Optical Coating Applications for Consumer and Industrial Polymer Displays

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Abstract

North American Coating Laboratories provides vacuum- and dip-applied thin film coatings to polymer manufacturers and suppliers across numerous market segments. These coatings are predominantly deposited on polycarbonate and acrylic substrates used in a wide variety of applications. In many cases, such vacuum-applied coatings as broadband anti-reflective treatments and polysiloxane dip-applied treatments improve the optical quality of polymers as well as extend the lifecycle of polymers in the field. This presentation will focus on the full spectrum of thin-film coatings that are currently being applied to polymers, resins and displays.

Introduction

For decades manufactured display lenses were comprised of glass which has substantial abrasion resistance, and solid optical characteristics. As the production of polymers became more refined numerous industries began to replace glass substrates for cost reduction, impact resistance, and in some cases weight reduction. With the push towards replacing glass with polymer based lenses, displays, and viewing devices increased, so to did the need for polymers to be treated with thin-film coating to closely match or outperform their glass counterparts. In this presentation we will discuss the myriad of options available for coating polymers, and some of the value a thin-film coating treatment can add to a base polymer substrate.

Introduction (continued)

Historically there was little to no attention paid to coating polymer displays, minus some crude spray coatings that protected them from the elements. For years consumers would clean commonly used polymers with various detergents and a cloth which after several cleanings would leave the device scratched and clouded rendering it almost impossible to see through. In the past decade or so, polymer manufacturers have begun to recognize the need to protect these displays in a variety of ways. Many polymer manufacturers have begun to use more advanced hardcoatings to prevent scratching and to provide a more durable surface for cleaning. Some manufacturers have begun to design and provide optics with coatings that reduce glare or reflections off the surface of the lens so that the displayed information is more easily viewed under varying lighting conditions.

Today there exists a variety of optical coating types and application methods to provide solutions to protection, durability and performance concerns for these polymer based displays.

Optical Quality Polymers/Plastics

There is a fair number of what are considered “optical quality” plastics available today for use in a variety of applications. These include:

- Acrylic (PMMA - Polymethyl Methacrylate)
- Polycarbonate (PC)
- Styrene
- Cyclic-olefin polymers such as Zeonex/Zeonor
- Cyclic-olefin co-polymers such as Topas, polyetherimide (Ultem)
- Other optical polymers

The two most widely used polymers are polycarbonate and acrylic (PMMA). These polymers are widely used due to their superior optical clarity and their optimum impact resistance. While these plastics are good for those reasons they are inherently very soft and extremely susceptible to scratching or hazing even through routine cleaning and handling. These polymers also react negatively with chemicals typically used in standard cleaning products such as isopropyl alcohol, acetone, and ammonia.

Types of Coatings

There are a variety of optical coatings that are currently used in a diverse number of industries for a myriad of applications. Optical coatings are employed by manufacturers of devices in the medical, consumer, hand-held electronics, military, automotive, and aeronautic industries to name a few. Below is a general overview of the types of coatings that manufacturers across different manufacturing verticals are currently employing:

Abrasion-Resistant Coatings

- **Polysiloxane Coatings**
  - These coatings are used to increase the durability and scratch resistance of the polymers they are deposited upon. They also exhibit very good chemical resistance which helps them to extend the lifecycle of the polymers in the field. Polysiloxane based coatings are clear abrasion resistant hardcoatings that are used in a variety of automotive, military, hand-held device, and medical applications. They are excellent base coatings when coupled with additional optical coatings for display purposes as they increase the durability of any additional coatings applied on top. A Polysiloxane coating is typically applied at a thickness of 3 – 5 microns and is completely transparent.

- **Vacuum Coatings**
  - These coatings are also used to increase durability but do not have the same level of abrasion resistance or chemical resistance as the polysiloxane type coatings. Vacuum hardcoatings are used when polysiloxane cannot be used due to part size or geometry. They are also a good base layer for some of the additional coatings for displays listed below.

- **Anti-Reflection/Anti-Glare Coatings-** are applied to a variety of polymers that are used for information display purposes. Uncoated lenses reflect about 8% of visible light and transmit approximately 92% of the light. With the addition of an anti-reflective coating light reflections are reduced to less than 1% providing enhanced clarity and contrast. Typical uses can be mechanical in nature such as a speedometer, or can be as complex as a hand-held touch screen device with intricate backlighting and LED patterning. Anti-Reflection/Anti-Glare Coatings are extremely popular with polymer manufacturers who produce high-end consumer products, and also with manufacturers who study the affect of light reflection on user interaction and comfort. These coatings are utilized by manufacturers of $100,000 dollar automobiles, all the way to standard consumer electronics, so added luxury is not always a main design feature of an added Anti-Reflection/Anti-Glare Coating.

- Anti-reflection coatings are predominantly applied after manufacturing and are deposited on the outer surfaces of a substrate. They reduce or eliminate wave reflection through the principle of destructive interference meaning the reflected light frequency is opposite of incoming incident light source so they cancel each other out. This provides broadband reduction of reflection across the visible light spectrum. Typically these treatments increase the total light transmission to as high as 99.5%. It is important to note that optical coatings do not reach perfect performance, though they are capable of reducing a surface's reflection coefficient to less than 0.1%.

- Anti-Glare coatings are predominantly applied in the molding process, but can be applied through spray or dip application in post-assembly situations. Anti-glare coatings are actually a micro pattern or roughened surface on the substrate or immediately below the substrates outer layer that use diffusion mechanisms to breakup the reflected light off 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. The principle drawback to using diffusive mechanisms to address external reflection (glare) has been that they sacrifice clarity and resolution of the intended image. Mechanically or chemically textured surfaces - or anti-glare coatings using suspended particles - reduce the glare but often at a significant trade off in image resolution and readability. While economical to apply, the trade off in image resolution represented by these anti-glare treatments often makes them an inferior solution to a manufacturers viewing requirements.

- The aforementioned coatings work best in combination with each other. When deployed individually they will both achieve decent results in glare reduction, however anti-reflective treatments are used best in applications where acuity and clarity of the image is of paramount concern. In conjunction with each other an anti-glare treatment teamed with an anti-reflective top-coating has been deemed the most effective way to eliminate glare and reflection while minimizing eyestrain and maintaining optimum visual acuity.

- **Hydrophobic Coatings-** Were pioneered in the ophthalmic industry to reduce smudging and oil build up on prescription eyewear, but have now migrated to the automotive, medical, and device industry. They are typically deposited through a vapor process, and form a permanent bond with the surface of the base polymer. Hydrophobic coatings act similar in nature to Rain-X® on a windshield in that improve the watershed capability of the substrate, and wick moisture from the surface of the substrate to the edge. The largest differentiator between Rain-X® and a hydrophobic treatment is that in the case of a hydrophobic treatment there is never a need for reapplication of the coating as they are permanently bonded to the base polymer.

- **Transparent Conductive Coatings (TCO)** Transparent Conductive Oxide's were pioneered in the military sector as a means to produce clear EMI/RFI shielding assemblies. While these coatings are optically clear, they conduct electricity. They are typically applied through electron beam vacuum deposition or sputter coating vacuum deposition. When applied to a surface they allow the manufacturer to install a buss bar to the substrate so that connections can be made and a continuous flow of electricity can be made for use in capacitive touch screen applications as seen in many new cell phones, PDA's and automotive navigation displays.

- **Dichroic/Color Filters-** Are angularly sensitive color coatings typically applied through glass to filter specific wavelengths of light. They are predominantly used in the lighting sector to improve the acuity and intensity of headlamps and fog lamps. They can take a clear lens and produce a red taillight color filter so the lamp appears clear when unlit and bright red when illuminated. Dichroic coatings and color filters were pioneered in the aeronautic industry for use in landing systems such as the VASI (Visual Approach Slope Indicator) and PAPI (Precision Approach Path Indicator).

- **Diamond-Like Carbon Coatings (DLC)-** Are an amorphous coating that are chemically inert and organic. These coatings are applied to glass and create a smooth, scratch-proof surface that is inherently hydrophobic. After application the only substance capable of scratching the surface of a DLC treated substrate is a diamond. Diamond-Like Carbon coatings are used heavily in the scanner industry for abrasion resistance on their scanners in the retail industry. DLC coatings are also heavily used for their anti-reflective properties in the Infra-red sector as they reflect Infra-red light waves in the 4-12 micron range.

- **Bandpass Filters-** are filter coatings made very popular during the telecom boom of the mid to late 90's these filters pass light wave frequencies within a certain range and reject (attenuate) light wave frequencies outside that range. Traditional light sources are being replaced by LEDs and bandpass filters may be used in conjunction with specific wavelength LED lighting. They are also used in some heads-up display applications.

- **Beamsplitters-** are a coating that divides a beam of light into separate beams. They are achieved by depositing varying layers of dielectric or metallic materials upon a substrate at different thicknesses. The most typical beamsplitter application is a 50/50 treatment that is 50% reflective and 50% transmissive. Partially transmitting metals make very useful beam-splitter coatings. Two common metals used for this purpose are Inconel and chrome. Metal beamsplitters are often very broad and can cover a much wider spectrum of wavelengths than their dielectric counterparts. Beamsplitters would be most commonly found in heads-up display applications or other novel imaging displays.

Application of Coating Combinations

- **Polysiloxane hardcoating & Anti-reflective coatings –** A polymer treated with a polysiloxane hardcoat yields excellent adhesion for an additional vacuum applied top coating. In most cases the top coating is an anti-reflective treatment, especially in the case of clear polymers. In these instances the polysiloxane basecoat actually improves the durability and longevity of the anti-reflective coating that is deposited on top of it. By hardening the base polymer with a polysiloxane hardcoating the anti-reflective coating itself becomes hardier in the field, and will resist abrasion more than when it is applied to a raw polymer.

- **Anti-reflective coatings & Hydrophobic Top coatings-** When used in conjunction with each other an anti-reflective coating and a hydrophobic top coating are an optimal solution for substrates that will be continually handled by the end user, or the manufacturer. In its raw state an anti-reflective coating is a series of microscopic peaks and valleys. Occasionally when anti-reflective coatings are handled improperly they show a predisposition to smudging through typical handling. A hydrophobic top coating essentially seals the microscopic peaks and valleys of an anti-reflective coating thus making the anti-reflective coating resistant to smudging, and the build up of oils, dust, and dirt. This treatment combination is most typically deployed on radio display cover lenses that are continually handled in the field and during assembly. Not only does this coating combination extend the lifecycle of the substrate, it also helps improve yield percentages during the manufacturing process by reducing the number of lenses smudged during assembly.

- **Mirror coatings & dielectric coatings-** When used in conjunction a standard aluminum or chrome mirror can achieve enhanced reflectivity by depositing dielectric layers on top of the base metallic coating layers. Typically an aluminum mirror coating will yield 85-88% reflectivity when deposited in its raw form onto either a polymer or glass substrate. When combined with dielectric top layers aluminum and chrome can achieve reflectivity performance of 95% or greater throughout the visible spectrum. This is a great advantage for precise applications that require high reflectivity such as imaging applications, and back up lighting systems. Typically engineering teams will explore the deposition of Ag (Silver) to achieve high reflectivity standards, however the reactive nature of Ag makes silver a less than desirable coating material due to it's tendency to oxidize rapidly in the field. With a trade off of typically less than 2% in reflectivity a mirror coating with a dielectric top coating is an optimum approach for achieving high reflectivity without risking oxidation and or coating failure in the field.

- **Indium Tin Oxide (ITO) coatings & Anti-reflective coatings-** This combination of coating technology is typically referred to as “Index Matched Indium Tin Oxide” or IMITO. A base coating of ITO will typically exhibit a bronze hue and achieve approximately 85% transmission with up to 15% reflectivity. With the addition of an anti-reflective topcoat to the ITO layer the transmission performance of ITO can be improved by 10-12% in some cases while maintaining good conductivity. The anti-reflective layer of coating or “Index Matched” layer is typically tuned to the refractive index of either the base substrate or to air. Although the anti-reflective layer will essentially seal the conductive layer of coating, manufacturers are still able to make connections to the substrate by utilizing a masking process around the outer diameter of the substrate. This masking can be achieved through tooling design, by pre-application of buss bars, or by photo masking the substrate. IMITO coatings are gaining popularity in the design phase of touch panel displays because they offer optimum visual clarity while maintaining consistent conductivity across the surface of the substrate. This is especially important in the design of resistive or capacitive touch panels because the electronics attached to the touch screen act to “absorb” the EMI and ultimately “bleed” the noise to ground. Thus a secondary benefit of resistive or capacitive touch screens is to act as a simple EMI filter.

Application Methods

Liquid Coating Techniques

Polysiloxane coatings are applied via one of three methods:

- **Dip –** Dip coating is the process method where a device or lens is submerged in hardcoating liquid (lacquer) and then is retracted at a specified withdrawal rate to maintain coating thickness and to minimize any “runs” or “drips” that may occur during extraction. These types of coatings are the most optically clear and are predominantly selected for displays requiring high optical clarity. Since the substrate is fully submerged, all surfaces that receive coating prior to either a thermal or UV light curing process. Through our experience we have deemed thermally cured polysiloxane to be the most abrasion resistant coating applied through this method. Dip application is the best method for treating parts with difficult geometries such as injection molded lenses and devices.

- **Spray –** This application method is used for non-optical quality parts such as headlamp covers. It is still optically clear, however, the surface of the substrate may have waves or a mottled effect commonly known as “orange peel.” This is often done in high-volume applications with an in-line process.

Application Methods (continued)

- **Flow –** Flow coating is commonly used on large flat surfaces to coat a single surface at a time. Often large sheets of acrylic or polycarbonate (on the order of 4' x 8' or larger) roll down the coating line via conveyor and are subjected to a continuous "flow" of hardcoating resin. This produces a fairly good surface quality and durability. These large sheets can then be cut down to display size parts for various applications. This cannot be used for 3-D parts or parts with a more sophisticated surface geometry.

Vacuum Coating Techniques

- **PVD (Physical Vapor Deposition) –** PVD coating is a vacuum applied hardcoating where the parts are suspended in tooling inside a vacuum chamber. The chamber is then evacuated of air and at the proper pressure a hard material is deposited onto the surface. Common materials for vacuum hardcoating are SiO_2 (Silicon Dioxide or quartz) and Al_2O_3 (Aluminum Oxide or Sapphire). Due to the nature of the deposition it is a line-of-sight process and only the surface of the part facing the source of the material is coated. Several type of PVD coating application methods exist including thermal evaporation, electron beam evaporation and sputtering.
- **CVD (Chemical Vapor Deposition) –** CVD coating is another vacuum process very similar to PVD. The deposition process is different in that a reactive gas is introduced into the vacuum chamber and then activated via a plasma source or ion beam to "flash" a layer of coating onto the entire part.

Looking Forward

The future holds a great deal of potential for polymer displays and other optical systems within medical, consumer, hand-held electronics, military, automotive, and aeronautic industries. Spurred by the evolution of technology a greater number of displays and other optical components are being introduced for consumer use. Standard display types are being designed to be larger and brighter and new display types like HUD (heads-up displays) and 3-D or holographic image displays are currently being developed for everyday use. With the explosion of on demand information, and readily available data that can be transmitted to consumers regardless of location it is safe to assume that the quantity, quality, and clarity of polymer based displays will continue along a path of rapid growth.

While this growth is exciting it does come with a fair amount of additional concerns for mechanical and electrical engineers at all levels of the supply chain. All of these technologies require some type of optical coating to either enhance their performance, improve their usability, or simply to further develop their sustainability within their designated market segment.

Summary

Optical coatings have become an integral part of displays and optical systems. As engineers and product design teams become more familiar and educated about coating options and their characteristics, they will continue to enhance the consumer's experience. As information becomes easier to distribute to mobile customers, manufacturers will continue to develop ways to provide data on demand. The cleanest and most consumer friendly platform to provide this data is through displays. When engineering teams approach the design and implementation phase of these devices it is important to ask some critical questions. Namely how will visual circumstances and environmental aspects of the consumers experience be effected when a display is added to the device they are utilizing. This makes collaborative efforts between design engineers and optical technology professionals vital to the continued growth of polymer display technology. By developing these partnerships and fostering them from the prototype phase to mass production, all involved entities will be able to deliver optical systems that far exceed technologies currently utilized in today's polymer marketplace.