Develop Functional Films and R2R Process

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Abstract

The ideal display's screen protections films; Anti-fingerprint (AFP) coated film, and anti-glare (AG) coated film, anti-sparkle coated film (AS), and anti-reflective (AR) coated film for displays screen have been produced at lower cost, have a higher transmittance, higher levels of scratch and abrasion resistance, good chemical resistance, excellent touch durability, and have improved flexibility property by using Kimoto's (KMT) roll-to-roll coating process. Furthermore, Kimoto Tech Inc. (KTI) has developed a high conductive Film by creating simple and effective coating method with PEDOT: PSS. These protective films are achieved via creating UV curable formulation and applying thinner UV hard coating on the PET and PC. Thin films coated from this composite possess excellent surface properties, mechanical, electric, and optical properties.

Kimoto's coating technology improves AFP, AG, AS, and AR properties by supplementing with consistent high surface morphology, high transparency, excellent abrasion resistance, and weather-ability. Kimoto adds value and functionality by applying a variety of proprietary coatings to plastic substrates on one or both sides.

Introduction

Touch functionality has been integrated in smartphone, tablet, laptops computer, and vehicle display to meet requirement of increased complexity and functionality of electronics along with the display area and readability improvements. With greater interest in optimizing the image quality and readability at high viewing angles and various lighting conditions, anti-fingerprint film, anti-glare, anti-reflective, and anti-sparkling films have been added on the top of displays screen by sol-gel, vacuum deposition, as well as sputtering method [1, 2, 3, 4, 5, 6, 7]. However, it is difficult to adjust surface morphology to increase readability, decrease sparkling by using organic and inorganic materials and without adversely affecting the cost of manufacturing of the protection film. Creation of formulation and proper coating method are key factors for the optimal performance in screen protection films. Screen protection films need to have fingerprint resistance, minimum sparkling, and provide the appropriate anti-glare and anti-reflective properties to meet required image clarity and readability under sunlight. Accordingly, a method in which an anti-fingerprint coating layer is formed by generating a waterproof/oilproof fluorine-containing thin film on the surface of displays or by coating the surface of displays with a waterproof silicone resin skeleton. We have developed a coated film that is capable of preventing the adherence of finger prints to displays or touch panels, as well as reducing their overall visibility, while maintaining the anti-fingerprint performance for a long period of time due to the film's superior durability and surface properties.

We have designed formulations for anti-fingerprint, anti-glare, anti-reflective, anti-sparkling films and roll to roll (R2R) high speed coating methods.

This paper consists of two parts: in which the first part details the development of AFP, AG, AR, AS films, as well as the roll to roll coating process, and the characterization of structure, optical, and morphological properties of coated materials; the second part, includes the optical and physical properties of UV hard coated, pressure sensitive adhesive (PSA), and conductive coated films.

Experiment and Roll to Roll Process

1. UV Curable Formulations

UV curable formulations for AFP, AG, AS, AR, each include oligomers and monomers obtained from Sartomer, and other companies (Urethane acrylic oligomers and monomers, Amine, hydroxyl, carboxylic acid, and ethylene oxide functional with functionalities from 3 to 9 were tested as a main ingredient of UV hard coating), photo initiators were from Ciba chemical, pigments from EVONIK industry (nano and micro size silica oxide), and additives were from BYK.

UV Curing condition: F600S, 600 watt/inch from Fusion was used.

2. The Coating Structures

AFP coating was applied one side of the substrate (PET or PC), AG coating was applied on one side or both side of the substrate, AS coating was applied to both side of the substrate, and AR coating was applied 2 or 3 layers on one side or both side of the substrate.

3. Coating Process

Kimoto.co.jp (KMT) and Kimoto Tech Inc. (KTI) has developed a roll-to-roll coating method using proprieties coating formulations. AFP, AS, AG, and AR coatings have been fabricated on 2 – 10 mil PETs, and 5 – 15 mil PC. Those UV hard coated films, PSA films, and Conductive films have been made on the KMT and KTI production line shown in Figure 1.

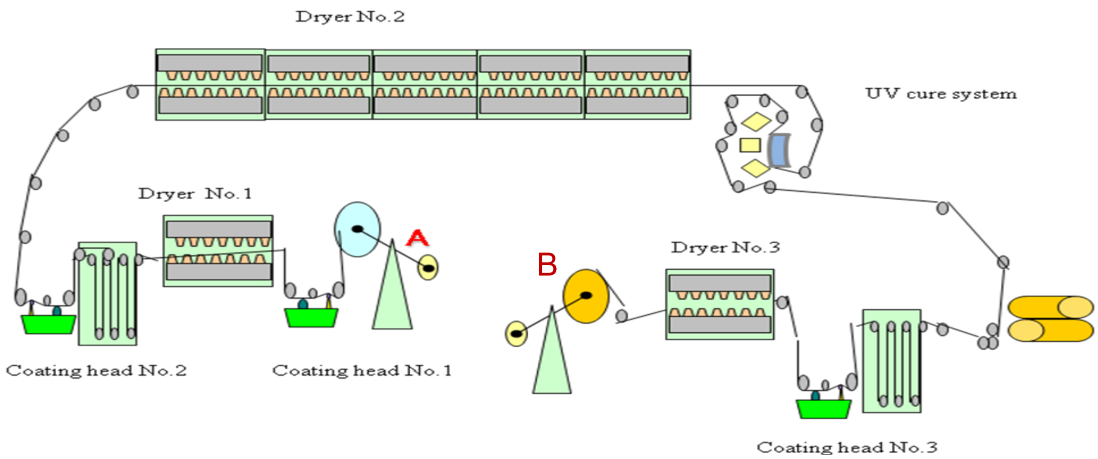


Figure 1: Kimoto Tech Inc.' Production Line

4. Characterization

Optical properties such as haze, clarity, and transmittance were measured by BYK Haze-Gard Plus; gloss was measured by BYK Gardner micro-TRI-gloss; Our adhesion test was performed by applying 1 inch of Nichiban tape to the coated film surface and this tape was pull off very quickly (min. three testing cycles); Surface scratch resistance was measured by applying 1000 g of pressure with the Lens coating hardness test KIT (tip of KIT was wrapped with a non-woven cloth), this weight is placed on the coated surface, and moves gently back and forth; Surface and cross section photographs of coated film were taken on SEM, S-3000N (Hitachi High-Technologies Corporation), Note: The angle of a photograph is 60 degrees; Contact angle was measured with data physics (data physics instrument GmbH -

OCA 15EC); Reflectance of coated film was measured by UV-Vis-NIR (Solid space – 3700, Shimadsu); Surface of coated film was evaluated by using Scanning Probe Microscope, SPM, NanoNaviReal Probe Station (Probe: DF20P2, Hitachi High-Technologies).

Results and Discussion

1. Anti-fingerprint Coated Film

Fingerprints and other surface contamination greatly impair the quality of the image and utility of the device showing in Figure 1. Fingerprint contains water, oil, and salt; therefore, anti-finger print film surface must be hydrophobic, hydrophilic, omniphobic, and scratches resistance [1, 2, 3, 4].

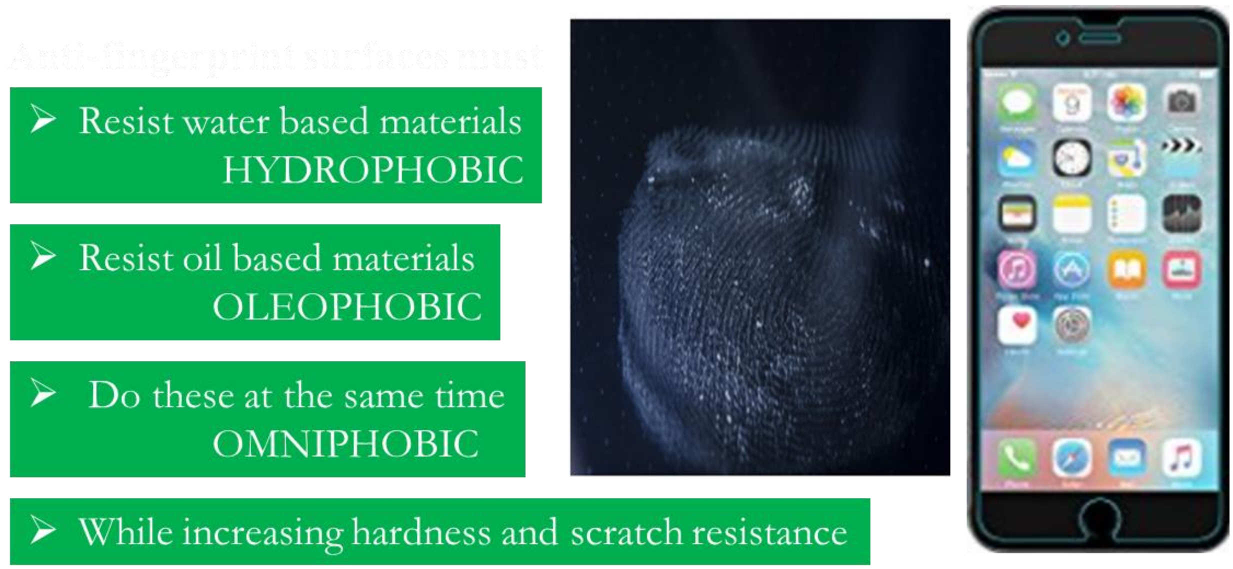
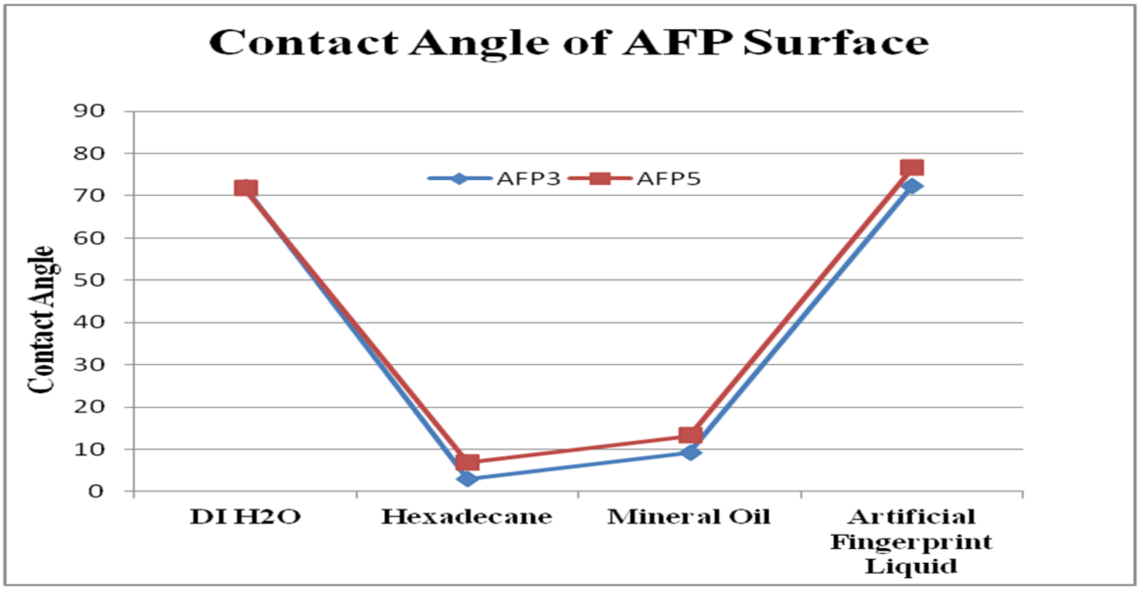


Figure 2. Fingerprint Image and Requirement

Ours smart formulation to create anti-fingerprint coating included 30-50 % of oligomer/monomers with 3-6 functionality, 1-3% of photo initiators, and 1-3 % of additives. The coated film has low surface energy; low surface roughness, low haze, high hardness, and reduced fingerprint visibility and "easy wipe" properties. Contact angle was measured using DI water, hexadecane, mineral oil, and artificial finger print liquid showing Figure 2. The contact angles of DI water and artificial finger print liquid on the AFP layer was 70 – 80 degrees; while those of hexadecane, mineral oil were between 3-14 degrees. The AFP surface showed less fingerprint visible & easy wipe out of finger print.



Urea	Lactic acid	Sodium pyrophosphate	Sodium chloride	Ethanol	Water
Formulation of 'Artificial Fingerprint Solution'					
1.0	4.6	8.0	7.0	20	1000

Figure 3. Contact Angle and Artificial Fingerprint Liquid

2. Anti-glare Coated Film

Both anti-glare and anti-reflective treatments represent ways to improve or optimize readability of a displayed image or set of characters [6, 7, 8]. Readability is essential for the optimum performance of any display, and we want the visual information to be read clearly, quickly and comfortably (minimal eyestrain). Both anti-glare and anti-reflective methods improve readability, but resolve the problem using different mechanisms to address the different causes of reduced readability.

Due to the naturally glossy surface of displays, external light is scattered from the surface, causing distractions to the user, distortion of the image, a decrease in image quality showing in Figure 4. To deal with the external sources of reflection, anti-glare uses diffusion mechanisms to break up the reflected light from the surface. Diffusion works by reducing the coherence of the reflected image, making these unwanted images unfocused to the eye, thereby reducing their interference with viewing of the intended image contained in the display.

We successfully produced UV hard coating formulations by dispersing micro and nano particle, the surface of coated film is showed in Figure 5. The optical properties and surface roughness are showing in the Table1. The AFP is optically clear UV hard coated film and has high clarity, low haze and surface roughness, and high gloss. The AG02, AG03, AG05, AG10 are all anti-glare films, and formulated by increasing amount of micro and nano particles. The gloss level was decreased, haze and surface roughness were slightly increased, and clarity was decreased when the amount of micro and nano particles were increased in the coating formulation of the AG films. Furthermore, the reflectance of light was decreased in the visible light range when the amount of micro and nano particles were increased showing in the Figure 6. The AG coating surface eliminated all reflective light and decreased gloss even though clarity was decreased, and haze was increased a little bit. The image appeared slightly haze with reduced contrast, but glare is minimized even under strong direct light. The anti-glare layer was formed for providing a film with an anti-glare property resulted from surface scattering and a hard coat property for preferably improving abrasion resistance of the film. Accordingly, the anti-glare layer preferably contains, as essential components, a translucent resin for providing the hard coat property, a micro and nano sized particle for providing the anti-glare property.

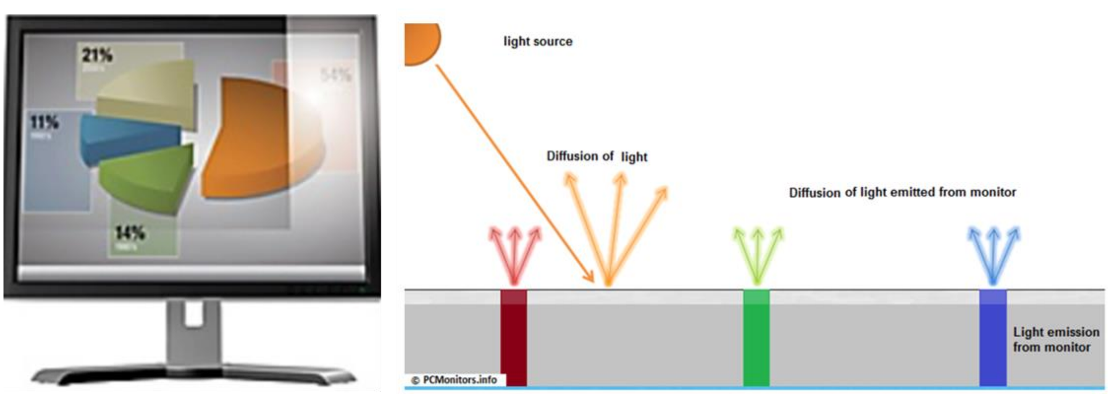


Figure 4. Glare Image and reflection of Light

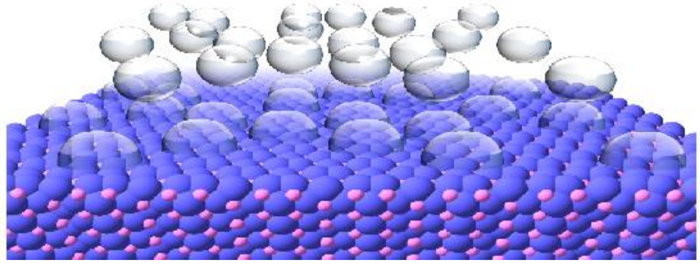


Figure 5. Morphology of Coated Film's Surface

Table 1 Optical Property and Surface roughness of AG Film

AG film	Clarity	Haze	Gloss 20^0	Ra
AFP	100	< 0.6	170 - 190	< 0.02
AG02	99	1.0-2.4	140 - 153	0.03 - 0.06
AG03	98	3.5-4.5	95 - 102	0.09 - 0.11
AG05	85	5.0-6.0	75 - 87	0.20 - 0.24
AG10	75	7.0-8.0	50 - 58	0.25 - 0.27

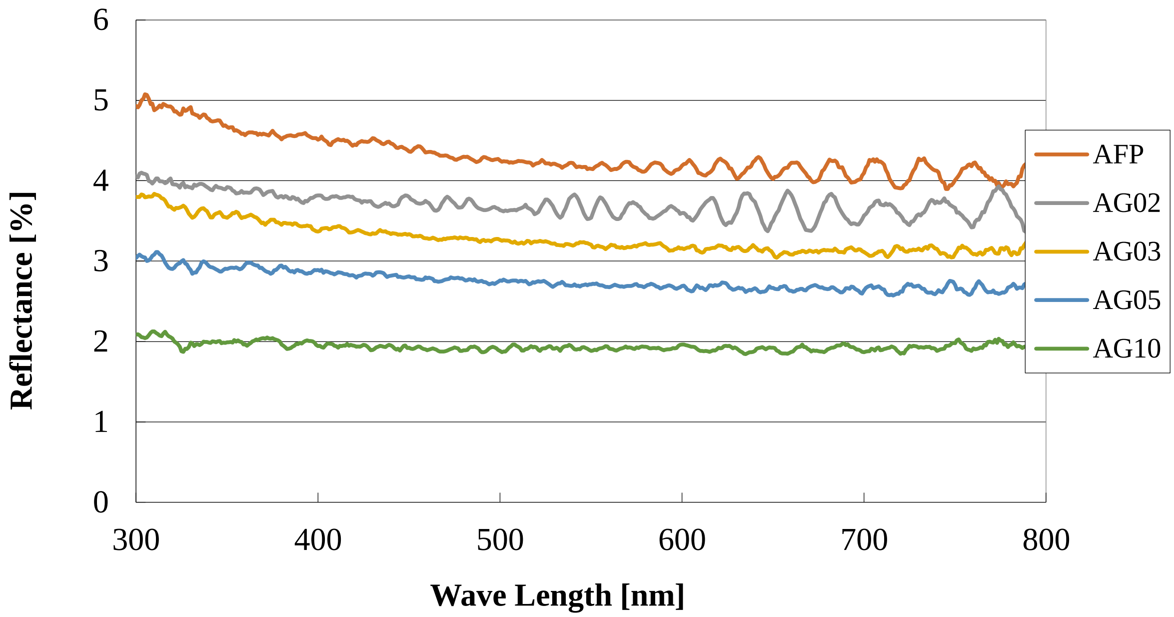


Figure 6. Reflectance of AG coated Film at the Visible Light

3. Anti-Sparkle Coated Film

AG treatments can be applied to the cover sheet that diffuse the reflections and thereby reduce their visibility. While these treatments can be effective in reducing the impact of surface reflections, they can sometimes produce a transmission artifact known as display sparkle where the displayed image appears to be covered by small colored highlights that scintillate with movement of the display and observer [7]. Sparkle artifact can be disturbing and can severely reduce perceived image and display quality.

KTI has developed both sides of UV hard coated film to eliminate sparkling issue. Bottom side is anti-glare coating on the PET; which is exactly the same as an Anti-Reflective coating, designed to eliminate reflection and subsequent interference with the image presented to the user. The upper side (AFP side) is clear UV hard coated side, and provides a property of easy to wipe out the finger print showing in Figure 7. Figure 8 shows monochromatic photographs of high sparkle and low sparkle screens whereas Figure 9 shows realistic visuals of high and low sparkle screen images, and the clear image was observed when low sparkle coated film was applied on the screen.

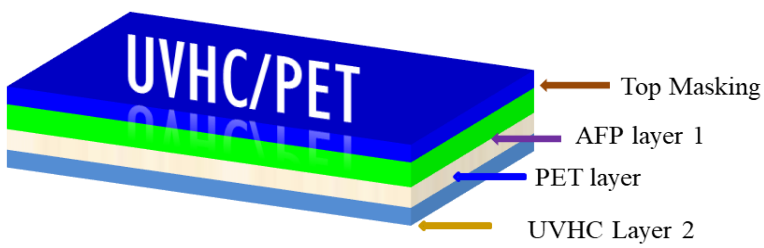


Figure 7. Structure of Coated Film

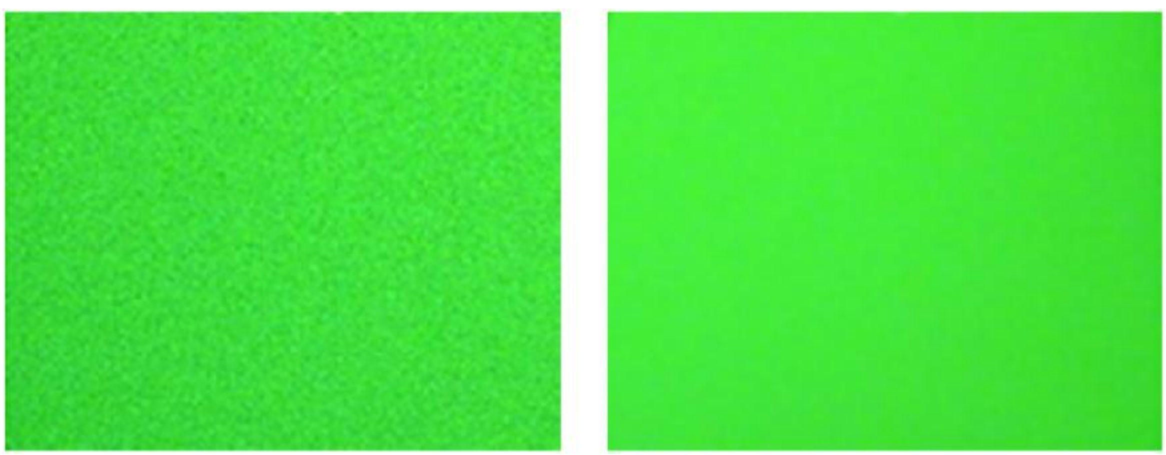


Figure 8. High Sparkle (left) and Low Sparkle (right) Photographs

Figure 9. High Sparkle (left) and Low Sparkle (right) Photographs

The formulation and surface of coated film was analyzed. The nano and micron size of pigment were used in the UV hard coating formulations, and optical and physical properties were measured, and sparkling was observed with score of 8-10 point on the monochromatic background (0 is labeled for no sparkle, and 10 is labeled for high sparkle). Higher sparkling image was observed when nano or micron size pigment was used individually in the formulations, and surface roughness was lower than 0.02 micron or higher than 0.06 micron. The clear readability and none sparkling image was noted when 0.3% of nano particle and 1-3 % of micron particle were used in the formulation, and surface roughness was 0.03-0.04 micron.

4. Anti-Reflective Coated Film

Because the largest change in refractive index occurs at the interface between air (n-1) and the substrate (n-1.5), an effective AR or AG coating of a display substrate should be present at the topmost layer, i.e., in direct contact with the air or ambient surroundings, and therefore, should be a sufficiently durable to protect the device against abrasions and scratches. An AR coating is generally more sophisticated than an AG coating. An AR coating normally requires creation of a precisely controlled multilayer structure that could engage reflections from each interface to a destructive interference in the viewing direction [9, 10, 11, 12, 13]. Such a multi-layered AR coating must have a prescribed combination of refractive index variations as well as controlled layer thickness to achieve the desired destructive interference over an entire visible spectrum.

The AR layer is only effective when the refractive indexes and thicknesses coordinate such that the destructive interferences occur among the reflections from several different interfaces and over a frequency range eliminating all reflections. However, constructing such a sophisticated and precisely layered structure is challenging, especially with regards to the processing speed and cost.

In this research, the 30-40 % of oligomer with 6-9 functionality, 10-20 % of monomer with 3-6 functionality, 5-10 % of nanoparticles with a precisely controlled size (ranging from several tenths to hundreds of nanometers) and several percent of additives were used in the UV hard coating formulations. The thickness of low reflective index layer was adjusted to 100-150 nanometers, the medium reflective index layer was 1.5 – 2.0 micron, and the substrate was 50-100 micron. The coated film structure is showing in Figure 11.

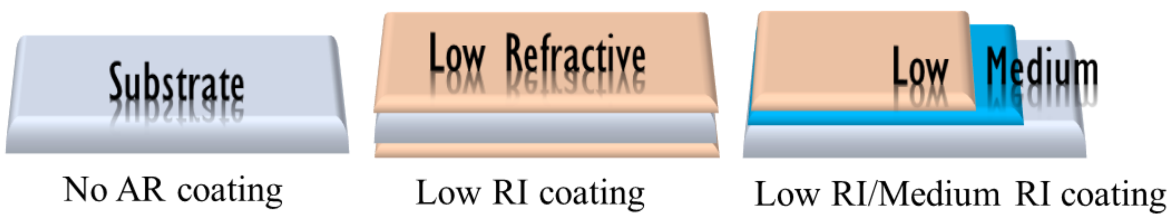


Figure 11. Structure of Coated Film

The substrate's total transmittance and haze was 93% and 0.8% respectively, and it improved to 95% and 0.5% when low reflective coating was applied on the both side of substrate. The transmittance was increased to 98%, and reflectance was decreased to less than 1.0 % after medium and low reflective coatings (AR/CHC/PET) were applied on the substrate, showing in Figure 12.

The lower reflective, higher transmittance, and lower cost screen protection film was created by adjusting UV hard coating formulation, coating thickness, and using roll to roll coating process.

Furthermore, Kimoto Tech Inc. (KTI) has also developed high conductive films by creating simple and effective coating method with PEDOT:PSS [14, 15, 16]. These are achieved by using thermal and UV curable formulations and applying thinner UV hard coating on the PET and PC. Thin films coated from this composite possess excellent surface, mechanical, electric and optical properties. KTI also has capability to coat multiple variations of PSA film for specific applications.

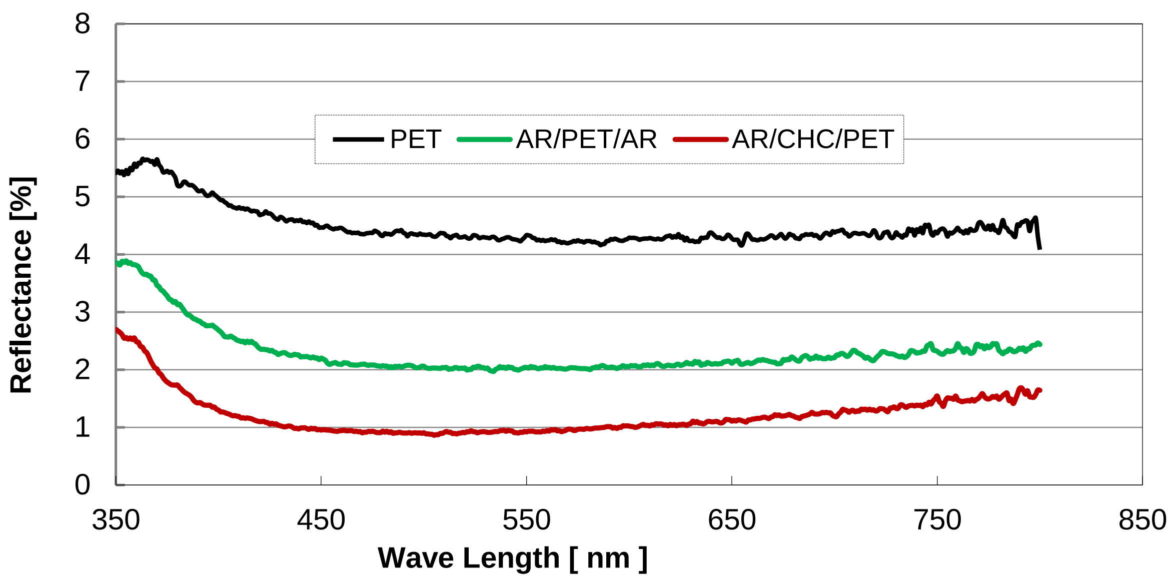


Figure 12. Reflectance of Coated Film

Conclusion

Kimoto's coating technology improves AFP, AG, AS, and AR properties by making smart formulation and creating coating process with consistent high surface morphology. Anti-fingerprint coated, and anti-glare coated, anti-sparkle coated, and anti-reflective coated films for displays screen protection have been produced at lower cost, higher transmittance, and higher scratch resistance, high abrasion resistance, good chemical resistance, excellent touch durability, and with improved flexibility at the Kimoto (KMT) by using roll-to-roll process.

Furthermore, Kimoto also adds value and functionality by applying a variety of proprietary coatings to plastic substrates on one or both surfaces. KTI has also developed hard-coated polyester and polycarbonate material offering excellent impact resistance, optical clarity, excellent abrasion resistance, and weather ability.

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