Convergence Study of High Refractive Index Polarized Glasses Lens with Photochromic and UV Blocking Function

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Abstract— Those who use convex or concave lenses should use sunglasses made from regular spectacle lenses. In this case, it uses a surface coating to block UV rays, so it is relatively vulnerable to UV protection. To this end, we developed a spectacle lens that can completely block ultraviolet light and suppress blue light by using a monomer that completely blocks the area below 410 nm and has a sunglasses function through photochromic function. A spectacle lens with photochromic, polarization and UV blocking functions was developed using a monomer with a high refractive index of 1.67. In the photochromic property, a recovery time of 2 minutes for light reaction and 5 minutes for dark reaction was obtained. Five layers of anti-reflection coating were applied to the surface of the lens to reduce the transmittance in the visible light region to 0.1 or less. ITO was applied to give an electromagnetic wave shielding function, and the thickness and conductivity of ITO were proportional to the result. The blue light emitted from the LED is reduced by more than 30% to reduce eye fatigue. UV rays were completely blocked below 410 nm.

Keywords—Ultra violet, Blue light, Sunglass, Photochromic, Eyeglass lenses

I. INTRODUCTION

Wear sunglasses to prevent glare. Sunglasses are very important to block UV rays. If UV protection is not used to reduce the amount of light, the pupils dilate, allowing more UV light to enter the eye. Methods to reduce sunlight include photochromic lenses containing photochromic materials [1-4], polarizing lenses using polarizing films [5-7], and methods of mixing dark colors have been studied and used. Recently, it has been found that blue light emitted from LEDs installed in smartphones and computer monitors is not good for the eyes, so blue light blocking lenses are emerging [8-11]. Photochromic and UV-blocking spectacle lens materials cannot be mixed. Because photochromic materials require UV light, but UV-blocking materials must block UV light.

A special method is required to solve this. In addition,

modern people who have used electronic devices such as smartphones for a long time need an electromagnetic wave shielding function. If the refractive index of ZrO₂ and ITO (indium tin oxide) is the same and applied to the anti-reflection multi-layer coating, the electromagnetic wave shielding function can be added to the spectacle lens. have.

UVA, UVB, and UVC are the ultraviolet rays emitted by the sun. The earth's ozone layer absorbs 97~99% and the rest reaches the surface of the earth, and 98.7% of the ultraviolet rays that reach the surface are UVA. In addition, gas discharge tubes dedicated to ultraviolet LEDs and ultraviolet laser devices also emit ultraviolet rays. In general, when the human body is exposed to ultraviolet rays, short-term or long-term skin damage such as erythema, burns, wrinkles, freckles, keratinization, and skin cancer may occur. Due to the recent destruction of the ozone layer by air pollutants and the increase in leisure activities, the human body is more exposed to the dangers of ultraviolet rays, and accordingly, efforts to protect the human body from ultraviolet rays are becoming more urgent. The shorter the wavelength of ultraviolet light, the more harmful it is to the body. This is because the energy of electromagnetic waves is inversely proportional to the wavelength. Energy is proportional to the frequency. That is, $E = hf$ (E : energy, h : Planck's constant, f : frequency). UV protection coating is applied to the lens to achieve UV protection, but when the coating is peeled off, the UV blocking function is reduced and it is harmful to the eyes. Therefore, if a lens is manufactured by containing a material having a UV blocking function in the monomer, which is the raw material of spectacle lenses, the UV blocking function is maintained even if the surface is damaged. On the other hand, the technology to completely block UV rays has gradually developed and lenses with a blocking function up to 400 nm have been developed, but they are mainly made by Japanese companies.

The development of a lens that completely blocks ultraviolet rays below 410 nm is necessary for healthy eyes

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II. FUNCTIONAL SUBSTANCES APPLIED TO DEVELOPMENT

A. Monomer for UV protection

A benzotriazole-based UV absorber with a molecular weight of 250-330 g/mol to absorb UV rays, B, a benzotriazole-based UV absorber with a molecular weight of 300-320 g/mol, and benzotriazole-based UV absorber with a molecular weight of 430-450 g/mol A UV absorber in which C, which is a benzotriazole-based UV absorber, was mixed was used. Table 1 shows the types of UV blocking monomers.

TABLE I
UV BLOCKING MONOMER TYPE

Type	Materials	Portion(%)
A	1,6-diisocyanatohexane	54
	2,5-diisocyanatomethylbic	46
B	2,3-Bis(2-mercaptoethylthio)propane-1-thiol	84
	[1,4]Dithian-2-yl-methanethiol	10
	2-9[1,4]Dithian-2-ylmethylsulfanyl)-ethanethiol	6
C	Pentaerythritoltetrakis	80
	3-Mercapto-propionic acid 3-hydroxy 2,2-bis-propylester	16
	3-Mercapto-propionic acid 3-hydroxy-2-hydroxymethyl-2-propyl ester	4

B. Photochromic Blockers

Photochromic lenses are usually made by preparing a photochromic resin composition in which a photochromic compound is mixed with a radically polymerizable monomer and then curing the resin composition.

It is mainly applied to acrylics, which are easy to mix with photochromic compounds, and can make lenses with good color change performance and optical properties,

mainly for medium and high refractive lenses. However, when the thickness of the lens is not uniform like a spectacle lens, there is a problem in that it is difficult to secure the uniformity of the coating. In the thick part of the lens, a lot of discoloration material is distributed, so the color density becomes thick while the discoloration sensitivity becomes dull. unevenness will occur. Therefore, a uniform thickness of the photochromic lens is required.

C. Indium Tin Oxide

Indium tin oxide is a mixture of indium oxide (In_2O_3) and tin oxide (SnO_2), and generally has a ratio of 90% In_2O_3 and 10% SnO_2 . It is often called transparent electrode or ITO. In a thin layer, it is transparent and colorless. In a lumpy state, it is yellowish-gray. The main characteristics of indium tin oxide are high electrical conductivity and good optical transparency. However, this feature only applies to thin films, and in the thick case, the charge carrier increases the metal's conductivity but reduces its transparency. Thin films of indium tin oxide are most commonly deposited on surfaces by electron beam deposition, vapor deposition, or sputtering techniques.

III. MANUFACTURE OF SPECTACLE LENSES AND PERFORMANCE TEST

A. Manufacturing process of spectacle lenses

- 1) Taping the upper mold.
- 2) Drop the discoloration composition on the upper mold recess.
- 3) A polarizing film is laminated on the color-changing composition placed in the concave part of the upper mold.
- 4) Pre-polymerize the color-changing composition. Pre-polymerization is preheated to 15° C(5 minutes), followed by polymerization at 15° C(6 hours), 15 to 60° C(4 hours), 60° C(10 hours), and 60 to 15° C(2 hours).
- 5) Widen the gap between the upper and lower molds to which the upper lens in the gel state and the polarizing film made by prepolymerizing the discoloration composition and tap again.
- 6) Inject the UV blocking composition through the space between the polarizing film and the lower mold.
- 7) Mainly polymerize the gel-like upper lens and UV-blocking composition. This polymerization is preheated to 25°C for 5 minutes, at 25-40°C for 7 hours, at 40-

50°C for 3 hours, at 50-65°C for 2 hours, at 65-95°C for 3 hours, at 95-120°C for 1 hour, at 120°C for 2 hours, at 120-70°C for 2 hours

C. Photochromic

Photochromism refers to the fact that a substance that is normally clear and transparent changes to dark gray or brown when exposed to ultraviolet light. This phenomenon is caused by a photochromic material, which can be used to make color-changing lenses, color-changing tiles, and the like. Photochromic lenses react to ultraviolet and violet light and are mainly affected by ultraviolet light. Therefore, it is transparent or colorless in a room without the influence of UV rays, but changes to dark brown or gray under the influence of UV rays when exposed to sunlight. This is different from regular sunglasses that are equally dark in both dark and bright places. In general, the monomer determines the refractive index of the spectacle lens. In the vicinity of the refractive index of 1.5, a material called CR39 was used, and in the vicinity of the refractive index of 1.6, a urethane-based monomer was used. A small amount of the photochromic material is mixed with this basic lens monomer. Various compounds are used for the photochromic compound. In general, the surface of plastic lenses is not strong enough to be easily scratched. Although many attempts have been made to compensate for this, in general, a silica component is coated on the surface of a plastic lens by immersing the lens in a solution in which the silica component is dissolved and taking it out. This method is called hard coating. Here, SiO₂ and ZrO₂ are alternately vacuum-deposited to add an anti-reflection function. Figure 1 shows the structure of a general spectacle lens. On the other hand, if ITO, a conductive material with the same refractive index as ZrO₂, is used, electromagnetic wave protection can be provided. When a relatively large amount of the photochromic compound is used, the photochromic property is improved, but the surface hardness is weakened. Because of this problem, it is important to adjust the ratio of the basic monomer and the photochromic compound, which is a lens material. It is also important how to apply the thickness of the photochromic lens. In general, if you use prescription glasses, you use regular lenses to color them when making sunglasses.

In this case, there was a disadvantage that the color density was different because the thickness around the center and the edge were different. The photochromic layer

also needs to maintain a constant thickness for the same reason. In this study, the problem was solved by placing a polarizing plate of a certain thickness on a certain photochromic layer and then making a layer that blocks ultraviolet and blue light. This is the first attempt according to the results of the domestic market research. This is because adhesion is not easy, but by controlling the polymerization temperature and time with pure monomers and a polarizing film, the adhesion was successful. Figure 1 illustrates the surface coating of spectacle lenses.

Fig. 1 The structure of spectacle lens

Photochromism was measured using Jasco's MV-3150 and LUS-373. The MV-3150, a portable spectrophotometer, can measure a spectrum at least every 5 msec. By measuring the spectrum at high speed, the time required for product inspection can be reduced by monitoring production lines, etc. and mapping measurements. Because it uses a diffraction grating driving function and optical fiber-free structure, it is compact, easy to handle, and can be widely used for field measurements and other applications. The portable spectrophotometer MV-3000 series consists of a spectrophotometer body and a light source. MV-3100/3150 measures between 200 and 800 nm in wavelength range, and LUS-373 uses light source D 2 + halogen light source in wavelength range of 200 to 1600 nm. When monitoring long lines, a pseudo-dual-beam mechanism can be integrated into the accessory to increase reliability. A reference calibration was performed between measurement and measurement using an optical path-switching mirror.

Since the stability of the spectrophotometer is affected by the ambient temperature, this mechanism is indispensable for long-term measurements such as date

crossings. The change in transmittance with respect to the time of the light reaction and the dark reaction was measured using this device, and the result shown in Figure 2 was obtained. Here, it can be seen that the light reaction takes about 2 minutes and the dark reaction takes about 5 minutes.

Fig. 2 Photochromism test result

On the other hand, it can be confirmed that the transmittance is at least less than 10% when the lens is darkened due to the light reaction.

D. Polarization

Polarization emits light that only vibrates in a certain direction. In general, sunlight vibrates with the same magnitude in all directions. When sunlight passes through a polarizer, it vibrates in one direction, which is said to be polarized. Scattered or surface-reflected light is polarized in a specific direction. Most of them are horizontally polarized, so if the polarizer is positioned vertically, the polarizer cannot pass through. It is for this reason that polarized sunglasses appeared. Polarized sunglasses can almost completely reduce reflections from asphalt or other reflections from driving at night. The method of bonding the polarizing film to the lens is sometimes attached using an adhesive, but has a disadvantage in that the transmittance is very poor. An improved method is a method of attaching a polarizing film by heating.

In this case, there is no problem in transmittance, but there is a problem in that the polarizing film is easily broken. There is a method of placing a polarizing film in

the monomer. Among them, there is a method of making a lens by putting a polarizing film inside a mold using a gasket mold, and molding a plastic containing a polarizing film by injecting a monomer into the mold. Since manual work requires a lot of skill, the technique of adjusting the upper and lower jigs using a pneumatic device is also used. However, it is basically impossible to reduce the thickness of the front side of the polarizing film to about 1mm by using a jig. This method has a disadvantage in that the thickness of the lens becomes thicker than necessary. Therefore, a new method that does not use a gasket mold is needed. In this paper, a method was used to make the front part of the polarizing film less than 1 mm by using adhesive tape instead of a gasket mold. That is, a method was used that does not require an upper and lower jig, an upper and lower supporter, a notch groove of the polarizing film, and a method capable of simply manufacturing a polarizing lens by prepolymerization and main polymerization. Using this method, the polarizing film can be uniformly combined with the lens, and it does not protrude out of the lens, so that it can be coated uniformly.

It is difficult to impart polarization to the spectacle lens material. Heat was applied to match the curvature of the polarizing film and the outer curvature of the lens. A polarizing film was placed on the back side of the photochromic layer of 1 mm. A monomer having a UV blocking function was put inside the polarizing film, and adhesive strength was maintained through the polymerization process. A polarizing film for sunglasses manufactured by PT&T Co., Ltd. was used as a polarizing film for sunglasses. The product name was Gray-37, and the polarization degree (PE) was 99.07 in the visible light range of 400-700 nm. Figure 5 shows the MPC-2200 multi-purpose large sample compartment used for measurements. The measurement wavelength range is 240 to 800 nm (MPC-2200). The maximum sample size is 305 mm × 50 mm T or 204 mm dia. × 300 mm T, in the case of reflection, the diameter is 305 mm × 50 mm T. The color, polarizing efficiency, and spectrum of the polarizing film used to manufacture the lens were measured. Figure 3 shows the spectrum of the polarization experiment, and Figure 4 shows the color and spectral diagram. The polarizing efficiency was 99.07%.

Fig. 3 Polarization measurement spectral data

- Luminous transmittance

Illumination	Value (%)
D65 10°	37.85
D65 2°	37.74
C 2°	37.74

- Color

Illumination	y	x	y	CTE I.*	CTE a*	CTE b*	PE(400~700nm)
D65 10°	37.85	0.3101	0.3269	67.91	0.07	-1.67	99.07%
D65 2°	37.74	0.3092	0.3240	67.83	0.49	-1.90	
C 2°	37.74	0.3065	0.3111	67.83	0.55	-1.90	

* PE : Polarizing efficiency

Fig. 4 Polarizing efficiency measurement

E. Ultraviolet ray protection

Ultraviolet ray has a wavelength of 100 to 400 nm, shorter than visible light, but longer than X-rays. The gas discharge tube of an ultraviolet LED or ultraviolet laser device is the only mechanism that emits ultraviolet rays. In general, when the human skin is exposed to ultraviolet rays, skin damage such as redness, burns, wrinkles, freckles, and skin keratinocyte phenomena may occur. In particular, exposure to UVA is known to weaken the immune system and cause skin cancer. Table 2 shows the types and properties of UV rays.

TABLE II
TYPES OF ULTRAVIOLET RAYS

Name	Wavelength	Energy/ photon
UVA	400 – 315 nm	3.10 – 3.94 eV
UVB	315 – 280 nm	3.94 – 4.43 eV
UVC	280 – 100 nm	4.43 – 12.4 eV
NUV	400 – 300 nm	3.10 – 4.13 eV
MUV	300 – 200 nm	4.13 – 6.20 eV
FUV	200 – 122 nm	6.20 – 10.16 eV
H Lyman-α	122 – 121 nm	10.16 – 10.25 eV
VUV	200 – 10 nm	6.20 – 124 eV
EUV	121 – 10 nm	10.25 – 124 eV

The sunscreen composition is 1,6-diisocyanatohexane, 2,5-diisocyanatomethylbic, 2,3-Bis(2-mercaptoethylthio) propane-1-thiol, [1,4]Dithian-2-yl-methanethiol, 2,9[1,4] Dithian-2-ylmethylsulfanylethanolthiol, Pentaerythritoltetrakis, 3-Mercapto-propionic acid 3-hydroxy-2,2-bis-propylester, 3-Mercapto-propionic acid 3-hydroxy-2-hydroxymethyl-2-propyl ester and sunscreen do. At least one of benzotriazole and benzophenone is used as a sunscreen, and it blocks 99% or more of UV rays entering the eyes, thereby preventing eye diseases such as glaucoma caused by UV rays.

Glass or plastic can be coated to reduce the amount of ultraviolet ray that passes through the transparent material. Such coatings are generally applicable to eyeglasses and automobile windows. UV filters are used to block the slightly sensitive invisible UV rays. The UV410 lens was tested spectrophotometrically and found to be completely blocked in the sub-410nm range. Figure 5 shows the transmission characteristics of the polarizing film. As a result of passing the 405nm laser pointer through the developed lens, it was confirmed that it was completely blocked. Figure 6 shows the UV protection characteristics of a general lens, and Figure 7 shows the UV protection result of the 410 lens.

Polarizing Material Transmission Characteristics

Fig. 5 Transmission characteristics of polarizing film

F. Blue light reduction

The CR39 and UV410 lenses were tested with a purple laser pointer. The purple laser pointer has a power of 5 mW and a wavelength of 405 nm. Figure 11 shows a typical spectacle lens effect after 405 nm projection. The purple dots are clearly visible on the screen. Figure 12 shows the effect of the newly developed spectacle lens, with no visible purple spots.

Fig. 6 Purple transmission property of CR39 lens

Fig. 7 UV blocking lens, purple beam cut off

We measured the transmittance of the developed sample lens using an ultraviolet visible light spectrophotometer. Figure 8 shows the difference in transmittance between the developed sample lens and the existing CR39 lens. Figure 9 shows the difference in transmittance between normal lenses and developed UV blocking lenses. The purple part is especially blocked, so more than 30% of the blue light is blocked overall.

Fig. 8 Comparison spectrum of sample lens and general lens

Fig. 9 Difference spectrum between sample lens and general lens

Figure 10 is a light transmittance of a polarizing lens with photochromic and UV blocking function.

Fig. 10 Spectrum of polarized lenses with photochromic and UV protection

Blue light is part of the visible spectrum in the 380-450 nm range. Blue light is emitted from smartphones and other electronic devices that have LED backlights installed. Natural light consists of a relatively continuous spectrum, including all colors. We should be concerned about the blue light peak of the LED flat panel. The blue frequency peak is clearly visible, an imbalanced energy distribution never seen in natural light. Not only does this artificial lighting cause oxidative stress in the eyes, which promotes medical conditions like age-related macular degeneration, but it can also disrupt hormonal balance, leading to chronic disease. Quite a few people suffer from temporary side effects when working on screens such as burns, stinging pains, eye stains, headaches, and unstable vision. However, blue light in the range of 465-496nm is beneficial to health because it regulates the circadian rhythm. Therefore, it is advisable to limit exposure to wavelength bands exhibiting potentially harmful blue light and especially to the increased risk.

As smartphones, tablets, and computers become more common, more and more people spend more time looking at the screen, increasing the number of people suffering from eye strain. One of these causes is believed to be the blue light emitted by the display of such devices. The shorter the wavelength, the stronger the energy of light, which can cause eye strain.

Blue light next to ultraviolet light in the electromagnetic spectrum has a shorter wavelength than other visible light.

It also tends to spread and is thought to cause flicker in vision. Blue light reduction can be attempted by coloring yellow lenses that absorb blue light. However, some consumers may avoid wearing yellow lenses. Instead, it uses the AR coating principle to increase the reflectivity of blue light, preventing blue light from passing through the lens.

On the other hand, if transparent and conductive ITO is applied, electromagnetic wave shielding effect and anti-reflection effect can be realized at the same time. However, the refractive indices of ZrO₂ and ITO are similar. Using this property, the anti-reflection effect and the electromagnetic wave shielding effect can be realized at the same time by improving the 5-layer anti-reflection layer to 6 layers. Table 3 shows the design values with electromagnetic shielding and anti-reflection effects applied, and Figure 11 shows the results of reflectance ratio after AR and EMI coating.

TABLE III
ANTI REFLECTION AND EMI COATING

Substrate Sample	SiO ₂ (nm)	ZrO ₂ (nm)	SiO ₂ (nm)	ZrO ₂ (nm)	ITO (nm)	SiO ₂ (nm)
No.1	150	20	21	30	52	81
No.2	150	20	21	25	57	81
No.3	150	20	21	20	62	81
No.4	150	20	21	15	67	81
No.5	150	20	21	10	72	81

In addition, by using the reflectivity of RGB, it is possible to change the surface color by changing the thickness of 5 layers and visualizing the color of the reflected light.

Fig. 11 Reflectance ratio after AR and EMI coating.

The electrical conductivity by ITO is proportional to the deposition thickness, and it changes in proportion to the electromagnetic shielding. Figure 12 shows that electrical conductivity and electromagnetic shielding effect are proportional.

Fig. 12 Shielding effect vs. surface electric conductivity

G. Monomer component analysis

The components of UV blocking monomer and photochromic monomer were tested at the Korea Research Institute of Chemical Convergence. As the test equipment, an Inductively Coupled Plasma Spectrometer (ICP: iCAP 7400, Thermo elemental, USA) was used. ICP analysis conditions are shown in Table 4.

TABLE IV
UV ICP ANALYSIS CONDITION

Item	Condition
Wavelength	166 nm ~ 782 nm
Nebulizer pump	50 (1.85 mL/min)
RF power (W)	1 150
Nebulizer flow (L/min)	0.5
Auxiliary gas flow (L/min)	0.5

The inorganic elements contained in the samples were pretreated according to EPA 3051A (Microwave assisted acid digestion of sediments, sludges, soils, and oils), and then the inorganic elements were analyzed according to EPA 6010D (Inductively coupled plasma optical emission spectrometry). Na, K, Mg, Ca, Ba, Ti, Zr, Mn, Cr, V, Fe, Co, Ni, Cu, Zn, Al, Si, Sb, P, As, Pb, Bi, B, Se, Cd, Mo and Sn were quantitatively analyzed. Eight elements such as Na, K, Mg, Ca, Fe, Al, Si, and P were identified, and the detection limit was 5 mg/kg. As a result of quantitative analysis, the content of P was the highest, followed by Ca. Table 5 shows the results of quantitative analysis of inorganic components.

TABLE V
INORGANIC ELEMENT QUANTITATIVE ANALYSIS (MG/KG)

Item	UV Protection	Photochromism
Na	33	26
K	7	6
Mg	6	7
Ca	52	51
Fe	12	6
Al	9	11
Si	6	18
P	796	424

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IV. CONCLUSION

Using a urethane-based monomer with a refractive index of 1.67, we developed a polarized spectacle lens with UV blocking, blue light reduction, and photochromic functions. Although spectacle lenses with each independent function have been released, a spectacle lens with a refractive index of 1.89 with such a comprehensive function has never been developed. In particular, UV protection is important for glasses wearers who use concave or convex lenses. The developed spectacle lens completely blocks wavelengths below 410nm of ultraviolet light and reduces blue light by more than 30%. The photochromic function was restored to its original state in 2 minutes in the dark reaction and 5 minutes in the light reaction. The polarization degree showed a good result of 99.07. Anti-reflection and electromagnetic wave shielding functions are provided through multi-layer coating. The reflectance obtained about 0.1% and the electromagnetic wave shielding function was proportional to the ITO thickness. The result will be good for spectacle wearers and sunglasses lovers.

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