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Electrical Contacts Get Off the Gold Standard

Though gold contacts have a reputation for being superior, contacts made from less expensive metals are often better.

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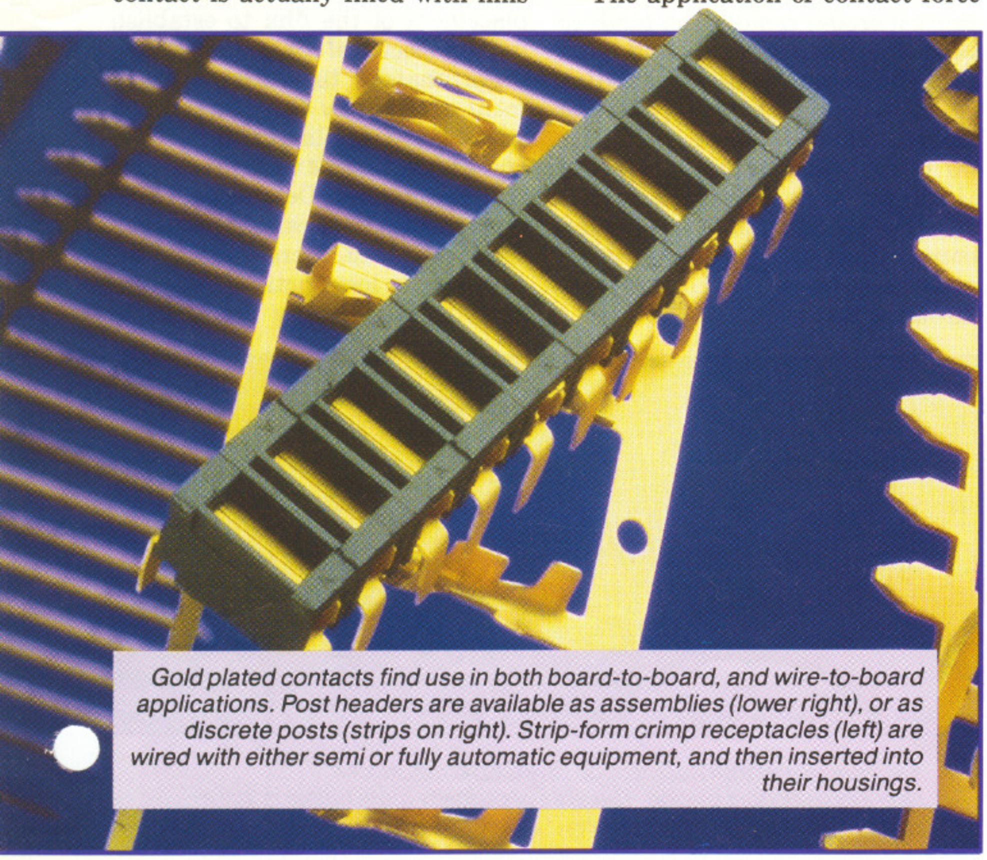
To the casual observer, the two surfaces of an electrical contact appear to form a large continuous interface. This seems especially true if the mating areas are smooth and have a close fit. But closer examination reveals that the surface of the typical contact is actually filled with hills and valleys. This three dimensional surface determines many of the contact's electrical qualities.

Only a contact's opposing peaks touch each other. The peaks, or "a-spots," constitute a fraction of the apparent contact area, often as little as 1%. A single a-spot (peak) is frequently just a few microinches in diameter.

The application of contact force enlarges a-spots and creates additional spots. The contact metal and its hardness determine the amount of increased area for a given force. But even for soft metals and high loads (several hundred grams of force), the total a-spot area remains a small fraction of the apparent surface in contact.

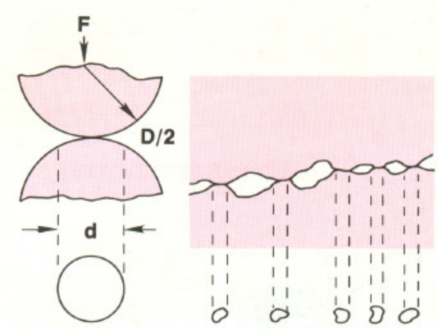
A-spots prevent current from passing evenly through a contact. The a-spots cause a constriction resistance in addition to the normal bulk resistance of the contact members. Constriction resistance is often cited interchangeably with contact resistance. However, the two are different. Contact resistance is the series resistance of constriction resistance and the resistance of any contaminants or films on the contact surface.



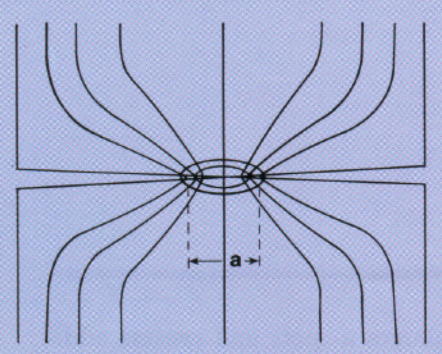
Gold plated contacts find use in both board-to-board, and wire-to-board applications. Post headers are available as assemblies (lower right), or as discrete posts (strips on right). Strip-form crimp receptacles (left) are wired with either semi or fully automatic equipment, and then inserted into their housings.

Contact

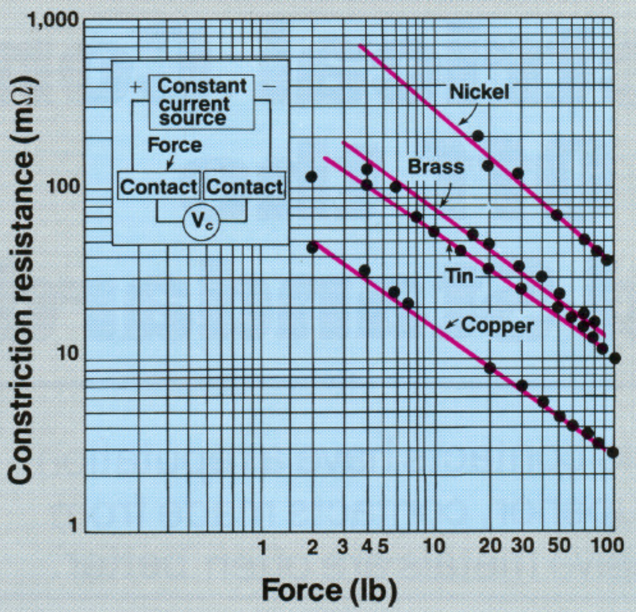
Good contact resistance is important for different reasons in different applications. For example, if the contact carries a large current, high resistance leads to power losses and contact heating.



Contact surfaces that appear smooth to the naked eye reveal their true nature with magnification. The drawing shows the multiple contact regions, called a-spots, of a contact interface.

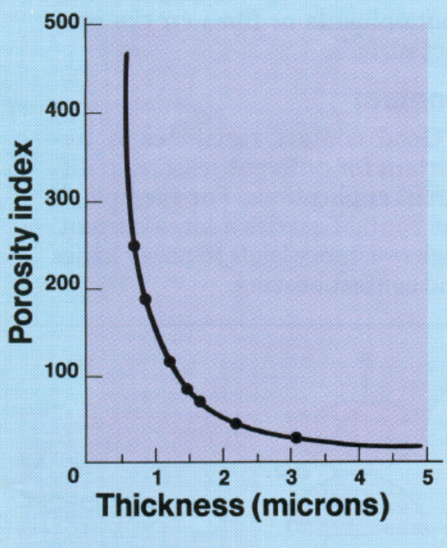


Contact current flow concentrates through the a-spots. As a result, contact resistance increases.



Contact resistance is partly determined by a metal's hardness, and by the force on the contact. For example, while tin has a higher resistivity than brass, it is softer. Therefore, tin has a higher contact area for a given force. The larger area reduces the constriction resistance.

However, high contact resistance can cause other ramifications in small signal applications. Here, it can be an indication that the contact is about to fail. For example, a circuit might work fine with a gold contact having a resistance of 100 mΩ. But resistance of this magnitude shows that the contact is failing — the interface has degraded.



As gold plating thickness increases, porosity decreases. But there is little benefit to plating beyond a few microns, because the number of pores remaining rapidly decreases. Therefore plating cost increases, due to the increased amount of gold used, but contact reliability stays about the same.

Gold is often thought to be the best contact material. Its low resistance and corrosion resistance (because it is a noble metal) are two often cited reasons. Gold's softness also helps increase the effective contact area.

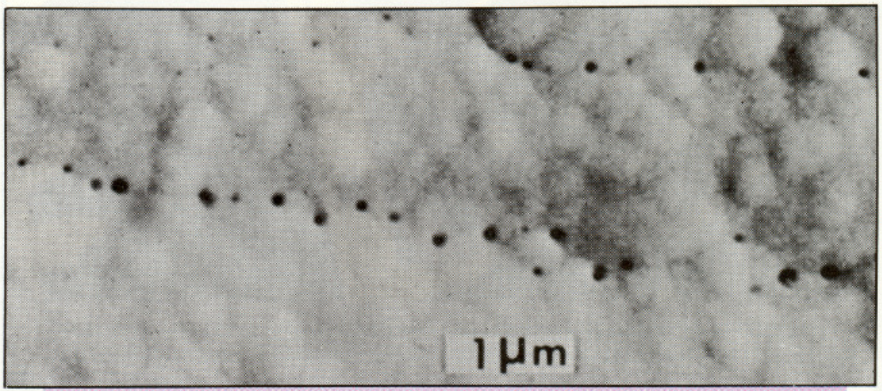
However, pure gold is not needed nor desirable for many contact applications. For instance, it is of no value in the presence of arcing because it erodes rapidly and tends to weld the contact shut. And pure gold should not be used for sliding contacts because it sticks, galls, and smears. (However, some gold alloys do make good sliding contacts.) Gold on high-pressure, semipermanent connections or in crimp connections is of dubious value other than for certain corrosive environments.

Finally, gold is expensive. Specifying pure gold contacts can needlessly increase product cost.

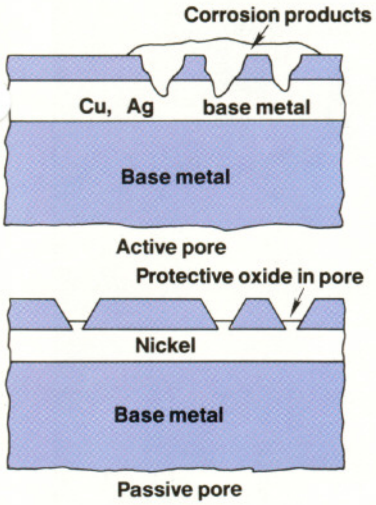
Not so noble

Though not a noble metal, tin is a suitable finish for many electrical connector applications. But because tin is always covered with a nonconductive oxide film, the connector design must provide for displacement of the film to establish reliable electrical contact.

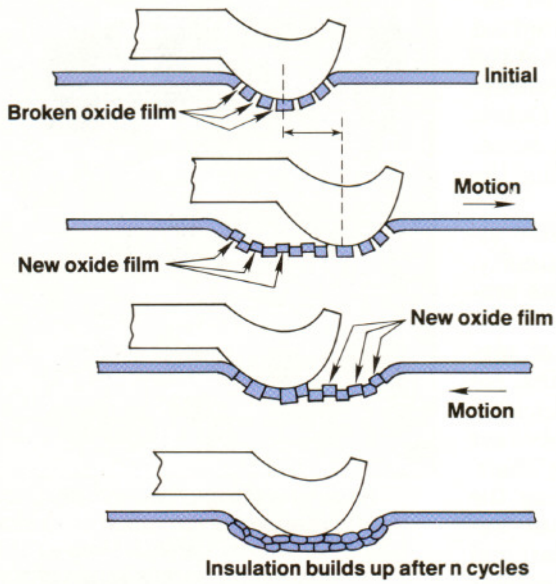
Fortunately, tin-oxide displacement is relatively easy. The reason is that tin oxide films are thin, hard, and brittle, but the underlying tin is soft and ductile. Despite its hardness, the tin oxide cannot support a significant load. It cracks easily because of its low ductility. The underlying tin readily deforms, so



A scanning electron microscope reveals the nature of a high-porosity gold plating. The area of porosity (dark holes) is still a small fraction of the total surface.



A nickel underplate reduces the corrosive effect of pores on gold plate by forming a passive film at the base of the pore site.



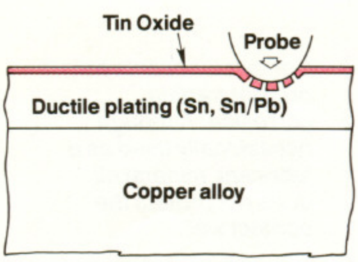
There are three phases in fretting corrosion. Initially, contact pressure is enough to break through the thin oxide film. As the contact moves, small pieces of the oxide film buildup at the contact interface. Finally, after a certain number of cycles, the tiny pieces of oxide form an insulating barrier.

cracks in the oxide widen as the tin flows. Tin extrudes into these cracks, establishing new areas of metallic contact. As a result, tin contacts have low contact resistance, comparable to that of gold at equivalent loads.

Once mated, tin contacts remain chemically stable (nonoxidizing) as long as the interface is not opened or disturbed. Opening or disturbing the contact exposes it to the atmosphere, resulting in reoxidation. Reoxidation is the major degradation mechanism for tin contacts.

Surprisingly, a major type of degradation in tin contacts results from microscopic (low amplitude) vibration. These micromotions are called fretting. Micromotions as small as a fraction of a mil are enough to fret the tin contact spots and allow formation of new oxide films on the exposed tin.

The problem with fretting is that insulating oxide mixes with the tin. The result is regions with significantly higher contact resistance.



Though tin readily forms an insulating oxide, it is common in contacts. The thin oxide is easily broken by the opposing contact, allowing current to flow.

A LITTLE NICKEL MAKES GOLD SHINE

The most advantageous and widespread use of gold contacts is in two areas. The first is low power or dry circuit applications. The second use for gold is on multiple-circuit separable connector contacts. Here, either many contacts must engage and disengage simultaneously, or size and mating force considerations keep contact force low. For example, multiposition connectors are probably best served with gold-plated contacts.

Gold plating alone does not guarantee a film-free contact surface for two key reasons. First, corrosion products which form elsewhere may migrate to the contact's surface. The second major cause of films on gold is base metal diffusion. Here, the gold is not continuous or thick enough to prevent diffusion of the base metal through it. Nickel underplates are beneficial in reducing both effects.

Electroplated gold first nucleates at isolated spots, then grows both laterally and vertically. But to prevent gold contact failure, the gold plate must be continuous. With enough lateral growth, there is a continuous gold layer over the contact surface.

If the film is too thin though, it will be porous. Porosity decreases rapidly as the film thickness increases, then levels off at a value dependent on the substrate and plating method. Tests show that a film less than 15 μin. thick tends to have excessive porosity. However, specifying a film thicker than about 50 μin. provides little benefit at increased cost.

A pore penetrating completely through the gold to the substrate is called an active pore site because it is subject to corrosion. Corrosion products build up within the pore and eventually reach the contact interface. This increases contact resistance and gives intermittent operation. For instance, if a pore penetrates to the copper substrate, copper-sulfur products will eventually migrate to the gold's surface.

Nickel helps because it produces a thin oxide film at the pore's base, inactivating the pore. Nickel itself also provides a migration barrier.

A nickel substrate reduces the required thickness of the gold film as well. The reason is that nickel is relatively hard and provides support for the gold.

In all, a nickel substrate reduces the amount of gold plating required and, thereby, the cost of the connector.

The combination of fretting and oxidation (corrosion) is called fretting corrosion, and is characterized by the presence of black spots at the point of motion. The spots indicate a buildup of tin oxide debris. Debris increases contact resistance, sometimes to the point of opening the circuit.

However, fretting does not always degrade electrical continuity. The determining factor is the motion itself.

There are three classes of mechanical micromotion: rocking, rotation, and translation. Rocking involves one part of the contact moving much like a rocking chair. Rotation results from twisting the contact. Both of these cause fretting corrosion. But translational (sliding) fretting can sometimes help clean a contact. Whether it does or not depends on the length of motion. Long movements, tens of mils, can wipe the contact clean and delay the increase of contact resistance.

However, regardless of the type of motion, any movement leads to fretting corrosion. Only the time it takes for the contact to fail is affected by the displacement length.

Numerous factors cause fretting and micromotions. For example, a cooling fan or motor may vibrate a printed circuit board and fret in the edge card connector. Or cable motions can cause fretting at the connector interface.

Differential thermal expansion (DTE) also causes fretting. In fact, DTE is often the most important and overlooked source of connector fretting. The cause of DTE is the use of different materials in a contact. For example, a printed circuit's edge connector has a fiberglass board and metal contact. The mating connector also has a metal connector, but often housed in a polymer shell. The three different materials cause thermally driven micromotions and fretting.

Fretting corrosion can be avoided in at least three ways. First, a noble-metal plating can replace the tin. Under some conditions, such as low insertion force, noble metal is mandatory. Second, fretting motions may be eliminated completely with rigid connectors; however, it is difficult to obtain such a high degree of mechanical stability. The third way is often the easiest and most cost effective. It involves applying a protective lubricant to the contact.

Fretting is the microscopic disruption of the contact interface. Eventually fretting cause the formation of an film. Unless these small film particles are removed, they can build into a thick insulating layer. The phenomenon is characterized by a series of black spots, as in the macrophotograph.

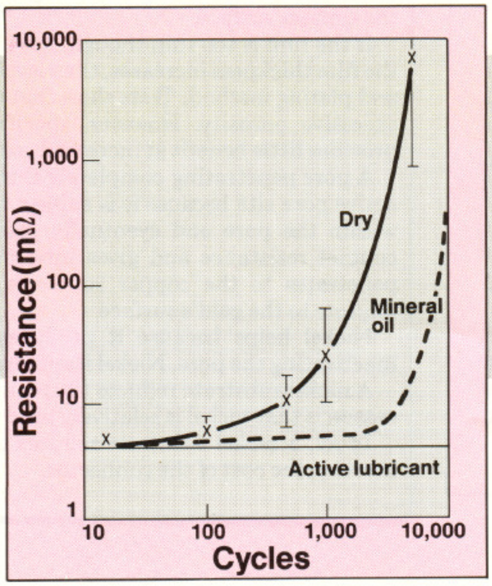
Let it slide

Contact lubricants are divided into two groups, those that reduce friction and those that make an environmental seal. Friction-reducing lubricants are most often used on gold contacts. The seal type is more closely associated with tin.

Surprisingly, lubricants can be extremely important for tin contacts when forces are low. The reason is as contact forces decrease, fretting increases. Therefore, the lubricant helps protect the tin because it is a barrier between the tin and atmosphere.

With higher contact forces, lubrication may be needed to reduce large-scale friction and wear. In this respect, lubrication permits higher contact forces than would otherwise be acceptable from mating force considerations alone.

The kind of lubricant used has an important effect on contact life. For example, mineral oil, though sometimes used as a lubricant, is effective for only a few cycles. Then, contact resistance rises dramatically. Mineral oil does not have the material properties to withstand the temperatures and wear requirements of most applications. However, lubricants designed specifically for electrical contacts provide stable contact performance to at least 20,000 cycles. This is the maximum number of cycles usually tested to. ■



Contact lubricants help prevent fretting corrosion. Although occasionally used as a lubricant, mineral oil does not protect the contact well.