Contact plating material options for electronic connectors

A comparison of hard gold and hard gold flashed palladium-nickel (80/20)

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1. Introduction

Plug-in connectors are used in a wide range of different environments and must perform reliably and consistently. Connector manufacturers must therefore focus on many aspects to ensure a good quality product. This includes consideration of the shape of the contacts, the number of contact points, the normal force, relaxation of the base material and both the chemical composition and thickness of the plated contact surfaces. When choosing the right plating solution connector manufacturers must pay careful attention to numerous technical requirements and physical demands. Until today, there are many different contact surfaces for connectors available on the market. Every contact surface has its unique characteristics and its own advantages. This white paper will give a short overview over the contact system and common surface coatings used for electronic connectors. Furthermore, the focus is on a comparison between hard gold and hard gold flashed palladium-nickel (80/20), because in the field of data transmission via electronic connectors these two coatings are the most common options used. Although this topic has been discussed earlier, there are still many questions. The respective characteristics and advantages of these two surfaces will be considered in more detail and confirmed by investigations done in the HARTING Quality & Technology Center.

2. Technical requirements for connectors

Plug-in connections are used wherever components or assemblies have to be connected temporarily. The range of applications is as wide as the technical requirements for connector systems (see Table 1). Electrical contacts have basically two main tasks: the possibility to mechanical separate an electrical connection and the transmission of electrical energy without losses in closed position [1]. To achieve this, the connector has to fulfill several technical requirements. The contact resistance should be low and of course stable, the thermal conductivity should be high so that the electrical heat is low and the current carrying capacity is high. The mating and unmating forces should be low and, therefore, the connector should have a good wear characteristic. Likewise, it must be resistant to external influences like shock, vibration, humidity and industrial atmosphere (corrosion resistance).

Contact resistance	↓
Thermal conductivity	↑
Electrical heat	↓
Current carrying capacity	↑
Insertion and withdrawal forces	↓
Wear resistance	↑
Shock resistance	↑
Vibration resistance	↑
Corrosion resistance	↑

Table 1: Technical requirements for the contact zone of connectors

These technical requirements and, therefore, the reliability of a connector system is not only defined by the used contact surface, it is also influenced by several different physical properties, which depend on each other. The performance is defined for instance by the shape of the contact, the number of contact points, the normal force as well as the relaxation behavior of the base material. To facilitate the introduction to the subject of the contact surfaces, first, a brief overview of the structure of a connector, and more specifically of the contact zone is given.

3. The contact system

The contact system consists of a male and a female contact with a spring element (see Figure 1). Male contacts are normally made of brass, because of its mechanical strength and no need for mechanical flexibility. Female contacts are normally made of bronze with greater spring properties and, therefore, a lower relaxation behavior, which ensures a stable contact normal force of the spring element during the complete lifetime of the connector system.

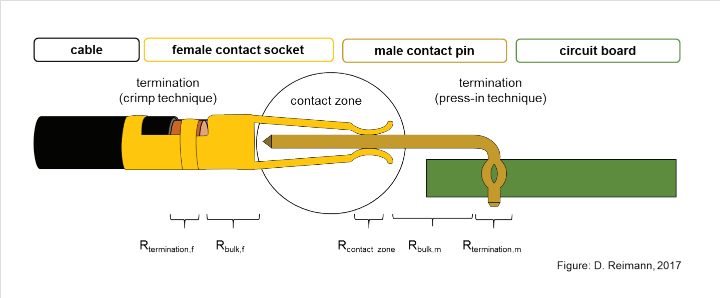

Figure 1: Schematic view of a contact system

3.1. The contact resistance

The total resistance of the connection system (R_{total}) consists of the contact resistance ($R_{contact\ zone}$) as well as the resistance of the bulk material (R_{bulk}) and the termination area ($R_{termination}$) of both contact partners (male + female) (see Figure 1).

$$R_{total} = R_{termination,f} + R_{bulk,f} + R_{contact\ zone} + R_{bulk,m} + R_{termination,m}$$

The area, at which macroscopically a contact occurs, is called "apparent contact area" (Aa). All solid surfaces are rough on the microscale, meaning, that the surface consists of peaks and troughs. Thus, a contact between two contact surfaces occurs only at discrete areas, the so-called "load bearing contact area" (Al), produced by the mechanical contact of so-called "asperities" on the two surfaces [2]. For low contact forces, this is just a small fraction of the apparent contact area. Due to impurities or contaminations, like oxides, the "effective contact area" (Ae), where the current is transmitted from one surface to another, is even smaller. This effective contact area is like a collection of small spots, the so-called "a-spots" [3]. Figure 2 shows a schematic view of two rough electrical interfaces in contact.

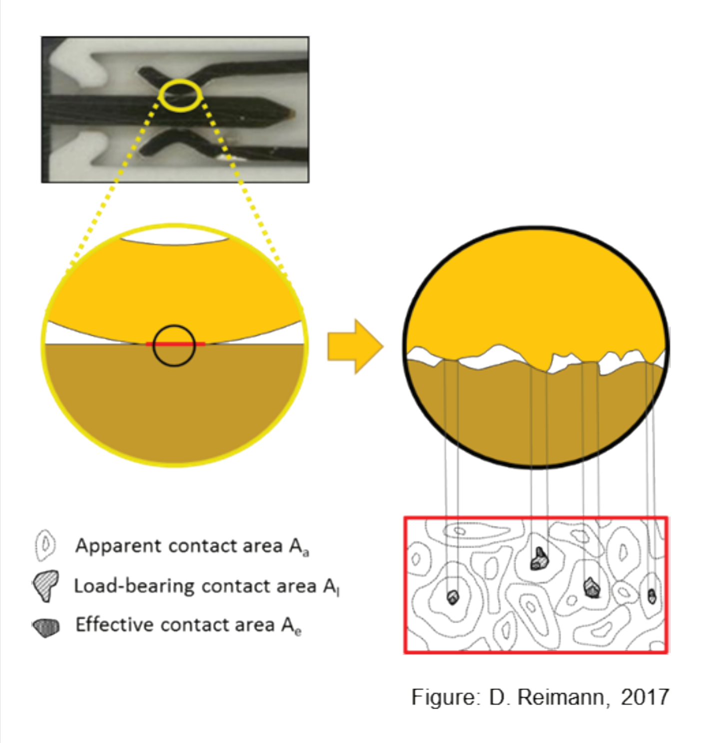

Figure 2: Schematic view of an electrical interface

Although the contact resistance makes only a small percentage of the total resistance of the circuit, it is one of the most important characteristics of an electrical contact. Strong fluctuations or strong increases can lead to malfunctions or even to the failure of a system [1]. The contact resistance of the contact zone is made up of the so-called "constriction resistance" (R_c) and the "film resistance" (R_f) caused by contaminations like oxides on the contact surface.

$$R_{contact\ zone} = R_c + R_f$$

The constriction resistance of closed connectors is caused by the constriction of the current lines in the area of the effective contact area. Figure 3 shows a schematic view of the current lines in a homogeneous metallic conductor compared to the current lines in a contact system with only one circular effective contact area (marked with a red circle) [1].

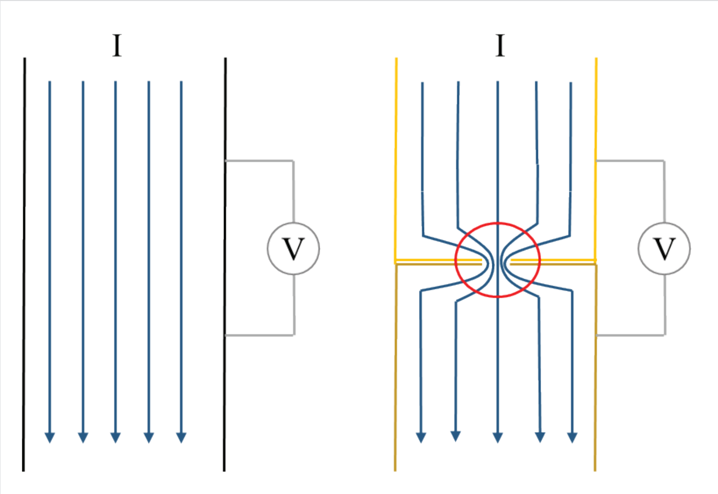

Figure 3: Schematic view of the current lines of a homogenous metallic conductor (left) and of a contact system with a circular effective contact area (right)

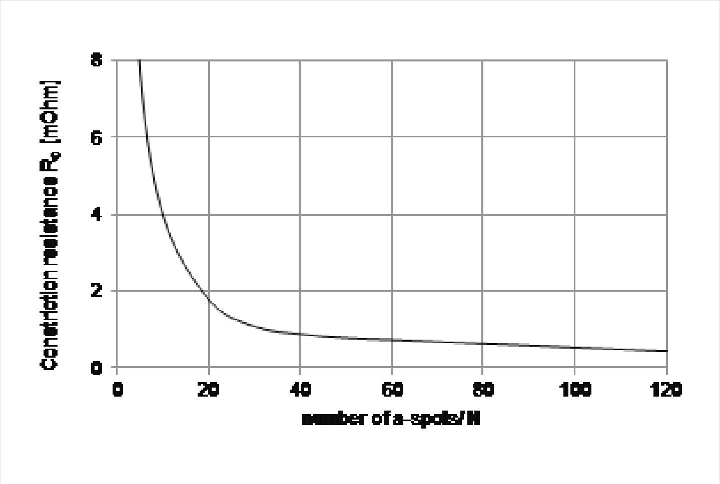

Figure 4: Constriction resistance in dependence of the number of a-spots

Due to mechanical deformation, the number and the area of a-spots and, therefore, the effective contact area increases with increasing contact normal force. As a result, the constriction resistance decreases with increasing contact force (see Figure 4). Higher normal forces also lead to lower film resistance due to fracturing of oxide films, resulting in an increase of the effective contact area.

4. The contact surface

4.1. Requirements

Plug-in connectors are used in a wide range of different environments, like heat or damp heat. They are also used for unfavorable environmental conditions in corrosive atmospheres. Thus, the contact surface of an electrical contact has to meet various requirements. Its purpose is to upgrade the contact substrate's properties [2], especially the corrosion resistance of the base material. Corrosion of the substrate leads to changes of the electrical properties due to formation of foreign layers, which increases the film resistance. In order to limit the influence of these foreign layers, the substrate is coated. Compared to uncoated base material, the coating allows reducing the contact normal force, which is needed to break the foreign layers [1].

The coating also has to have a high electrical and thermal conductivity with low friction and wear. However, high wear resistance is always a compromise between low insertion and withdrawal forces and a high contact force for a large and stable contact area and, therefore, a low and stable contact resistance.

There are two main wear mechanism. On the one hand, the mechanical wear of the contact surface due to plug-in operations, which leads after a certain time to an exposure of the none-noble intermediate layer or even the base material, which are more prone to corrosion. On the other hand, the fretting wear of the contact surface caused by temperature changes or vibrations resulting in small oscillatory movements (fretting motions < 125 µm [2]). This typically results into fretting corrosion by building highly resistive corrosive products like oxides in the contact interface. In the case of noble metal plated contacts, the fretting corrosion starts when the contact surface is worn through and the nickel intermediate layer or the copper alloy has been exposed. Non-noble metal contact surfaces like tin are always very prone to fretting corrosion [1, 2].

4.2. Common galvanic contact surfaces

There are multiple contact surfaces available on the market to meet these requirements. Although the focus of this paper is the comparison between hard gold and hard gold flashed palladium-nickel (80/20), other common contact surface will be briefly presented below (Figure 5).
Contact surfaces can be distinguished into noble and non-noble contact surfaces. Non-noble surfaces are mainly used in the standard consumer market. In the industrial market and for machines or equipment, where 100 % security and quality over the whole lifetime is needed, noble surfaces are preferred.

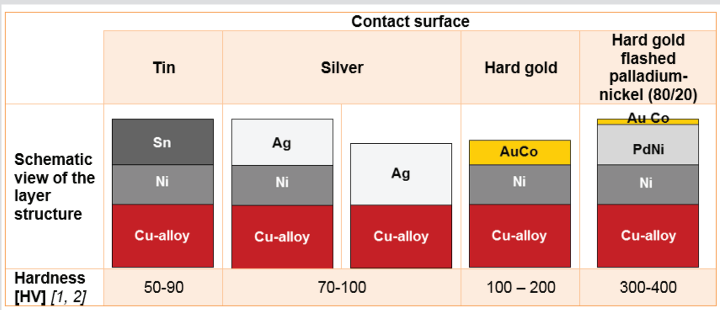

Figure 5: Overview of the most common surface coatings for the contact zone

4.2.1. Non-noble contact surface

4.2.1.1. Tin

Tin belongs to the non-noble metals. The main advantage of this metal is its low price. Consequently, it is used as a surface coating mainly in the automotive industry; if not too severe vibration or temperature changes are expected. It forms a hard tin oxide layer on its surface and is susceptible to fretting. To achieve a good and stable effective contact area and, thus, a low and stable contact resistance, this oxide layer has to be plastically deformed and broken by a high normal force, or more precisely by a high surface pressure. The fact that this high normal force is needed and that tin has a relatively high coefficient of friction leads to high insertion and withdrawal forces and, therefore, to increased wear. This limits the number of mating cycles to approximately 20. Thus, it is ideal for high volume applications, where multiple mating cycles are not required [4] and for the termination area for press-in or soldered electrical contacts.

4.2.2. Noble contact surfaces

4.2.2.1. Silver

Silver belongs to the noble metals. It has the highest electrical and thermal conductivity of all metals. Silver shows a high affinity to sulfur-containing gases. Thus, traces of hydrogen sulfide are sufficient to color silver by forming silver sulfide (tarnishing) [4], resulting in a smooth and very thin layer. It is removed when the contacts are mated and unmated or can be electrically broken down through by higher voltages and currents, the so-called “fritting”. This and a passivation on top of the silver surface guarantees a very low contact resistance for a long time. In case of very low currents or voltages, the silver sulfide layer cannot be electrically broken down, so that small changes to the transmitted signal will be encountered. As a result, silver is mainly used for high-current contacts.

4.2.2.2. Hard gold

Gold is the most noble metal and, therefore, it has the highest resistance to corrosion, which is its main advantage. Pure gold is the softest noble metal, so that gold alloys with cobalt, nickel or iron are used as contact surfaces, the so-called “hard gold” [4]. There is an absorption layer built on top of the hard gold surface, which can be broken very easily with very low normal forces. Similarly, the coefficients of friction and, thus, the insertion and withdrawal forces of gold surfaces are rather low. This leads into very low wear and, therefore, to a high number of mating cycles. Thus, gold is also suitable for low voltages, corrosive environments and ideal for coatings of connectors in the data and signal range. The main disadvantage of hard gold is its high cost and its price-dependence on the stock market.

4.2.2.3. Hard gold flashed palladium-nickel (80/20)

Palladium is a noble metal. Due to its catalytic effect, it tends to form an insulating frictional brown polymer in atmospheres containing traces of organic compounds when palladium contacts are subjected to motion relative to each other (fretting) [4]. This effect is called “brown powder” effect. Therefore, often a palladium-nickel alloy is used as contact surface, with all the advantages of palladium, but the nickel prevents the “brown powder” effect. The hard gold flash on top of the palladium-nickel surface serves as a solid lubricant and as a corrosion protection. This coating system has a hard palladium-nickel undercoat with low coefficient of friction. This leads into very low wear and, therefore, to a high number of mating cycles. The hard gold flashed palladium-nickel coating is particularly suitable for low voltages typically used for data and signal transmission and in a corrosive environment.

5. Selection of the right surface

Since the majority of the functional disorder in connectors are caused by the contact elements, the most common defect mechanism of the connectors contact surface are corrosion and wear of the layer [1]. These degradation mechanisms have a big impact on the performance of the contact. Thus, the proper selection of the contact finish requires an understanding of the characteristics of the different contact surfaces and of the engineering requirements [2]. To make it simple for customers to define the right connector for their application different performance levels are defined in standards like IEC 60 603-2 [5]. Hard gold as well as hard gold flashed palladium-nickel (80/20) both fulfill these requirements (see Table 2). This provides advantages for the customer as well as for the manufacturer. The customers do not have to define technical characteristics like maximum contact resistance, number of mating cycles, plating or ageing procedure individually by themselves. They can just choose a defined performance level and the connector manufacturer is responsible to fulfill the required specification. On the other hand, the standardization gives the manufacturer some freedom to achieve these performance levels by using new technologies for example, in the field of stamping or plating or by using new materials, base materials as well as surface coatings, which are under continuous development and which have an important impact on the performance of the connector.

PERFORMANCE LEVEL	3	2	1
Number of mating cycles	50	400	500
Corrosive stress (mixed flowing gas test Cl_2 / NO_2 / H_2S / SO_2)	No	4 days	10 days
Functional requirement	No functional impairment.		
Optical requirement	No abrasion of the contact finish through to the base material.		

Table 2: Performance levels 1-3 as per IEC 60 603-2 [5]

6. Comparison of hard gold and hard gold flashed palladium-nickel (80/20)

The most technical concern against hard gold flashed palladium-nickel (80/20) is about the fretting corrosion behavior. Additional to the release test (according to IEC 60 603-2 [5]), the test specimens were subjected to a fretting test based on Telcordia GR-1217, to verify all the existing theoretical comparison between gold and palladium. Therefore, HARTING did a specific comparison of identical DIN 41612 connectors type C (see Figure 6 and Figure 7) with these two contact surfaces. The Corporate Technology Services (CTS) of HARTING AG & Co. KG, which tests as an independent service provider for the entire HARTING Technology Group the products to ensure the quality, performed all the tests. The accreditation according to DIN EN ISO/IEC 17025 ensures the independence of the laboratory and the high quality of the results.

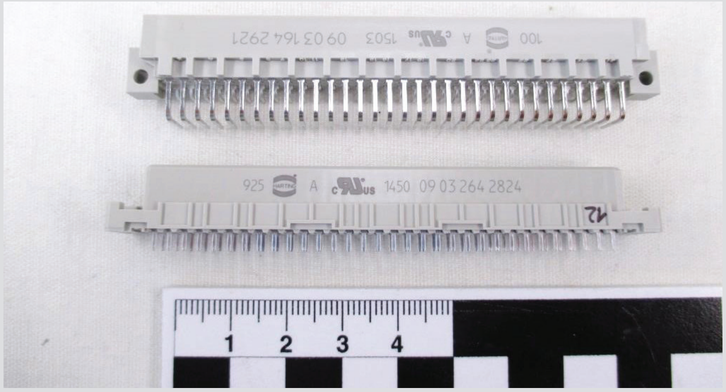

Figure 6: DIN-Signal type C male (top) and female (bottom)

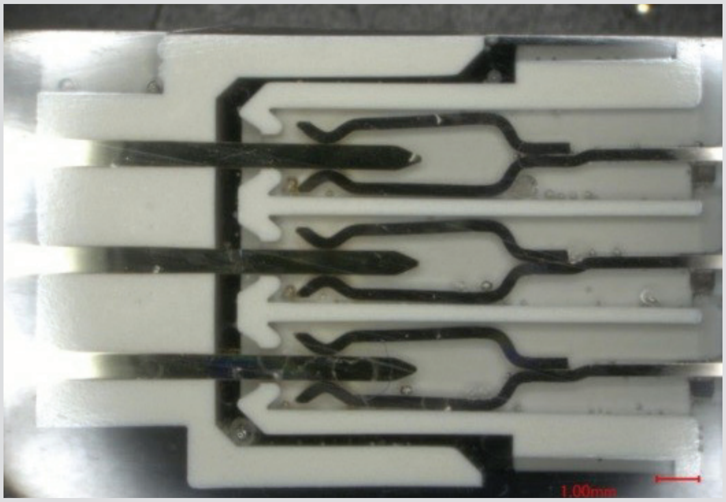

Figure 7: DIN-Signal type C female cross view

6.1. Test specimen

The surface coatings of the two samples have the following layout:

- Sample type 1: DIN 41612 connectors type C
  - contact surface: 2 µm Ni + 1.85 µm AuCo
- Sample type 2: DIN 41612 connectors type C (performance level 1)
  - contact surface: 2 µm Ni + 0.4 µm PdNi (80/20) and 0.05 µm AuCo

For the interpretation of the results it should be taken into account that the layer thickness of the sample type 1 with hard gold is four times thicker (AuCo: 1.85 µm) than the layer thickness of hard gold flashed palladium-nickel (80/20) of sample type 2 (PdNi: 0.4 µm).

6.2. Test arrangement

The fretting tests were performed with a tribometer in the HARTING internal laboratory. The test procedure based on Telcordia GR-1217 - Fretting and Lubrication Tests [6], which evaluates the risk of fretting for the combination of a specific connector hardware and micro-motion caused by fan vibration or thermal cycling. The distance of the micro motion were set to 48 µm. The applied frequency of the test was 10 Hz. The contact resistance was measured with the LLCR method (Low-Level Contact Resistance, a dry film contact resistance measurement) according to contact resistance test of IEC 60603-2 (1995-09) at the ends as well as in the middle of the wear track. This LLCR method avoids the reduction of the contact resistance of the contact interface through electrical and thermal breakdown. If the contact resistance of a contact exceeds 20 mOhm, the contact failed the test.

6.3. Results

Both sample types fulfill connector specification IEC 60 603-2 [5]. Regarding the fretting test the hard gold flashed palladium-nickel (80/20) withstands up to 300,000 cycles until the point of failure. After this the contact surface is worn through and the nickel underlayer as well as the copper alloy have started to oxidize (see Figure 8A) resulting in an increase of the contact resistance. Compared to hard gold flashed palladium-nickel (80/20), hard gold surface withstands up to 900,000 cycles until the point of failure due to its 4 times thicker nobel-metal layer thickness. The contact surface is also worn through and the nickel started to oxidize (see Figure 8B) which causes an increase of the contact resistance.

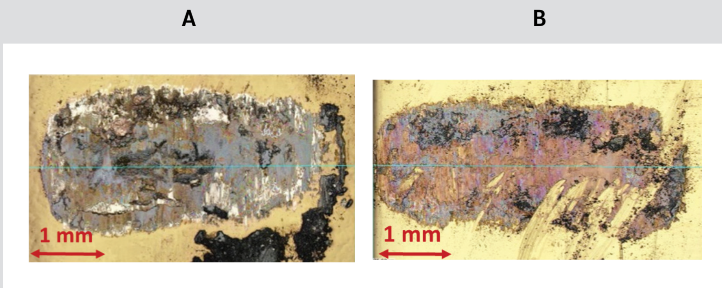

Figure 8: Hard gold flashed palladium-nickel (80/20) contact surface after 300,000 fretting cycles (A), hard gold contact surface after 900,000 fretting cycles (B) (performed at a digital microscope Keyence VHX 1000 D)

Both contact surfaces show the same wear characteristics. At first, the noble material is worn through. When the nickel is exposed, it starts to oxidize. At the beginning, there is still some noble metal in the wear track, so that the contact resistance is still lower than 20 mOhm. When there are only corrosion products left in the wear track, the contact resistance increases and the contact fails. One of the reasons for the good fretting behavior of the tested gold layer is the four times higher thickness compared to palladium-nickel. Therefore, the time until the hard gold layer is worn through is increased.

7. Summary

In the area of electronic connectors hard gold and hard gold flashed palladium-nickel (80/20) are the most common options used as contact surfaces for connectors in the data range. Both surfaces fulfill the connector specification IEC 60 603-2 [5]. Thus, hard gold flashed palladium-nickel (80/20) is a good and established solution for all applications using the performance levels according to international connector specifications IEC 60 603-2 [5]. For much higher demand, especially with more fretting motion cycles, traditionally gold is still prefered. Nevertheless, hard gold flashed palladium-nickel (80/20) offers the advantage of an enhanced price-performance ratio and additionally it is more independent of speculation on the stock market compared to hard gold.

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