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Development of Blue Light Cut Films Using a Roll-to-Roll Nano Micro Coating System

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In this study a coating experiment was performed to fabricate blue light cut films, which represent a 390~430 nm cut off rate of more than 40% and a transmittance rate of more than 90%, using a roll-to-roll nano micro coating system. The study also analyzed the characteristics of the blue light cut films. Thus, the hardness, which is more than 3H, is ensured through fabricating films using a Sol-Gel process that will determine the proper hardness level. Also, the experiment shows excellent results by cutting blue light through a mixing blue light powder.

Keywords: PET film, Hard coating, UV resin, Ultra transparent optical film, Blue light cut

1. INTRODUCTION

Recently, the average increase in smart phone usage times is threating the health of eyes. Average daily smart phone usage times in students and workers exceed more than three hours and that causes fatigues in most eyes. The eyes become fatigued due to the blue light generated in smart phone displays. This blue light is usually generated from crystal displays used in mobile devices, which use LED light sources such as back lights, and represents a wavelength of 390~430 nm. As eyes are exposed to crystal displays with a large amount of such blue light, the muscles of the eyes must continuously move to be focused and that causes the eye to be fatigued. In particular, as eyes are excessively exposed to the blue light, it will can cause presbyopia in early age which shows xerophthalmia with dimmed eyesight. Thus, some countries such as Japan and Taiwan have a 30% cut off rate for the amount of blue light some products can generate. In Korea, however, developments of these products are still not conducted due to the lack of recognition in the hazardousness of the blue light. Therefore, in this study a study on developing blue

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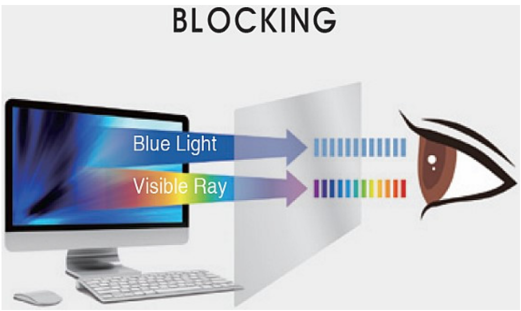

Fig. 1. Blue light.

light cut films, which satisfy a 390 430 nm cut off rate of more than 40% and a transmittance rate of more than 90%, was implemented using a nano micro coating system.

Figure 1 illustrates an example of the blue light.

2. EXPERIMENTS

In fabricating blue light cut films that show proper hardness, high light transmittance, and excellent cut off rate levels, developing core materials, designing and compounding hard coating, and performing coating processes are required.

For developing core materials used in this study, the following experiment was performed. In the results of analyzing different materials such as titanium, zirconium, alumina, and nano silica, the titanium represents a milky color and that causes a problem of ensuring transmittance. In the case of the zirconium, it is expensive and that may present a problem of commercializing its products. In the case of the titanium, it shows difficulty in distributed control due to its large particle sizes. In the case of the nano silica, it is selected as a proper material because it is inexpensive and satisfies transmittance, hardness, and flexibility. As shown in Fig. 2, functional sols were fabricated using the nano silica. Also, the sols were tested and the ZrO_2 was the best fit.

Figure 3 shows a mixing process of organic-inorganic sols using the selected function sol. The mixing was implemented for 12 hours and was aged at room temperature for 24 hours in order to maintain its distribution and solution stability. Then, a coating solution was compounded by measuring the appearance, solids, viscosity, and specific gravity of the mixture.

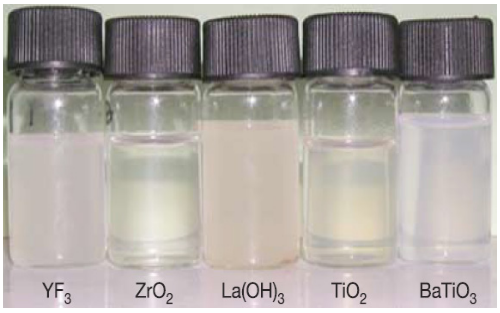

Fig. 2. Test of functional sols.

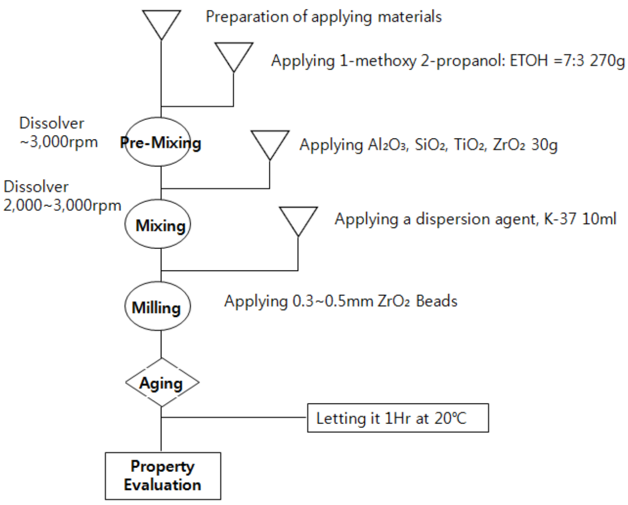

Fig. 3. Process of mixing organic-inorganic sols.

Fig. 4. Compounding process of organic-inorganic sols.

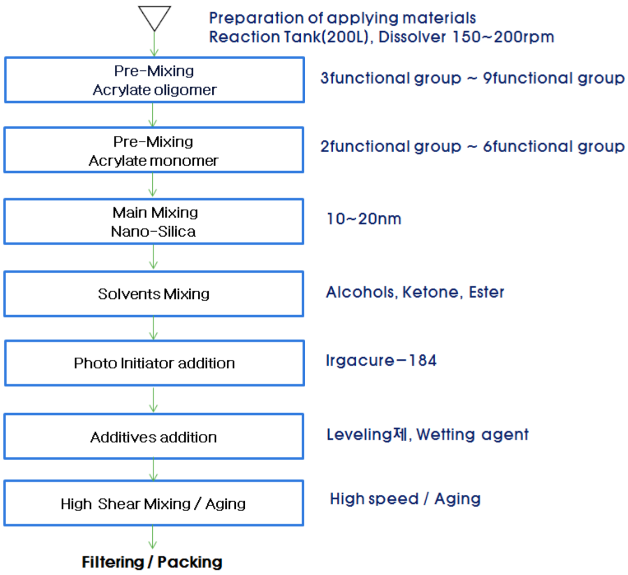

Fig. 5. Process of fabricating a high hardness coating solution.

Table 1. Results of the UV hardening TEST.

UV Light (mJ/cm^2)	Line Speed (m/min)	Sampling Sectors				Remarks
		0m	100m	200m	300m	
310	14	Yellowing	Yellowing Thermal Deformation(curl)	Yellowing Thermal Deformation(curl)	Yellowing Thermal Deformation(curl)	
	17	Poor hardening	-	Slight yellowing	Poor hardening Slight thermal Deformation	
	20	Poor hardening Slight thermal Deformation	Poor hardening Slight thermal Deformation	Poor hardening	Poor hardening Slight thermal Deformation	
	23	Poor hardening	Poor hardening	Poor hardening	Poor hardening	
330	14	Yellowing Thermal Deformation(curl)	Yellowing Thermal Deformation(curl)	Resin bubble Yellowing	Yellowing Thermal Deformation(curl)	
	17	Slight Yellowing	-	-	-	O
	20	-	-	Poor hardening Slight thermal Deformation	Poor hardening	
	23	Poor hardening	Poor hardening Slight thermal Deformation	Poor hardening	Poor hardening	
350	14	Yellowing Thermal Deformation(curl)	Resin bubble Yellowing	Resin bubble Yellowing	Resin bubble Yellowing	
	17	Resin bubble Yellowing	Yellowing Thermal Deformation(curl)	Yellowing Thermal Deformation(curl)	Yellowing Thermal Deformation(curl)	
	20	Yellowing Thermal Deformation(curl)	Yellowing Thermal Deformation(curl)	Yellowing Thermal Deformation(curl)	Yellowing Thermal Deformation(curl)	
	23	Yellowing, Poor hardening Thermal Deformation(curl)	Poor hardening Thermal Deformation(curl)	Poor hardening Thermal Deformation(curl)	Poor hardening Thermal Deformation(curl)	
370	14	Resin bubble cracks	Resin bubbles	Resin bubble cracks	Resin bubbles	
	17	Yellowing Thermal Deformation(curl)	Resin bubble Yellowing	Resin bubble Yellowing	Yellowing Thermal Deformation(curl)	
	20	Resin bubble yellowing	Yellowing Thermal Deformation(curl)	Yellowing Thermal Deformation(curl)	Yellowing Thermal Deformation(curl)	
	23	Yellowing, Poor hardening Thermal Deformation(curl)	Yellowing, Poor hardening Thermal Deformation(curl)	Poor hardening Thermal Deformation(curl)	Poor hardening Thermal Deformation(curl)	

Figure 4 and Fig. 5 represent the mixing process of organic-inorganic sols and the compounding process of a high hardness coating solution, respectively.

A blue light cut solution was fabricated through an additional mixing process by which the blue light powder, TYD 57, was applied to the high hardness coating solution compounded through the previous process. The coating was implemented using a roll-to-roll nano micro coating system with the fabricated blue light solution. In this coating process, the UV hardening condition plays the most important role in this process. There were some breakages in coating products due to the insufficient hardening of the blue light solution according to the passage of UV hardening times. Thus, several experiments were repeated for determining the optimal condition in this process as shown in Table 1.

3. RESULTS AND DISCUSSION

In this study, different coating processes were implemented using the blue light cut solution, which is compounded through an organic-inorganic sol-gel process. The blue light cut off rates of the blue light cut film were measured at wavelengths of 390~430 nm using a spectrometer (CM-3700d).

Figure 6 represents a trend of increasing cut off rates according to the increase in the amount of blue light cut dyes in each category. However, it showed no large increases in the cut off rates compared to the contents of dyes. In the case of the test with the lowest content, it is considered that a prescription of 0.5% is an acceptable level in its efficient point of view for applying the dye because it shows the cut off rates more than 40%. In addition, in the case of the prescription of UV99-2, tests were additionally implemented by mixing it with others because it has an effect of cutting low wavelength blue lights. In the tests, the cut off rates presented in Table 2 were used to mixing 0.5% of the blue light solution with 0.8% UV 99-2.

In the blue light cut off rates presented in Fig. 7, it has excellent cut off rates at 390~430 nm, more than 43% compared to that of commercial products.

Table 3 shows the numerical data from Fig. 7. It showed that

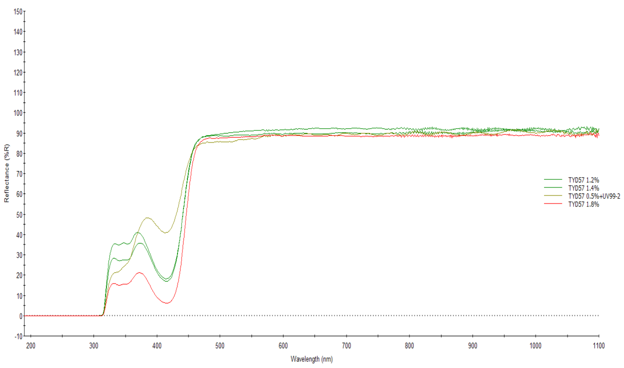

Fig. 6. Blue light cut off rates.

Table 2. Cut off rate for wavelengths.

Transmittance (%) for Wavelengths	Blue Light 1.8%	Blue Light 1.4%	Blue Light 1.2%	Blue Light 0.5% +UV99-2
320 nm	7.4 (82.6)	13.5 (76.5)	16.0 (74.0)	9.4 (80.6)
350 nm	15.6 (74.4)	27.5 (62.5)	35.7 (54.3)	24.9 (65.1)
370 nm	21.0 (69.0)	35.4 (54.6)	41.0 (49.0)	41.1 (48.9)
390 nm	**14.2 (75.8)**	**28.1 (61.9)**	**29.7 (60.3)**	**47.7 (42.3)**
410 nm	**6.5 (83.5)**	**17.5 (72.5)**	**18.7 (71.3)**	**41.0 (49.0)**
430 nm	**11.9 (78.1)**	**26.1 (63.9)**	**27.1 (62.9)**	**49.2 (40.8)**
465 nm	83.9	86.4	86.0	83.9
546 nm	88.1	88.9	91.0	87.1
590 nm	88.8	89.7	91.5	89.2
635 nm	88.4	89.9	91.9	89.4

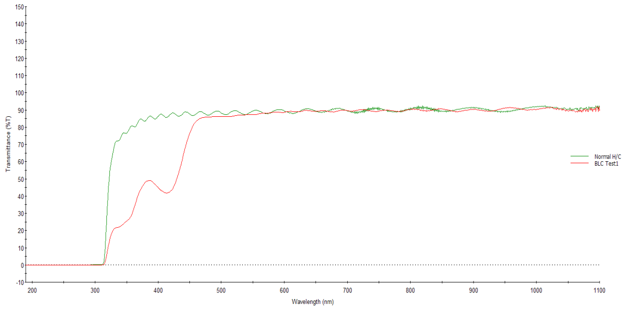

Fig. 7. Blue light cut off rates.

Table 3. Cut off rate for wavelengths.

Transmittance(%) for Wavelengths	General HC	BLC-Test (130820)
320 nm	39.1	9.4 (80.6)
350 nm	76.4	25.4 (64.6)
370 nm	84.1	41.3 (48.7)
390 nm	**86.0**	**47.6 (42.4)**
410 nm	**86.1**	**40.8 (49.2)**
430 nm	**86.7**	**48.9 (41.1)**
465 nm	89.0	84.7
546 nm	88.5	87.3
590 nm	90.1	88.7
635 nm	90.6	89.7

Table 4. Transmittance measurement results.

	Transmittance (D65)	Haze (D1003-97)	Unit
1	91.43	0.79	%
2	91.22	0.82	%
3	91.08	0.76	%

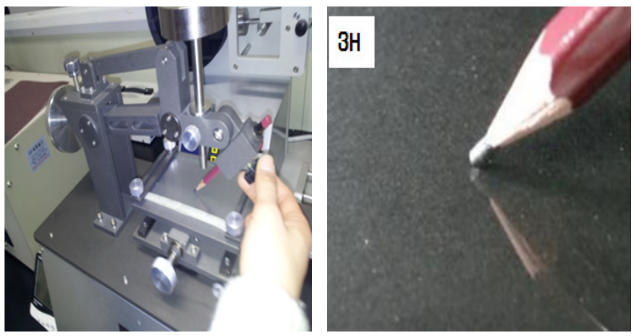

Fig. 8. Hardness test of the blue light cut film.

the cut off rates, which are the most important factor in blue light cut films, are induced at an excellent level. Also, in the measurements of the transmittance and Haze for evaluating other functions the results are acceptable as shown in Table 4.

One of the important factors in films is hardness. The hardness of the fabricated blue light cut film was measured using a pencil hardness tester as presented in Fig. 8. In the hardness measurement results, it shows acceptable levels as scratches are not measured up to 3H.

Finally, adhesive strength tests were implemented as shown in Fig. 9. The surface of the films was scratched using a cross cutter and a piece of 3M tape was attached at the scratch, detaching it.

Table 5. Hardness measurement results.

Test Load	First	Second	Third
3H	No Scratches	No Scratches	No Scratches

Fig. 9. Adhesive strength test.

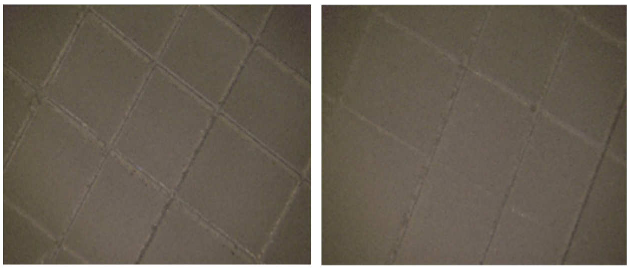

Fig. 10. Results of the adhesive strength test.

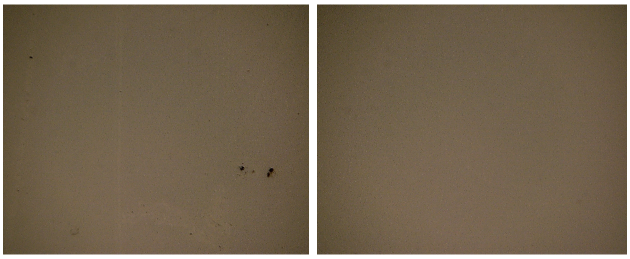

Fig. 11. Removing foreign objects (Left: foreign objects, Right: removed objects).

Then, an optical microscope was used to check some damaged points of the coating at the scratched point. In the results, there were no damaged and detached points as shown in Fig. 10. Thus, the coating is acceptable.

Figure 11 shows removing foreign objects (Left: foreign objects, Right: removed objects)

In summary, the development of blue light cut films performed in this study represents excellent results with the 390~430 nm cut off rates of more than 43%, the HAZE less than 1.1%, and the hardness of 3H. It is noted that there exists some foreign objects, which are dye particles on the surface of the films caused by the dispersion during its coating solution mixing process. Therefore, for improving foreign objects the mixing was performed with a mixing ratio of MEK:toluene as 1:1 instead of using the conventional method, which uses MEK only. It shows improvements in removing such foreign objects.

4. CONCLUSIONS

The blue light cut films were developed by an optimal mixing ratio and repetitional experiments. The films represent excellent blue light cut effects and homogeneous characteristics without particle residues because of its excellent dispersion. In addition, it shows advantages in the films such as excellent durability and high hardness. It is expected that it will make inroads into foreign functional film markets with competitiveness in price and quality.

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