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Feasibility study on quality evaluation of Jadeite-jade color green based on GemDialogue color chip

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Abstract The paper studied quality evaluation of Jadeite-jade color green through GemDialogue. There are five green-related color codes in GemDialogue, including G2Y, Y2G, G, B2G and G2B. After parametric analysis on three measured color masks with different combinations, we clarified the color change rules of different color codes and zones superimposed by different color masks. First of all, based on CIE 1976 $L^*a^*b^*$ uniform color space system, the color range of 728-piece Jadeite-jade color green was determined: $L^*\in(5.64,\ 64.17)$, $h_0\in(125.21,\ 171.10)$, and $C^*\in(10.53,\ 85.89)$, namely conforming the appearance characteristics of Jadeite-jade color green. Then, five green-related color codes in GemDialogue color chip system were selected to test the color changes of 50 color bands with combination of three color masks in different superposition forms. The changes of color hue, lightness and chroma between the color codes and zones before and after combination were considered as the indicators. The results show that changes of hue angle for standard green color codes is consistent with that of yellow color codes, but opposite to that of blue color codes. In the process changing from yellow to blue, the overall lightness moves from high to low values, in line with the sensory fact that naked eyes perceives higher lightness of yellow color than that of the blue. The overall color chroma of five color bands significantly reduces with fading yellow hue and increasing blue hue.

Keywords Jadeite-jade color green · GemDialogue · Color chip · Color band · Color mask

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1 Introduction

Jadeite-jade, one of the jade varieties, is formed by polycrystalline ore under complicated and variable conditions. The native color green of Jadeite jade is caused by transitional metal ion. The forming process of Jadeite jade includes stages of diagenesis and jade formation, while the native color green is generated in the late stage of jade formation. Under specific conditions of relatively-high pressure and low temperature, the original rocks rich in Na and Al becomes Jadeitite after metamorphic crystallization and deformation. Lots of crystal field theories on jadeite structure show that there are two main forms of color ghost: (1) Metamorphic Differentiation: Under the metamorphic environment with unique temperature, traces of color-causing ions of Cr^{3+} and Fe^{3+} in uniform jadeite experience activation and migration. The irons concentrate in the local area with enrichment to replace Al^{3+} ions in the hard crystal $NaAlSi_2O_6$, leading to color generation. (2) Ductile Deformation: The ductile rock undergoes ductile deformation with tectonic stress under the condition of high pressure. The fluid rich in color-causing ions of Cr^{3+} and Fe^{3+}, generated by the double metasomatism of Jadeitite and ultrabasic enclosure, intrude into plastically deforming area. Thus, the dynamic re-formed particles caused by plastic deformation undergo alternating substitution effects in the process of nucleation and growth, integrating irons of Cr^{3+} and Fe^{3+} into jadeite lattice for coloring.

The coloring process of Jadeite is complex with a variety of forms in gaudy, depth and distribution of Jadeite jade color green. It has no uniform colors as optical homogeneous monocrystalline gem, or pleochroism resulting from optical heterogeneity of crystal, or color zonal distribution caused by growing environment. As a result, the effects of trueing form and transparency brings lots of difficulties for Jadeite jade color green.

In contrast, quality evaluation system of diamond is relatively complete, with the world 4C Standard advocated by the Gemological Institute of America (GIA). The color quality of colorless/light yellow/light brown/brown diamonds/Fancy diamonds is divided into nine grades, including Fancy Vivid, Fancy Intense, Fancy Deep, Fancy Dark, Fancy, Fancy Light, Light, Very Light and Faint. Advantages and disadvantages of color quality are quantitatively evaluated based on Munsell Physical Color Chip System, striving to maximize the sensation of human visual intuition.

Currently, GemDialogue created by Howard Rubin is another world-known color chip system specific to jewelry in addition to Munsell color chips. In GemDialogue, the color chips are compared with physical colors. The first step is to describe the color chip corresponding to the gem color. Then, the grade of gemstones color undergoes corresponding conversion with color chips, classifying the quality grades through different color band strengths of different gemstones, namely completing chroma positioning. Finally, the influence of color mask on the color is considered to complete color quality evaluation [1]. Therefore, it is more appropriate to apply GemDialogue color chip to color comparisons of Jadeite jade. In selection of color mask, transparent black/gray color masks and brown masks are adopted as most of the colored gemstones are transparent. For opaque colored gemstones [15] (such as green opaque Jadeite jade), black/white color mask can be used for assisted colorimetry.

As an internationally popular colorimetric tool of color gem, GemDialogue color chip can be used for quality evaluation through accurate comparison with gem colors. However, reflections on the top and bottom facets of faceted gemstones, it is difficult to effectively identify the lack of color. In quality evaluation of Jadeite jade with relatively low transparency and flat smooth cutting cabochon, GemDialogue can successfully avoid uncertainty of color evaluation brought by high transparency and cutting. The error can be effectively reduced, with improved colorimetric accuracy.

2 Samples and experiments

(1) Select related green color chips to test color index and define theoretical range of green; (2) Select Jadeite-jade color green samples to confirm actual range. (3) As the physical colorimetry range of Jadeite-jade color green was smaller than the theoretical range of green and colors related to green hue, the scope of green color chips were further selected by actual range of Jadeite-jade color green.

The 728 pieces polished cabochon jadeite-jade with smooth surface, fine texture and high purity were selected as samples, where all these gemstones ranged from 6 mm × 7 mm × 5 mm to 10 mm × 12 mm × 8 mm, below the upper limit of China National Standard (50 mm × 30 mm × 50 mm). Meanwhile, they displayed even color within the range from bluish green to vivid green to yellowish green, with continuous changes of color mask and depth.

2.1 Quantitative analysis of color green

Based on the uniform color space of CIE 1976 L*a*b*, spectrophotometer Color i5 was used to collect reflective signals from Jadeite-Jade surface via the integrating sphere. Test conditions were described as follows: Specular component setting-excluded (SCE); CIE recommended light source: D_{65} [3, 17, 18]; spectral range: 360 nm-750 nm; measurement time < 2.5 s (flash & data acquisition); wavelength interval: 10 nm; voltage: 240 V; current 50~60HZ.

All 728 pieces of Jadeite-Jade color green were plotted in the uniform color space CIE 1976 L*a*b* [19, 20]. It is illustrated that most colors of Jadeite jade are concentrated in yellowish green with medium-low lightness, but even without blue hue (See Figs. 1 and 2).

2.2 Color chip selection

The national standard of China GB/T 23885-2009 "Jadeite Grading" provides that the hue of Jadeite-jade color green is divided into green (yellowish), green and green (slightly blue) [6]. Therefore, the study on Jadeite-jade color green should include pure green and the green with varying degrees of blue and yellow hue.

As a result, five green color chips in GemDialogue were selected, including G2Y, Y2G, G, B2G and G2B. In terms of color mask, green Jadeite jade has no single solid color due to complex geological conditions. The background is usually blended with gray and brown hue, thus black/gray and brown transparent color masks were selected as combined color codes for color simulation. For the green Jadeite jade with poor transparency, black/white opaque color masks were adopted for auxiliary colorimetry.

2.3 Testing color index of color chips

Test objects were color indexes of five green related color chips in GemDialogue and three color masks under all color combinations. Each color parameter of color chips was quantitatively characterized to establish GemDialogue color chip index database, providing data

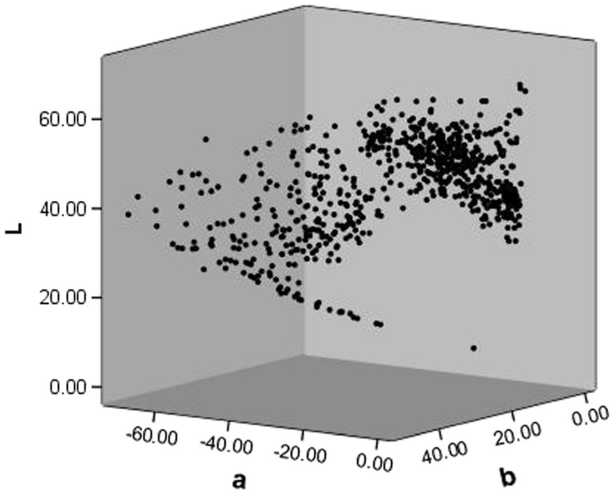

Fig. 1 Color green plots of jadeite-jade in the uniform color space CIE 1976 $L^*a^*b^*$. Note: $L^*\in(5.64,64.17)$, $h_0\in(125.21,171.10)$, $C^*\in(10.53,85.89)$, $a^*\in(-69.87,-6.17)$, $b^*\in(1.63,49.94)$

support for subsequent feasibility study on quality evaluation of Jadeite-jade color green with GemDialogue color chips.

According to test principles of the national standard "Jadeite Grading", X-Rite SP60 portable spherical spectrophotometer was adopted for color parameter testing. Test conditions are as follows: CIE recommended light source of D_{65} (6504 K), A (2856 K) and F_2 (4150 K) [5, 12]; reflective sampling modes, including specular reflection setting (SCI mode); 2 ° standard test field of view; measurement range of 360-750 nm; measurement time < 2.5 s; the wavelength interval of 10 nm; the voltage of 240 V; and the current of 50HZ. The measured tristimulus values of the samples were quantified by conversion of CIE 1976 L*a*b* uniform color space, with Munsell true color system as the color comparison system [2, 4, 10, 16].

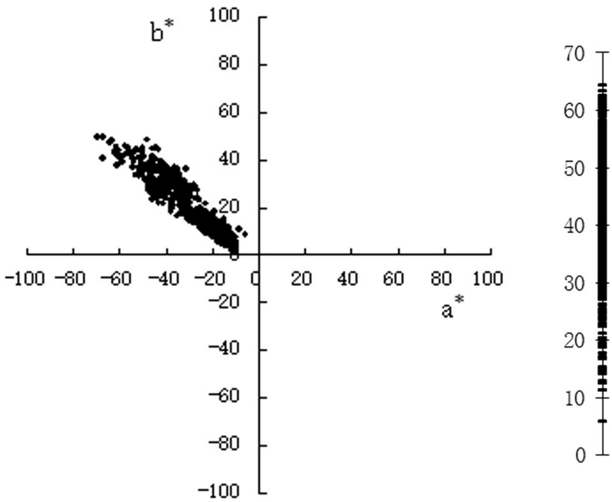

Fig. 2 Chromaticity and lightness plots of jadeite-jade's green in the uniform color space CIE 1976 $L^*a^*b^*$

The tristimulus values were converted to CIE 1976 $L^*a^*b^*$ uniform color space coordinates:

$$\begin{aligned} L^* &= 116\ (Y/Yn)\ 1/3{-}16 \qquad\qquad Y/Yn > 0.01 \\ a^* &= 500[(X/Xn)1/3{-}(Y/Yn)1/3] \\ b^* &= 200[(Y/Yn)1/3{-}(Z/Zn)1/3] \end{aligned}$$

where X, Y and Z are tristimulus values of test samples; Xn, Yn and Zn the tristimulus values of CIE standard illuminants; L* is lightness; a* and b* are chroma.

2.4 Experiment design of color chip test

Five color chips in GemDialogue were tested based on CIE 1976 L*a*b* uniform color space. Each color chip had ten color bands. After testing the color of each color band, ten color bands of color chips were further combined with ten color bands of each color mask in sequence. Among the three color masks, transparent black/gray and brown color masks were arranged in ways of upper cover and lower-level placement; only lower-level placement was adopted in the opaque black/white mask.

There were a total of five modes for the three color bands. Three kinds of standard light sources D_{65}, A and F_2 were selected, corresponding to sources of identified analog daylight, incandescent light and cold white fluorescent light (CWF) of jade hand samples, respectively. Five items were obtained, including chromatic coordinates a* and b*, as well as L*, C* and h_0 corresponding to lightness, chroma and hue of actual physical quantities, respectively.

Therefore, the total number of tested color bands per color chip was 510. Each color band was tested under three light sources. Five color chips were tested for a total of 510 × 3 × 5 = 7650 sets of data under the condition without color mask and the condition with matching of five color masks. Each set of data contained five color indexes of L*, a*, b*, C* and h_0 (the number of data before screening) in original record data. In order to reduce the error, each group of tests was measured for three times in a row to obtain arithmetic average values (See Table 1).

According to the Chinese national standard "Jadeite Grading", Jadeite-jade color green can be graded into following levels based on dominant wavelength value of spectral color (λ): Green

Table 1 Tests of color zones from color chips with different color masks

Color Code(×5)	Color band(×10)	Color mask(×5)	Color mask value(×10)	Color band(+1)	Light source(×3)
G2Y	100	Transparent black/gray Overlying	100	100	D_{65}
Y2G	90	Transparent black/gray Underlay	90	90	A
G	80	Transparent black/gray Overlying	80	80	F_2
B2G	70	Opaque black/white Underlay	70	70	
G2B	60	Brown Underlay	60	60	
	50		50	50	
	40		40	40	
	30		30	30	
	20		20	20	
	10		10	10	

(G), 500 nm ≤ λ < 530 nm; yellowish green (yG), 530 nm ≤ λ < 550 nm; bluish green (bG), 490 nm ≤ λ < 500 nm [6]. Taking into account a large number of previous studies [7–9, 11, 13, 14, 21], the dominant wavelength range of spectral color of real green Jadeite-jade color is larger than the range of 490 nm ≤ λ < 550 nm as stipulated by "Jadeite Grading". After conversion to hue angle, the range of $h_0 \in (120, 180)$ was selected to divide the color. A total of 3536 sets of data were screened out after removing the original data with significant hue deviation.

2.5 Instrument stability analysis

Similarity measurement of statistical distance correlation was performed for the test results. Pearson correlation coefficients or Cosine correlation values were used to represent the stability of test result accuracy of color chips.

Five color bands of G color codes in GemDialogue were selected in verification experiment, and in-situ tests were conducted for three times on the same color band. Each test interval was less than one minute (See Table 2).

Similarity measurement analysis was adopted for test variables due to analysis accuracy.

Through statistical analysis software SPSS19.0, it is calculated that the data similarity coefficient between three test batches is 1.000 (See Table 3). It indicates that there is high similarity between each measurement, with consistent results. Meanwhile, X-Rite SP60 portable spherical spectrophotometer is proved to have high test stability to meet the requirements of GemDialogue color chip for accurate tests of color indexes.

3 Results discussion

The color band test of each color code was carried out sequentially from 100 to 10, with the six test steps in sequence: (1) 1-10 meant single color code, namely non-superimposition with color mask. The color band from 100 to 10 was recorded as Interval I. (2) 11-110 was the single color code overlaid by black/gray transparent color mask, which was marked as Interval II. (3) 111-210 was the single color code superposed by black/gray transparent color mask in sublevel, recorded as Interval III. (4) 211-310 was the single color code overlaid by transparent brown color mask, denoted as Interval IV. (5) 311-410 was the single color code superposed by transparent brown color mask in sublevel, marked as Interval V. (6) 411-510 was the single color code superposed by opaque black/white color mask in sublevel, recorded as interval VI. There were a total of 510 tested color bands for each color code.

3.1 Color hue division of green GemDialogue color chip

Overall, the hue angle increases with the order of G2Y, Y2G, G, B2G and G2B. That is, with the gradual weakening yellow hue and continuous increasing blue hue, the hue angle has an obvious trend of gradual increase, under the condition of unchanged main color hue of green.

Among the five green color codes, the hue angle of G shows a decreasing trend in all six intervals. It indicates that with the decreasing sequence number of color codes and bands (decreasing chroma), the color hues of color bands and those superposed with different color masks slightly turns to blue hue. After superposition with brown color masks (Intervals IV and V), the hue angle of color bands presents an increasing trend. After overlapping with black/

Table 2 The color similarity calculation of five color bands of color chip G

		G/100	G/80	G/60	G/40	G/20
Simulated color		RGB (0, 148, 75) $L^*a^*b^*$ (54, -48, 29)	RGB (0, 165, 93) $L^*a^*b^*$ (60, -51, 27)	RGB (32, 176, 118) $L^*a^*b^*$ (64, -48, 19)	RGB (92, 187, 137) $L^*a^*b^*$ (69, -38, 16)	RGB (148, 206, 170) $L^*a^*b^*$ (78, -25, 12)
L^*	1	53.87	61.19	68.07	73.34	80.94
	2	53.85	61.21	68.13	73.48	80.91
	3	53.87	61.13	68.20	73.32	80.76
	Av.	53.86	61.18	68.13	73.38	80.87
	De.	(0.02%, -0.02%)	(0.05%, -0.08%)	(0.10%, -0.09%)	(0.14%, -0.08%)	(0.09%, -0.14%)
a^*	1	-70.48	-67.65	-56.54	-44.03	-27.16
	2	-70.45	-67.53	-56.60	-44.13	-27.15
	3	-70.46	-67.36	-57.10	-44.06	-27.09
	Av.	-70.46	-67.51	-56.75	-44.07	-27.13
	De.	(0.03%, -0.01%)	(0.21%, -0.22%)	(0.62%, -0.37%)	(0.14%, -0.09%)	(0.11%, -0.15%)
b^*	1	27.68	26.33	22.23	18.27	13.00
	2	27.65	26.27	22.24	18.29	13.00
	3	27.66	26.18	22.39	18.31	12.99
	Av.	27.66	26.26	22.29	18.29	13.00
	De.	(0.07%, -0.04%)	(0.27%, -0.30%)	(0.45%, -0.27%)	(0.11%, -0.11%)	(0.00%, -0.08%)
$\Delta E_{(1-2)}$		0.047	0.136	0.085	0.173	0.032
$\Delta E_{(2-3)}$		0.024	0.208	0.527	0.176	0.162
$\Delta E_{(1-3)}$		0.028	0.332	0.597	0.054	0.193
$\overline{\Delta E_{Av.}}$		0.033	0.225	0.403	0.134	0.129

Av. is the average, *De.* is the deviation range, *ΔE* is the color difference, $\overline{\Delta E_{Av.}}$ is the average color difference

gray transparent masks (Intervals II and III) and black/white opaque masks (Interval VI), the hue angle of color bands decreases in the opposite direction, but the variation range of color hue is far below the effect of brown mask on color band. It indicates that the damage of brown as the background color to standard green is much larger than that of color gray.

Table 3 The similarity of test parameters of five color bands

	L^*			a^*			b^*		
	1	2	3	1	2	3	1	2	3
1	1.000	–	–	1.000	–	–	1.000	–	–
2	1.000	1.000	–	1.000	1.000	–	1.000	1.000	–
3	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

With the superimposition of brown transparent color masks from high to low, the hue angle of color band gradually increase, namely turning from standard green to blue hue. Superimposed with black/gray transparent color mask (Intervals II and III) and black/white opaque color masks (Interval VI) from high to low, the hue angle gradually reduces, namely turning from standard green to yellow hue. Meanwhile, the hue angle of color band superimposed with brown color mask is lower than that of the single color band without superimposed color masks. With sublevel superimposition of black/gray transparent color masks (Interval III) and black/white opaque color masks (Interval VI), the hue angle value of color bands is higher than that of single color bands without superimposed color masks. It indicates that suitable gray scale will raise the hue angle, namely turning standard green to slightly blue hue (See Fig. 3).

Comparing the two color codes with yellow hues G2Y and Y2G, it is found that the overall trend of color hue changes of the three color bands is highly consistent before and after

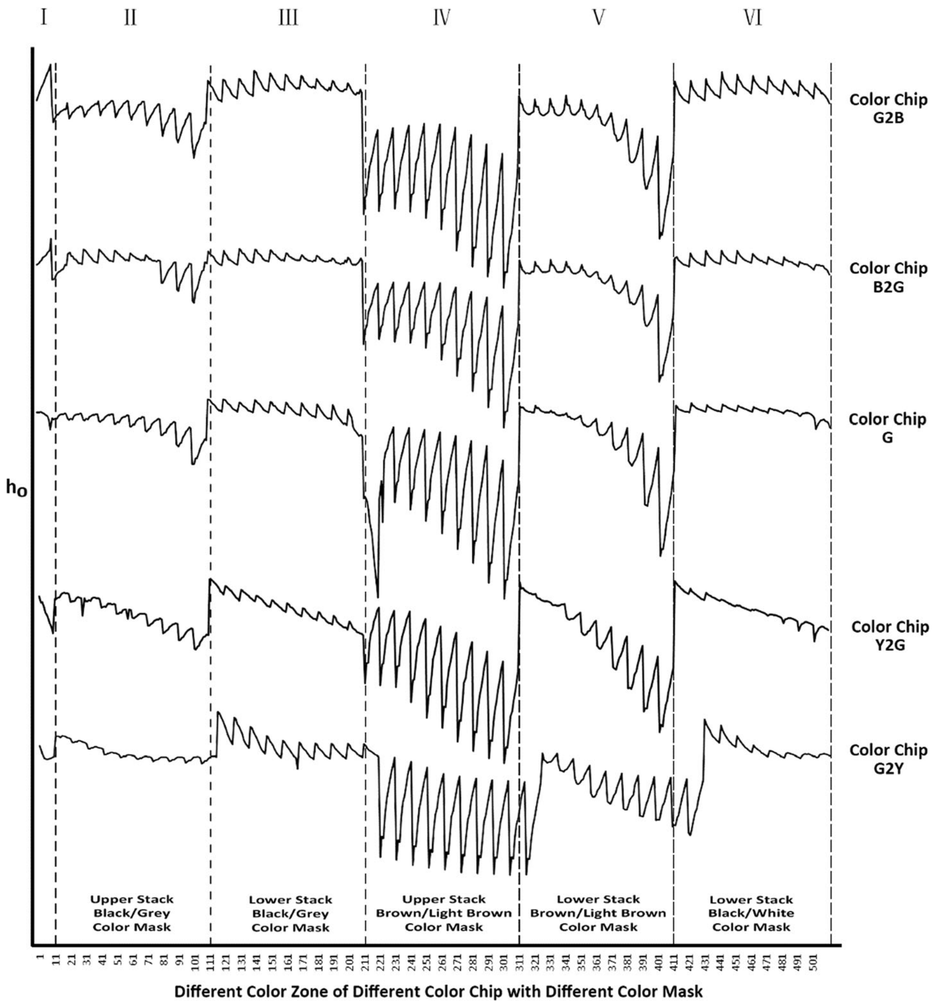

Fig. 3 The changes of 5 color chips' hue without or with different color masks

superimposition with different color masks. Meanwhile, the color hue changes of different color bands superimposed with the same color mask also show a high degree of consistency, with obvious similarities. It indicates that the color codes of greenish yellow G2Y, yellowish green Y2G and green G have consistent change rules of color hues in color bands. In other words, when superimposed with different color masks, the color hues with or without yellowish green hues have near-simultaneous tendency to be influenced by gray and brown hues.

Except for color codes of G2Y, Y2G and G in Interval I, the two color codes B2G and G2B with blue hue have similar change rules of color hue angles among other combinations superimposed with color masks. In conclusion, for single color bands of color codes without superposition of any color masks, there are similar change rules of hue angles for color bands between B2G and G2B with blue secondary hue. However, the hue angle changes of B2G and G2B are opposite to that of green color codes and those with yellow hue. Therefore, it is necessary to distinguish change rules of color green with different secondary color hues.

In terms of the effect of superimposed brown color masks on color bands, the amount of standard green is largely reduced by expanding the change range of color hues. Thus, the effect is obviously higher than that of gray color masks, which shows significantly negative effect of background color on Jadeite-jade color green.

3.2 Lightness division of green GemDialogue color chip

As a relatively independent factor among three elements of color, lightness has visual and highest weight in evaluating GemDialogue color chips with known hues. Therefore, lightness can even become the primary factor when evaluating quality of Jadeite-jade color green.

Among the five color codes, the lightness of standard green G shows an increasing trend for each part of the six intervals. Meanwhile, the change trend is the same as that of other four color codes (See Fig. 4).

In GemDialogue color codes, the lightness value increases from high color band values to low values. When controlling the variable of color bands, the lightness of color masks successively increases with the color band values from 100 to 10. According to comparison of data distribution diagram, we can draw following conclusions: (1) Single color code without superimposition of color masks has the highest lightness value, indicating that superimposition of color masks can significantly reduce lightness value. (2) The color masks have higher effects on lightness when they are superimposed in upper level. (3) Compared with the two color bands of black/gray transparent and black/white opaque color masks, brown color masks have higher effects on the change of lightness values. In other words, varying degrees of gray color hue have more obvious influence on Jadeite-jade color green than brown color hue. (4) For comparison among single color codes, the lightness value decreases with the color hue changing from color yellow to blue, in the order of G2Y, Y2G, G, B2G and G2B. This conclusion is consistent with the fact that the lightness of yellowish green is higher than that of bluish green.

3.3 Chroma division of Green GemDialogue color chip

In quality evaluation of Jadeite-jade color green, chroma is the direct reflection of chroma, which can represents the intensity degree of color green. According to Chinese national standard GB/T 23885-2009 “Jadeite Grading”, the chroma is divided into five levels, which corresponds to reference value C/% of GemDialogue color chroma. The chroma levels are

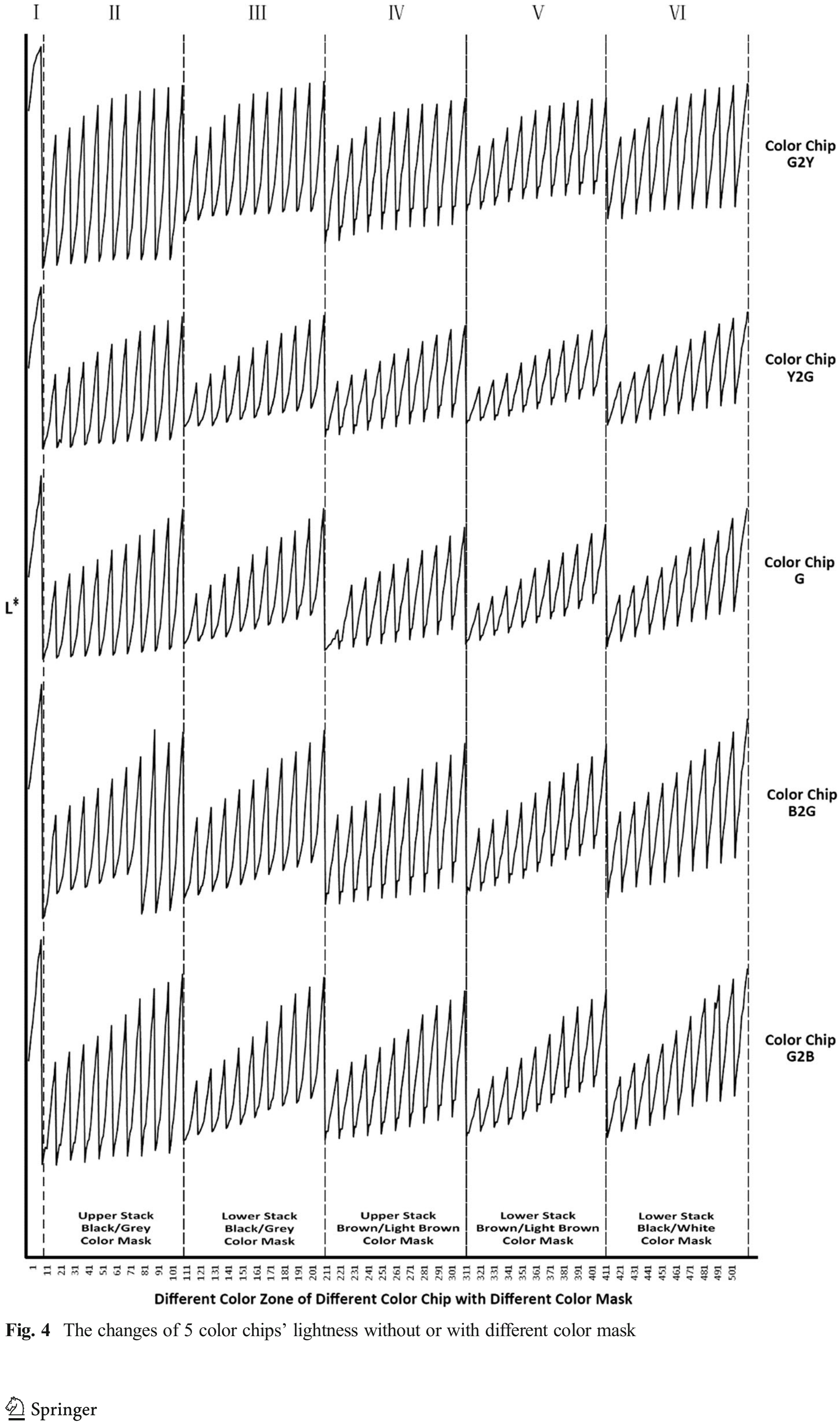

Fig. 4 The changes of 5 color chips' lightness without or with different color mask

divided into Extremely Thick (Ch1, C ≥ 85), Thick (Ch2, 55 ≤ C < 85), Relatively Thick (Ch3, 45 ≤ C < 65), Relatively Light (Ch4, 25 ≤ C < 45) and Light (Ch5, 5 ≤ C < 25). The work conducted quantitative analysis of color chroma.

For stand green G color code without superimposition of any color masks (Interval I) the chroma of single-color-code band has the highest value of 75.10. The highest point occurs in the second color band that is a single 90 color band, denoted as $C^*_{G90} = 75.10$. It indicates that the theoretical maximum chroma of color green can reach 75.10. When superimposed with two transparent color masks, the chroma of color bands for G color code firstly increases and then decreases in each interval. $C^*_{-G80/GB10} = 46.32$ is the highest chroma for color band 10 with black/gray transparent color mask overlaid by color band 80; $C^*_{G90/GB10} = 62.56$ the highest chroma for color band 10 superimposed with color band 90 in lower level. They are higher than corresponding values of color band 10 with black/brown masks overlaid by color band 80 ($C^*_{-G80/GB10} = 43.92$) and that of color band 10 with black/brown masks overlaid by color band 90 ($C^*_{G90/GB10} = 58.74$), respectively. It is proved that the brown hue has a greater damage to green chroma than gray hue.

The chroma of color band shows an overall decreasing trend when superimposed with black/white opaque mask. The highest color chroma of color band 10 superimposed with color band 100 in lower level is $C^*_{G100/GB10} = 65.01$, ranking only second to that of single-color band without superimposition. It indicates that the chroma of color green of substrate opaque gray is higher than that of other transparent superimposed color masks. In contrast, the chroma change rule of color bands of G2Y and Y2G yellow-hue color codes is slightly different with that of G color bands. For example, for the single-color codes of G2Y and Y2G without superimposition of color masks (Interval I), $C^*_{G2Y80} = 81.49$, and $C^*_{Y2G80} = 74.37$. The position of highest chroma slightly shifts backwards in each interval. This shows that yellow hue can lead to the highest chroma of color green under relatively low intensity. Moreover, the green chroma is also significantly improved with increasing yellow hue. In other words, yellowish green shows Fancy Vivid rather than Fancy Intense, which is in line with the fact that naked-eye Jadeite-jade color green with yellow hue has more vivid color perception (See Fig. 5).

Meanwhile, comparing 10 intervals of G2Y and Y2G superimposed with color masks, the chroma of Y2G superimposed with brown transparent color masks in lower level (Interval V.) and black/white opaque color masks (Interval VI) is slightly lower than that of color code G, namely $\left(C^*_{Y2G80/B10} = 58.13\right) < \left(C^*_{G90/B10} = 58.74\right)$, and $\left(C^*_{Y2G80/GW10} = 64.09\right) < \left(C^*_{G100/GW10} = 65.01\right)$. But beyond that, the chroma values of remaining eight intervals are higher than corresponding values of G. This indicates that yellow hue can significantly enhance the chroma of color green.

Similarly, when comparing the chroma change rules of G2B and B2G color bands with that of G, it is found that the trend is opposite to yellow-hue green. For G2B and B2G single-color codes without superimposition with color masks (Interval I), $C^*_{B2G100} = 72.41$, and $C^*_{G2B100} = 55.31$. The position where the highest chroma value occurring in each interval slightly moves forward. It indicates that blue hue leads to the occurrence of highest chroma in the position of highest intensity. Moreover, the chroma of color green decreases rapidly with the intensifying blue hue. That is, bluish green shows more Fancy Dark instead of Fancy Intense, in line with the fact that Jadeite-jade color green with blue hue is darker that perceived by the naked eyes.

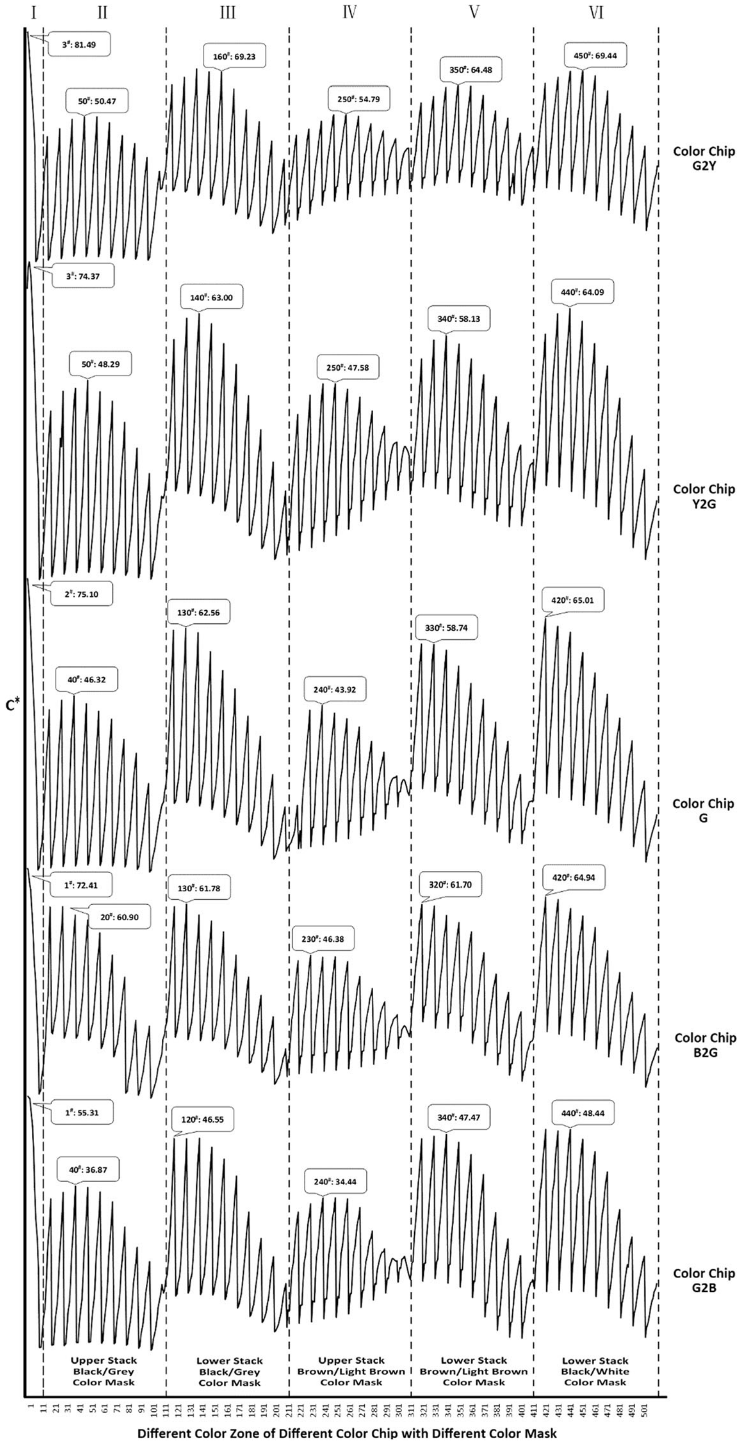

Fig. 5 The changes of 5 color chips' chroma without or with different color mask

Meanwhile, 10 intervals of G2B and B2G superimposed with color masks were compared. For B2G overlaid with black/gray transparent color masks (Interval II) and brown transparent color masks (Interval IV) as well as that of superimposed with black/white opaque color masks in lower level (Interval V), the chroma is slightly higher than that of color code G, namely $\left(C^*_{-B2G100/GG10} = 60.90\right) > \left(C^*_{-G80/GG10} = 46.32\right)$; $\left(C^*_{-B2G90/B10} = 46.38\right) > \left(C^*_{-G80/B10} = 43.92\right)$; and $\left(C^*_{B2G100/B10} = 61.70\right) > \left(C^*_{G80/B10} = 58.74\right)$. But beyond that, the chroma values of remaining seven intervals are lower than corresponding values of G. It is proved that blue hue can significantly inhibit the chroma of color green, while brown hue in the middle level and blue hue in post level make appropriate contribution to color green.

The results of chroma analysis show that: (1) When the single-color code is not superimposed with color masks, the highest chroma is concentrated on the high color bands, including 100 of bluish green, 90 of standard green and 80 of yellowish green. It indicates that the color green becomes more Fancy Intense with the increase of blue hue, while it becomes more Fancy Vivid with the increase of yellow hue. (2) The chroma of color bands increases with the decreasing color band values of superimposed color masks (reducing chroma value). (3) Lower-level superimposition of transparent color masks is conducive to appearance of high chroma of color bands.

4 Conclusions

After analysis on color indexes of five color codes in GemDialogue color chip and those with different combinations of color mask superimposition, we derive following conclusions:

(1) The formula for linear change of hue angle average in five color codes is y = 23.21× + 86.06, where the values of x are taken as 1, 2, 3, 4 and 5 to represent five color codes; y is the average of hue angle; the average difference of hue angle between different color codes is $\overline{\Delta h_0} = 23.21$. G2Y and Y2G with yellow hue have the same change trend of hue angle with that of standard green G. There is similar change trend of hue angle between B2G and G2B with blue hue. The hue angle values of color codes show increasing or decreasing trend according to different parts.

(2) For each color code of GemDialogue color chip, the lightness increases with the decrease of color band values. Controlling variable of color codes, the lightness increases with decreasing color band values of color masks from 100 to 10. Single-color code without superimposition of color masks has the highest overall lightness. Superimposition of color masks has influence on declining lightness, where overlaid color masks have greater impact on the lightness values. For superimposition of black/gray transparent and black/white opaque color masks, the lightness range of color code bands is larger than that of superimposed brown color masks. It indicates that different degrees of color gray have more obvious effects on the lightness of color codes than brown color masks. In comparison between single-color codes, the lightness decreases as the color hue changes from yellow to blue in the order of G2Y, Y2G, G, B2G and G2B. This is in line with the fact that naked eyes perceive higher lightness of color yellow than that of blue hue.

(3) When single-color code is not superimposed with color masks, the highest chroma values of color bands mostly concentrate in the middle and high color bands. Wherein, the highest chroma values of greenish yellow, yellowish green and color green occur at color bands of 90 and 80; the highest chroma values of bluish green and greenish blue occur at color bands of 100. As the color hue changes from yellow, green to blue, the highest chroma values show a shift to the high color bands. The chroma values of color bands increase with decreasing color bands of color masks, with obviously negative correlation. The highest chroma value of each small color segment is superimposed with the minimum color band 10. It indicates that the chroma values increases with the decrease of color band values of black/gray transparent, brown transparent and black/white opaque color masks. The chroma values of color codes after superimposition of color masks are lower than that of single-color codes. That is, the black/gray and brown color hues reduce the chroma of color bands. The chroma values of color bands with upper superimposed color masks are significantly lower than those of the lower-level superimposition. Although the five color codes have similar lower limit of chroma, the overall chroma decreases obviously with weakening yellow hue and increasing blue hue.

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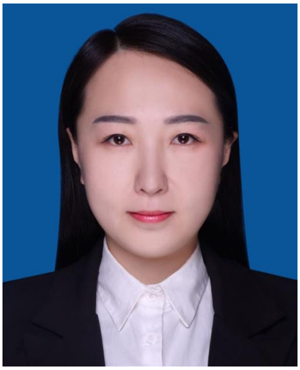

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