AMP INCORPORATED

Technical Report

Golden Rules: Guidelines For The Use Of Gold On Connector Contacts

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GOLDEN RULES

GOLD IS AN EXCELLENT ELECTRICAL CONDUCTOR AND A HIGHLY STABLE NOBLE METAL WHICH EXHIBITS THE FOLLOWING CONTACT PROPERTIES:

1. Gold coatings are recommended for high reliability applications
2. Gold coatings can be used in corrosive environments
3. Gold coatings can be used for high durability
4. Gold coatings can be used with low normal force and low wipe
5. Thin gold coatings can establish a stable low resistance contact
6. Gold is not susceptible to fretting degradation
7. Gold contact performance can be enhanced with lubrication
8. Gold coatings require the use of a suitable underlayer, such as nickel
9. Gold coating thickness depends on application requirements
10. Gold can be used for low level circuit conditions
11. Gold contacts can be used at elevated temperatures
12. Gold contacts should not be mated to tin contacts
13. Gold contacts are not recommended for "Hot Make and Break" applications

Golden Rules: Guidelines For The Use Of Gold On Connector Contacts

ABSTRACT

Gold is generally specified as a contact coating for low level signal voltage and current applications, and where high reliability is a major consideration. In critical applications where there is no opportunity to repair or remate a defective connection, the use of a protective gold coating provides an added margin of safety because gold is inert in most connector application environments. A set of guidelines has been compiled which will assure optimum performance of gold coated contacts.

INTRODUCTION

High connector reliability can be achieved by using a gold coating on the electrical contacts. Gold, when applied to the contact interface, has the capability of providing a stable and low contact resistance over the operating life of most applications. This is due to its inertness to most environments. At normal operating temperatures, gold does not chemically interact with any environmental constituents to form electrically insulating films. In the absence of surface films, metal-to-metal contact is readily established and maintained, even at low normal forces and under low wipe conditions. Because of these characteristics, gold is the material of choice for applications having low signal voltage and current and for separable multiple circuit connectors where low insertion and withdrawal forces are required.

Pure gold exhibits relatively poor sliding wear performance. Since pure gold is a soft metal, it tends to gall and smear under high pressure sliding conditions. This tendency is mitigated by adding hardeners such as cobalt or nickel to the gold coating. However, the use of hardening agents has some detrimental effects on the environmental inertness of the coating . Problems related to durability, hardening additives, and porosity can be avoided by using gold with a sufficient thickness along with an appropriate underlayer.

The following is a discussion of criteria which are important to consider when optimizing the performance of gold coatings on electrical contacts. A listing of the criteria is given on the preceding page.

GUIDELINES

Thirteen guidelines have been formulated for the use of gold coatings on electrical contacts:

***Golden Rule No. 1*: Gold Coatings Are Recommended For High Reliability Applications**[1, 18, 21, 22]

In connector applications where reliability is critical, the separable contact interface must be protected from environmental deterioration. Gold is recognized as the best material to use for this purpose. When applied to the interface of a separable connector, gold has all of the qualities needed to maintain a stable and low contact resistance over the operating life of most applications. Because gold is a noble metal, it does not chemically interact with any constituents normally found in a connector environment to form an electrically insulating film. Gold is also a good electrical and thermal conductor.

Deterioration of a gold-to-gold contact interface is caused by physical damage and/or accumulation of external corrosion products on the surface. This damage can be minimized through appropriate connector design.

***Golden Rule No. 2*: Gold Coatings Can Be Used In Corrosive Environments**[1, 11, 13-15, 17, 18, 21, 25-27]

Environments which contain high humidity and/or corrosive pollutants, such as sulfur or chlorine containing gases, can attack metals like copper or nickel to form corrosion products which disrupt electrical contact. However, gold does not degrade under the environmental conditions that are likely to be encountered by electronic components.

The protection offered by gold can be compromised if there are pores or cracks in the coating. These act as openings through which atmospheric pollutants can attack the substrate metal to form insulating corrosion products. A limited amount of porosity can be tolerated depending upon the severity of the contact's service environment.

Because gold is a noble metal and because thin gold platings tend to be porous, gold coatings are susceptible to the creep of base metal corrosion products across the surface of the gold after formation at pore sites and edge boundaries. Corrosion creep can be inhibited by applying an overall nickel coating prior to application of the gold. The nickel underlayer serves as a diffusion barrier to most base metal constituents, and nickel corrosion products are self limiting, passive and not susceptible to corrosion creep.

***Golden Rule No.3*: Gold Coatings Can Be Used For High Durability**[1, 2, 5, 6, 10, 12]

Coating a contact with pure (i.e. soft) gold generally results in a connector with low durability and high insertion forces (i.e., high coefficient of friction), especially when the thickness is greater than 0.13 microns (5 microinches).

In practice, gold coatings are usually hardened by adding small amounts cobalt or nickel to the gold. Such coatings are defined as 'hard gold' and produce coatings with a low coefficient of friction and excellent durability characteristics. Hard gold coated contacts can generally withstand hundreds to thousands of durability cycles without failing.

The durability of hard gold coatings can be enhanced by using an underlayer having a hardness value that is greater than that of gold and which will provide mechanical support. Nickel is generally recommended as an underlayer for this purpose. Lubricants are also effective at increasing the durability of gold coatings. Generally, lubrication can increase the durability of a gold contact by an order of magnitude.

Golden Rule No. 4: Gold Coatings Can Be Used With Low Normal Force And Low Wipe[1, 20]

Metal-to-metal contact is required if good electrical continuity is to be established at a separable contact interface Most metals used in electrical circuits interact with the environment, particularly oxygen, to form oxides that are hard and electrically insulating. A large normal force and/or wipe is required to displace this film and form a conductive path through which current can flow. In contrast, gold does not form an insulating film. Therefore, small normal forces on the order of 10-20 grams (0.35-0.71 ounces) with wipe less than 0.254 mm (0.010 in.) are sufficient to establish an acceptable value of contact resistance. However, the use of normal forces greater than 10-20 grams (0.35-0.71 ounces) enhances the mechanical stability of the contact interface and reduces the potential for fretting disturbances which can lead to contamination / degradation of the contact interface.

Golden Rule No. 5: Thin Gold Coatings Can Establish A Stable Low Resistance Contact[1, 4, 15, 19, 25-27]

Contacts with gold coating thickness between 0.03 microns (1 microinch) and 2.5 microns (100 microinches) exhibit stable low contact resistance at normal forces measured down to 10 grams (0.35 ounces).

Two limitations which can result from reduced plating thickness are an increase in plating porosity and decreased durability. Either of these can lead to an increase in contact resistance through corrosion of the exposed base metal.

Porosity can result in corrosion at exposed copper alloy base metal locations where pores in the gold coincide with pores in the nickel barrier plate. It can also occur where pores in the gold allow attack of the nickel to eventually expose the copper alloy base metal. In typical environments, exposed nickel is significantly less reactive than exposed copper.

Thinner gold coatings have lower durability which means that the contact can withstand less insertion cycling, fretting, DTE, mechanical vibration, etc. before wear-through to the base metal occurs. Once the contact interface motion has resulted in wear-through of the gold coating, fretting degradation of the base material takes place.

Golden Rule No. 6: Gold Is Not Susceptible To Fretting Degradation[1, 7, 9]

Fretting occurs when the interface between contacting surfaces undergoes repetitive low amplitude relative motion. This fretting action continuously exposes fresh, clean surfaces which can react chemically with the environment to form reaction products. This process (fretting degradation) will produce high contact resistance because of the buildup of insulating material in the contact area. Since gold is a noble metal and does not form corrosion product films, fretting degradation will not occur prior to wear-through of the gold coating.

Gold Rule No. 7: Gold Contact Performance Can Be Enhanced With Lubrication[1, 2, 25-27]

When gold coatings are treated with the proper lubricant, the coefficient of friction may be reduced by a factor of two, or more. Therefore, the use of proper lubricants is an effective way to reduce insertion force and wear during contact mating. Durability, expressed as the number of mating cycles to wear-through of the gold, can often be dramatically improved by lubricating the contacts. In addition to reducing wear, suitable lubricants have also been shown to significantly decrease environmental degradation of porous gold coatings by protecting any exposed base metal from corrosive environmental constituents.

Golden Rule No.8: Gold Coatings Require The Use Of A Suitable Underlayer, Such As Nickel[1, 10, 11, 17, 18, 24-27]

Gold coatings on contacts, particularly those that are electroplated, should be applied over a high-quality underlayer such as nickel. A nickel underlayer can act as a:

(1) Pore-Corrosion Inhibitor - A nickel underplate will form passive oxides at the base of pores. The underplate will serve as a pore corrosion inhibitor provided the environment does not contain significant amounts of acidic pollutants, in particular, Chlorine.

(2) Corrosion Creep Inhibitor - Nickel will act as a barrier to corrosion product migration.

(3) Diffusion Barrier - A nickel underplate will inhibit the diffusion of base metal constituents of the contact spring (such as copper and zinc) to the gold surface, where they could oxidize and form an insulating film of corrosion product.

(4) Mechanically Supporting Underlayer for Contacting Surfaces - A relatively hard underplate, such as nickel, can serve as a mechanical support for the gold coating, and increase its durability.

The nickel underplating must be continuous and have sufficient thickness to perform the particular function for which it is intended. As a general rule, a minimum thickness of 1.3 microns (50 microinches) of nickel should be used.

Golden Rule No. 9: Gold Coating Thickness Depends On Application Requirements[1, 3, 6]

The choice of a suitable gold coating thickness depends on the degree of durability and environmental protection required by the application. Due to the high cost of gold, it is prudent to keep the gold coating thickness as low as is appropriate for the application requirements.

Increasing the thickness of a hard gold coating increases durability. The following laboratory results for the wear-through of a hard gold coating to the 1.3 micron (50 microinch) thick nickel underplate serve as a comparison of trends. The data given below are for a 0.635 cm. (0.250 in.) diameter ball wiped a distance of 1.27 cm. (0.500 in.) under a normal force of 100 grams for each cycle.

Thickness		Cycles to
microns	**micro-in.**	**Failure**
0.4	15	200
0.8	30	1000
1.3	50	2000

In general, a 0.8 micron (30 microinch) coating of hard gold over a minimum of 1.3 microns (50 microinches) of nickel gives a degree of durability considered adequate for most connector applications. Thin coatings of 0.03 - 0.1 microns (1 - 4 microinches) of hard or soft gold over nickel underplate should be used only for applications in which the risk of fretting is minimal.

Increasing the thickness of a gold coating tends to decrease the porosity which reduces the contacts' vulnerability to pore corrosion.

In general, a 0.8 micron (30 microinch) coating of hard gold over a minimum of 1.3 microns (50 microinches) of nickel provides exceptional environmental protection. Contacts coated with a thin hard or soft gold coating on the order of 0.03 - 0.1 microns (1 - 4 microinches) in thickness over a nickel underlayer can be used in benign environment applications.

Golden Rule No.10: **Gold Coatings Can Be Used For Low Level Circuit Conditions**[1]

Clean gold contacts exhibit ohmic behavior even at extremely low values of current. That is, the contact resistance is independent of the magnitude or direction of the current flow within the contact. Measurements made at currents as low as 1 nanoampere have verified the functionality of a clean gold contact interface. Furthermore, gold is a noble metal and is most likely to remain free of corrosion products and/or films which may exhibit non-ohmic behavior at low level circuit conditions.

Golden Rule No.11: **Gold Contacts Can Be Used At Elevated Temperatures**[1, 16]

Gold is an accepted material for elevated temperature applications. The material system used (gold hardness, gold thickness, underlayer) should be chosen and qualified for the intended application.

For elevated temperature applications (>125^{o}C), the nominal nickel and gold thickness should be increased, and consideration should be given to the use of a soft gold over hard gold composite.

Golden Rule No.12 : **Gold Contacts Should Not Be Mated To Tin Contacts**[1, 8, 23]

The gold-to-tin contact interface is susceptible to fretting corrosion. In addition to the normal fretting process, there is a related mechanism of transfer of tin to the gold interface which ultimately leads to a buildup of tin oxide on the harder gold surface. Disruption of this oxide is more difficult than for the case of tin oxide on tin.

Golden Rule No.13: **Gold Coatings Are Not Recommended For Hot Make And Break**[1]

Arcing of gold contacts will erode the gold and reduce the interface reliability. If a hot make and break application requires the use of gold contacts, then the contact design should incorporate a 'make-first break-last' contact area which is separate from the mated contact area. The purpose of the 'make-first break-last' contact area is to confine the arc damage to somewhere other than the mated contact area.

SUMMARY

The objective of these guidelines is to identify the performance characteristics of gold and to recommend the application conditions for which the optimum performance of gold contacts can be attained and high reliability assured. The use of these guidelines should aid in achieving the most appropriate solution for a given application.

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