Physical Vapor Deposition and UV Curable Coatings

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Abstract

Environmental concerns with traditional chrome plating continue to expand. Parts finishers worldwide are searching for alternative that provides the visual appearance and durability of chrome plate, but without the environmental side effects and costs associated with this decades old process. "Chrome look" processes and coatings for decorative and automotive lighting PVD applications have been used in the UV curable coating industry for over twenty years. As development of UV curable coatings for PVD has progressed, so has the understanding of the PVD process and its unique capabilities and applications.

This paper will address the current chrome plating process, advantages of PVD as chrome alternative, challenges associated with the various steps and layers of PVD applications, and suggestions for successful implementation of UV/PVD systems.

General background

Physical Vapor Deposition (PVD) has been used in automotive lighting applications (behind the lens) with thermal and UV cured systems since the mid 1980's. Since that time, PVD has been used successfully for decorative applications on first and second surfaces (in multiple industries) to include: cosmetic packaging, appliance handles and knobs, and interior / exterior automotive applications such as air bag emblems and door spears.

- ✓ The greatest uses of PVD technology for interior and exterior automotive applications seem to be occurring in Asia and Europe -primarily with thermal cure basecoat and topcoat technology.
- ✓ A basecoat is often required to provide an optimum surface to metallize on top of. Thermal cure basecoat technology has some limitations in application, mostly due to long cycle times (often measured in hours) associated with sufficient cure. A common complaint with thermal cure technologies is that "it acts more like paint" and has limitations in performance.
- ✓ UV coatings inherently have potential for better scratch, abrasion and chemical resistance, and has the advantage of near instantaneous cure to avoid the long processing times and high WIP of thermal cure technology. UV curable systems allow for in line production systems and smaller footprints that can then help improve the overall cost model of PVD technology.

Overview of chrome plating

Chrome plating is a process that involves the electroplating of a thin veneer of chromium onto an underlying metal. Chrome plating can be classified as either “hard chrome plating” or “decorative chrome plating”. Hard chrome plating is chrome plating that has been applied as a fairly heavy coating (usually measured in thousandths of an inch) for wear resistance, lubricity, oil retention, etc. Some examples would be hydraulic cylinder rods, rollers, piston rings, mold surfaces, thread guides, and gun bores. 'Hard chrome' is not really harder than other chrome plating, it is simply called “hard” because it is thick enough for a hardness measurement to be performed on it. Hard chrome plating is almost always applied to items that are made of hardened steel, is metallic in appearance, but is not particularly reflective or decorative.

TABLE I—Electroplating Process Parameters

Process	Chemicals	Temp. (F)	Time Min.	Time Max.
Etch	Chromic acid Sulfuric acid Trivalent Cr	156	600 sec	660 sec
Neutralizer	Hydrochloric acid	83	72 sec	100 sec
Pre-dip	Hydrochloric acid	Ambient	100 sec	200 sec
Activator	Hydrochloric acid Sodium chloride	83	160 sec	180 sec
Accelerator	Sodium chloride	135	115 sec	120 sec
Electroless Nickel	Ammonia	93	500 sec	530 sec
Nickel Activator	Sulfuric acid	Ambient	45 sec	90 sec
Copper Immersion	Copper sulfate Sulfuric acid	80	130 sec	200 sec
Copper Strike	Copper sulfate Sulfuric acid Hydrochloric acid	80	430 sec	540 sec
Acid Copper	Copper sulfate Sulfuric acid	71	2,410 sec	2,600 sec
Copper Activator	Sulfuric acid Peroxide	86	105 sec	150 sec
Semi-bright Nickel	Nickel sulfate Nickel chloride Boric acid	138	2,680 sec	2,900 sec
Bright Nickel	Nickel sulfate Nickel chloride Boric	132	840 sec	880 sec
Duplex Nickel	Nickel sulfate Nickel chloride Boric	142	145 sec	249 sec
Chromium Rinse	Chromic acid	Ambient	50 sec	60 sec
Chromium	Chromic acid Sulfuric acid Fluoride	112	120 sec	280 sec
Hot Rinse	DI			
Cold Spray Rinse	DI			
Hot Rinse	DI			

total Time Min.	8232 seconds 137.2
total Time Max	9737 seconds 162.2

Decorative chrome plating is sometimes called “nickel-chrome” because it involves electroplating nickel onto the object before plating the chrome (it sometimes also involves electroplating copper onto the object before the nickel, as well). The nickel plating provides smoothness to the substrate, much of the corrosion resistance, and most all of the reflectivity associated with chrome appearance. Decorative chrome plating is exceptionally thin and is measured in millionths of an inch rather than in thousandths. When you look at a decorative chrome plated surface, such as a wheel or truck bumper, most of what you are seeing is actually the visual effects of the underlying nickel plating. A chrome layer then adds a bluish cast (compared to the somewhat yellowish cast of nickel), protects the nickel layer against tarnish, minimizes scratching, and symbiotically contributes to corrosion resistance. A key point to remember is that without a brilliant, leveled nickel undercoating, you will not have a reflective, decorative chrome surface.

Chrome plating, whether decorative or hard, is a lengthy process that involves immersion into multiple chemical baths as shown in Table 1. [1] This is *not* considered an environmentally friendly process; resulting in electroplating becoming the United States very first categorically regulated industry. This means that all of the waste products from this industry -- even very dilute rinse water -- are, as a matter of law, regulated -even if the particular substance is so dilute that it is actually harmless. Legal obligations for chrome plating companies include: permitting, pretreatment of waste water, hazardous waste manifesting, waste accumulation by permit, and “cradle to grave ownership of waste and byproducts. (EPA CFR431)

Despite the hazards of chrome plating, the end product *is* aesthetically pleasing and considered desirable by consumers. When decorative chrome plating is processed properly, it is a durable product. When short cuts are taken, the end product can fail in the field. Finishers have been asking for a safer, greener, quicker alternative without sacrificing appearance and performance.

Overview of PVD

PVD (Physical Vapor Deposition) is the deposition of a metal onto a substrate through changes in the physical state of the metal (solid to gas to solid). When used in conjunction with a UV coatings process, a basecoat is applied to the substrate, a very thin layer (700-1000 angstroms) of metal is deposited, and then encapsulated by a UV topcoat to seal and protect the underlying layers (See figure 1). To understand how thin the layer of PVD actually is, consider that a typical UV coatings thickness for PVD applications is 25 microns or 0.98 mil. 1.0 mil is 25,400 nanometers. An angstrom is described as one hundred millionth of a meter or 10^{-10} or *0.1 nanometers.*

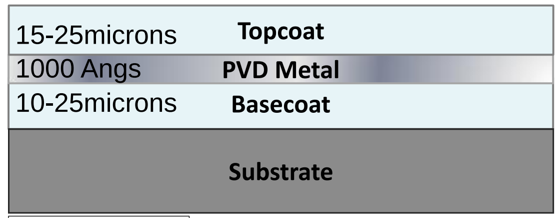

Figure 1: UV / PVD system

With PVD, a wide variety of metals can be deposited including aluminum, chromium, titanium, stainless steel, nickel chrome, tin, etc. The PVD layer can be deposited by a variety of methods including but not limited to thermal evaporation, cathodic arc, sputtering, pulsed laser deposition and electron beam deposition. The two more common methods we will focus on here are thermal evaporation and sputtering. Both are done in a vacuum, but the metals are deposited differently.

Thermal Evaporation is the deposition of a metal via thermal vaporization in a vacuum environment. The metal is in the form of a cane. It is placed inside a tungsten coil; the number of coils can vary depending on size of the chamber. Once the chamber is pumped down to a vacuum, the tungsten filaments are heated to around 1200°F, enough to melt the metal. The power to the filaments is then increased to roughly double the temperature and the metal is evaporated. The metal then re-condenses on the parts in the chamber. This method is mainly used for pure elements, such as aluminum.

Sputtering is the deposition process where atoms on a solid metal target are ejected into a gas phase due to bombardment of the material by high energy ions. The bombardment releases atoms from the metal target, which are deposited directly onto the part within the vacuum chamber. Metal thickness will vary depending on the cycle time and power applied to the target.

Both pure elements and alloys can be used in thermal evaporative or sputtering chambers, but each will deposit the elements and alloys differently. For elements, the final deposit is pure by both thermal evaporative and sputtering, but due to the method of deposition, the appearance and color can be slightly different. For alloys, with thermal evaporation, the metal with the lowest melt temperature will evaporate first and deposit onto the part, thus instead of having a blended deposition, there will be distinct metal layers. For example with nickel chrome, nickel melts at 2647°F [2] while chromium has a melting point of 3374° [3]. When thermally evaporated, the nickel will melt first, evaporate, and then condense on the parts - followed by the melting, evaporation and deposition of the chromium: two distinct layers of metal. *With sputtering, the two metals will deposit at the same time to have a true nickel chromium alloy.*

Benefits of PVD

Environmentally Friendly: Environmentally, there is no question that PVD / UV coatings are the better choice. With no hexavalent chromium exposure or disposal, no hazardous waste to report, and full recyclability (due to the metal layer thickness in a nanometer scale), PVD + UV coatings work with UV to make for a much safer production environment.

Increased throughput: From applying basecoat until packaging of the finished part, the cycle time for PVD can be as short as 15 minutes. In contrast, traditional chrome plating as described in Table 1 above can take up to 2.7 hours (dependent upon the desired chrome thickness).

Wide Range of Plastic Substrates: Traditional chrome plating is limited to plateable grade substrate (ABS and PC/ABS). Certain thermoplastics, like PA/PPE, cannot be chrome plated due to either chemical attack or the duration in high temperature baths (up to 140 °F for 11 minutes) causing substrate deformation. With PVD, the possibility of substrate selection is opened greatly. ABS, PC/ABS, etc. does not need to be a plateable grade material when used in conjunction with a good UV basecoat. Thus said, with PVD and UV processing there still needs to be consideration of best fit of substrate to the process.

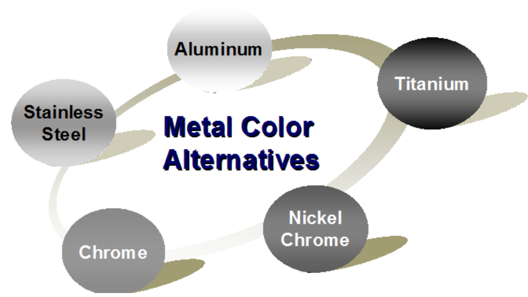

Figure 2: Differnt types of metal yield different color effects

Wide Range of Appearances: PVD equipment suppliers are able to achieve numerous metal colors by using a mixture of various metals and gases within the vacuum chamber (see later section on limitations of color by PVD process). In addition, the top coat can be modified to provide a satin or low gloss finish, which has become popular especially for interior automotive applications. Although this same color affect can be achieved by using a chrome plating process, the part must first go through a lengthy preparation process. Also, tinted clear coats can be formulated to achieve different design effects.

Flexibility: Applications that require physical flexibility have not been chrome plated successfully. Limitations in plastic design for chrome plating are associated with how the plating is attracted to the part and where the plating may have more tendencies to build up. UV / PVD may provide an alternative. One of the key limitations in this development will be the flexibility of the PVD layer. Aluminum is quite flexible, but does not demonstrate good properties for exterior applications. Chromium and its alloys will work for exterior applications but are rigid and susceptible to cracking on flexible substrates. To obtain the highest level of flexibility, coating and metal choices are critical.

Lower cost: In considering cost, one must consider the entire process in terms of space, energy, emission, equipment capital etc. Some cost benefits of PVD include

- ✓ Elimination of Chemical Disposal
- ✓ Reduced Steps In Process, Reduced Cycle Time
- ✓ Smaller Footprint
- ✓ Minimizes need to outsource

The UV/PVD line having a smaller footprint is a huge advantage for potential end finishers who are considering bringing the finishing in-house, which allows for better quality control of the end product.

Dependent upon line configurations and metallizer capacity, it is possible for finishers to see cost reductions per part of up to 20%.

Considerations for PVD success

The main target of the UV-curable coating development for PVD was to provide an alternative to traditional inorganic chromium with a layered system of organic and inorganic materials. As illustrated previously in figure 1, this involves applying a UV basecoat on the substrate followed by a PVD metal layer, and lastly the UV protective topcoat. Challenges associated with the development of each of these layers and the processing of each are explained in the following paragraphs.

Part design: Part design needs to consider part paintability. From an application standpoint, sharp edges, deep recesses and location of parting lines can affect the success and optimization of the application (not only for paint, but also for the PVD process). Furthermore, as UV coatings are line of sight cure, both part design and part racking position in relation to lamp configuration need to be considered to ensure adequate cure of the coating and avoid any areas of tackiness or uncured coating. Uncured material can have a negative effect in the PVD chamber especially on pumps and in pulling the vacuum.

PVD sputtering deposition is also line of sight, so part design or movement of the part in front of the target may be necessary for covering and consistency of PVD thickness/appearance.
Finally, the nature of the racking should be noted to consider that metal racking could interfere with the PVD process by arcing or attraction of the PVD metal to a particular area.

Substrate: A wide variety of thermoset and thermoplastic substrates can be coated with a UV basecoat to achieve a bright finish. BMC, PC, ABS, PC / ABS, PA / PPE, and PC / PBT are commonly used plastics for rigid and semi-rigid automotive parts. The substrate surface is critical to the film formulation process and for obtaining good adhesion of the basecoat to the substrate; or for the PVD to substrate in direct- substrate to metallization processes. The substrate surface should be characterized to the extent necessary to obtain a reproducible film. Care must be taken that the surface properties of the substrate are not changed by cleaning processes or recontamination, either outside the deposition system or inside the deposition chamber during processing. [4]

Typical challenges of substrate for PVD are similar to other painting applications. For injection molding it is important to choose substrate with melt and flow characteristics that adequately match the part design and can mold in desired cycled times. Additionally designing the part with sufficient gate height and width in relation to the overall part size is critical to avoid issues of low pack/hold or high stress where key properties or paintability could be compromised. Stress affects surface tension of the part. The more stress, the less paintable the part will be. It should also be noted that substrate stress may not manifest itself immediately, but may shorten the lifetime of the part and finish. Also, as it is economically desirable to recycle substrate or to use regrind material, this should be managed appropriately as not to disrupt paintability or performance. In short:

- ✓ Substrate tooling and surface quality affect the appearance of the finished part as *the basecoat may not cover all surface defects.*
- ✓ PVD system flexibility (for flexible substrates such as TPEE) is a balance between a stable surface rigidity vs. structural flexibility. It needs to be rigid enough for the deposited PVD to stay aligned to keep the highly reflected surface, but flexible enough to not crack when flexed.

- ✓ Heat must be considered to avoid deformation of the substrate**.** Coatings with weathering requirements will need more UV energy and intensity to cure properly. This adds more heat to the substrate**.** If the surface deforms, the PVD film will become stressed, potentially causing failure.

UV Basecoat: The surface that the metal is deposited on must be smooth and continuous. If it is not, the metal will not be reflective leading to a dull appearance. This demands that molds must be maintained in optimum condition and polished regularly to ensure the surface of the parts are free from defects. Some parts are direct metalized; however, this requires a higher or more expensive grade of thermoplastic (substrate) to accomplish.

Furthermore, achieving direct adhesion of the metal layer to plastic can be more difficult than when that same metal layer is used in conjunction with a basecoat. Direct metallization is a skilled art and there is limited knowledge and expertise of finishers who can do this with consistent success. There are inherent performance limitations of a direct metalized system such as lower resistance to moisture (or a greater tendency to delaminate), thus, the number of relevant applications for direct metallization to plastic substrate would be limited primarily to interior applications.

For the most robust system and for adequate performance of an exterior durable UV +PVD system, a UV curable basecoat is necessary. A successful coating must have excellent adhesion to a variety of substrates as well as be able to accept PVD metals. Chromium is more durable than aluminum and is preferred for exterior applications, thus a basecoat must be formulated specifically to PVD Chromium metal. Due to chromium, being a very rigid metal, many commercial basecoats that work well with aluminum may not work with chromium. Stress cracking is a very common failure mode if the basecoat is not formulated specific for PVD chromium. Many thermal cure coatings lack the proper cross link density to be used with the more rigid metals. Considerations for basecoat formulation include:

- ✓ Formulation of the basecoat must optimize its acceptance of PVD metal (adhesion) while avoiding stress cracking.
- ✓ Multiple DOE's have shown that an etch or pretreatment step of the basecoat is critical for good basecoat to PVD adhesion.
- ✓ Known paintability issues must be considered: adhesion for multiple substrate part design vs. paint Rheology vs. application method and orange peel, or lack thereof for optimal smoothness and reflectivity (appearance) since the reflective surface exacerbates any flaws.
- ✓ UV cure still incorporates residual heat due to a heated convection, IR flash, or combination prior to the UV cure. Matching the type of lamps used (arc vs. microwave) (stationary mounted vs. robotic cure) vs. energy/intensity requirements vs. heat sensitivity of the substrate all must be taken into account.

Consideration of these in formulation influences the process window for performance.

PVD application: There are many different PVD application machines and manufacturers to include: Vergason Technology Inc., Mustang Vacuum Systems, Innovative Systems Engineering, Oerlikon Balzers Hartec, Leybold Optics, Automated Vacuum Systems, Kolzer, ISYS Inc., etc. These technologies each have different processing windows that must be optimized to achieve acceptable basecoat-PVD-Topcoat system performance. It should also be said that different models from a specific manufacturer may react slightly different or have different efficiencies based on the internal mechanics of the machine:

Leybold: *design flexibility, roots pumps / fast chamber evacuation times*

Vergason*: dry air venting / quick pump down*
Mustang*: magnetron sputtering cathodes, fast cycle times, proprietary process to influence adhesion*
Hartec: *metal layering technology, use of different gas atmosphere in the metallization chamber for color / appearance creation*

Most metallizing equipment technologies have the capability to treat basecoat surfaces in inert gas plasmas that can result in microscopic texturing of the basecoat giving improved adhesion strengths between basecoats and PVD layers. This comes with a warning. Recent test data suggests that surfaces may be over treated creating a weakened near-surface region and reduced film adhesion. A few comments based upon our work with basecoat etch cycles:

- ✓ Etching of the basecoat matters: too much or too little etching will affect performance properties. Etching seems to change the surface chemistry of the basecoat.
- ✓ We suspect etching time, pressure, gas, and voltage may have different performance effects across different machine technology. Recent lab tests show passing performance results on panels without basecoat etching on one PVD machine. Similar testing on a separate and different PVD machine failed considerably without basecoat etching.
- ✓ Some metallizers can etch with air or oxygen. Some systems cannot as it would burn up the ion source filaments.

UV Topcoat: To protect the metal, a top coat needs to be applied. This can vary from a thin layer of in-chamber siloxane or to a thicker thermal or UV curable top coat. The choice will vary depending on application and needed performance requirements. In some instances, there is investigation or proposal to not use a topcoat whereby a very thick layer of PVD will be used. For exterior purposes, there are currently OEM approved thermal, two component coatings and thermal powder coatings on the market. However, these coatings are not a panacea. The 2K coatings lack both environmental and processing friendliness. Powder coatings are more environmentally friendly, however, not only do the long bake times hinder productivity, the high temperatures required to cure the powder will not work with most thermoplastic substrates. An ultraviolet cured coating can satisfy both the environmental and process requests of the finishers and OEM's.

Although initial topcoat adhesion to chromium is relatively easy to achieve, maintaining that adhesion after humidity, water immersion, thermal cycling, and weathering can be a bigger challenge. In order to balance proper adhesion to chromium and maximize abrasion, scratch, moisture and chemical resistance, it is imperative to find the balance formulation between too rigid to get adhesion and too soft to pass resistance testing.

A properly formulated UV curable top coat will have gravel chip resistance; resistances to various solvents and cleaners, humidity / water soak; Xenon accelerated weathering and at least 2 years natural weathering.

In a direct comparison with chromium, PVD samples with a UV curable top coat show much performance equal to decorative chrome plating. PVD has superior performance to hydrofluoric acid tests. *Chrome plating has shown to have superior scratch resistance to PVD*. However, if the UV top coat is compared to approved paint systems in the market today – such as 2K clear coat for automotive bumpers and fascia's or thermal cure powder for automotive clear coats – differences in scratch resistance are harder to quantify. A key point is that the highly reflective surfaces of PVD exacerbate any imperfections or scratches in the topcoat.

UV inherently has higher crosslink density and hardness than thermal cure technology and can achieve better scratch and abrasion versus thermal cure, but it is still difficult to match chrome plate scratch resistance.

Processing techniques such as cure in an inert environment (like nitrogen) can minimize oxygen inhibition and improve hardness. This too is an exercise in economics because the added cost of creating an inert environment may not justify the added performance. On three dimensional parts, it is typically difficult justify these economics vs. added performance. Considerations when using topcoats for PVD:

Table 2: Specular reflectance		
Element	**bare**	**+ topcoat**
Traditional chrome plate	60.0	49.5
Chrome / aluminum	78.0	70.0
Chrome (machine 1)	53.5	37.8
Chrome (machine 2	60.5	49.5
Chrome (machine 3)	57.3	45.5
PVD Cr (Hartec) + TC	78.0	70.0
Aluminum (machine 1)	89.0	84.0
Aluminum (machine 2)	85.8	78.3
Dark Chrome	28.6	17.3
*The higher the number, the brighter the appearance		

- ✓ A "Darkening" or "Yellowing" appearance of PVD when compared to traditional chrome plate. This appearance change is caused by application of topcoats and is a specular reflectance issue. [See Table 2]
- ✓ Achieving and maintaining adhesion after exposure / testing -especially with chromium
- ✓ Cost effective performance
- ✓ Hardness and scratch / abrasion resistance due to organic coatings (PVD) vs. inorganic chrome plate targets. Key targets for the next generation of UV topcoat will be to achieve greater hardness, and scratch/ abrasion resistance to narrow the gap between coating and chrome plate.

Color matching and gloss may be controlled through additions to the UV topcoat. However**,** when incorporating tints into the topcoat chemistry, careful consideration must be given to formulation and rheology to ensure there is consistency of film build and no collection points when the coating is applied. This becomes more of a challenge with complex three dimensional parts or when part designs incorporate sharp edges. Another challenge with tinting clearcoats for PVD is the fact that the highly reflective surface will easily show any incompatibilities (haze) or poor dispersion of the pigment. It is important to incorporate proper tint dispersions to obtain the clarity and appearance of tinted metal.

Typically, dyes would be considered ideal for such clarity, but often dyes do not provide adequate light fastness and color stability to withstand rigorous performance targets. Finally as with any pigmented system, even pigment distribution and preventing flocculation or mottling is a challenge.

For gloss control, there are also concerns. Some matting agents when incorporated into UV can change the properties of cure, thus careful consideration for appropriate matting agents are required in formulation.

Suggestions for implementation

Process control: PVD is a *process* with interrelated functions that must be controlled in order to ensure product performance and repeatable product quality. Clean rooms to achieve a perfect class A surface are required as dirt defects in a PVD system are magnified- and much more visible than conventional 2K or clear UV coating systems. Automation should be considered in lieu of handling by operators as finger printing and other contaminants all affect the appearance and performance of PVD coated parts. UV cure must also be strictly measured and controlled. UV energy should be measured with a radiometer in the part position, the same distance from the lamp, same angle as the part, etc. Intensity is generally not as important for basecoats as it is for topcoats, but strict adherence to the TDS is recommended. Other critical success factors for PVD systems include:

Part design: Part geometry plays an important role for both appearance and part performance. In addition to the part being paintable, avoid deep recesses, grooves, etc. Avoid high substrate stress; proper gate design is a must. Substrate must also be matched to the end application; thermal, mechanical, chemically stable. Platable grades of substrate generally work better for PVD than traditional non-platable grades. This is mainly due to non-platable grades being of lower quality (impurities from manufacture or compounding, surface defects, etc.). Finally, high quality mold / tool – must be highly polished (and maintained that way). Part design and substrate is the first step for a high quality, reflective finish.

Application of basecoat: In some ways this goes back to process control. Basecoat must be applied and processed within an acceptable and defined window as described on technical data sheets. Finishers should target the middle of DFT range over surfaces requiring performance. Heated flash is exceptionally important for the basecoat to flow and level properly, and ironically, is often overlooked by finishers. A good heated flash will ramp up the target temperature inside the target time window – holding at that temperature is not necessary. This is a surface temperature concern and serves to drive out residual basecoat solvents and to relax an otherwise rigid resin system.

Part orientation during metallization: Finishers need to avoid masking if possible. You should build / design PVD fixtures so that they do not interfere with the metalizing process. Additionally, a "double shot" or secondary plating process is not recommended and is very difficult to control without local contamination.

Application of topcoat. Recommendations for topcoat processing are very similar to the success factors as listed above for basecoat except that UV energy and intensity will likely be much greater - especially in regard to exterior durable topcoats. UV topcoats require a minimum intensity of 200 mw/cm^2 (UVA). Studies have shown that without the recommended intensity, performance attributes of the topcoat will suffer.

Equipment selection is critical: There are various opinions in the industry regarding the PVD metal layer itself – target arrangement within the metallizer, layering of single metal, alloy, co sputtering, layered techniques – and what the best means might be to achieve color, appearance, and durability. Optimized settings for each machine / process are part specific and can also vary by type and manufacturer of equipment. Machine design will determine whether or not there is an etch cycle, which gas, how much pressure, how much power, etc – all of which effect layer thickness, part performance, and overall cycle time. Finally, regardless of machine design or type, proper equipment maintenance is essential for machine uptime, but especially for part cleanliness.

OEM specifications: PVD is a "chrome alternative" not a *chrome replacement*. PVD utilizes basecoats and topcoats to not only protect the metal layer, but to protect the substrate as well. Though UV topcoats are known for their durability and scratch resistance, they are not equal to chrome plating in terms of scratch and abrasion resistance or resistance to thermal shock. The weaknesses and failure modes for traditional chrome plating will be different than the weaknesses and failure modes of PVD. Thus, it is important for OEM's to understand that PVD related specifications should incorporate different requirements that heavily include attributes of paint and coatings rather than those of traditional chrome plating. This does not mean all chrome plating requirements should be neglected, but rather it needs to be blended and optimized for evaluation and approval of the PVD process.

Conclusion

PVD with UV coatings is a viable *alternative* to chrome plating for interior and exterior applications but at this point cannot be considered a *replacement.* The first generation of UV coatings development for PVD was directed to the automotive, cosmetic, and consumer appliance markets. Development at that time focused on achieving adequate adhesion between the substrate and PVD layer, and between the PVD layer and UV topcoat. Challenges included initial adhesion, eliminating stress cracking due to the PVD process, elimination of dirt, and overall system appearance. There have been a number of commercial launches for PVD and UV coatings: chrome look interior automotive door spears, exterior automotive taillight trim, and a commercial soap dispenser for public restrooms to name a few. From these launches there has been a wealth of information learned and subsequent developments. From substrate molding, to coatings formulation and application, to the use of the metallizer, to proper cure and processing of each: all have their own challenges and characteristics that must be paid attention to in order to a highly durable, bright chrome, environmentally friendly alternative to conventional chrome plating.

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