The Performance Implications of Silver as a Contact Finish in Traditionally Gold Finished Contact Applications

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Abstract—**Recent increases in gold metal prices have renewed interest in finding lower cost connector finishes. Silver is perceived as a possible alternative due to its 'near noble' nature, superior conductivity characteristics, and relatively low cost. The two finish types have very different performance characteristics and are typically not used in the same kinds of applications. Because silver is not 'as noble' as gold, there are some inherent risks for applying silver in typical gold finished contact interface applications. This paper will present relevant data to illustrate the mechanical and electrical performance implications of using silver at the performance levels typically required for gold finished connector applications – to improve understanding of the performance trade-offs associated with applying silver in historically gold finished applications.**

Keywords-silver, tarnish, connector, contact resistance, coefficient of friction, durability

I. INTRODUCTION

Silver has a long history of performing well in the tarnished state in higher normal force/lower durability power applications and similar signal applications. Most signal connectors require significantly lower normal force and higher durability. The fact that silver will tarnish in most connector environments and is not a durable finish may present a problem for silver used in these lower normal force/higher durability signal connector applications. Increases in the cost of gold metal has provided motivation and interest in expanding the use of silver as an alternative signal separable contact interface finish in applications typically considered appropriate for hard gold finishes. There are potential risks associated with applying and testing silver finished contacts in applications appropriate for hard gold.

A. Silver Finishes

Silver has a unique combination of material properties such as the highest thermal and electrical conductivity of any metal and a relatively low hardness. Theory and experience show how these aspects lead to relatively low electrical contact resistance values for mated clean silver surfaces [5, 6, 7, 8]. This unique combination of properties also leads to superior joule heating thermal performance. These performance attributes make it attractive for power applications.

The material characteristics that make silver contact finishes function well electrically also contribute to its inherently poor mechanical contact performance. Clean silver's high coefficient of friction characteristics can lead to relatively high insertion forces and relatively poor durability performance.

Silver also does not have the 'noble' character of gold. It will readily form surface tarnish films when exposed to some reducible sulfur bearing connector application atmospheres; as well as less common chloride bearing connector environments. Silver tarnish films can appear to be anywhere from tan, to more commonly blue, to black in more severe cases. Typical connector environment field exposure studies of silver plated connectors have shown that the tarnish films that form are predominantly covalently bonded semi-conducting α silver sulfide (Ag_2S) and to a lesser extent, small amounts of more insulating and potentially harder to displace silver chloride ($AgCl$) [1, 2, 3, 4, 9, 10, 11, 12, 13]. These field generated tarnish films were found to be semi-conductive at ambient temperatures, inherently soft, and relatively easily displaced with contact interface wipe at sufficient normal loads.

In addition to silver plated finishes being susceptible to tarnishing, they are also susceptible to the same substrate material corrosion migration as hard gold plated finishes. If excessive substrate material corrosion products (e.g. substrate diffusion and/or pore site migration) are incorporated into the silver tarnish film, contact resistance issues may occur [14, 15].

Environmental shielding can be an effective way to reduce or prevent silver tarnish films from forming. Examples of environmental shielding methods are the use of connector housings (open, closed, or actively sealed), equipment enclosures, environmental controls, greases or gels, reduced sulfur and/or sulfur absorbing packing material. They can all serve to limit the flow of corrosive elements to the silver contact surfaces. Surface treatments can also be used to improve the environmental resistance as well as improve the durability performance of silver finished contacts when appropriate. For a surface treatment to be effective, it has to perform without losing functionality or causing an unacceptable increase in contact resistance. They can be rendered ineffective if removed during assembly and use, or exposed to conditions outside of their proper operating range.

The combination of these silver qualities leads to a set of conservative design recommendations for silver finished separable connector contacts. These would include the use of relatively high normal loads on the order of at least 250 cN, incorporation of wipe, and limitation of durability requirements to 10 or fewer wear cycles. Relative to hard gold applications, these higher force/wipe levels further limit the durability of silver finishes and contribute to the high insertion forces found with clean silver contacts. Silver is usually inappropriate for high durability applications. Finish recommendations would be to use at least 2 micrometers of silver along with a minimum 1.25 micrometer thick nickel underplate. Silver is commonly used without a nickel underplate; though with significantly thicker silver plating. Additionally, the use of some level of environmental shielding may be warranted.

B. Environmental Testing: Mixed Flowing Gas Environment Exposure and Silver Finished Contact Surfaces

Accelerated Environmental testing is done by exposing contact surfaces to elevated levels of single or multiple corrosive gases under specific temperature and humidity conditions. This type of exposure is usually done as part of a product qualification test sequence for specified time intervals.

Mixed Flowing Gas (MFG) accelerated environmental life test methods were developed after a long process of comparing laboratory to field trial data for a variety of connector finishes. In the end, no industry accepted accelerated MFG laboratory vs. field life correlations could be developed for silver. These MFG environments were determined to be excessive generating films with a variety of morphologies, chemistries, and properties which are not necessarily directly representative of field exposure generated films. This is attributed to factors such as the complexity of the silver corrosion process, the synergy between multiple gases, and the fact that silver is so sensitive to erratic fluctuations in hydrogen sulfide gas levels [1, 2, 3, 4, 9, 12, 16, 17]. MFG testing was ultimately developed primarily for gold finished nickel plated copper alloy substrates [19, 20]. Alternate single gas testing environments (e.g. hydrogen sulfide, flowers of sulfur) were also determined to be misleadingly benign and also not representative of silver finished contact field exposures [1, 2, 3, 9].

The tarnishing of silver surfaces is driven by the presence of moisture, H_2S and Cl_2 in these accelerated environments. The presence of moisture is needed for silver to tarnish in response to corrosive environments. This moisture allows for the dissolution of corrosive elements leading to dissolution of metallic silver. Surface water films can either form as monolayers generated by humidity, or in a condensed form [2, 4]. Silver tarnishing has been reported as both positively dependant on [4, 18], and independent of [10, 11], increasing relative humidity levels depending on the exposure environment. Silver sulfide (Ag_2S) forms when silver atoms react with reduced sulfur (HS-). The primary source of this reduced sulfur is dissolved gaseous hydrogen sulfide (H_2S), or to a lesser extent (less prevalent in the atmosphere) hydrolyzed carbonyl sulfide (COS) [3, 4, 16, 17]. Hydrogen sulfide comes from sources such as organic decay, combustion processes, volcanic activity, paper mills, sewage plants, and high sulfur packaging materials.

Silver is sensitive to the presence of chloride (Cl-) and will react to form silver chloride (AgCl) [2, 4, 10, 16]. Chloride can come from species such as dissolved hydrochloric acid (HCl) or other chloride containing particulates (e.g. NaCl). Reports have shown that the higher the level of silver chloride in the tarnish film (relative to the level of softer semi-conductive silver sulfide), the more insulating and harder to displace the film becomes upon wipe [2, 3, 9, 10, 12]. This can potentially lead to contact resistance issues at thinner tarnish film levels.

Silver may not react directly with chlorine gas (Cl_2), but its presence is considered to have a synergistic effect on silver tarnish formation when combined with hydrogen sulfide gas. This is especially evident on silver surfaces exposed to accelerating environments containing both hydrogen sulfide and chlorine gas. Exposure of silver surfaces to MFG or single gas accelerated laboratory environments will generally lead to a greater rate of tarnish film formation with sometimes a greater level of silver chloride than is found on most field tarnished samples [2, 3, 9, 10, 12, 16]. If the ratio of hydrogen sulfide to chlorine is great enough, the film growth rate has been reported to deviate from linear and approach parabolic.

Silver tarnish films don't develop with a uniform morphology and can be mixed with substrate corrosion products. This can make growth rate determination difficult and potentially misleading. The reality is that chlorine gas, commonly used in mixed flowing gas testing, is virtually non-existent in the atmosphere. The H_2S/Cl_2 synergy may account for silver chloride level and contact resistance performance discrepancies between field and accelerated environment exposed silver surfaces.

II. SAMPLES AND EQUIPMENT/TESTING PROCEDURES

This testing was done to gain a better understanding of where and when silver can be applied in connector applications usually reserved for hard gold finishes. There are both electrical and mechanical performance risks, as well as potential issues with testing silver using methods deemed appropriate for gold applications.

A. Silver Finished Samples

Samples with silver plating thickness near the minimum of what is typically used in silver finished connectors with a nickel underplate (~ 2 micrometers) were used for this testing. Hemispherical cap (nominal radius 2.5 mm) rider and flat coupon sample geometry combinations were used representing a less severe relatively smooth contact surface combination. All the samples were made from 0.4 mm thick H04 temper C51100 phosphor bronze (CuSn4) rolled strip. These samples were made using standard connector industry high speed reel-to-reel production processes. Plating thickness measurements were done using X-ray Fluorescence (XRF) techniques. Table I lists the relevant sample parameters. The silver samples had been stored in a lab atmosphere for approximately one year before this testing was done and had a minor amount of tarnish on the surface at a level not quantifiable by X-ray Diffraction (XRD) techniques.

TABLE I.   TOPOGRAPHY ROUGHNESS PARAMETERS

		Silver Plating thicknesses (micrometers)	
	RMS Roughness (micrometers)	Ag	Ni underplate
cap	0.25	2.39	1.63
flat	0.47	2.38	1.60
Surface Condition	'as stored ~ 1 year' (slight tarnishing)		

B.   Test Environments

Even though there is no established correlation between field exposure and laboratory Mixed Flowing Gas (MFG) exposures (film quality or functionality), these exposures will repeatably generate a significant level of silver sulfide and/or silver chloride containing tarnish films on silver finished contact surfaces. There are several versions of MFG in use for gold plated contacts, but the most common are the EIA 364-65 four gas Class IIa (Indoor) and Class IIIa (Outdoor) [Table II].

TABLE II.   STANDARD MIXED FLOWING GAS ENVIRONMENTS

EIA 364-65 (Electrical Connector/Socket Test Procedures Including Environmental Classifications)			
	CIIa (Indoor)		CIIIa (Outdoor)
H$_2$S (ppb)	**10 ± 5**		**100 ± 20**
Cl$_2$ (ppb)	**10 ± 3**		**20 ± 5**
SO$_2$ (ppb)	100 ± 20		200 ± 50
NO$_2$ (ppb)	200 ± 50		200 ± 50
Temperature (°C)	30 ± 1		30 ± 1
Humidity (%RH)	**70 ± 2**		**70 ± 2**

Historically, the MFG environments used to generate silver tarnish involved a great variety of gas/humidity levels and combinations with varying results [1, 2, 3, 9 – 13, 16, 19]. These MFG environments were different in one way or another than the current CIIa (Indoor) and CIIIa (Outdoor) environments. Since CIIa and CIIIa are routinely used to test hard gold plated contact surfaces, if silver is applied to such contacts, silver plated surfaces may be exposed to such testing.

Hard gold over nickel finished surfaces exposed to CIIa and CIIIA generate the same substrate material corrosion products at pore sites. Since the H$_2$S level of the CIIIa environment is 10 times that of the CIIa environment, the films that formed on silver finished surfaces should differ in quality due to the synergistic effect between the levels of H$_2$S and Cl$_2$ described in the literature.

C.   Contact Resistance Probe (CRP)

4-wire dry circuit contact resistance measurements were taken at variable loads, followed by wipe at load, using a computer controlled Contact Resistance Probe (CRP). Each individual contact resistance measurement is an average of a series of readings made under both forward and reverse current DC steady-state 4-wire dry circuit (50mA/50mV limited) conditions. The maximum contact resistance the instrument is capable of reading under these dry circuit conditions is 1kΩ. All measurements are taken under lab atmosphere conditions.

The coupon of a mating half is mounted to the X/Y table with an incorporated load cell. The current-out and voltage-out leads are attached to opposing sides of the mounted flat coupon. The hemispherical cap is mounted to the tip of the probe head which can move in the vertical z direction. The current-in connection is made at the outer rim of the cap and the voltage-in lead makes contact at the bottom of the back of the 'cup' of the cap. Further information and images of this instrument can be found in reference 8.

D.   Friction Measurement Instrument

For friction testing, the hemispherical rider and flat are mounted on the friction apparatus. The hemispherical cap is dead weight loaded against the flat which is horizontally moved with reciprocating simple harmonic motion. The reciprocating motion is produced using a micrometer adjustable eccentric cam driven DC motor. The reciprocating table holds a load cell attached to a precision slide which is used to make the lateral force measurements from which the coefficient of friction measurements are calculated. The sliding distance was set at 1 cm. Images and more detailed information on this instrument can be found in reference 21.

E.   Testing Conditions

Multiple CIIa and CIIIa MFG exposures were used to generate samples for testing. Data is reported here for exposures done at 1 and 5 days where the samples were fully exposed with no form of shielding. Exposures of 10 and 20 days proved to be excessive for making dry circuit readings. As a result, a comparison of 1 and 5 days exposure data is reported in this study. Data reported here was drawn from multiple testing projects carried out over a period of time.

The resulting tarnish films were characterized by X-ray Diffraction (XRD) using a Cu-Kα radiation source and a low incident grazing angle to improve the ability to resolve thin surface films.

The functional contact testing included both electrical contact resistance (CR) and mechanical Coefficient of Friction (COF) testing. The contact resistance and COF testing was done at both minimum silver normal loads (250 cN and 200 cN) and at a normal load appropriate for hard gold (50cN). Dry circuit (50mA/50mV) contact resistance readings were taken at load, both before and 'after 'wipe' at load.

Additional testing was done on silver finished surfaces that had surface treatments applied prior to exposure. One capable of providing both environmental exposure resistance and lubricity (HM15 lubricant – a proprietary Tyco Electronics formulation) and one primarily designed to provide environmental exposure resistance (Evabrite S ® treatment).

Both were solvent based and applied via 'dip and dry' techniques.

III. RESULTS AND DISCUSSION

A. Tarnish Film Characterisitics (CIIa vs. CIIIa vs. Field Exposure)

There were two main differences between the 'less severe' CIIa (Indoor) and the 'more severe' CIIIa (Outdoor) class MFG environments pertaining to silver tarnishing: gas levels and the ratios. The two gases contained in these MFG's that most effect the level of silver tarnish are H_2S and Cl_2. CIIIa has 10 times the amount of H_2S and twice the level of Cl_2. Therefore, the less severe CIIa (Indoor) actually has a five times greater Cl_2/H_2S ratio than the more severe CIIIa (Outdoor). This leads to the generation of two different tarnish films. The greater ratio of Cl_2/H_2S in the CIIa environment generated a predominantly AgCl tarnish film where the lower ratio Cl_2/H_2S in the CIIIa led to a predominantly Ag_2S tarnish film. XRD data in Figures 1 and 2 show the difference in tarnish film quality generated by CIIa and CIIIa exposures. These differences can also be seen in the light microscope images of the samples in figure 3, though there is some differences in describing what the 'eye can see' and what a light microscope will image. The 1 day CIIIa exposed silver have a distinct blue coloration where the original silver color cannot be seen. The 1 day CIIa exposed silver surfaces have a brown appearance where the visual characteristics of the metallic silver finish can still be seen. Both CIIa and CIIIa 5 day exposure samples have a more black appearance 'by eye.' As reported in the literature, field exposed silver surfaces form predominantly Ag_2S films. The predominantly Ag_2S nature and blue color of a representative field exposed sample (approximately 3 years in an unprotected storage environment) can be seen in both the XRD analysis and light microgaph in figure 4. Therefore, the CIIIa exposure may be more representative of field exposures in most cases, though there is no lifetime performance correlation to the test.
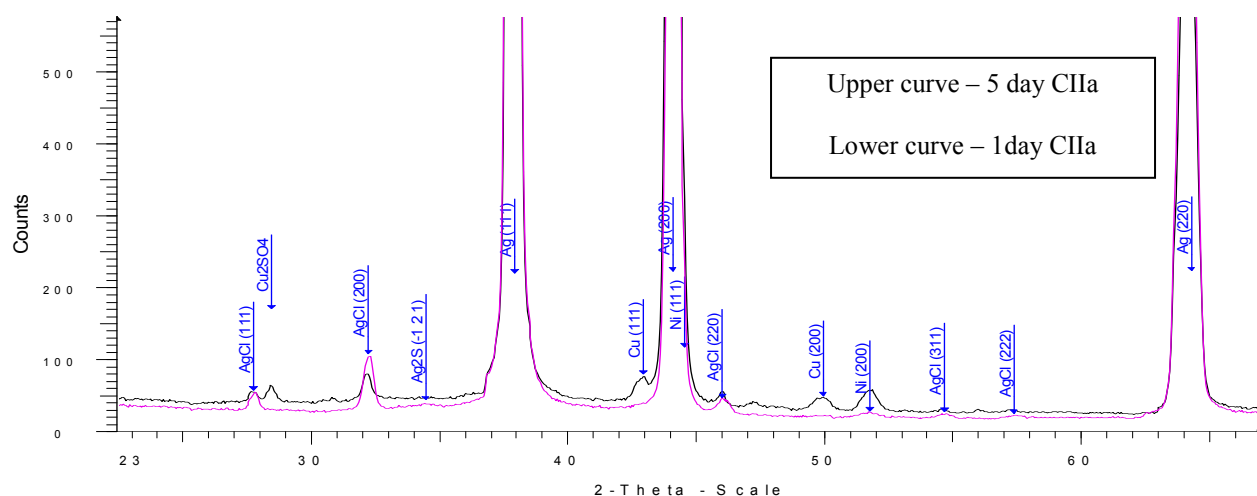

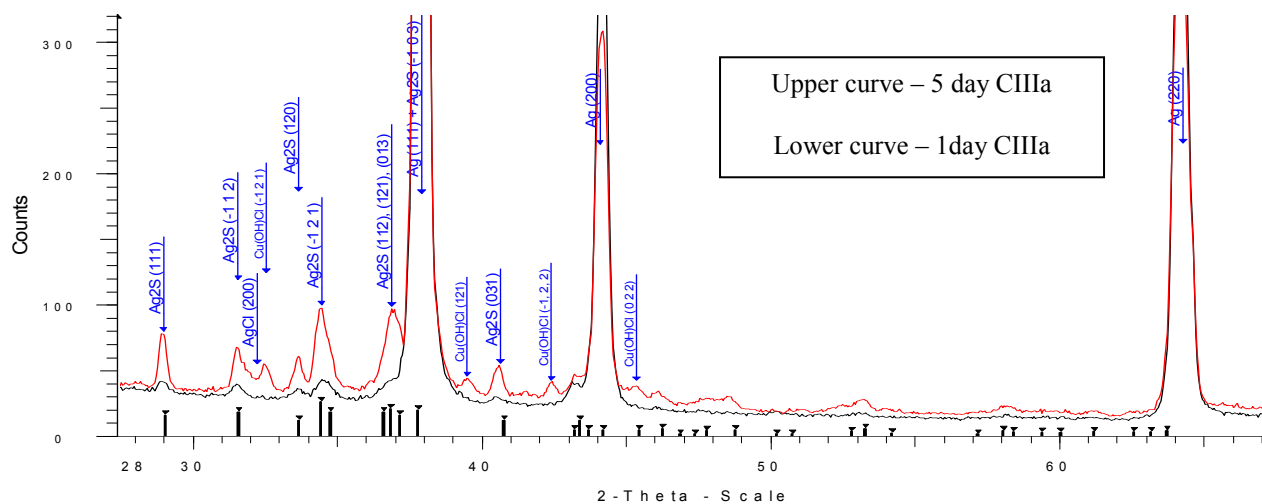Figure 1. XRD spectrum taken from CIIa exposed silver plated surfaces (1 and 5 days)

Figure 2. XRD spectrum taken from CIIIa exposed silver plated surfaces (1 and 5 days) – ▼ indicate Ag_2S peak locations
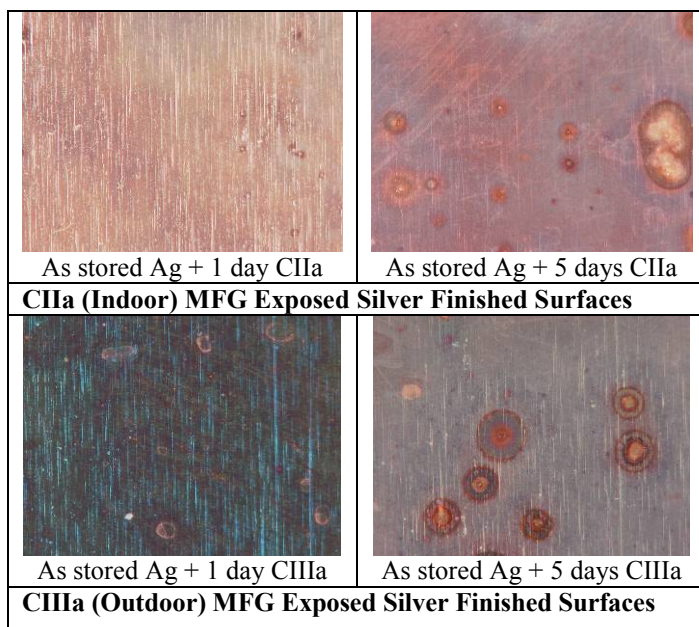
As stored Ag + 1 day CIIa	As stored Ag + 5 days CIIa
CIIa (Indoor) MFG Exposed Silver Finished Surfaces	
As stored Ag + 1 day CIIIa	As stored Ag + 5 days CIIIa
CIIIa (Outdoor) MFG Exposed Silver Finished Surfaces	

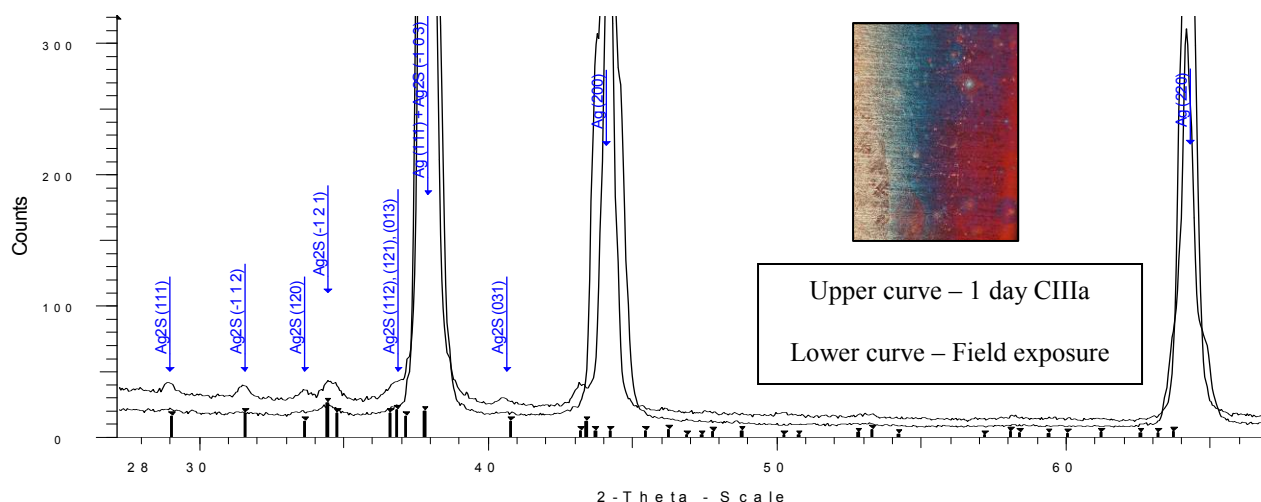Figure 3.   Optical micrographs of CIIa and CIIIa (Outdoor) MFG exposed silver finished surfaces taken at (100x)

B.   Contact Resistance Data Taken at 250cN Normal Load for Tarnished Silver Finished Surfaces

Figure 5 shows contact resistance data from these silver finished samples measured at 250cN load (open symbol data points <u>without</u> center cross) along with data taken after 500 micrometers forward and back wipe (solid symbol data points <u>with</u> center cross). The contact resistance results for each state are represented by two data points: an average value plus one standard deviation (solid symbols) and a maximum value (open symbols). Each data point set represents at least 18 individual measurements (figures 5, 8, and 12). The sample conditions tested were pre-MFG exposed states (as-plated and as-stored) as well as after 1 day and 5 days of both CIIa and CIIIa exposure. The contact resistance axis is on a log scale.

Figure 4.   XRD spectrum taken from a field exposed silver plated surface (inset image of the surface) – ▼ indicate Ag_2S peak locations

Figure 5.   Contact resistance data taken at 250cN load in the 'as loaded' and the 'after wipe' at load state for various exposure states

Since the CRP does not resolve data greater than 1kΩ, the additional bar graph data is necessary to show what percentage of the data (right axis of the graph) is 1kΩ or greater. The bars represent data from the 'as loaded' or the 'after wipe' states as designated on the graphs. These 'open circuit' readings (R ≥ 1kΩ) could not be included in the average + 1 standard deviation and maximum values reported. Therefore, the 'out of range' reading information needs to be included even though the resistance values were too high for the CRP to report an actual value.

When comparing the as-plated and the as-stored silver finished contact resistance data, the effect of any residual tarnish that formed during lab storage is neglible. All subsequent MFG exposures were done on as-stored silver finished samples.

For many signal applications there is a limit of a change (delta) in contact resistance of 10mΩ. With that metric, only the as-plated, as-stored, and 1 day CIIa MFG exposed samples 'passed' in the 'as loaded' state before wipe (figure 5). In the 'after wipe' state, only the 5 days CIIIa exposure, a relatively severe exposure, did not 'pass' this arbitrary 10mΩ delta contact resistance metric. Of all the sample conditions in the 'after wipe' group that 'passed', the highest values were an average of 1.40mΩ, standard deviation of 1.76mΩ, and a maximum of 7.9 mΩ for the 1 day CIIIa exposed samples. This shows the benefit that wipe can have for a tarnished silver contact surface.

C. Wipe and tarnished silver surfaces

Wipe is a very effective way to remove silver tarnish from a contact interface (figures 6 and 7). Looking at the wipe marks left by the CRP, there were two varieties: where there was no pore site substrate corrosion and where there was pore site substrate corrosion. Figure 6 shows micrographs of such wipe marks from the 5 day CIIIa contact resistance samples (H$_2$S films). The ≥ 1kΩ readings represented by the 'after wipe' bar graph data in figure 8 were taken from sites as shown in figure 6 b) where the level of copper corrosion product (EDX analysis) within the film around a corrosion pore sites was too great to make good electrical contact; even after wipe.
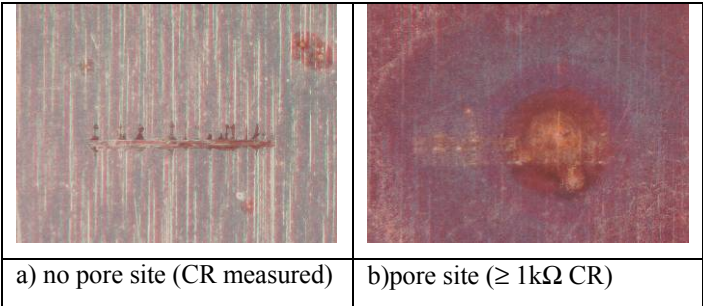

a) no pore site (CR measured)	b)pore site (≥ 1kΩ CR)

Figure 6.   Representative contact resitance measurement wipe tracks (500 micrometers long) from a 5 day CIIIa exposed Ag finished surface 50 cN load

Some limited testing was done where the spot on the cap rider used to make the readings was not changed between readings while the location on the flat coupon for each successive measurement was moved to a new location. This way, the cap surface experienced an increasing number of wipe cycles with each wipe cycle. Therefore, each successive flat surface measurement location had an undisturbed tarnish film prior to probing and wipe. Figure 7 shows two such flat wipe tracks taken using a 1 day CIIIa exposed silver finished cap rider and flat coupon pair: the 1st flat wipe track (a) and the 9th flat wipe track (b). The degree of silver metal exposure and track width on the flat increased with increasing number of wipe cycles. This illustrates both the value of wipe for tarnished silver samples as well as the potential increase in wear associated with increased wipe.
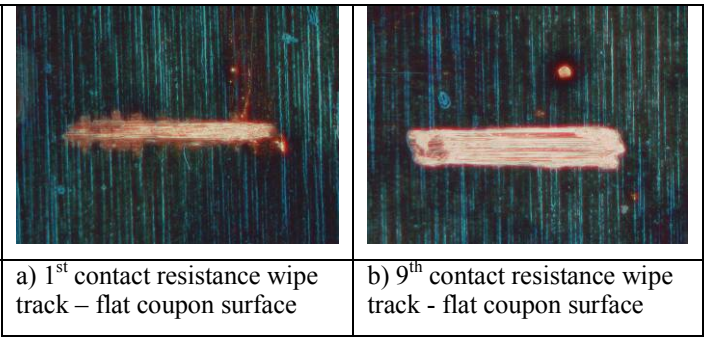

a) 1st contact resistance wipe track – flat coupon surface	b) 9th contact resistance wipe track - flat coupon surface

Figure 7.   Representative contact resistance measurement forward and back wipe tracks (500 micrometers long) @ 250 cN load using a 1 day CIIIa exposed Ag finished surface. The cap rider spot was not changed between sucessive measurements while the flat coupon measurement location was changed betweeen readings

D. Contact Resistance Data Taken at 50cN NormalLoad for Tarnished Silver Finished Surfaces

If silver were to be applied in a typical hard gold finished application, the normal load may be more on the order of 50 cN. The data in figure 8 is plotted in the same manner as in Figure 5; the difference being that a normal load of 50cN was used instead. Using the 10mΩ delta contact resistance metric, the risk of using such a low normal load for a silver finished surface is illustrated. Only the as-stored and the 1 day CIIa exposed samples were able to meet a 10mΩ delta contact resistance limit: with or without wipe. Even after wipe at 50 cN, 30% of the contact resistance readings taken on the 5 days CIIIa samples exceeded the 1kΩ measurement capability of the instrument. If silver were to be used in a situation where this level of tarnish would occur, it is likely it would fail without some form of environmental shielding and possibly a more severe geometry. Any shielding used would have to be capable of preventing this level of corrosion in an application. More severe geometries may be better able to break through tarnish films; but could lead to further durability decreases for a finish that already has poor durability characteristics.
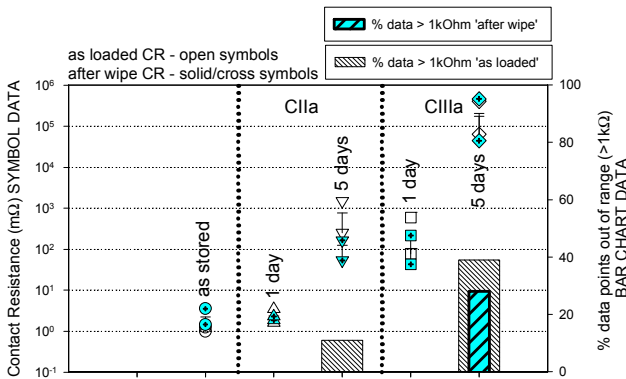

Figure 8.   Contact resistance data taken at 50cN load in the 'as loaded' and the 'after wipe' at load state for various exposure states

E. Coefficient of Friction/Durability Evaluation

Clean hard gold has a coefficient of friction (COF) on the order of 0.3 to 0.4. COF measurements were taken on silver

and all data shown are the median and maximum value for a combination of at least three friction tests. The data in Figure 9 shows that as-stored silver has a significantly greater COF (~ 1.25 or greater) than hard gold. Hard gold contacts many times are specified for 50 durability cycles or greater. Silver finished contacts are usually specified for 10 or fewer durability cycles. The difference in COF illustrates the difference in the durability of the two finishes.
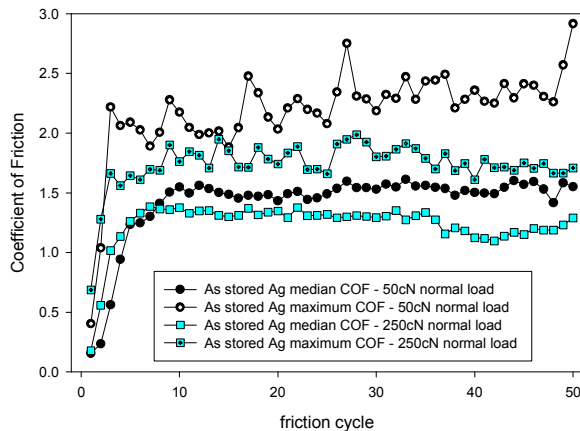

Figure 9. Median and Maximum Coefficient of Friction data for as-stored silver finished surfaces: data taken at 250cN, 1 cm wear track

The presence of even minor amounts of silver tarnish at the surface can weaken the adhesive metal-to-metal contact interface bonds by providing a shearable layer at the asperity junctions – leading to a lower COF. The minor amounts of storage tarnish found on these as stored silver surfaces reduces the COF for the initial cycles (1-4) only - even at the higher normal loads (250cN) more typically used with silver finished contacts. The COF values taken for the samples at 50 cN (median and max) are higher than the ones taken at 250cN. This has to do with the wear mechanism. The difference is evident when comparing the 250cN and 50cN (figure 10) cap rider wear marks. At the higher 250cN load, more of the harder nickel underplate is exposed which serves to make the sliding surface a composite structure of both the relatively soft silver and the relatively hard nickel – therefore the effective COF is lowered. This could lead to a greater risk of nickel corrosion in the contact area. This is why silver is not considered a durable finish. The wear marks for the testing done at 50cN to 50 cycles have no nickel exposure and are more representative of silver galling. This could lead to a risk of excessive insertion forces.

This combination of higher normal forces and silver's high coefficient of friction does have the benefit of promoting vibrational stability by promoting attenuation of the transfer of mechanically or thermally driven relative micro-motion (e.g. fretting) to a contact interface. Silver itself is not susceptible to fretting oxidation in typical connector environments but silver is susceptible to severe adhesive fretting motion wear. If mechanical cycling conditions are severe enough for fretting motion to occur, this could quickly lead to exposure of nickel and/or copper substrate materials which are susceptible to fretting oxidation failures and unacceptable contact resistance

increases. How any fretting motion would or could be imparted to a contact interface is entirely dependant on the connector design and the application.
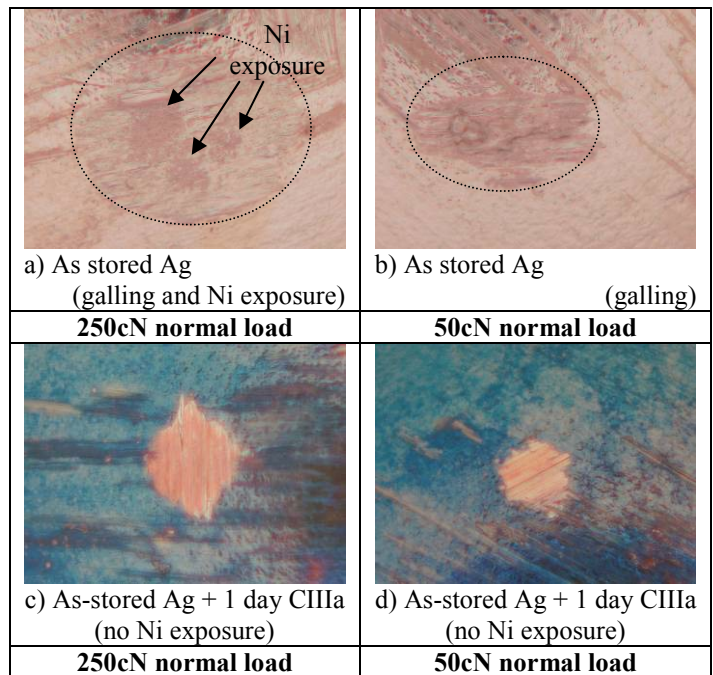

Figure 10. Representative optical micrographs of 50 cycle cap rider COF wear marks. One cm long wear track cycling (400x micrographs)
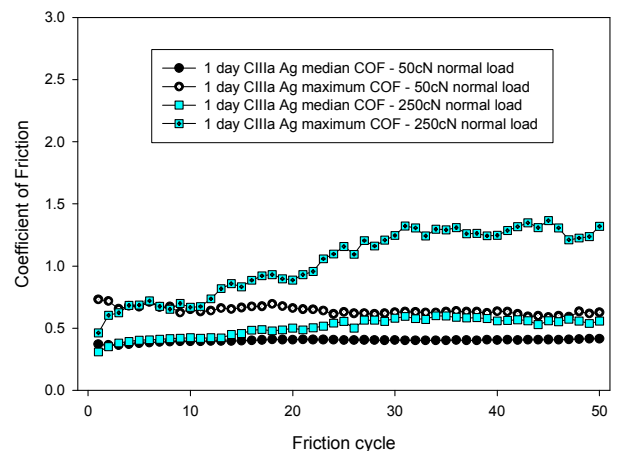

Figure 11. Median and Maximum Coefficient of Friction data for 1 day CIIIa exposed silver finished surfaces: data taken at 250cN and 50cN, 1 cm wear track

More extensive tarnish films can impart a significant level of COF reduction resulting in less wear. The difference in the cap rider wear area can be seen when comparing the as-stored and the 1 day CIIIa exposed wear marks shown in figure 10. Figure 11 shows that 1 day CIIIa exposed tarnished silver surface can have a median COF less than 0.5. Even at 50 cycles where the maximum COF gets up to ~ 1.25, the reduction in COF imparted by the existence of the tarnish film can be seen when compared to the as-stored condition data shown in figure 9. Figure 11 also shows that at 250cN load, the COF reducing

effect of this tarnish film starts to degrade after about 10 cycles of durability. The maximum COF steadily increases after about 10 cycles wear. At 50cN normal load, the tarnish film tends to stay effective even up to 50 cycles of durability. Field generated tarnish films tend to have a similar effect, but it would be as variable as the field tarnish films themselves.

F.   The Use of Surface Treatments on Silver Finished Surfaces

Not only is silver susceptible to tarnishing itself, figures 3 and 6 shows that silver finished surfaces are also susceptible to the same pore site substrate corrosion migration as hard gold finishes when exposed to these types of MFG corrosive atmospheres. Many silver surface treatments are intended to prevent tarnishing of the silver itself. They also may need to mitigate corrosion at pore sites and/or impart lubricity to a contact interface like hard gold surface treatments.

Figure 12 shows comparative before and after CIIIa MFG exposure contact resistance data for treated silver finished surfaces, as well as after exposure data for silver with no surface treatment. Such treatments can be quite effective at attenuating silver tarnishing and/or pore site corrosion if used under appropriate conditions.
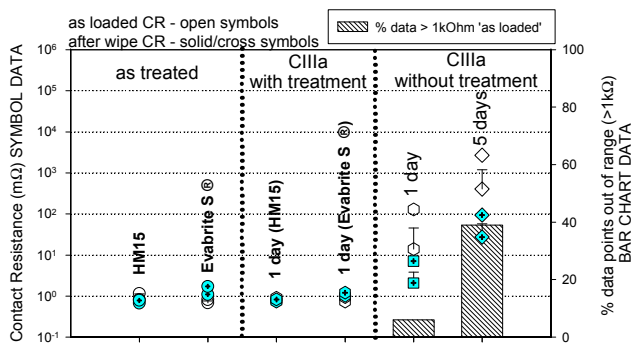

Figure 12. Contact resistance data taken at 250cN load in the 'as loaded' and the 'after wipe'at load state for various exposure and surface treatments

Figure 13 shows similar comparative COF data. Not only do surface treatments attenuate tarnish film formation, they also provide COF reduction. The presence of tarnish films can also have a significant COF reducing effect. Since tarnish film formation processes are not self limiting and are so unpredictable, they cannot necessarily be expected to consistently provide COF and/or wear reduction.

Figure 13 also shows the potential risks associated with using a surface treatment outside of its proper operating range. If the surface treatment is exposed to a temperature at which it is not stable, it may cease to function depending on the duration of the excessive thermal exposure. In this case, surface treated samples were exposed to 125°C for 100 hours. Both surface treatments provided some level of COF reduction as-applied, but the effect of the Evabrite S ® was eliminated when the surfaces were exposed to 100 hours at 125°C prior to friction testing.
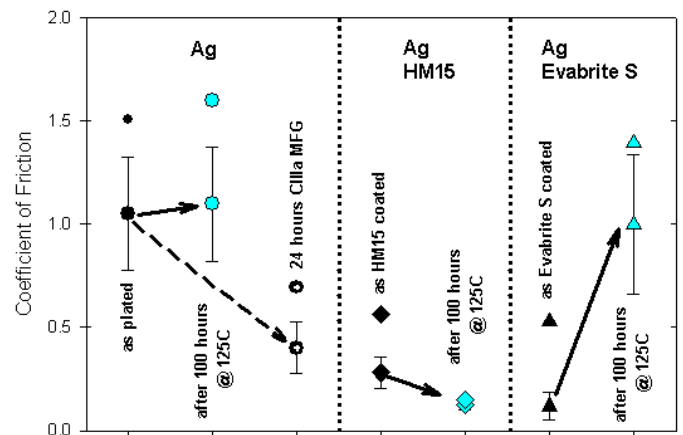

Figure 13. 5th cycle Coefficient of Friction data taken at 200 cN load with a 1 cm wear track length - median ± 1 standard deviation and maximum COF values for silver finished surfaces with designated levels of treatment and/or exposure

IV.   CONCLUSIONS

What a connector designer needs to achieve is sufficient wear resistance, durability levels, insertion force, and stable contact resistance performance at the lowest cost possible for a given application. Applying silver in a hard gold finished connector design/application will most likely degrade these performance factors, though it may be a viable cost effective finish for some situations. Determining the 'appropriateness' of switching hard gold to silver would be very connector design, performance requirement, testing and application condition dependant.

▪ It is recommended to use an appropriate silver surface treatment. Surface treatments can be used to attenuate corrosion processes as well improve wear, durability, insertion force performance. Any selected surface treatment would have to be appropriate for the 'lifetime' exposure of the intended application.

▪ The use of environmental shielding is recommended for silver finished contacts. What level of shielding is entirely dependant on performance requirements and the environmental conditions in which the connector design will be used. At the very least it is recommended to use a closed housing design. In more severe applications, or situations where a surface treatment cannot be effectively used, a sealed connector design may be needed. There are environments where the use of silver may not be appropriate. Commonly cited application environments where the use of silver finished contact is not recommended are paper mills (large amount of ambient H_2S) and marine environments (chloride ions from NaCl). Silver is used in these situations if sufficiently sealed, but testing may need to be done to evaluate the ability of the design to exclude corrosive elements.

▪ The use of reduced sulfur, sulfur absorbing, and or closed bag packaging materials is recommended to reduce the risk of excessive tarnishing that may occur in storage and shipping environments.

- Incorporation of wipe into a silver finished contact design is recommended to facilitate the removal of any tarnish films that may form in the contact interface. Wipe effectiveness might be improved through the use of higher normal forces and/or more severe contact geometries, but these approaches may lead to degraded wear, insertion force and durability performance.

- Another method used with some silver contacts is multiple contact redundant designs. There are limited situations where this method can be employed.

- The use of a lower normal force can lead to improved wear and durability performance, but also a reduction in wiping effectiveness. If the level of tarnish formed and retained in the contact area is excessive, it could lead to contact resistance issues – depending on the application requirements and conditions.

- Adjusting performance requirements of a connector to levels more appropriate for a silver finish (e.g. lower mating cycles) may be a way to allow silver to be a suitable finish for a particular hard gold design. For example, many times the required number of mating cycles for a connector design is functionally excessive. Reducing the number of required cycles may make silver a viable lower cost alternative finish.

- If switching finish of a design from gold to silver, one cannot ignore the qualification testing requirements. A test appropriate for gold will likely not be appropriate for silver. Testing concerns cannot be ignored.

- One other concern not addressed in this paper is silver electromigration failures. This may be a risk for designs with smaller conductor spacing under susceptible conditions [22 - 25].

It is all a balance between performance levels and cost. The data shows that silver may be a viable finish for some lower normal force/durability hard gold connector applications. That is if the potential for tarnish formation, increased COF and reduced wear performance are properly managed within a connector design.

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