Rapid Cycle Vacuum Deposition Techniques & Materials - A Plating Alternative

G. Vergason, S. Gaur, Vergason Technology, Inc., Van Etten, New York

ABSTRACT

Due to effluent management and expanding environmental regulations for nickel, chrome and other metals, vacuum based Physical Vapor Deposition (PVD) techniques are being utilized as a replacement for traditional wet-plating methods. PVD coatings do not require conductive substrates and have virtually no harmful effluents. Cathodic Arc (Arc Vaporization) and Sputter deposition technologies can apply metals, such as aluminum, brass, copper, stainless steels, chromium, and other materials, with simple fixturing and masking not possible with wet plating methods. This paper focuses on the coating technologies of Cathodic Arc and Sputtering, the materials being deposited, and the rapid cycle metalizing equipment used to produce sub-minute cycle times for the application of metallic coatings on polymer substrates.

For more information, contact:

Gary Vergason
Vergason Technology, Inc.
88 State Route 224
Van Etten, New York 14889

Telephone: 607.589.4429
Fax: 607.589.6955
E-mail: gvergason@vergason.com

INTRODUCTION

For many years, wet plating techniques have been used to apply metallic finishes on plastic substrates for decorative, reflective, electronic shielding and tribological applications. Due to increased environmental regulation of waste products and complexities of masking for wet plating operations, PVD vacuum coating processes have gained popularity for the application of metals on polymers. These techniques use the inherent directional deposition process along with simple mechanical masking to apply coatings specifically on the critical areas. The masking fixtures are typically constructed of laser-cut stainless steel, electro-form nickel, thermo-set and vacuum formed polymers [1].

Stylists and designers can specify a variety of PVD deposited materials not available with wet plating processes. These materials can be tailored for color, surface texture, reflectivity and functionality [2]. PVD techniques are also not limited to single metal coatings. Alloys and reactive materials can easily be deposited.

Since all PVD coatings take place in a vacuum chamber under low pressures (10^{-3} to 10^{-9} Torr), close control of contaminating gases yields high purity in the deposited films. The main categories of PVD processing are vacuum evaporation, sputter deposition, and ion plating as depicted in Fig 1 [3].

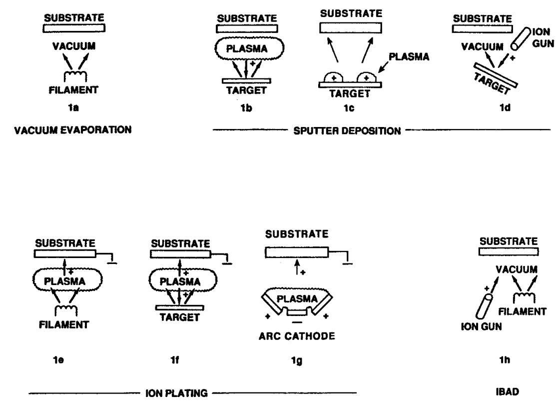

Figure 1. PVD processing techniques: (1a) vacuum evaporation, (1b and 1c) sputter deposition in a plasma environment, (1d) sputter deposition in a vacuum, (1e) ion plating in a plasma environment with a thermal evaporation source, (1f) ion plating with a sputtering source, (1g) ion plating with an arc vaporization source and, (1h) ion beam assisted deposition with a thermal evaporation source and ion bombardment from an ion gun.

Sputter deposition vaporizes particles from a surface (target-main component of coating material) and deposits them on the substrate. Physical sputtering is a non-thermal vaporization process where the target surface atoms are physically ejected by momentum transfer from an atomic-sized energetic bombarding particles which are usually a gaseous ions accelerated from a plasma. Typical sputtering processing uses high voltages at low currents. Low and high melting point materials can be deposited in a non-reactive or reactive (compounds such as titanium nitride) process. Operating pressures are in the low milliTorr range and distances from the source to the substrate are short, usually tens of millimeters. Figure 2 shows a typical magnatron sputtering devise.


Figure 2. Sputter Deposition Devise

Arc vapor deposition uses a high current, low-voltage arc to vaporize a cathodic electrode (cathodic arc) or anodic electrode (anodic arc) and deposit the material on a substrate. The vaporized material is highly ionized and can be deposited in a non-reactive or reactive process. High melting point materials are best deposited with the process as microparticle generation (particles several microns in diameter) increases with lower melting point materials. Operating pressures are in the 10^{-3} to 10^{-5} Torr range and source to substrate distances are usually hundreds of millimeters. A cathodic arc depostion devise is shown in Figure 3.


Figure 3. Arc Vaporization Devise

Vacuum evaporation uses a thermal source to vaporize and transport the coating material to the substrate with a line-of-sight trajectory having little or no collisions with gas molecules. This method is usually selected when low melting point materials (aluminum, etc.) are being deposited and ion damage to the substrate must be kept to a minimum [4]. Deposition rates can be very high 10-100Å (1-10 nanometers) per second. Distances from the thermal source and substrates can be hundreds of millimeters. Figure 4 shows a (thermal) tungsten filament devise

All the above processes can be utilized with or without substrate biasing and can be enhanced using ion generators with various process gases.

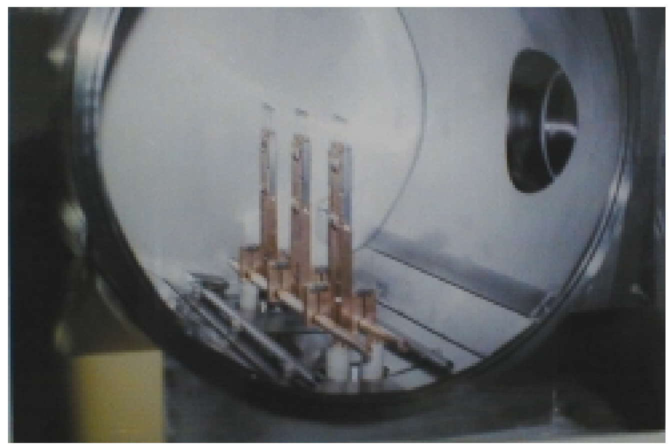
Figure 4. Filament Evaporation Devise

EQUIPMENT USED

Coating Equipment

Equipment used for all experiments conducted were production rapid cycle coating systems in their typical dirty, wet and full states (not clean, dry and empty). All systems utilized production fixtures and previously used source materials (sputter targets and arc cathodes). Figure 5 shows a rapid cycle coating system for sputtering and cathodic arc coatings. Figure 6 depicts a typical small batch thermal (tungsten filament) coating system.

Figure 5. Sputtering and Arc Coating System

Figure 6. Filament Coating System

Fixturing Used

Figure 7 and figure 8 show the laser-cut stainless steel/electo-form nickel and vacuum formed PETG fixtures used. These fixtures can be easily cleaned using conventional glass bead blasting, chemical stripping and reverse plating. These light weight fixtures can be in the disc shape that use the chamber back plate deposition ports or in a drum shape utilizing the side deposition ports of the chamber

Substrates and Analysis

1 X 3-inch glass slide substrates were masked and taped to fixturing discs for coating. Slides for sputtered depositions were rotated 3-inches from the sputtering targets. Slides for the arc depositions were rotated 6-inches from the arc source. Slides for the thermal depositions were statically arranged 12-inches from the tungsten filaments. The flat surface of the slides was positioned towards the deposition devices.

Thickness and roughness testing was performed with a Tencor P-10 Profilometer. Reflectivity measurements were performed at 514nm wavelength with an Ocean Optics SD-1000 Spectrometer. Microscopy was performed with a JOEL JSM-840 Scanning Electron Microscope.

Figure 7. Laser-cut/Electro-Form Disc

Figure 8. Vacuum Formed PETG Disc

EXPERIMENTS

Reflectance of Materials by Deposition Technique

Aluminum, 300 series stainless steel, and chrome were deposited using sputtering, arc or thermal deposition techniques. Table 1 shows the measured reflectance percentages from the glass slides, by the deposition technique and the material deposited.

Table I: Reflective percentages by deposition technique and material deposited.

	Aluminum	Stainless Steel	Chrome
Sputtering	92	60	63
Arc		60	64
Thermal	93		

It can be noted that the reflectivities measured from the sputtered coatings closely follows reported percentages at 500 nm [5]:

Aluminum	92%
Stainless Steel	60%
Chrome	65%

Arc deposited materials measured lower than normal reflectivities due to included nitrogen which contaminated the films and microparticles on the surface. All micrographs were taken at 3,500X, 65 degree tilt.

The sputtered aluminum coatings and the thermal aluminum coatings had similar reflectivities with slightly different surface profiles. These profiles are shown in Figures 9a and 9b. Figures 10a and 10b show the surface profiles of sputtered stainless steel and arc stainless steel. Figures 11a and 11b show the surfaces of sputtered chrome and arc chrome.

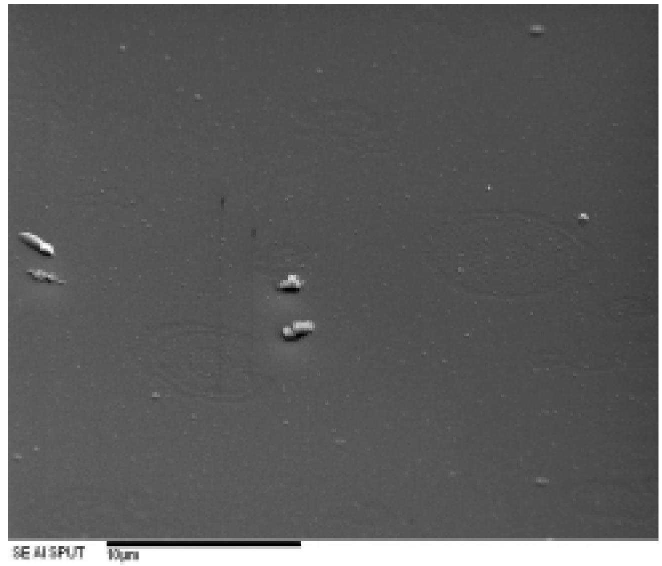

Figure 9a: Sputter Deposited Aluminum

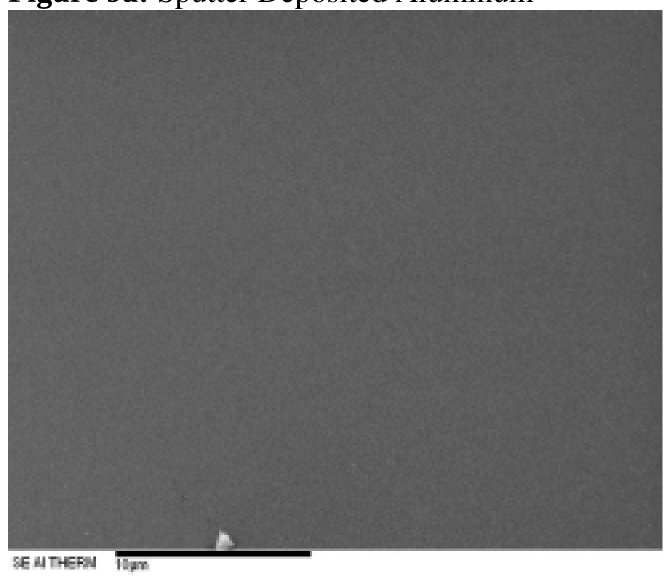

Figure 9b: Thermally Deposited Aluminum

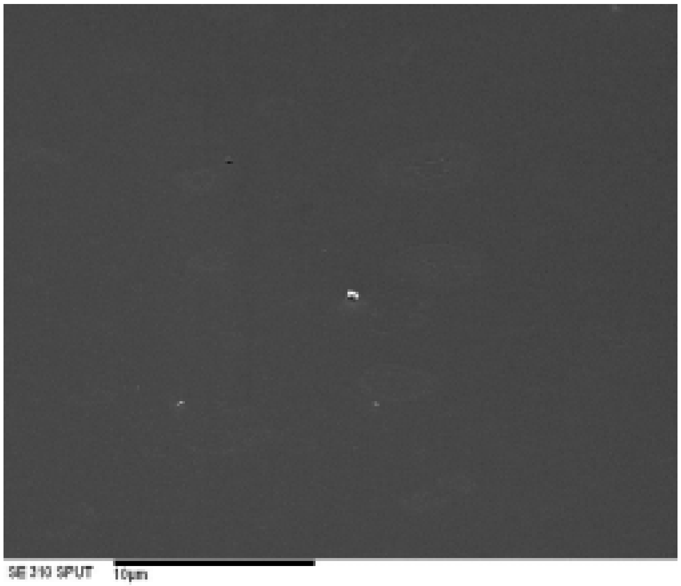

Figure 10a: Sputter Deposited Stainless Steel

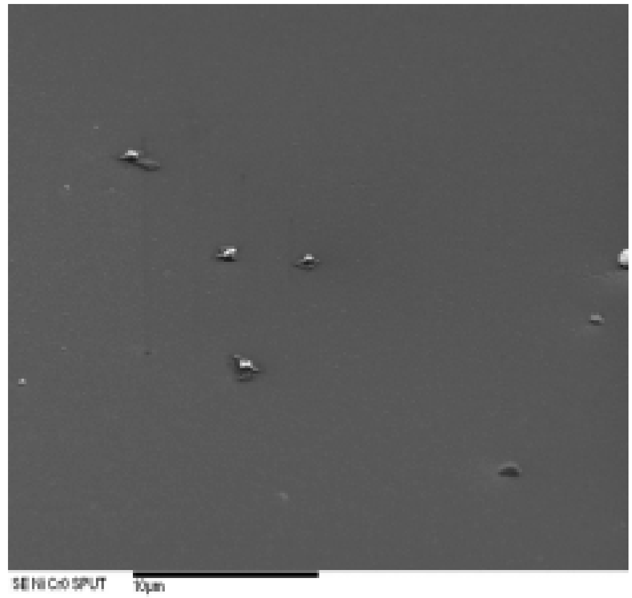

Figure 11a: Sputter Deposited Chrome

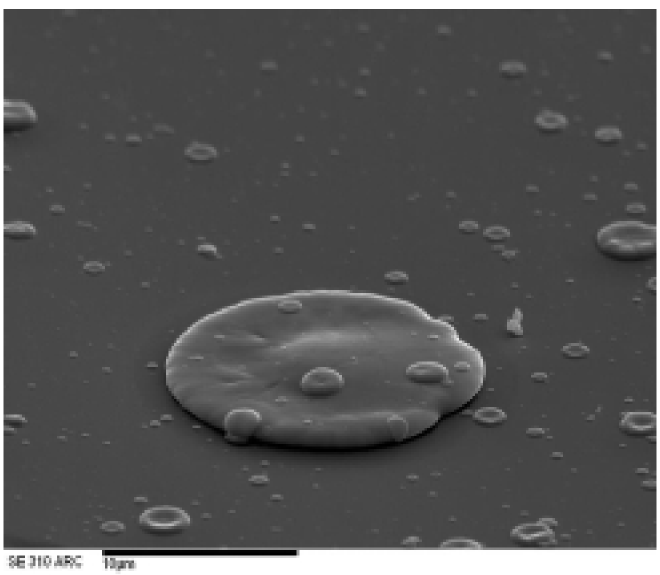

Figure 10b: Arc Deposited Stainless Steel

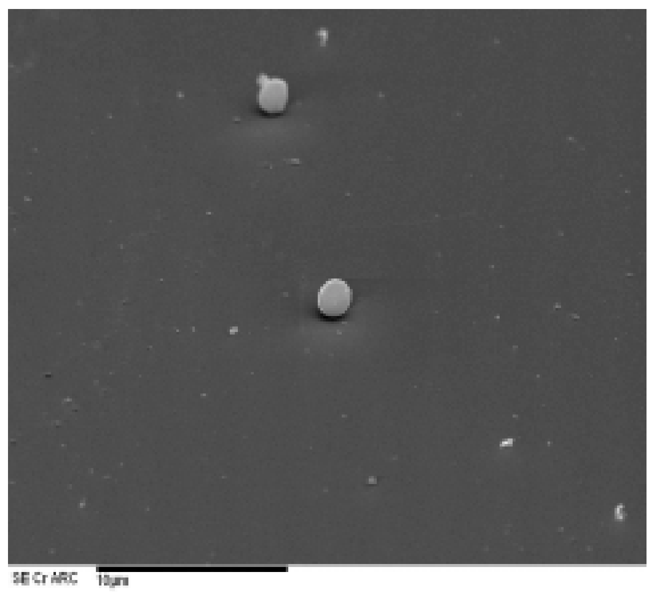

Figure 11b: Arc Deposited Chrome

Thickness vs Reflectance - Sputtering

For all materials deposited, the reflectance increases with thickness at first and then levels out as shown in Figure 12. Aluminum coatings were the most reflective, followed by chrome, stainless steel, and nickel/chrome, respectively. The similarity of the chemical composition of the last three coatings should be noted as the reflectance values for these are close to each other. When using this information for practical applications, coating thickness and required reflectance should be weighed against the cost of the material and the designers color requirements.

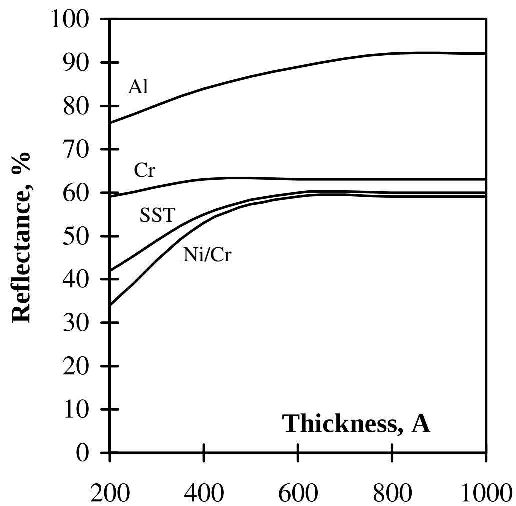

Figure 12. Thickness vs Reflectance - Sputtering

Thickness vs Roughness - Arc

Thickness vs roughness results of stainless steel and chrome are shown in Figure 13. As noted, the roughness of the stainless steel coating is considerably higher than the chrome coatings. Chrome arc coatings were equal in roughness to the chrome sputtered coatings with a Ra of 10 to 15Å.

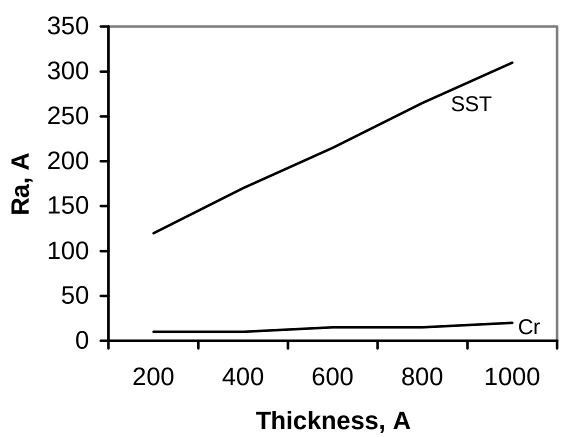

Figure 13: Thickness vs Roughness (Ra) - Arc

Table II compares the Ra of sputtered, arc and thermal depositions of the materials reported. Arc produces a rougher coating using cathodes of lower melting point materials.

Table II: Comparative Ra (Å) of sputtered, arc and thermal coatings

	Al	SST	Cr
Sputter	24-38	44-78	10
Arc		200-600	25
Thermal	2-5	3-6(NiCr)	

As in previously performed work, the surface roughness increases with the number of fixture revolutions even if the total coating time is the same. This means greater number of passes in front of the deposition devise introduces undesirable surface roughness in the coating. A single pass deposition is favored by Cambey et al in the studies [6]

Conclusion

With sputtering and cathodic arc deposition techniques, today's designer can select from aluminum, stainless steel, nickel/chrome, chrome, and other materials for direct replacement of electroplated materials used in decorative and reflective applications on plastic substrates. When the surface quality of the plastic allows for direct metalization, these PVD techniques yield excellent adhesion and film properties. These technologies and materials bring tailored solutions, flexibility, cost savings and improved quality yields to a variety of markets. Low cost fixturing used with these line-of-sight deposition techniques allow for simple masking of substrates with complex geometries.

Of the three deposition techniques, sputtering offers the widest range of coatings, from low to high melting point materials, with a high degree of process control and production repeatability.

References

1. G.Vergason and A.Papa, *Rapid Cycle Coating Techniques for Cell Manufacturing*, SVC, 40th Tech. Conf. Proc., 1997.

2. G.Vergason and S.Gaur, *Selection of Materials and Techniques for Performance Coatings,* SVC, 42nd Tech Conf. Proc, 1999.

3. D.Mattox, *Handbook of Physical Vapor Deposition (PVD) Processing,* Noyes Publications, Westwood, New Jersey, 1998, p.4.

4. D.V.Rigney, *Metals Handbook Ninth Edition*, W.G.Wood, Coordinator, ASM, Ohio, 1982, pg. 387..

5. *Handbook of Chemistry and Physics*,79th Edition, D.R.Lide, Ed.-in-Chief, CRC press, NY, 1998.

6. L.A.Cambey and S.Weinig, *Sputtering and its Applications - the Present Status*, Advances in Surface Coating Technology-International Conference, (1978).