lighting. Various types of lighting and lighting environments produce different appearances for the same diamond. GIA's cut study found that most manufacturers and diamond dealers commonly use (diffused) overhead fluorescent lights and/or desk lamps with daylight-equivalent fluorescent bulbs to cut diamonds or evaluate the quality of diamond cutting in general (Moses et al., 2004). The authors also noted, though, that this type of diffused lighting suppresses the appearance of fire; as a rule, then, retail environments provide spot or point source lighting (often with some overall diffused lighting as well) to accentuate fire.

Diffused Lighting. A faceted diamond's appearance depends on several factors: clarity, color, quality of finish, arrangement of facets, proportions, lighting, and how the diamond is positioned relative to the observer. At a normal viewing distance (10–20 in. from the eyes) in a diffusely lit environment, the reflection of the observer's head and upper torso (seen as dark areas by the observer due to contrast with the lighting environment) combines with light leakage from the pavilion facets to cause dark areas in the reflection pattern (Harding, 1975; Moses et al., 2004). With motion, the light reflection pattern and accompanying sparkle comprise the traditional aspect of scintillation. Additionally, Moses at al. (2004) found that the dynamic or static pattern of light return is critical to face-up appearance, with an attractive diamond having a balance of dark and light areas.

If diffraction gratings are etched onto facets that are normally reflected as the white portions of a face-up pattern (dynamic or static), less of this bright light is returned. Consequently, brightness suffers when these diamonds are observed in diffused light. In contrast, etching the areas usually seen as dark reflections makes them appear somewhat brighter. Although for the most part the conventionally cut diamonds were perceived to have a better overall appearance in diffused light than the plasma-etched stones, some of the authors and outside observers indicated that in diffused lighting they perceived a slight improvement in the diamonds etched with pattern C.

Spot Lighting. In most conventionally cut diamonds, fire is observed as either small ("pinpoint") or large flashes of spectral colors. During GIA's observation testing (conducted from 2001 to 2004; Moses et al., 2004), some observers preferred pinpoint fire, while others preferred broader color flashes. The fire observed in the plasma-etched diamonds was perceived by the authors and outside observers as pinpoint flashes, with many small flashes happening at the same time, regardless of how much the diamond was moved.

Pinpoint fire is too subtle to be easily noticed in diffused lighting environments, but it is readily apparent with spot lighting, especially in an environment with relatively dark surroundings. The stronger the contrast between the spot lighting and the ambient environment, the more dramatic the fire appears to be. In this study, we found that the diamonds cut with diffraction grating pattern C

Figure 16. This octagonal step-cut fancy brown diamond (0.43 ct) is shown face-up in diffused light (top left) and spot lighting (top right) prior to plasma etching. In both instances, there is little fire. After processing with a modified pattern C adapted to this shape, the diamond looks much the same in diffused light (bottom left) but has a more dynamic face-up appearance and obvious fire in spot lighting (bottom right). Photos by Robert Weldon.

were consistently perceived to have more fire than their conventionally cut counterparts, although two of the outside observers commented that they preferred broad flashes of fire.

Mixed Lighting. Most people work and live in either diffused or mixed lighting; only occasionally does spot lighting dominate. When a diffraction grating was applied without regard to face-up pattern (i.e., figure 4A), the authors found the resulting diamond to be less attractive in mixed lighting. Conversely, with a grating applied to improve the face-up pattern (figures 4C and 16), as in no. 37, observers found the diamond to be clearly more attractive than comparable diamonds without diffraction grating.

Other Considerations. Step-cut fancy-color diamonds typically have little dispersion, either in diffused or spot lighting, and it is the novelty of the cut or the heightened color of the diamond that appeals to consumers. The authors noted that diffraction grating patterns added fire to this type of diamond when observed with spot lighting, though they made little difference with diffused lighting (figure 16).

Identifying Nanocut Plasma-etched Diamonds. The simplest method to identify plasma-etched diamonds is to examine the pavilion facets with at least 10× magnification. A facet modified with the diffraction grating will appear unpolished, and spot lighting reflected through or back from the grating will be observed as dispersed colored light (again, see figure 11).

Grading. GIA does not provide cut grades for plasma-etched diamonds. Diamonds with these diffraction grating patterns will be described as having "plasma-etching features" in the comments section of their grading reports.

CONCLUSION

Microlithographic and pattern-transfer etching techniques common in the semiconductor industry were used to create high-resolution diffraction grating patterns on specific facets of several diamonds. With careful optical modeling to determine the precise positions and dimensions of the diffraction gratings, we were able to modify light reflection and refraction from the diamond to induce additional spectral dispersion and, consequently, a more fiery appearance in both mixed and spot lighting. To minimize reduction of brightness, we selected facets for modification that otherwise would have resulted in dark areas seen face-up.

These preliminary results introduce a new approach to cutting diamonds: plasma etching. At this point, it is only being applied to enhance fire in conventionally cut diamonds. A new company, Rockoco Inc., has introduced this cutting style under the Nanocut trademark.

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