Diamond Scintillation and Quality Evaluation

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Abstract. The quality of a diamond is not only affected by the 4Cs but also affected by fire and scintillation. The relationship between the color, clarity, fluorescence, and scintillation of a diamond is obtained by associating its scintillation area and gemological characteristics. Take images of 18 round bright cut diamonds in total, for each to rotate 30° to take one and get 12 images by rotating a circle. Rotate the images to the same angle, cut out the square image of 1000*1000 pixels, then calculate the color difference of the image of adjacent angles, and then judge whether scintillation occurs at each point to get the scintillation area of the diamond. The results showed that the lighter the color, the better the clarity and the weaker the fluorescence, then the larger the scintillation area and the more obvious the scintillation. This indicates that the scintillation area has a certain reference value for diamond quality evaluation.

1. Introduction
The static properties of diamonds have been studied in depth. With the help of weighted light returns (WLR) model Hemphill et al (1998) made comprehensive analysis of multiple crown angle, pavilion angle and table size combinations as well as ray trace the 3D model of diamond, found that different combinations can produce the same results, and gave the advice to improve the brilliance in diamond cutting. Zhang et al (2006) proposed that only diamonds that meet the requirements of precise cutting grinding ratio and high symmetry can produce the pattern of eight arrows and eight hearts. Liu et al (2014) on the one hand, collected images of colorless synthetic cubic zirconia which was similar to diamonds in optical properties; on the other hand, input cutting parameters of samples, establish models, and simulate the optical effect pattern of samples. The comparison between the two verified the feasibility of studying lightness through diamond models. What’s more, Moses et al (2004) believed that the quality evaluation of diamonds should not only unify the observation environment, consider personal preferences and understand the market tendency, but also comprehensively take the interaction of various facet of diamonds integrated into account instead of being limited to a few attributes. Reinitz et al (2001) emphasized that every facet matters in a round brilliant diamond. Therefore, Caspi et al (1997) pointed out that diamond dealers had significantly improved the processing and output level of rough stones, despite the short history of using computer automated analysis, cutting and polishing. Not only in the field of diamond processing, but the diamond rating has also already entered the stage of software automation. Wang et al (2011) pointed out that diamond cutting analysis can be completed automatically by the instrument.

In addition, Yu et al (2016) calculated the total reflection of the plane model of the incident light of the vertical section of the diamond and found that the diamond has the maximum light return value and a smaller dark area ratio when pavilion angle within the range of 39.0° ~ 41.0°. When the size of the pavilion angle is fixed, there is a unique crown angle to enable the diamond to achieve the best fire effect. Reinitz et al (2001) analyzed the relationship between diamond fire and various parameters
with the help of a 3D mathematical model and pointed out that in some cases, subtle changes in various attributes would significantly affect the final fire and lightness effect. In addition to computer modeling, Fourier Transform Infrared Spectroscopy (FTIR) has also been widely used in the classification of diamonds, the identification of synthetic diamonds, and researches on colored diamonds. King et al (2005) discussed the genesis of yellow diamonds and further divided them into 5 groups according to their absorption spectra. Shigley et al (2015) further studied the absorption spectra of diamonds of various colors and found that diamonds with different absorption spectra and different types can present similar colors. Yan discussed the feasibility of distinguishing CVD synthetic diamonds from natural diamonds through the fluorescence characteristics of DiamondView diamonds. Since the synthetic diamond has already reached the level of gems, Breeding et al (2009) still suggested sending the uncertain type of diamond to the gemology laboratory for further testing even after he had put forward the methods of the absorption spectrum, gem microscope, electric conductivity and so on. In other aspects, studies on the setting of diamond selection lamps showed that it is more appropriate to sort cut diamonds above VG level when the incidence angle of diamond lamp is between 20° and 25°.

However, further research is needed to determine the specific relationship between the dynamic characteristics of a diamond, such as its scintillation as well as clarity, lightness, and fluorescence. Scintillation refers to the light produced by the diamond as seen by the observer when the diamond, light source or observer moves. In order to better study the relationship between diamond scintillation and quality, we use the color difference to quantitatively analyze the scintillation phenomenon in diamond pictures, and the relationship between gemological characteristics and scintillation of diamonds is studied by quantifying these factors.

2. Sample Overview and Image Processing

2.1. Experimental Samples

We used a total of 18 round brilliant cut diamonds, the sizes of which are ranged from 0.300 ct to 0.387 ct, the color grading: D ~ H; the cutting, polishing, and symmetry grading: VG and above. And the cutting parameters: the table size is 58% ± 3%; the total depth is 61.4% ± 3.1%; the pavilion depth is 43% ± 1%; the crown angle range is 32.5° ~ 37.5°. As shown in table 1.

| Number | Weight/ct | Color | Clarity | Fluorescent | Total depth/% | Table size/% | Crown angle/° | Pavilion depth/% | Cut | Polish | Symmetry | Scintillation area |
|--------|-----------|-------|---------|-------------|---------------|--------------|---------------|-----------------|-----|--------|----------|------------------|
| D-3-51 | 0.300     | D     | VVS1    | FNT         | 61.7          | 56           | 36.0          | 42.0            | VG  | VG     | VG       | 4.40%            |
| D-3-52 | 0.302     | D     | VVS1    | NON         | 62.2          | 59           | 37.0          | 42.5            | VG  | VG     | EX       | 2.73%            |
| D-3-53 | 0.313     | D     | VVS1    | NON         | 61.5          | 56           | 34.5          | 43.5            | VG  | VG     | EX       | 4.37%            |
| D-5-10 | 0.387     | E     | VVS1    | MED         | 62.6          | 55           | 34.5          | 44.0            | VG  | VG     | EX       | 0.42%            |
| D-5-14 | 0.300     | F     | VS1     | NON         | 64.5          | 56           | 37.0          | 43.0            | VG  | VG     | EX       | 0.26%            |
| D-5-15 | 0.344     | F     | VS2     | FNT         | 59.7          | 60           | 32.5          | 43.5            | EX  | EX     | EX       | 0.43%            |
| D-5-16 | 0.316     | G     | VVS1    | NON         | 61.2          | 58           | 34.5          | 43.5            | EX  | EX     | EX       | 0.32%            |
| D-5-17 | 0.331     | G     | VS2     | MED         | 61.3          | 55           | 34.0          | 43.0            | EX  | EX     | VG       | 0.34%            |
| D-5-18 | 0.302     | G     | SI1     | NON         | 63.8          | 56           | 37.5          | 43.0            | VG  | VG     | EX       | 0.56%            |
| D-5-19 | 0.381     | G     | SI2     | NON         | 66.3          | 56           | 37.5          | 43.5            | EX  | EX     | EX       | 0.25%            |
| D-5-20 | 0.345     | H     | VVS1    | MED         | 62.7          | 55           | 35.0          | 43.5            | VG  | VG     | EX       | 0.53%            |
| D-5-4  | 0.300     | F     | SI1     | NON         | 60.8          | 56           | 33.0          | 43.5            | EX  | EX     | VG       | 1.17%            |
| D-5-5  | 0.318     | G     | IF      | NON         | 62.3          | 56           | 35.0          | 43.0            | EX  | EX     | EX       | 0.64%            |
| D-5-7  | 0.306     | D     | SI1     | NON         | 60.1          | 59           | 33.5          | 43.0            | EX  | VG     | EX       | 1.23%            |
| D-5-8  | 0.302     | D     | VS2     | NON         | 62.6          | 55           | 33.0          | 44.0            | EX  | EX     | VG       | 0.53%            |
| D-5-9  | 0.303     | D     | SI2     | NON         | 58.3          | 61           | 32.5          | 43.0            | VG  | VG     | EX       | 1.25%            |
| KS1    | 0.306     | E     | IF      | NON         | 61.1          | 57           | 34.5          | 43.5            | EX  | VG     | EX       | 1.81%            |
| KS2    | 0.305     | E     | VVS1    | NON         | 62.3          | 57           | 35.0          | 43.5            | EX  | VG     | EX       | 2.87%            |
2.2. Photography and Preprocessing
Under the condition of indoor natural light scattering, control the shooting background to be pure black, take an image of each diamond every 30° rotation, and get 12 images by rotating once. Then remove the edge of the image and rotate it to the same angle to get 12 figures of the diamond. As shown in figure 1.

![Figure 1. Diamond rotates 360°](image)

2.3. Calculate the Colorimetry Component of the Image
Colorimetry studies the change and relation of color. In CIE 1976 colorimetry space, color has L, a and b components to quantify color. The judgment of scintillation between two pictures can refer to the color difference, lightness difference and hue difference of two pictures.

Take images of a diamond at 240° and 270° (9th and 10th of figure 1) as an example. Apply `applycform` function in MATLAB to calculate these two images to get the results of color difference, lightness difference, and hue difference. Five pictures (a) ~ (e) in figure 2 represent rotating the diamond 240° and 270° respectively, as well as the hue difference, color difference and lightness difference between them. In figure (a), (b), (d) and (e), two flashing areas are marked with gray and black respectively at the same position, named as the upper and the lower region. As can be seen from the figure (a) and (b) pp the upper region shows a significant scintillation, while only the left part of the lower region shows scintillation. The performance of the color difference in the upper region is very similar to the lightness difference, but the noise suppression in the lower region is obviously better than the lightness difference. Although the lightness difference can show the change of lightness in the upper region, there is too much noise information in the lower region, that is, the lightness difference cannot well filter out the noise interference. As for the hue difference, it shows no information in two regions, so we take no account of it. Considering comprehensively, the color difference is selected as the criterion of scintillation.
As can be seen from the color difference diagram, there are other areas with obvious color difference changes which haven’t been mentioned, corresponding to the scintillation areas in figure (a) and (b).

![Figure 2. Images and colorimetry component of diamonds](image)

2.4. Scintillation Area

In CIELAB colorimetry space, the unit of color difference is NBS. As can be seen from the figure a and b, a distinct scintillation occurs in the upper region; in the lower region, the left half shows a more obvious scintillation, while the right half shows only a slight change in lightness, which should not be judged as scintillation. In the upper region of the color difference diagram, the color difference value of this region is shown in the diagram is about 10 NBS to above 90 NBS. There are some color differences in the left half of the lower region. Some regions about 60 NBS show obvious scintillation, while other regions on the right (below 40 NBS) shows an only slight change in lightness and should not be judged as scintillation. Therefore, take 60% of the maximum color difference as the threshold. When the color difference value exceeds 60% of the maximum value, the point determines that scintillation has occurred. Although this standard will sacrifice the effective value of some scintillation areas, it can filter out the influence of the non-flashing part.

Calculate the color difference of each pixel of the two images with 30° adjacent of the diamond, and determine the scintillation successively. The scintillation area $S$ of the diamond is defined as $N_s$ divided by the total number of pixel points $N$: 
The calculation above was performed on all adjacent images of 12 images with 360°, and the arithmetic mean value was taken. The result was expressed as a percentage to obtain the scintillation area of a diamond. After all the diamonds are photographed, processed and computed, each diamond corresponds to a scintillation area. The result is given in table 1.

3. Effect of Gemological Properties of Diamond on Scintillation Area

3.1. Quantification of Diamond Index

Three attributes of clarity, color, and fluorescence of diamond are selected to quantify each one. The advantages and disadvantages of each attribute are represented by numbers, with 0 representing the best index and 8 representing the worst index. For example, the "clarity" attribute is represented by 0 to 8 from FL to P1. Color grade D, E, F, G, and H are represented by 0, 2, 4, 6 and 8 respectively. Fluorescence NON is 0, FNT is 4 and MED is 8, as given in table 2. In this way, the gemological characteristics of diamonds are quantified into the Numbers 0~8 for uniform comparison.

| Table 2. Diamond index grading quantification |
|-------------------------------|-----------------|---------------|
|     | Clarity | Color | Fluorescence |
| Index |        |      |             |
| 0     | IF      | D    | NON         |
| 1     | VVS1    | -    | -           |
| 2     | VVS2    | E    | -           |
| 3     | VS1     | -    | -           |
| 4     | VS2     | F    | FNT         |
| 5     | SI1     | -    | -           |
| 6     | SI2     | G    | -           |
| 7     | SI3     | -    | -           |
| 8     | P1      | H    | MED         |

3.2. Plot Results

Take the scintillation area as the independent variable and the above three indexes as dependent variables to make scatter plots respectively, and observe the correlation between each attribute and the scintillation area. In this way, scatter plots of the three properties and their regression curves are obtained, as shown in figure 3. With the increase of scintillation area, all three properties have a decreasing tendency, that is, the lighter the color of the diamond, the better the clarity, the weaker the fluorescence, then the larger the scintillation area, the more obvious the scintillation.

4. Conclusion

After calculating the scintillation area through the color difference of adjacent angle pictures of diamonds, it is found that:

1. The higher the clarity, the lighter the color, the weaker the fluorescence of the diamond, then the larger the scintillation area, the stronger the scintillation.
2. Take a picture of the diamond every 30°, rotate it to the same angle, and calculate the color difference between two adjacent pictures, and then find the area of the scintillation. The lightness difference will magnify subtle changes in lightness and interfere with real scintillation areas. The hue difference, which performance is the worst, cannot reflect scintillation, so choose color difference as the criterion of scintillation.
3. The area of scintillation is related to the gemological characteristics of a diamond. The clarity, color, and fluorescence are quantified as 0 ~ 8, and it is found that the scintillation area of a diamond
is positively correlated with its quality and can be used as one of the reference standards to measure the quality of a diamond. The influence of clarity, color, fluorescence and other attributes on scintillation area conforms to the GIA and GB standards for diamond quality identification, which also verifies the rationality that the weaker the fluorescence, the higher the value.

Figure 3. The relationship between scintillation area and gemological properties

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