The preferred display color temperature (Non-transparent vs. Transparent Display)

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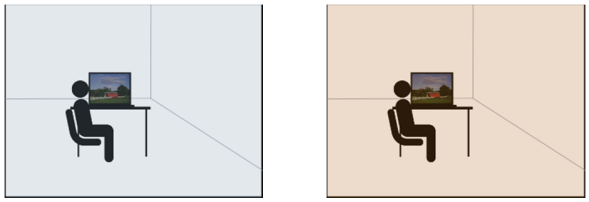
Abstract

The preferred color temperature of a non-transparent display and an OLED transparent display was investigated. 24-inch LCD monitor was used to simulate both types of displays shown under two-different background color temperature (3000K and 6500K) conditions. Twenty observers participated the psychophysical experiment in a dark room. They were asked to choose the most preferred display image among the images having 9 different color temperatures. The results showed that as the color temperature of the surround decreases, the preferred color temperature of the monitor also decreases. Also it is found that the preferred color temperature of the total white (the monitor white plus transmitted light) of OLED transparent display is similar with that of the non-transparent display.

Introduction

Nowadays, displays are used under various surround conditions from a dark night to bright daylight. Such surround conditions have wide range of luminance levels and color temperatures. For example, people usually use their laptop in many different places such as office, house and coffee shop. In comparison with the office, surround color temperature in the coffee shop is more yellowish.

As shown in Figure1, though a color temperature of a display is fixed, the monitor white looks like keep changing because of the color temperature changes of the surround. Especially the effect of surround condition on display image quality becomes more significant for the transparent display [1,2].



(a) (b)

***Figure 1**. Different surround conditions: (a) fluorescent light such as in office environment, (b) incandescent light such as in cafe*

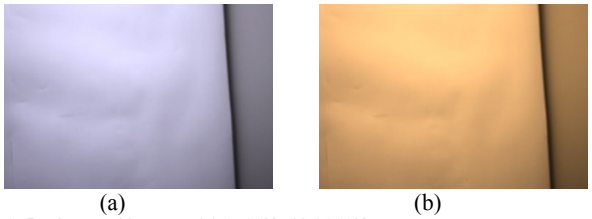
To preserve the image quality regardless of the viewing condition, the display color temperature needs to be adjusted considering the surround condition. However, there are only a few studies about the preferred display color temperature under various ambient lighting conditions. Also only recently, researches on image quality of a OLED transparent display has been started [1,2].

In this study, the most preferred display color temperature was investigated by simulating an non-transparent and an OLED transparent display having various display color temperatures shown under two-different background color temperature (3000K and 6500K) conditions.

Test Image Simulation Method

Since OLED transparent display is not in the market yet, 24-inch wide color gamut LCD display is used to simulate a non-transparent and an OLED transparent displays showed under two different surround conditions. The peak white of the LCD display was 239 cd/m^2 and the resolution of LCD display was 1920x1200.

Figure 2 shows two images used as background scene. One background image has 3000K color temperature and the other has 6500K color temperature. The average luminance of both image is 139.5 cd/m^2 and the resolution is 1920x1200.

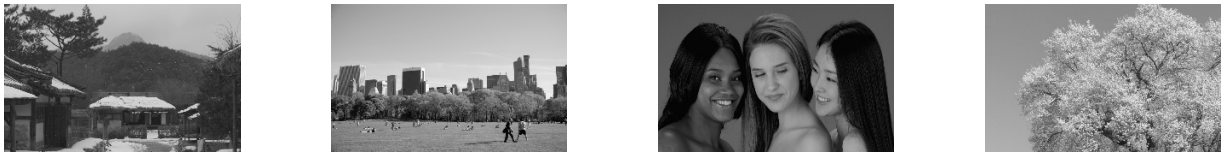


(a) (b)

***Figure 2**. Background images: (a) 6500K, (b) 3000K*

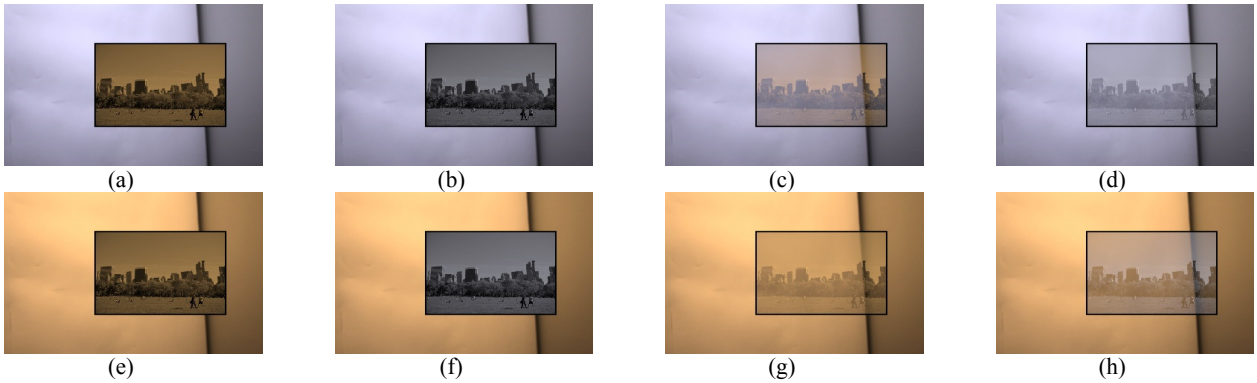
To simulate both non-transparent and transparent display, it is assumed that both displays have sRGB color gamut and 2.2 gamma with 70 cd/m^2 peak white. Also it is assumed that color temperatures of both displays are adjustable from 3000K to 7000 K with 500K intervals. The degree of transparency of OLED transparent display is set to 40%.

Four pictorial images were selected covering skin, fruits and landscapes for the experiment and each image was converted into gray scale using CIELAB L* scale. Each image had 960x600 resolution. Figure 3 shows the test images for psychophysical experiment.



(a) (b) (c) (d)

Figure 3*.Test images for psychophysical experiment: (a) cottage, (b) park, (c) people and (d) tree*



(a) (b) (c) (d)

(e) (f) (g) (h)

Figure 4*. Example of test images: (a) 3000K OLED display under 6500K surround, (b) 6500K OLED display under 6500K surround, (c) 3000K OLED transparent display under 6500K surround, (d) 6500K OLED transparent display under 6500K surround, (e) 3000K OLED display under 3000K surround, (f) 6500K OLED display under 3000K surround, (g) 3000K OLED transparent display under 3000K surround, (h) 6500K OLED transparent display under 3000K surround*

CIEXYZ values of the background image and that of the test image summed up for each pixel to simulate the display showing on different background scenes. To simulate display bezel, black frame was added. The resulting CIEXYZ values were converted into RGB values using inverse LCD monitor characterization model. Figure 4 shows examples of test images.

Therefore total 144 test images (= 4 images x 9 color temperatures x 2 display types x 2 background color temperatures) were prepared for psychophysical experiment. These images were shown on the 24 inch LCD display in a dark room.

Psychophysical Experiment

Twenty university students (Female: 10, Male: 10) having normal color vision participated in the experiment. Ishilhara test and 100 Farnsworth-Munsell hue test were tested to confirm whether they have normal color vision or not. In a dark room, observers sat in front of 24-inch LCD monitor showing the background image. After 5 minutes adaptation in each background, they were asked to select the most preferred color temperature among 9 different display color temperatures. The method of limit was used in this experiment. They observed the images, increasing or decreasing color temperatures using a keyboard, and then chose only one color temperatures among them. There was no time limitation.

The same experiment was repeated to check the repeatability of participant. Therefore, each participant choose 32 color temperature responses (= 4 images x 2 display types x 2 background color temperatures x 2 trials) and all the responses from each participant were average to analyze the data. Figure 5 shows the procedure of this experiment.

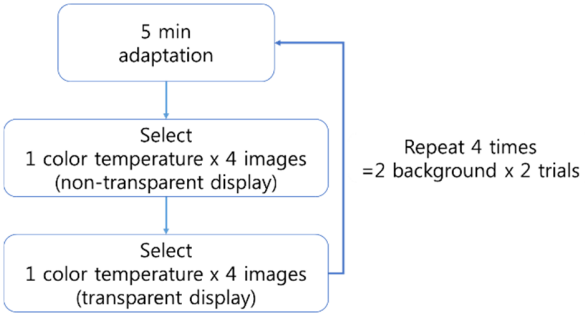


Figure 5*. Experiment procedure*

Experimental Results

To evaluate the repeatability of each participant, coefficient of variation (CV) was calculated. Figure 6 shows repeatability of each participant. Average CV of total participant is 7.8. The maximum CV is 11.8 and the minimum CV is 1.7. Since there was no outlier, all participant's data were used for analysis.

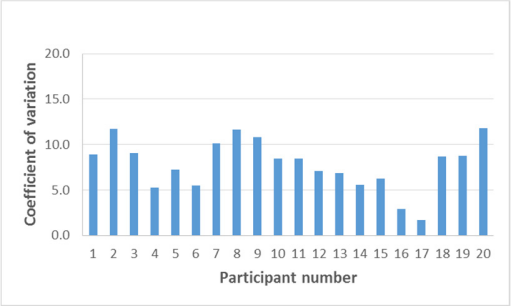


Figure 6*.Coefficient of variation for repeatability*

Table 1. Result of the experiment

Surround color temperature (K)	Cottage		Park		People		Tree	
	Non-trans.	Trans.	Non-trans.	Trans.	Non-trans.	Trans.	Non-trans.	Trans.
3000	4525	5475	4875	5388	4950	5688	4938	5438
6500	6225	5713	5975	5938	5913	5400	6263	5875

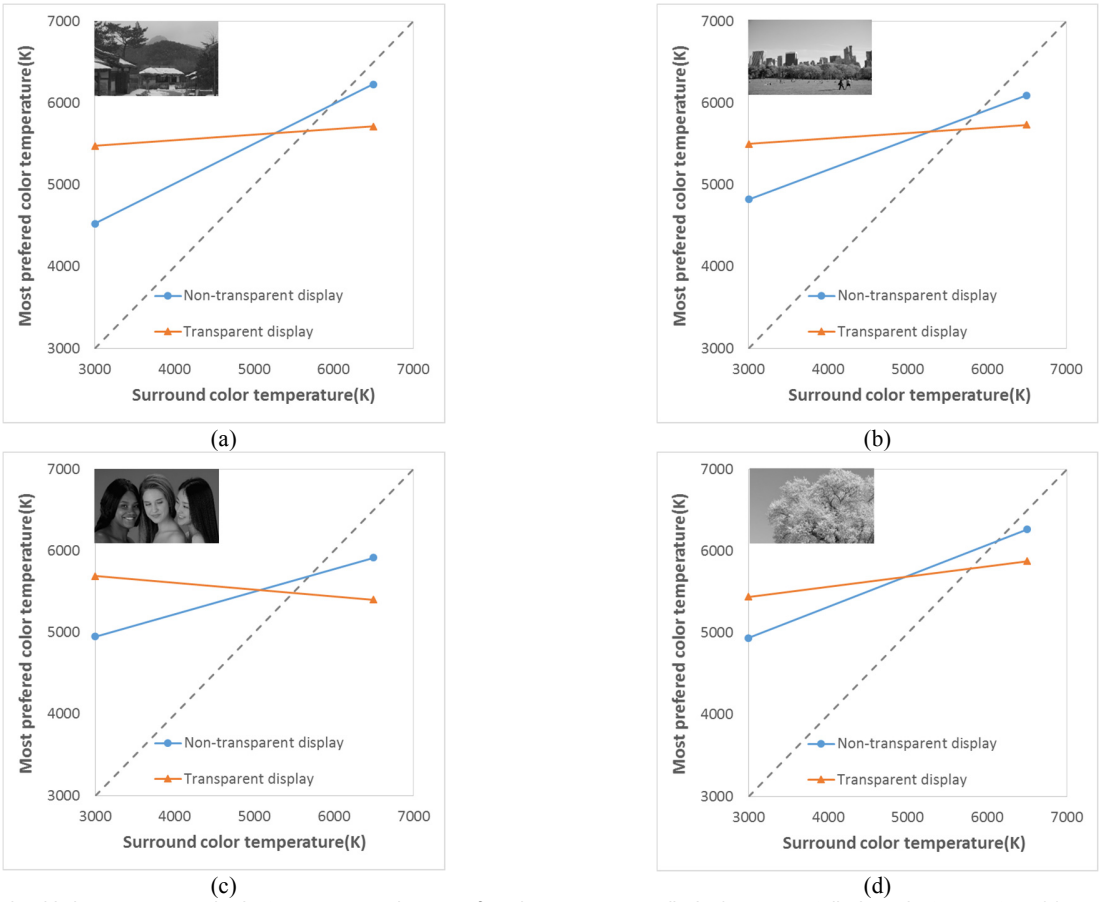


***Figure 7**. Relationship between surround color temperature and most preferred non-transparent display/ transparent display color temperature: (a) cottage, (b) park, (c) people and (d) tree*

Table 1 and Figure 7 summarize the average data. At first, it is notable that both display type and surround color temperature affect the preferred display color temperature significantly. Though the preferred display color temperature is not strongly affected by the image contents, the 'people' image's preferred display color temperature of transparent display is slightly lower than others. The transmitted 6500K surround luminance made the skin tone more bluish. Therefore to make the skin tone natural, participant tended to select lower color temperature.

Figure 8 directly compares the preferred monitor color temerature bewteen two different display types where x-axis is the most preferred color temperature of non-transparent display and y-axis is the most preferred color temperature of transparent display in each test image. On the average, when the surround color temperature is 6500K, the averaged most preferred color temperature are 6156K for a non-transparent display and 5794K for a transparent display. When the color temperature of a background scene is 3000K, the averaged most preferred color temperature are 4919K for non-transparent display and 5631K for transparent display. This result indicates that as the surround color temperature is lowered, lower monitor color tempereture is preferred. Higher display color temperature is preferred for the transparent display than that of non-transparent display especially when the surround color temperature is low. Figure 9 shows the reslut of cottage image as an example of preferred color temperature changes by the surround conditions and display types.

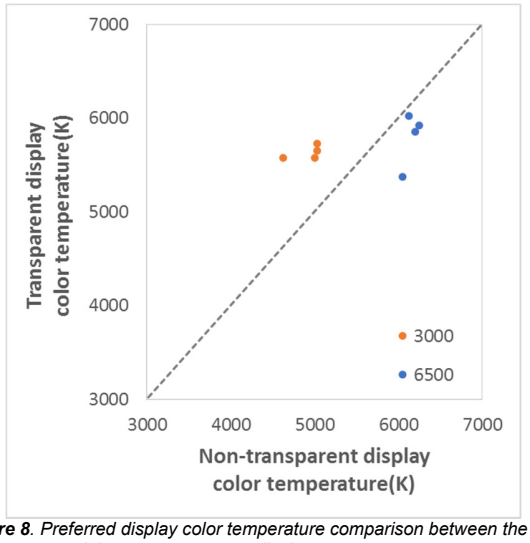


***Figure 8**. Preferred display color temperature comparison between the OLED transparent and the non-transparent displays*

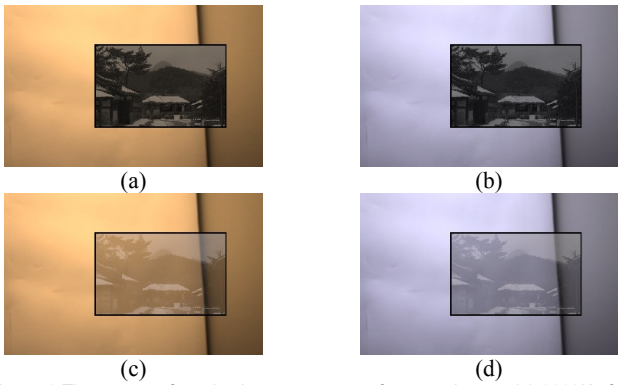


***Figure 9**.The most preferred color temperature of cottage image: (a) 6200K of non-transparent display, (b) 5850K of not-transparent display, (c) 4625K of transparent display and (d) 5850K of transparent display*

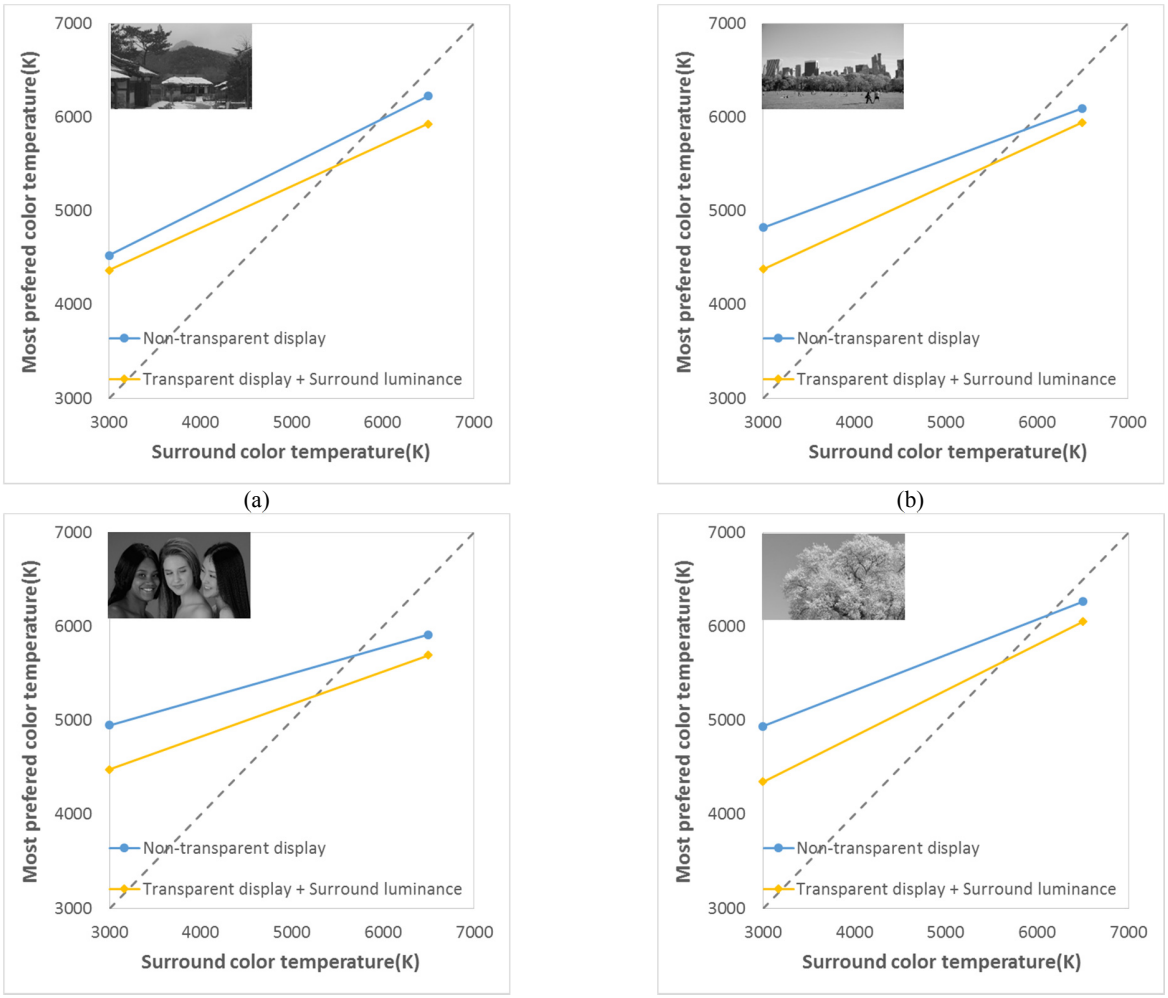


***Figure 10**.Relationship between surround color temperature and most preferred non-transparent display/ total white color temperature: (a) cottage, (b) park, (c) people and (d) tree*

In the case of transparent display, observers were watching not only the self-luminous display image but also transmitted background image. Therefore the preferred display color temperature difference between two display types is further analyzied by considering this situation. For the OLED transprent display result, the color temperature of total white i.e. addition of the display white and the transmitted background light was calculated.

Figure 10 compares the color temperature of non-transparent display and that of total white as a function of surround color temperature and Figure 11 shows the direct comparison between the total white of the transparent display and the non-transparent display data. It is notable that the trend of total white color temperature is similar with that of non-transparent display color temperature. Also, the preferred total white color temperature is always a little lower than the preferred non-transparent display color temperature.

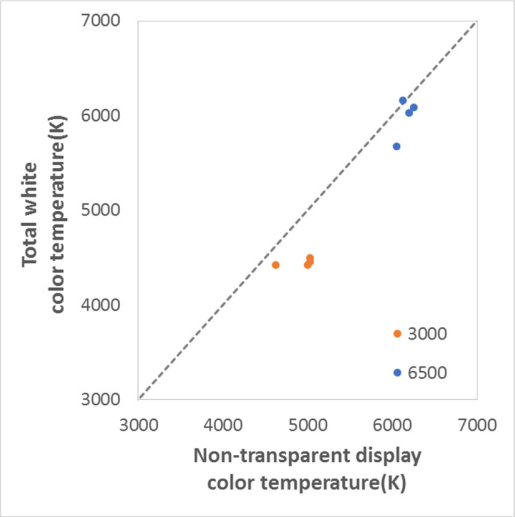


***Figure 11**. Preferred display color temperature comparison between the total white of OLED transparent and the non-transparent displays*

Figure 12 summarizes the overall result. The major findings of this study are as follows: (1) the most preferred color temperature of the monitor also decreases, as the color temperature of the surround decreases. (2) the preferred color temperature of total white of transparent display is slightly lower than that of non-transparent display at each surround color temperature.

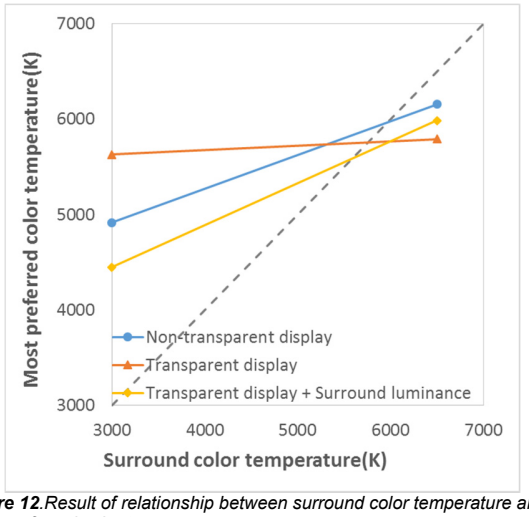


***Figure 12**.Result of relationship between surround color temperature and most preferred color temperature.*

Conclusion

The most preferred color temperature of an OLED non-transparent display and that of 40% OLED transparent display was investigated under 3000K and 6500K surround conditions. The simulated images on the LCD display were used to simulate the background scene and non-transparent/ transparent display.

Twenty university students were participated in this experiment. After 5 minute adaptation in each background image, they asked to choose the most preferred color temperature of display. Same experiment was repeated to confirm the repeatability of each participant.

Based on the psychophysical experiment results from twenty participant with four test images, it is discovered that the most preferred display color temperature decreases, as surround color temperature decreases. Moreover, people tend to prefer slight lower color temperature for total white of transparent display i.e. addition of the transparent diplay white and the transmitted background light than color temperature for non-transparent display.

This study implies that the display color temperature needs to be controlled considering the surround color temperature. Especially to find the preferred color temperature of the transparent display, the transmitted background scene should be considered. Since the current study is based on the limited experimental condition, more thorough experiments are required to confirm the current study result.

Acknowledgements

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References

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Author Biography

Hyeyoung Ha received her BS in human factors and affective engineering from UNIST(2015). Since then now she is a MS student of human and systems engineering in UNIST. Her work has focused on the display color appearance.

Youngshin Kwak received her BS in physics from the Ehwa Woman's University (1995) and her Ph.D in color science from University of Derby(2003). Now she is an associate professor of human factors and systems engineering in UNIST. Her work has focused on the human color perception, color emotion, visual appearance, and image quality of 2D and 3D images. She is on the director of Vison 1 in CIE.

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Young-jun Seo is a senior engineer of Samsung Display Ltd., South Korea. He received his MS in Electrical Engineering from Hanyang University(2006). His work has focused on the appearance modeling and the improvement of image quality for display.

Byungchoon Yang received his BS, MS, and Ph.D(2002) in Electrical Engineering from Seoul National University. After a couple years of Post Doctorial discipline in University of Connecticut and BC Berkeley, he joined LCD Division of Samsung Electronics in 2004. He has been working on the color science and the optical signal processing area including the LED Backlight and the holographic technology in Samsung Display R&D center.