The over-grading of blue-fluorescent diamonds: the problem, the proof and the solutions

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Abstract: Decades after the establishment in the mid-twentieth-century of ultraviolet-free illumination for colour grading a diamond, an examination of diamond trade and laboratory grading practices finds nearly everyone employing some type of fluorescent tube lighting containing significant ultraviolet. This paper demonstrates and quantifies the over-grading of blue-fluorescent diamonds that often can result. Simple methods are proposed that, by themselves or in combination, provide inexpensive and workable solutions to resolve this problem.

Keywords: colour grading, diamond, fluorescence

Introduction

For over a hundred years, it has been recognized that the light yellowish tints in a type 1a diamond combine with the various amounts of blue fluorescence, stimulated by daylight and other illumination containing ultraviolet (UV) energy, to give blue-fluorescent diamonds a whiter perceived colour than the colour seen in lighting where fluorescence is not stimulated to a noticeable degree.

The problem is how to colour grade blue-fluorescing diamonds, which can appear a whiter colour grade in daylight than their colour as seen indoors under typical artificial lighting.

Not long after Robert Shipley founded the Gemological Institute of America (GIA) in 1931, he recruited academic members to a GIA advisory board to help advance the gemmology movement in America. An important contributor among these members, especially in the field of diamond science, evaluation and valuation, was Frank Wade. Wade was a pioneer in America of "the first series of scientific articles (from 1915 to 1948) on diamonds and gems written especially for the jeweler" (Gilbertson, 2007). Given his own studies and input from diamond experts and educators like Wade, it is no surprise to find Shipley concerned about fluorescence in the colour grading of diamonds. He addressed this fluorescent diamond grading problem in *Gems & Gemology,* 1941. There he says: "One of the most important causes of the anomalies that so often trouble a diamond grader is the change of colour shown by many fluorescent stones when viewed under different light conditions. Often a fluorescent diamond which appears slightly yellowish under artificial light, appears distinctly bluish in daylight" (Shipley and Liddicoat, 1941).

This simple term 'daylight' disguises the large variation in UV content depending on time of day, geographic location, and whether or not the day was sunny or cloudy. With the perceived colour of fluorescent diamonds varying with the illumination, what lighting should be used in laboratory colour grading? Historically, the standard lighting for colour grading was 'northern daylight', such as that through north-facing windows, for example in the Israel Diamond Exchange *(Figure 1).*

In 1941, the GIA produced their first diamond colour grading instrument called the Diamolite (later renamed the DiamondLite), using an incandescent filament type of light source and a 'daylight filter' which produced "the equivalent of north light without the UV radiation" (GIA, 1969). At the same time the GIA stated that "a reasonably good substitute for the DiamondLite can be made by adapting a simple desk lamp fixture containing cool white fluorescent tubes". However, they caution: "The disadvantage of this kind of illumination is that fluorescent tubes emit a significant percentage of UV radiation. Although this does not affect the grading of non-

Figure 1: Trading floor of the Israel Diamond Exchange. (Inset) A closer look at the lights in use.
Courtesy of the Israel Diamond Exchange.

fluorescent stones, it causes fluorescent diamonds to be graded higher than is actually warranted due to the neutralizing, or masking effect, of the fluorescent colour on the true body colour" (GIA, 1969). Yet, by the 1970s we find that gemmologists and the diamond trade worldwide are universally using some form of UV-emitting fluorescent light to colour grade diamonds. An important example is the later version of the GIA DiamondLite that substituted unfiltered fluorescent tubes for the daylight-corrected incandescent light source in the early model.

In 1997, Moses *et al.* indicated that digital radiometer readings of UV content revealed similar intensities of long-wave UV content in four sources of fluorescent lighting including the Verilux tubes in the DiamondLite. They also found "indirect daylight through our windows has about as much UV radiation as the fluorescent light sources". With the GIA's finding that "fluorescent lighting" and "daylight through a window" have a similar amount of UV radiation, it would be expected that blue-fluorescing diamonds would be perceived to be whiter in daylight through a window and in the DiamondLite than they would when viewed on social occasions in indoor artificial lighting.

In 2008, King *et al.* described the evolution of colour grading lights and how the original UV-free source had changed to one with characteristics of daylight including its fluorescence-stimulating UV component. They concluded: "We believe that a standard light source for diamond colour grading should have key characteristics of daylight, including a UV component." (King *et al.*, 2008, p.320.)

GIA's study findings and conclusions are best summed up in the words of Moses (2001) who stated the GIA belief "that the best man-made light sources reproduce all the characteristics of traditional north daylight, including the 'good deal' of UV ... Not only do members of the trade typically buy and sell diamonds under lighting conditions that have a UV component, but they also colour grade them with a lamp that has

Figure 2: Six diamonds graded I colour in a DiamondLite showing a range of fluorescence. Picture reproduced courtesy of GIA; these three photographs were used in the assembly of Figure 3, I colour set pictured in the paper by Moses et al., 1997, p. 249

some UV content. Grading in a UV-free environment is contrary to this accepted practice and will cause confusion." (Moses, 2001).

However, not addressed in the 1997 and 2008 articles was consideration of the intensity of the UV and visible-violet (VV) energy present at typical light-to-diamond distances in normal viewing circumstances compared to the energy intensity present at the much closer distances to the lighting in grading instruments.

The key point is that most diamonds are seen in most forms of artificial illumination at night or indoors out of daylight, and in these viewing environments the UV and visible violet are too weak to stimulate grade-whitening fluorescence. In contrast, the relatively strong UV and visible violet at typical distances of 1 to 7 in. from the fluorescent tubes of grading instruments can stimulate a good deal of fluorescence which whitens the appearance of a diamond. The use of such unfiltered fluorescent lighting has today become almost universal and is an abandonment of the diamond grading standards originally established by GIA in accordance with diamond-trade practice at that time.

A closer look at the Israel Diamond Exchange in *Figure 1 (inset)* reveals the kind of fluorescent desk lamps being used in diamond grading. There is nearly universal use of fluorescent lighting in spite of it being the very same source of grading illumination that was originally considered by many to result in the over-grading of fluorescent diamonds. Corrective solutions are needed to this almost universal use of some form of fluorescent light to colour-grade diamonds at major grading laboratories and within the trade.

Where is the proof of the over-grading of many blue-fluorescing diamonds? To quote Tashey (2009): "I was shocked when I made the initial discovery, by placing a clear, UV filter, plastic film between the Verilux lamps in the GIA DiamondLite and the diamonds to be graded, that stones with very strong blue fluorescence could change to a lower colour by three or four letter grades." He spoke of a 0.89 ct marquise brilliant with 'Very Strong Blue' fluorescence: "In the DiamondLite [Verilux lamps, without UV filter] this stone was graded table down as a high 'D'. ... When viewed table down, with the UV filter between the lamps and the diamond, the colour grade of the diamond shifted to that of a low 'H'." Tashey (2000) had earlier found that diamonds with 'medium' to 'strong' blue fluorescence generally shifted one to two colour grades when the filter was used.

This example in a 'Very-Strong-Blue' fluorescing marquise diamond of close to a five grade colour improvement to high D in the DiamondLite from the UV-free colour grade of low H may be met with disbelief by professionals in the trade, all of whom grade in some form of UV-containing fluorescent illumination, and so have not witnessed this large a shift in colour. However, the data base in the current investigation contains a 0.63 ct marquise diamond with a similar close to five grade improvement in the DiamondLite over its unimproved colour as determined in UV-free artificial lighting.

Evidence of the over grading of blue-fluorescent diamonds was also contained in a photograph in the paper by Moses *et al*. (1997). Their *Figure 2* includes a set of six diamonds graded I colour in the DiamondLite and these show clear colour differences. The photograph was taken in incandescent illumination (Erica Van Pelt, pers. comm.,) which (by its nature and distance from the subject) was UV-free compared to the DiamondLite. This picture is reproduced here courtesy of GIA *(Figure 2)* and affords an opportunity to relate the colour differences, particularly in the face-up images, to the strengths of fluorescence. The fluorescent strengths, from left to right, are: 1 Medium, 2 Very Strong, 3 Faint, 4 Strong, 5 None and 6 Strong

Stones 2, 4 and 6 appear to have substantially more colour than the other three in spite of having been graded as I colour. It is no coincidence that these are the three with the strongest blue fluorescence. Revealed in this relatively UV-free lighting of the photographer is the darker colour unenhanced by blue fluorescence of the strongly fluorescing members of this I colour set.

While the difference is apparent, the magnitude of over-grading relative to the colour unenhanced by fluorescence cannot be quantified from this photograph. That quantification was accomplished by analysis of grading of the 25 diamond data base central to this study.

Figure 3: The 25-diamond data base in lighting showing diamond brilliance and fire.

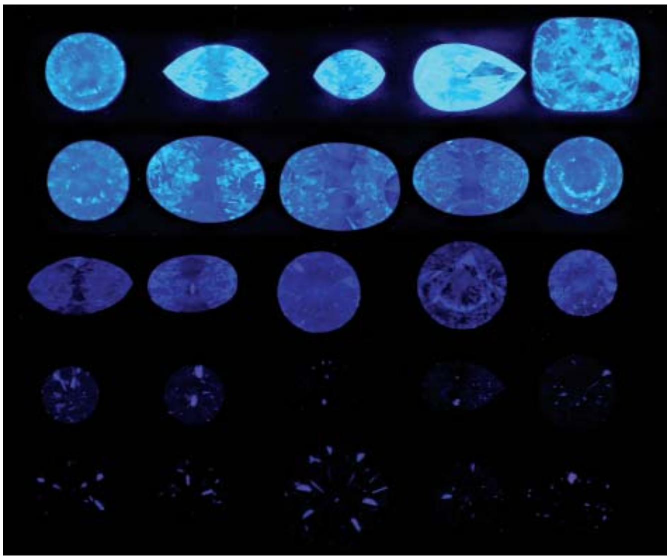

Figure 4: The 25-diamond data base in long wave UV 'black lighting'. Not to be mistaken for fluorescence are the flashes of visible violet reflected from the diamonds with negligible fluorescence in rows four and five.

Investigation

To explore and quantify the extent of the over-grading of blue fluorescent diamonds, and find possible solutions to this problem, a set of 25 diamonds with fluorescent strengths from 'none' to 'very strong' was assembled . The analysis contains not only the author's grading of the diamonds in several lighting environments, including the DiamondLite and the DiamondDock, but also the grading of GIA's Gem Testing Laboratory (GIA GTL) and the American Gem Society's Laboratory (AGSL). GIA's current grading environment and light grading standard consists of grading at a 7 in. distance from the twin 17 in. Verilux fluorescent tubes in their DiamondDock. It is the standard in use at GTL since 2000 (R. Geurtz, pers. comm.). The GIA grading reports on the diamonds in this study are all dated post-millennium. AGSL's grading of these diamonds was likewise accomplished in a DiamondDock.

One goal was to determine the range of perceived colour improvement or change in each fluorescent strength category caused by grading in these various lighting circumstances. A second goal was to investigate techniques to create illumination in which fluorescence is not noticeably stimulated. This was pursued both by using new, UV-free LED lighting and by modifications to currently used fluorescent tube lighting.

Observations on the five fluorescence strengths in the 25-diamond data base.

Investigation and photography of the fluorescence properties of the data base's 25 diamonds utilized a Raytech UV Lamp (black light), Model LS-88, with an LW-8, 8 in., 6W, mercury vapour, LWUV tube. This delivers an intensity of UV radiation centred near 360 nm of 180 μW/cm² at a distance of six inches.

The 25 diamonds are set out in *Figure 3* in five rows of five diamonds of each fluorescent strength. They are numbered from 1 to 25 from left to right and top to bottom. Strengths of blue fluorescence are indicated in grading reports by the major laboratories with the descriptions of Very Strong Blue, Strong Blue, Medium Blue, Faint or None. These five groups of fluorescent strength are visually apparent in *Figure 4*.

There can be variation in these descriptions from lab to lab especially for borderline stones. Nevertheless, for the purposes of this study it is desirable to assess fluorescence as accurately as possible.

Observations of blue fluorescence in particular data-base diamonds

Looking at *Figure 4*, the 'Very Strong Blue' fluorescing diamonds, 2, 3 and 4 appear the strongest fluorescing in this category. Diamond 5 is borderline with GIA calling it 'Strong Blue' and AGS 'Very Strong Blue'. Diamonds 1 and 6 appear identical in strength with both called 'Very Strong Blue' by AGS and a third lab, International Gemological Institute (IGI) calling 6 only 'Strong Blue'. The laboratories' descriptions were in agreement in the rest of the row of 'Strong Blue' diamonds: 7, 8, 9 and 10. The 'Medium Blue' row of diamonds 11–15 were so graded by everyone with the exception of 15 which only GIA called 'Strong Blue'.

So, this analysis and the photograph in *Figure 4* show reasonable consistency in describing fluorescent strength with an occasional miscategorization or equivocal borderline case.

Note the wide range of intensity in the 'Very Strong Blue' category. The ten diamonds in the 'Faint' and 'None' categories (which AGSL calls Negligible) are important to this investigation as a control group to provide data concerning variation in colour grading when there is no variability due to fluorescence.

Measurements of UV content in natural and artificial lighting

The degree of any perceived colour improvement due to fluorescence is proportional to both the diamond's

Box A: Analysis of fluorescence of diamond No. 5 in this investigation

Thomas Hainschwang has kindly provided the following details: fluorescence measurements of the 3.02 ct diamond 5 were obtained by exciting the diamond with near-monochromatic light in steps of 5 nm from 340 to 415 nm, produced from a Xenon light source via a monochromator; by this technique it is possible to excite fluorescence with any desired wavelength of the lightsource. The fluorescence was recorded for each excitation wavelength with a high sensitivity CCD spectrometer and the results normalized. Each recorded curve (in black) in *Figure A* represents fluorescence spectrum excited by the the near-monochromatic light tuned to distinct wavelengths. To give an example, the first emission curve in *Figure A* represents the intensity of the fluorescence of the diamond when excited by near-monochromatic light with a central wavelength of 340 nm. The 3D graph in *Figure A* thus shows the fluorescence intensity profile when the diamond is excited with such near-monochromatic light of various wavelengths.

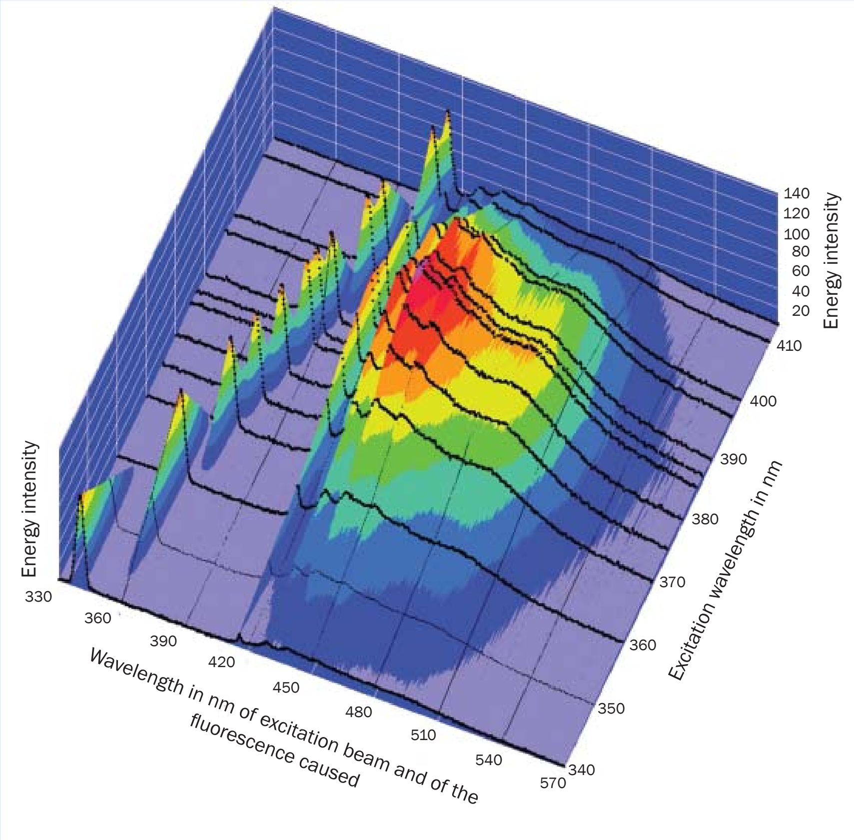

Figure A. Blue fluorescence intensity stimulated by UV and visible-violet radiation in diamond no. 5. The peaks of the near-monochromatic exciters are shown in the line of peaks on the left, and the fluorescence generated in the diamond is the colour-contoured profile centre-right. Energy intensity is shown in arbitrary units and colour-coded with red being the most intense. Courtesy of Thomas Hainschwang, Gemlab.

These curves show what early diamond industry experts did not know, not just UV light, but also visible light up to 415 nm excites the blue fluorescence caused by the N3 centre (three nitrogen atoms surrounding a vacancy) in any diamond containing appreciable concentrations of A and B aggregates, and consequently N3 centres. Consequently wavelengths up to 415 nm can be important contributors to blue fluorescence in Cape Series diamonds. At normal viewing distances from artificial illumination the violet light intensity, just like the UV, is too weak to excite noticeable fluorescence. But observation too close to either fluorescent or incandescent lighting, where the intensity exceeds about 400 fc or 4000 lux, was found to excite blue fluorescence (fc and lux are the units used in photometry as measures of visible light intensity, as perceived by the human eye. They are analogous to the radiometric unit μW/cm², but with the intensity at each wavelength weighted according to the luminosity function, a standardized model of human visual brightness perception.)

fluorescent strength and the strength of the UV energy from the light source used in grading. A Dazor Model 5.7 (UVA + B) total UV instrument was employed to measure the amount of UV present in each lighting environment. This meter was calibrated to NIST standards, and measures the UV band from 280–400 nm over a range of 0 to 1999 μW/cm².

Typical measurements of UV in blue sky, northern daylight in Maryland, at 11:00 a.m. 7 December 2008, were 500–600 μW/cm². The UV rapidly increased as the detector was rotated south and the vicinity of the sun was approached. Near but not including direct sun, the reading quickly exceeded the meter range of 1999 μW/cm². Hazy overcast and cloudy skies absorb UV and were observed to reduce these figures by more than a factor of two. On 8 March 2009 at noon on an overcast day readings in north light of 800–1100 μW/cm² were obtained. This large and highly variable amount of UV in natural daylight makes it clear why this illumination is unsuitable for consistent grading of fluorescent diamonds.

Discussions of lighting standards for colour grading are often concerned with the variability of daylight's colour temperature, which ranges from the reddish light of early morning and evening to the bluish mid-day light from a cloudless north sky. The historical north-daylight standard for colour grading was derived from the traditional lighting from large north-facing window areas in diamond bourses in the Northern Hemisphere *(Figure 1)*, and the restriction of grading times to between late morning and early afternoon. A colour temperature of 6500K is widely accepted. The more problematic, often unknown and neglected consideration for accurate and consistent colour grading is the variable stimulation of blue fluorescence by the highly variable amounts of UV and visible violet present in daylight from open sky, or from north-facing windows, and the fluorescent lighting used in diamond colour grading.

Away from open daylight and indoors, the UV intensities dropped by factors of 100 to 1000, and in typical artificial light to less than 1μW/cm². The greatest indoor sources of UV at noon were large glass windows and doors which faced daylight. These large glass areas filter out short wave UV, but pass a proportion of long wave UV. At the window surface the reading at the December 2008 date and time was 150 μW/cm² dropping to 65 μW/cm² at 3 ft and 35 μW/cm² at 6 ft.

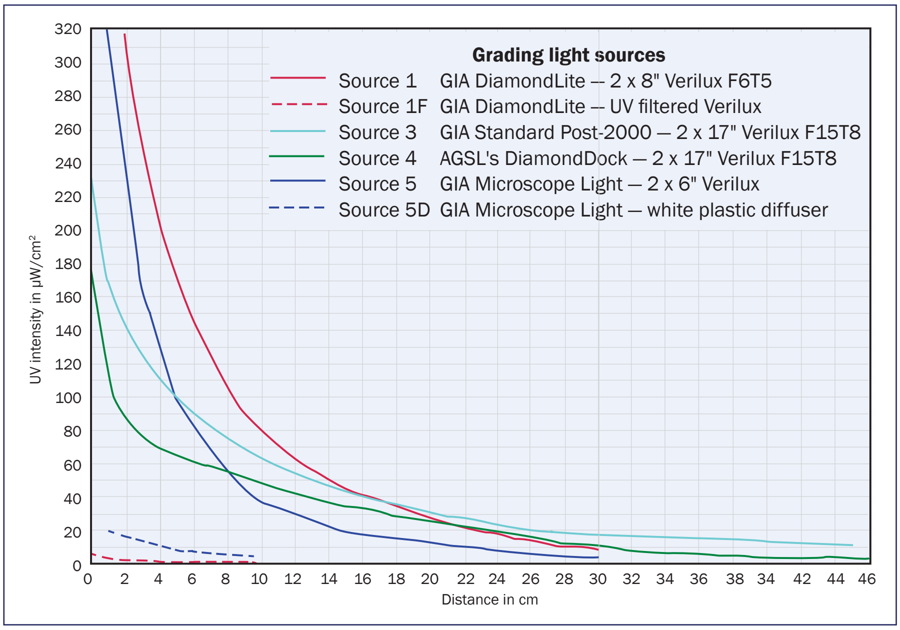

Figure 5: Reduction in intensity of UV with distance from study light sources.

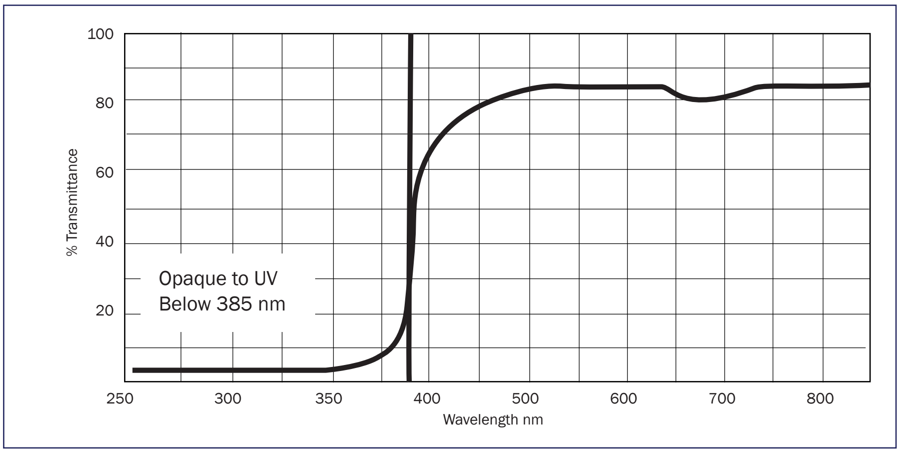

Figure 6: Graph of transmittance of polycarbonate UV filter. Courtesy of Dazor Lighting Manufacturing.

In all other areas illuminated by artificial fluorescent and incandescent ceiling illumination the readings at typical 3–4 ft viewing distances from ceiling lights were an essentially UV-free, 0–1 μW/cm². These readings are consistent with results from extensive surveys conducted by the author and others and provide support for the observation that at distances of more than 3 ft from artificial illumination, including ceiling mounted fluorescent lighting, indoor light is essentially UV free. In addition, because the light intensity is below 400 fc, usually under 100 fc and often less than 50 fc, there is no noticeable stimulation of fluorescence from the visible violet.

The light sources used in this investigation were measured for UV energy intensity, which was plotted as a function of distance from the source. The graph in *Figure 5* shows those curves of UV fall off with distance from Source 1 and 1F (UV filtered), the DiamondLite; Source 3, a two tube desk lamp with the post 2000 GIA Lighting Standard of the twin Verilux tubes used in the DiamondDock; Source 4, AGSL's DiamondDock and Source 5 and 5D (diffused), the GIA Microscope Light. These plots document the high amount of UV present at close grading distances from all of the unfiltered fluorescent light tubes, and also show the rapid fall off with distance from them. Sources 3 and 4 (the cyan and green curves), both employing the post 2000 GIA standard grading illumination of twin 17" Verilux tubes are important examples showing the variability of this standard's UV component.

Lexan and Makrolon polycarbonate filters were used when experimenting with the removal of UV from the various lights used in grading. Polycarbonate plastic is particularly suited to removing UV without significant or noticeable effect on the visible light spectrum. Note that the dashed Source 1F red curve in *Figure 5* shows that the UV has been reduced to less than 1 μW/cm² within 3 in. of the DiamondLite filtered with Lexan polycarbonate plastic. It is opaque to UV below 385 nm and is transparent

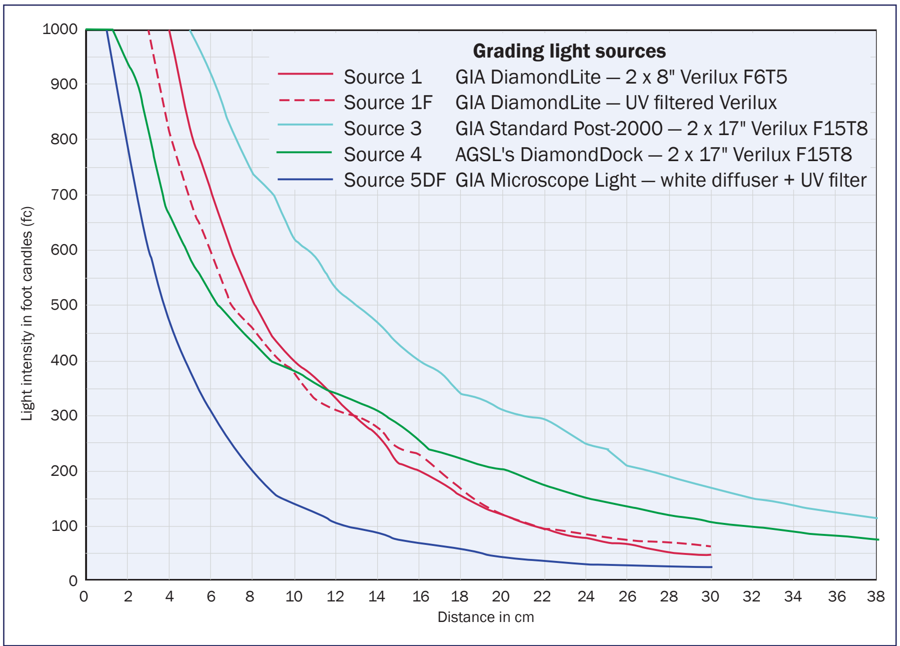

Figure 7: Reduction of light intensity with distance from study light sources.

to the visible spectrum. The range of wavelengths visible to the human eye is often listed as 400 to 700 nm, but "for the human eye, the visible radiations range from violet light, in which the shortest rays are about 380 nm, to red light, in which the longest rays are about 750 nm." (Curtis and Barnes, 1994). It should be stressed however that the eyes of any one individual may not possess this wide range. So for some fortunate individuals there could be 20 nm overlap between UV and visible violet from 380 to 400 nm. This region is at the transmission edge of the polycarbonate filter (see *Figure 6*).

Because the visible wavelengths at and below the 415.2 nm, N3-centre in diamond also excite blue fluorescence (see Box A), it was additionally important to measure the light intensity as a function of the distance from each of the grading lights to explore the visible light component's influence on grading of fluorescent diamonds. Measurements in foot candles of visible light intensity at different grading distances were obtained using a GE Light meter, Type 217. The curves in *Figure 7* show light intensity reduction with distance from four of the grading light sources. The shapes of these curves are broadly similar to the unfiltered UV curves, because the rate of reduction with distance is a function of the lighting geometry and essentially the same for visible and UV wavelengths.

Colour grading instruments and their light-source properties

Seven sources of light were investigated to study their influence on the colour grading of each of the five levels of diamond fluorescent strength present in the 25 diamonds. Each light source was used unfiltered or with the UV component filtered out.

1. The DiamondLite

The DiamondLite, shown in *Figure 8*, contains two Verilux F6T5 fluorescent tubes. In the 1960s it replaced the original Diamolite, renamed DiamondLite, which Shipley had designed to be largely UV free. It incorporated Verilux fluorescent tubes also believed to have a "minimum of UV." In the 1990s it came to be realized that their output contained a significant component of UV.

Because of the rapid increase in both UV and visible light intensity on coming close to the Diamondlite's fluorescent tubes, a colour grade given to a blue-fluorescent diamond could be significantly influenced by how close to these tubes it was graded. Conversations with former and current GIA GTL diamond graders indicate that grading was done between 1 and 4 in. from the fluorescent tubes to the diamonds in the DiamondLight tray or on a white plastic sheet on the instrument base. Grading practice varied somewhat at different times and with different graders. K. Hurwit (pers. comm., 2009), grader of diamond masters, relates that she adhered to Liddicoat's instruction to grade in the tray on the base, but would sometimes elevate the tray for a better view. Senior diamond grader, P. Yantzer, related a standard lab practice used by him and other lab graders since 1972; they placed the diamond table-down, with master stones, toward the rear on a flat sheet of plastic on the base and tilted or elevated this sheet towards the light when comparing to the masters (Yantzer, pers. comm., 2009).

In the 1 to 4 in. range available for grading in the DiamondLite, there are significant amounts and large ranges of UV and visible-violet energy. This variation makes for inconsistent colour grading of blue-fluorescent diamonds. The grading of the data-base diamonds was done between 2 and 3 in. beneath the tubes. At this typical grading distance a spot reading found the UV energy to be about 150 μW/cm², and the light intensity about 600 fc. As the radial distance from the diamonds to the nearest of the twin Verilux tubes increases from 1 to 4 in. the UV decreases from the vicinity of 300 μW/cm² to 80 μW/cm², as shown in *Figure 5*. These are the greatest amounts of UV found among the seven lighting environments investigated, and provide the reason that the unfiltered DiamondLite was found to cause the greatest whitening and, consequently, the greatest over-grading of blue-fluorescent diamonds.

2. GIA DiamondDock

At the turn of the twenty-first century the GIA discontinued the manufacture and use of the DiamondLite and replaced it with the DiamondDock, which employs two 17 in. F15T8VLX Verilux full spectrum fluorescent tubes. Diamonds

Figure 8: GIA DiamondLite containing two Verilux F6T5 fluorescent tubes.

Figure 9: Grading in the DiamondDock at the AGS Laboratory with (inset) a 10-diamond master set. Courtesy of AGSL.

are graded on a white tray placed on the DiamondDock shelf, which means that there is a 7 in. grading distance from the light tubes (see discussion below). The basic technical specifications of the DiamondDock lighting were given by King *et al*. (2008), and include:

- Stable, fluorescent lamps 17 in. (43 cm) or longer
- An intensity of light in the range of 2000–4500 lux at the surface of the grading tray
- An 8–10 in. distance between the lamps and the grading tray
- A colour spectrum close to CIE D55-D65
- A colour temperature between 5500 K and 6500 K
- A colour rendering index of 90 or above
- No noticeable output in the short- or medium-wave UV range (or a filter available to eliminate UV in this range)
- An emission for long-wave UV (between 315 and 400 nm, close to the reference spectrum of D55-D65)

It should be stated that although a grading distance of 8 to10 in. is specified, the maximum distance in the box that the diamonds can be positioned from the lamps is 7 in. Looking in *Figure 5* at the green graph of reduction in intensity of UV with distance in the AGSL's DiamondDock, the UV intensity at 7 in, is 28 μW/cm² falling to 17 μW/cm² at 10 in. The UV intensity is 65% higher at 7 in. compared to that at 10 in. The exact distance is important to establish what is, in essence, the chosen standard amount of UV and visible violet. GIA researcher R. Geurtz (pers. comm.) confirmed that the distance between the light source and the diamond will be close to 7 in.. He explains: "With the distance between shelf and the centre of the bulb at 8 to 10 in., the distance between the diamond and the surface of the bulb is around 7 in." But he notes another important point: the allowed range of light intensity of 2000–4500 lux at the surface of the grading tray means that the amount of UV and visible violet also can vary over the same 2.25 times range. Such an allowed range of UV and visible violet could lead, in different instruments, to different colour grades for a blue fluorescent diamond.

3. Floating arm desk lamp

For the multitude of owners of a standard floating-arm desk lamp, throughout the global diamond trade, this may be the most economical solution for those desiring compatibility with the GIA's DiamondDock. Two 17 in. F15T8VLX Verilux 'full spectrum' fluorescent tubes (the GIA standard lighting used in the DiamondDock) provide the light. Grading was done, without UV filtering at the 7 in. distance, as in the DiamondDock.

Figure 10: Microscope light fitted with white diffuser and Lexan UV filter.

4. AGSL DiamondDock

The DiamondDock in use at the AGS Laboratory is shown in *Figure 9;* the inset shows their ten-diamond E–N master set.

5. GIA microscope fluorescent light

GIA microscopes have provided a less expensive alternative to grading in a standard lightbox. These are fitted with a swing arm light attached to the front of the microscope stage, containing twin Verilux, 6 in. fluorescent tubes, whose light is filtered and diffused with a white plastic cover. This was a daylight-balanced grading light recommended to GIA students and is used to this day by many gemmologists and appraisers (the author included) as lighting for both diamond colour grading and final judgements of clarity grade. The author's

Table I: Colour grades of 25 diamonds with a range of fluorescence strengths.

				Grading of data base in lighting sources with different amounts of UV and VV energy									
				Source 1		Source 2	Source 3	Source 4	Source 5		Source 6		Source 7
				GIA DiamondLite		GIA DiamondDock	Two Verilux	AGSL's DiamondDock	GIA Microscope Lamp		Dazor – Lumileds		Philips 4 × 32 W
			Grading distance	2–3 in.		7 in.	7 in.	7 in.	1 in.		3–5 in.		36 in.
				No filter	UV filter	No filter	No filter	No filter	Diffuser (D)	D+UV filter	Diffuser	Diffuser	Diffuser
			Intensity (fc) at grading distance	600 fc	600 fc		350 fc	230 fc	600 fc	600 fc	600 fc	200 fc	200 fc
			Ultraviolet (UV-A) at grading distance	150 $\mu W/cm^2$	1 $\mu W/cm^2$		33 $\mu W/cm^2$	31 $\mu W/cm^2$	9 $\mu W/cm^2$	1 $\mu W/cm^2$	0 $\mu W/cm^2$	0 $\mu W/cm^2$	0 $\mu W/cm^2$
			Grader[1]	MDC		GIA GTL	MDC	AGSL	MDC		MDC		MDC
No.	Cut	Weight (ct)	Fluorescence										
Diamonds with GIA report													
1	R	0.92	VST Blue	E	G	E	G	F		G		H	H
2	M	0.63	VST Blue	E	H	F	G	G	G	H	I		J
4	P	1.13	VST Blue	F	H	H	H	H		H		J	J
5	C	3.02	ST Blue (VST)[2]	D	D	D	D	D		D	E		E
7	O	2.01	ST Blue	E	E	E	E	F		E	F		G
8	O	2.02	ST Blue	E	E	E	E	F		E	F		G
9	O	1.56	ST Blue	E	F	F	E	F		F	G		G
10	R	1.00	ST Blue	E	E	E	E	G		F		G	G
12	O	0.68	MED Blue	F	F	F	F	G		F	F		G
13	R	1.09	MED Blue	G	G	G	G	G		G	G		G
15	R	0.59	ST Blue (MED)	E	E	E	E	F		E		E	E
20	R	1.01	None	J	J	J	J	J		J	J		J
21	R	0.77	None	G	G	G	G	H		G	G		G
22	R	0.73	None	G	G	G	G	G		G	G		G
23	R	2.28	None	H	H	I	H	H	H	H	H		H
Diamonds without GIA report						Non-GIA grading							
3	M	0.50	VST Blue	E	G		G	G		H	H		I
6	R	1.05	ST Blue	I	J	I(IGI)	I	I	I	J	J		K
11	M	0.84	MED Blue	G	G		G	H		G	H		H
14	R	1.50	MED Blue	G	H		G	H		G	H		H
16	R	0.50	Faint	D	D	D(EGL)	D	D		D	D		D
17	R	0.42	Faint	D	D		D	E		D	D		D
18	P	0.70	Faint	G	G		G	G		G	G		G
19	P	0.62	Faint	D	D		D	D		D	D		D
24	R	0.71	None	H	H		H	H		H	H		H
25	M	0.71	None	D	D		D	D		D	D		D

NB 1. Grader abbreviations: MDC = M.D. Cowing; GIA GTL = Gemological Institute of America Gem Testing Laboratory; AGSL = American Gem Society Laboratory; IGI = International Gemological Institute; EGL = European Gemmological Laboratories.

2. Brackets in this column indicate an AGSL opinion where it differs from that of GIA.

microscope light with the addition of a Lexan polycarbonate UV filter is shown in *Figure 10*. Unfiltered, at a distance of about an inch, this light has a strong UV component of 200 μW/cm² and a strong visible light intensity of 1000 fc. The standard white plastic diffuser reduces the UV to 10 μW/cm² and the light intensity to 800 fc. With the addition of a Lexan filter, the UV drops to a small 1 μW/cm² and the light intensity to 740 fc.

In the Verilux tubes in the DiamondLite and all commercial mercury vapour fluorescent lighting, at typical close grading distances the visible-violet wavelengths add to the stimulation of blue fluorescence formerly attributed only to UV. Even after filtering out UV, the visible violet present in light intensities at or above about 600 fc was found to whiten some 'Strong' and 'Very Strong Blue' fluorescent diamonds. To prevent the energy in the visible violet from noticeably affecting fluorescent diamond colour, provisional tests indicate that the maximum fluorescent-tube light intensity should not exceed 400 fc. This compares with the lighting intensity range of 2000–4500 lux listed by King *et al.* (2008), this being the equivalent of 186–418 fc.

6. LED desk lamp

In order to investigate the potential of LED technology for use in diamond colour grading, especially as a solution to the over-grading of blue-fluorescing diamonds, a white LED light, which emits no UV, was tested. It contains six high-power 'lumiled' LEDs with a high quality, thermally-managed, consistent 6000 K colour. An additional feature of this lamp, of interest because of visible-violet stimulation of blue fluorescence, is the ability to dim the light while maintaining its colour temperature. Initial grading of the 25 diamonds in the data base indicated that at a brightness of 600 fc the grades recorded were slightly whiter than those recorded in light of 200 fc (i.e. within the range recommended above); in the absence of UV this was attributed to fluorescence stimulation by the visible violet.

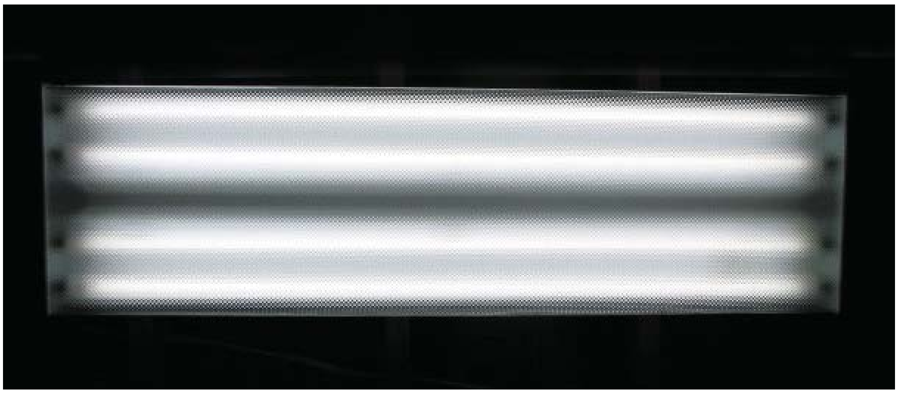

Figure 11: Overhead north-daylight balanced, (D65) fluorescent lighting.

7. Northern daylight balanced ceiling-mounted fluorescent light

The colour of a diamond can be seen and graded against master diamonds at distances from daylight fluorescent overhead illumination of 3 to 4 ft. Such distances are typical of those at which diamonds are viewed in a variety of social occasions. At this distance there is negligible UV and the amount of visible violet is not strong enough to whiten the colour grade. The example of this lighting chosen was the overhead daylight fluorescent light *(Figure 11)* containing four, 32 W Philips F32T8/DX tubes behind a clear plastic diffuser. Almost any artificial ceiling lighting could have been used, since at normal diamond viewing distances such illumination is essentially UV-free and has a visible light intensity which does not stimulate noticeable fluorescence. This lighting has a colour temperature of 6500 K, and at a distance of 3 ft, an intensity of 200 fc with no measureable UV.

Evaluation of the grading of the 25 diamonds

In *Table I* are the colour grades of the 25 diamonds in the data base obtained in each of the light environments.

To get a better visual understanding of the changes in grading which relate to different fluorescent strengths and light sources, the letter grades were changed to integers, 0 for D, 1 for E and so on. The integer number of grades improvement over the colour determined in the absence of fluorescence stimulation was then recorded in the 3-D scatter plot in *Figure 12* for each light source arranged in UV-strength order from the back: Row 1, Source 1, the unfiltered DiamondLite having the most UV to Row 6, Source 6, LED lighting front-left having no UV. In order of decreasing UV, Row 2, Source 2 is GIA's grading in the DD, Row 3, Source 3 is the author's grading in GIA standard DD type lighting, Row 4, Source 4 is AGSL grading in their DD, and Row 5, Source 5 is the author's grading in the UV-filtered and white-plastic-diffused microscope lighting.

Examination of the chart and scatter plot supports the observations of whitening from blue fluorescence made by Tashey (2009). The improvement due to blue fluorescence from both the UV and visible violet in 'Very Strong' blue-fluorescing diamonds was found to be up to four and one-half grades. By filtering out the UV it was calculated that between one and two grades of this four and a half was due to stimulation by the remaining energy post filtering, chiefly the visible-violet. In 'Strong Blue' fluorescent diamonds, the colour-change due to fluorescence was typically two grades. In 'Medium Blue' fluorescent diamonds the change was generally between zero and one grade. As expected, no differences in grade from UV stimulation were found in the 'Faint' and 'None' categories of diamond.

An issue arising in the course of this investigation was the observation by the author and many other gemmologists

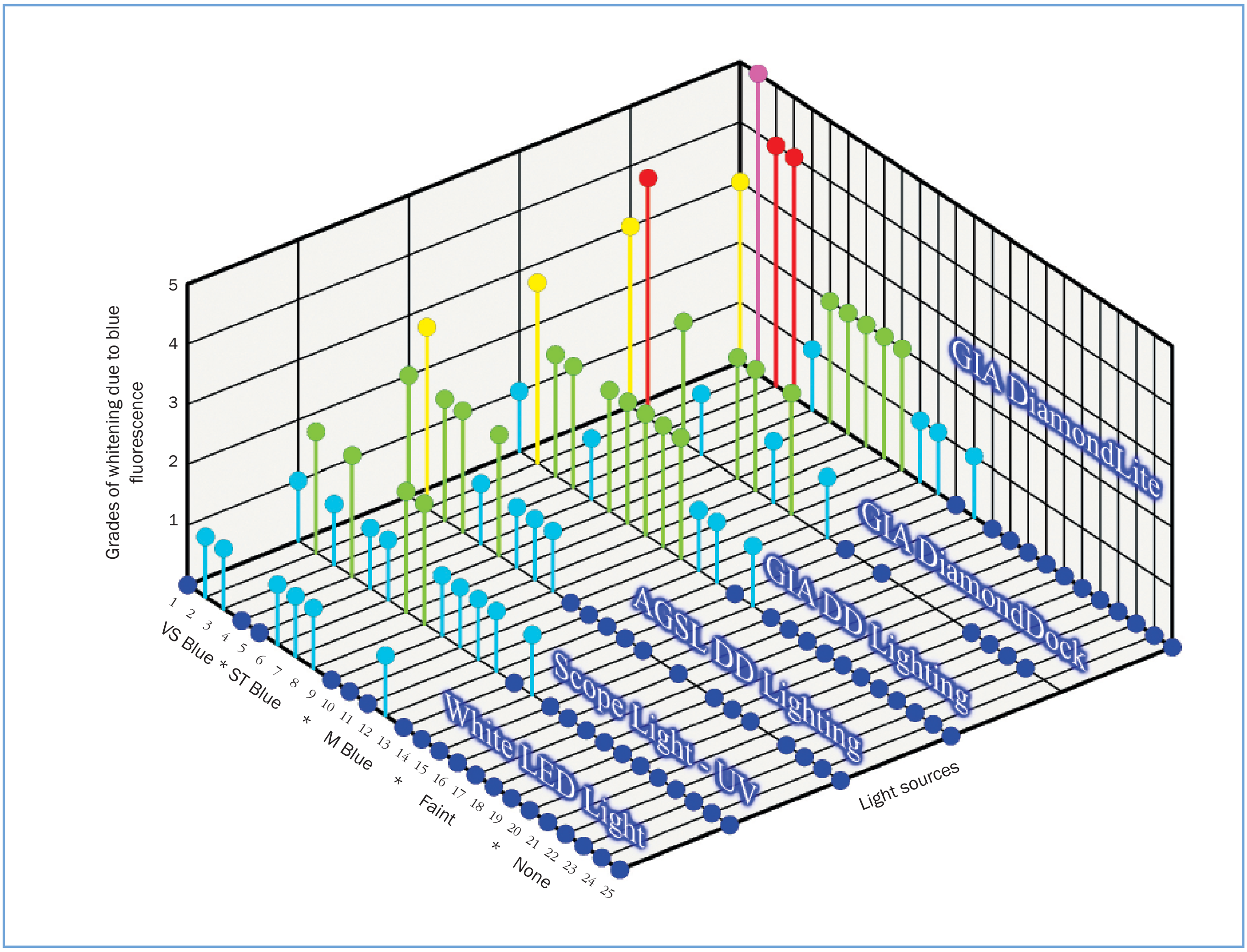

Figure 12: Scatter plot of grade changes of 25 diamonds under different light sources. The diamond numbers and their fluorescence characteristics are on the lower left; the light source numbers from the right are in sequence 1 (DiamondLite) to 6 (white LED light) — see text and Table I.

of a whitish, foggy fluorescence in 'Strong Blue' fluorescent diamonds seen in the high intensity incandescent light of the dark field illumination in gemmological microscopes. This study found that fluorescence stimulation from the relatively intense incandescent illumination that exists at short distances in gemmological microscopes and in other high intensity incandescent lighting was capable of causing colour improvement in some 'Strong' and 'Very Strong' blue-fluorescent diamonds. Even after filtering out UV from the high intensity incandescent microscope lighting, the excitation from the remaining narrow band of visible violet up to 415.2 nm was observed to stimulate this fluorescence. These observations of fluorescence stimulation from the UV and visible violet at short distances in high intensity incandescent lighting point to why not only fluorescent grading light but also incandescent light must be UV filtered and of intensity below 400 fc to grade fluorescent diamond colour consistently and unenhanced by blue fluorescence.

What was learned from the grading of 25 diamonds in different light environments

Degree of over-grading of 'Very Strong Blue' fluorescent diamonds

First and foremost is the documentation in 'Very Strong Blue' diamonds 2, 3 and 4 of a four grade improvement in the unfiltered DiamondLite (DL) compared with the colour grade in UV-free light. Diamond 2 changed from J to F in DiamondDock (DD) (GIA) to borderline E in the DiamondLite (DL), and to G in AGSL's DD. Diamond 3 with a grade of I was a low E in the DL; and diamond 4 with a grade of J changed to F in the unfiltered DL.

Stone 4 is particularly important to note, because its grading in the DL compared to its grading in the current DD standard illustrates the consequences of the change in GIA lighting standards brought about by the switch from grading at a distance of 2 to 4 in. in the DL, to 7 in. in the DD. Contrast the grade of F obtained in the unfiltered DL with the H obtained by GIA, AGS and the author in the DD lighting. H is two grades lower and closer to the grade of J obtained in UV-free light. This is due to the much lower UV content and light intensity at the working distance of 7 in. in the DD. In changing from grading in the DL to the DD, the UV content in the lighting decreases from the vicinity of 150 μW/cm² to around 31 μW/cm², and the light intensity from 820 fc to 225 fc. The colour grade of J is obtained in both the Source 6, LED lighting with zero UV and the ceiling-mounted Source 7, fluorescent lighting.

So the changes from DiamondLite to DiamondDock and in procedure from grading at 2 to 4 in. to grading at 7 in. result in a lowering of both the UV and visible violet, and a consequent change in this instance of two letter grades closer to the unimproved colour for a 'Very Strong Blue' fluorescent diamond.

Box B: Effect of fluorescence on diamond values in the gem trade

Example of inadequate discounting of fluorescent diamonds

Stone 4 is a textbook example of a 'false colour' diamond warned about by Wade in 1916. Based upon the possible over-grading of this type of fluorescent diamond, it would be reasonable to conclude that typical trade discounting of substantially sized 'Very Strong Blues' like 4 may be insufficient. For example, a 3 ct pear-shaped F VS2 'Very Strong Blue', might be discounted between 10 and 20% from its asking price of $54,000 to around $45,900. At its grade of J in UV-free light its corresponding price would be $33,600, well below the trade's typical discounted price of $45,900. (Note: the significance of these high wholesale asking prices from Rapaport (2009) lies more in their comparative values than in the absolute amounts.)

Example of over discounting of the rarer diamonds historically described as 'blue white'

Consider how unreasonable the current practice is of applying similar discounts to all 'Very Strong Blue' fluorescent diamonds in a particular colour and clarity range without knowledge of their colour in UV-free light. Where diamond 4 is likely not to be discounted enough, it appears unfair to similarly discount diamond 5, a 3.02 ct cushion shaped D VS1 'Very Strong Blue' that holds its colour within a grade in UV-free light. Diamond 5 is one of the rarer fluorescent diamonds whose price today would be discounted the same percentage from $73,000 to $62,000. Its price at its grade of E in UV-free light would be $69,000, $7000 above its discounted price. This rare D with its blue-white appearance in daylight, should command the premium it once did over the more common diamonds that are graded D because of their fluorescence.

This data base clearly indicates that these rare diamonds in the blue fluorescence strengths of 'Very Strong', 'Strong' and 'Medium' that hold their colour in the absence of UV can be unfairly discounted.

Degree of over grading of strong and medium blue fluorescent diamonds

Looking at the scatter plot of the 'Strong Blue' diamonds 6 to 10 a quite consistent two grade whitening is evident in the unfiltered DiamondLite as well as in the DiamondDock standard Verilux lighting used in the GIA and the author's grading, compared with the grades obtained in UV-free light. AGSL's grading of these 'Strong Blue' diamonds differed, obtaining on average only one grade of whitening in their DiamondDock lighting. Judging from this limited sample size, the change in lighting from the DiamondLite to the DiamondDock, while clearly reducing the likely amount of over-grading in 'Very Strong Blue' diamonds, appears to result in a less consistent reduction in the 'Strong Blue' fluorescent diamonds. The same can be said for the less consistent reduction seen in the half to one grade whitening typically seen in the 'Medium Blue' diamonds in the unfiltered DiamondLite. This lack of consistency is related to the stated range in strength of UV and visible light in the unfiltered Diamond Dock lighting.

Overall though, the scatter plot of this limited number of the five strengths of fluorescence shows a direct correlation between UV content in the grading light and diamond fluorescent strength, and the likely number of grades of whitening compared with their colour in UV-free light. Counting from the back in *Figure 11,* GIA's Source 2, DD grading, the author's grading in Source 3, DiamondDock fluorescent light, and AGSL's grading in their Source 4 DiamondDock, all use the new Verilux lighting in the DiamondDock. Although well within the allowed variation in strength in the current DiamondDock standard lighting, the grading of the data base diamonds by GTL and AGSL in this lighting varied by as much as two grades and was as much as four grades whiter than grades obtained in UV-free light.

Solutions to the over-grading of blue-fluorescent diamonds

The curves in *Figure 5* illustrate that the UV energy in fluorescent and other indoor artificial illumination falls off rapidly with distance from the source. The reduction in UV with distance could provide a partial solution to the over-grading of blue-fluorescent diamonds: this is to grade the diamond at a sufficient distance from UV-containing grading lights that any fluorescence in the diamond being graded is not stimulated beyond faint. This study found no colour difference due to fluorescence in the strengths of 'Faint' and 'None'. However, because lab grading is done from about

2 to 10 in. from fluorescent tubes with significant fluorescence-stimulating UV and visible violet, increases in grading distance within that range can help, but do not solve the problem of over-grading diamonds with fluorescent strengths of 'Medium Blue', 'Strong Blue' and 'Very Strong Blue'.

The change in the lighting characteristics from the DL lighting environment containing upwards of 150 μW/cm^2 to DD lighting having in the vicinity of 30 μW/cm^2 was seen to reduce the typical amount of overgrading in Very Strong Blues from as much as four grades to two grades. With this change in the standard grading light the potential for over grading has been reduced but not eliminated.

A more practical way to eliminate UV in grading illumination, and at the same time not noticeably affect the visible spectrum is filtration by polycarbonate plastic, such as Lexan or Makrolon. As shown in *Figure 6,* polycarbonate is an effective and inexpensive filter to remove UV below 385 nm. At the same time there is negligible change to the visible spectrum that could affect grading the D-Z tints of yellow in diamond.

To reduce fluorescence stimulated by visible violet, an equally practical and inexpensive solution is the use of flat-white plastic diffusers which attenuate violet and all visible wavelengths equally. Below 400 fc or about 4000 lux, the reduced amount of visible violet does not excite noticeable fluorescence, and the diamond's colour is unaffected. Such white diffusers have the additional feature of reducing spectral reflections and glare. They were employed on GIA microscope lights *(Figure 10)* for this purpose and to filter UV.

Another solution with potential is the use of white LED technology. In this investigation, a Dazor LED desk lamp not only provided inherently UV-free grading light, but was dimmable without change in colour temperature down to 2000–4000 lux, so as not to stimulate fluorescence from the visible violet. Possible concerns about differences between LEDs and fluorescent lights in their colour rendering indexes (CRIs) should be resolved with further comparative studies in both diamond grading environments.

Conclusions

The term 'blue-white' had been synonymous with top diamond colour for centuries. But after the explosion in supply of Cape-series diamonds from South Africa in the late nineteenth century, the term was so misused that it became as synonymous with deception as with fine quality. In the early twentieth century, Wade (1916) warned diamond dealers to be "on their guard" against blue-fluorescent, 'false colour' diamonds that failed to hold their colour (colourlessness) in all lighting conditions. Those that didn't were penalized in value to the extent to which their body colour was revealed to be yellowish (Cape) when seen in artificial lighting. The more yellow the unimproved colour, the less the stone's value.

In social situations, diamonds are most commonly seen at viewing distances of a few feet in many kinds of artificial illumination at night or indoors away from daylight. In these viewing environments the UV and visible violet are too weak to stimulate grade-whitening fluorescence. This is in contrast to most colour grading environments where the diamond is typically 2 to 7 in. from fluorescent lighting with significant UV and visible-violet components.

Only by grading in lighting that does not stimulate grade whitening fluorescence can grading consistency be achieved. Yet, today gemmologists are advised to use unfiltered UV-containing fluorescent lighting that approximates northern daylight as the standard for colour grading. This requirement for UV in the lighting is an abandonment of Shipley's colour grading philosophy. In addition, the variability in UV in fluorescent lighting is a cause of inconsistent grading of fluorescent diamonds.

It is time to solve the problem of over-grading blue-fluorescent diamonds. The desired grade for a blue-fluorescent diamond should be re-established as that colour seen in typical artificial lighting where fluorescence is not noticeably stimulated.

Since lab grading is done close to fluorescent tubes, the use is recommended of a polycarbonate plastic (Lexan or Makrolon are examples) as an effective and inexpensive filter to remove UV below 385 nm. This polycarbonate filter is designed to screen out UV only, avoiding noticeable alteration of the visible spectrum.

Wavelengths in the visible-violet must also be reduced so they too do not stimulate noticeable fluorescence. This can be accomplished without altering the diamond's colour by keeping the visible light intensity below 400 fc by means of a white plastic diffuser. In addition to lowering the light intensity, such white diffusers were recommended to reduce UV and also reduce spectral reflections and glare from the diamonds being graded.

A different but equally effective solution is to use white LEDs such as this investigation's Dazor LED desk lamp. It not only provides inherently UV-free grading light, but is dimmable without change in colour temperature down to 200–400 fc (about 2000–4000 lux).

Either solution would be consistent with the aim that diamonds should be examined for their unenhanced body colour in lighting free of UV which is diffused to the extent that neither UV nor visible-violet excite any significant fluorescence.

A return to this procedure would benefit the diamond industry in a variety of ways. First it would remove the distrust and stigma attached to fluorescent diamonds. Second, the rarer blue-fluorescent diamonds that hold their high-white colour in the absence of fluorescence would be recognized for their superior beauty and rarity. Thirdly, blue-fluorescent diamonds could be shown to whiten, and sometimes appear blue-white in natural daylight. Promoting this advantage in comparison with non-fluorescent diamonds of similar grade would be of substantial benefit in the marketing of blue fluorescent diamonds.

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