Low-cost tin, as a plating for contacts, can sometimes be as good as gold

Contact force, wear requirements, circuit voltage and current—these are only some of the factors that a designer must trade off before he can safely pick tin- or gold-plated contacts for his system

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☐ An electroplater remarked recently that after all the work that goes into an electrical connector—the high-powered design engineering, followed by precision stamping and forming, high-speed assembly, and application tooling—the ultimate success of the product still depends on the last few micrometers of material which he puts on the contact surface.

Press an IC into its socket, or home a printed-circuit board into an edgeboard connector, or couple two cable connectors together—it is the contact surface that must complete the circuit and assure the uninhibited flow of electric current. This is no trivial matter; in a growing number of cases, system designers are learning that the over-all reliability of an electronic system depends as much on its interconnections as on any active solid-state device.

Generally, the most reliable contact material available is gold, which therefore has come into widespread use in multiple-circuit, separable connectors. But to come to grips with the question of whether costly gold can be eliminated in a particular application, we first must consider the reasons for its success as a contact material.

The case for gold

Gold is a noble metal: it does not react with other substances. In particular, it does not react with the atmosphere to tarnish or form oxides on its surface. No other metal, not even platinum or rhodium, is so completely free of oxide films.

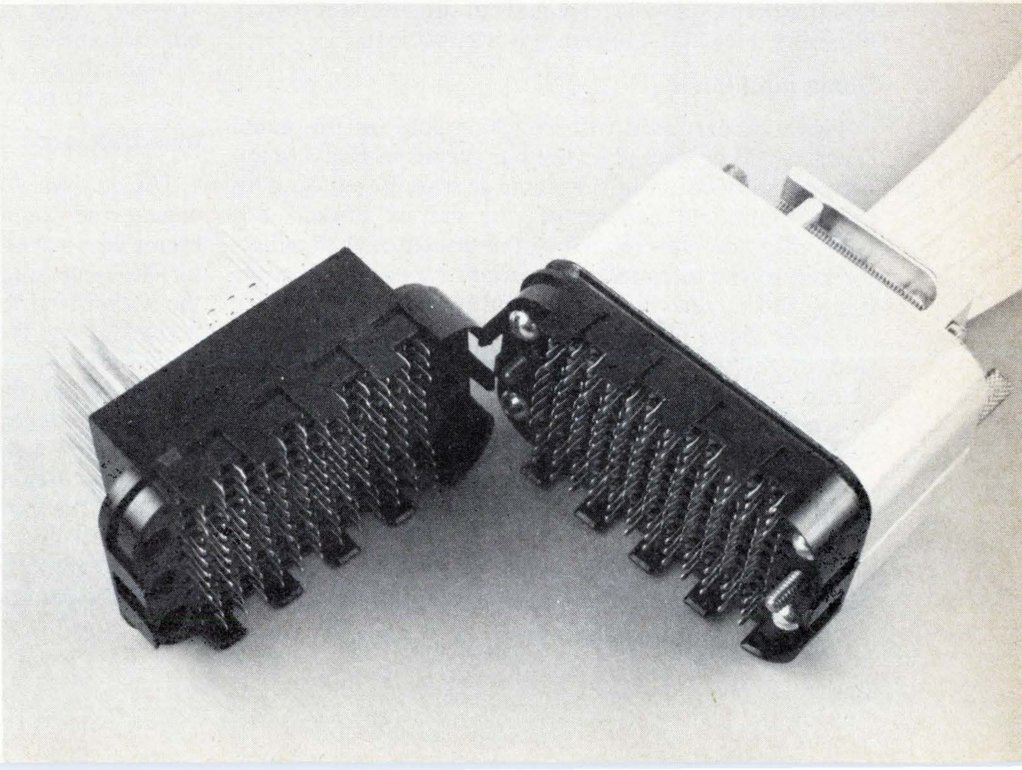
This is a very important asset because a mere microinch of oxide or sulfide film can raise contact resistance from 1 milliohm to thousands of ohms. Even films that are broken but not wholly removed during contact engagement can easily cause contact resistance to vary by factors of 10, 100, or 1,000. Any film present has to be removed, whether mechanically, electrically, chemically, or thermally, before adequate electrical contact can be established.

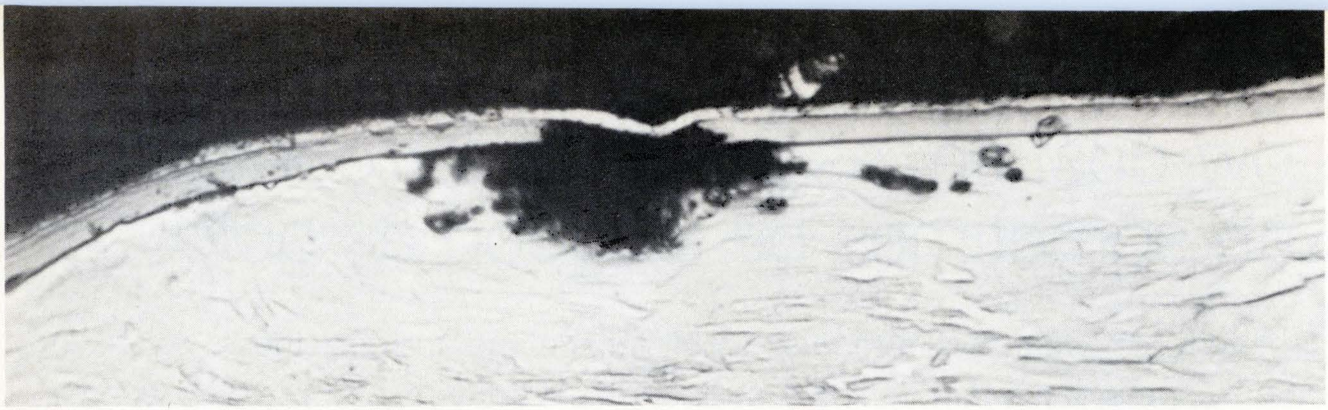
The gold plating on a contact must be pore-free and thick enough to prevent the beryllium copper or other metal below it from diffusing through. To stop this diffusion, a barrier underplate, such as nickel, is often used. Furthermore, the gold plating itself must be free of impurities and/or alloying elements that might form films on an otherwise clean surface.

If the porosity and purity criteria are not met, the gold on the plated contact must be considered a non-noble metal, and problems like the one in Fig. 1 can develop. Here, the contact was given a porous gold plating and subjected to a nitric acid vapor. In just two hours, the vapor penetrated the gold surface, ate through the nickel underplate, and attacked the underlying copper. A gold plate that can withstand such a hostile environment without degradation is costly to apply because, over and above the basic cost of the metal itself, is the cost of processing it into an adequate plating solution.

However, the nobility of gold is neither needed nor desirable in all contact applications. For instance, it's of no value in arcing contacts where it erodes rapidly and tends to weld. The sliding wear characteristics of pure

Gold or tin? Platings measured in microinches are crucial to an effective electrical contact on connectors such as this 120-pin connector pair capable of carrying 7.5 amperes per pin. But choosing gold plate can boost connector cost by as much as 50%. A multiplicity of factors determine which plating, if any, is necessary.





1. Trouble. If pores exist in gold plating, contaminants can destroy the contact face. This contact was attacked by a nitric acid vapor that in just two hours penetrated the 30 microinches of gold, attacked the nickel underplate, and ate into the copper beneath.

gold are not very favorable. It tends to stick, smear, and wear off in high-pressure, semipermanent connectors or in crimp connections, where it should not be used except in certain corrosive environments.

Tin as an alternative

Tin alloys are popular alternatives because they are relatively inexpensive. However, both pure tin and its alloys form oxide films when exposed to air. In even a moderately severe environment a tin surface can become heavily coated with oxides or other insulating corrosion products. The black inclusions in Fig. 2 are the oxide that developed in a normal room atmosphere and that has actually been driven deep into the 200-microinch-thick tin plate by the lateral motion between the contact shown and an identical mate.

What makes tin useful for contacts is the relative ease with which any oxide film can be mechanically broken through so that a low-resistance metal-to-metal contact is established with the underlying tin base. However, certain minimum values of force, motion, and geometry are required to assure that this breakthrough occurs.

Thin films can also be punctured by the application of voltage across a contact pair. When a large enough voltage is assured, films can no longer threaten contact reliability. For instance, unplated brass contacts are acceptable in 110-volt appliance plugs and sockets even though films are present. On the other hand, in connectors that handle low-level signals in the millivolt region, film resistance at the interface is very critical.

Some guidelines

The engineer faced with choosing gold- or tin-plated contacts will be helped by the bar graphs in Fig. 3 to approach the decision in a systematic way. Based on both theory and field experience, the graphs present two types of guidelines, related to the design of the connector and to the intended application. As disclosed in the figure, there are twilight areas and regions of overlap, so no single factor is likely to be decisive. Only a combination of factors can indicate which way the ultimate choice will go.

Contact force is important in the gold versus tin decision because it is vital to both surface cleaning and a low contact resistance. The normal contact force is measured along a perpendicular to the contact interface. Force is deliberately preferred to pressure because the actual interface area over which the force is applied is generally unknown and depends upon both the size and the geometry of the contacts. The area also varies with the force applied and the amount of slide during the engagement.

When contact forces are below 30 grams, they are usually insufficient to break through oxide film, regardless of the geometry of the contact. Here, gold is mandatory (Fig. 3), except where the absolute level of contact resistance is unimportant—be it milliohms or kilohms—or where the applied voltage is high enough to puncture whatever films may be present.

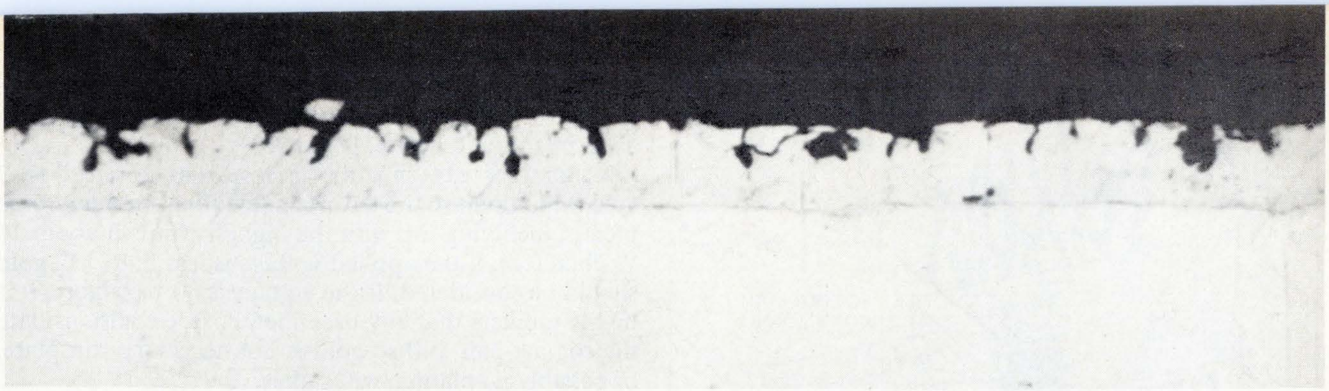
In the twilight zone between 30 and 100 grams in Fig. 3—and many multiple-pin connectors and IC sockets are in this range—other considerations become more important. If a good sliding action occurs during engagements and the environment is mild or protective, tin plating could be satisfactory down to 30 grams force. Conversely if normal force engagement occurs on a smooth surface with almost no sliding action, in adverse environments, it may be necessary to use gold at 100 grams or higher.

Normally, however, a contact force of 100 grams will almost certainly break any contact film mechanically, so that a tin-plated interface can be selected with the assurance that contact resistance will be low.

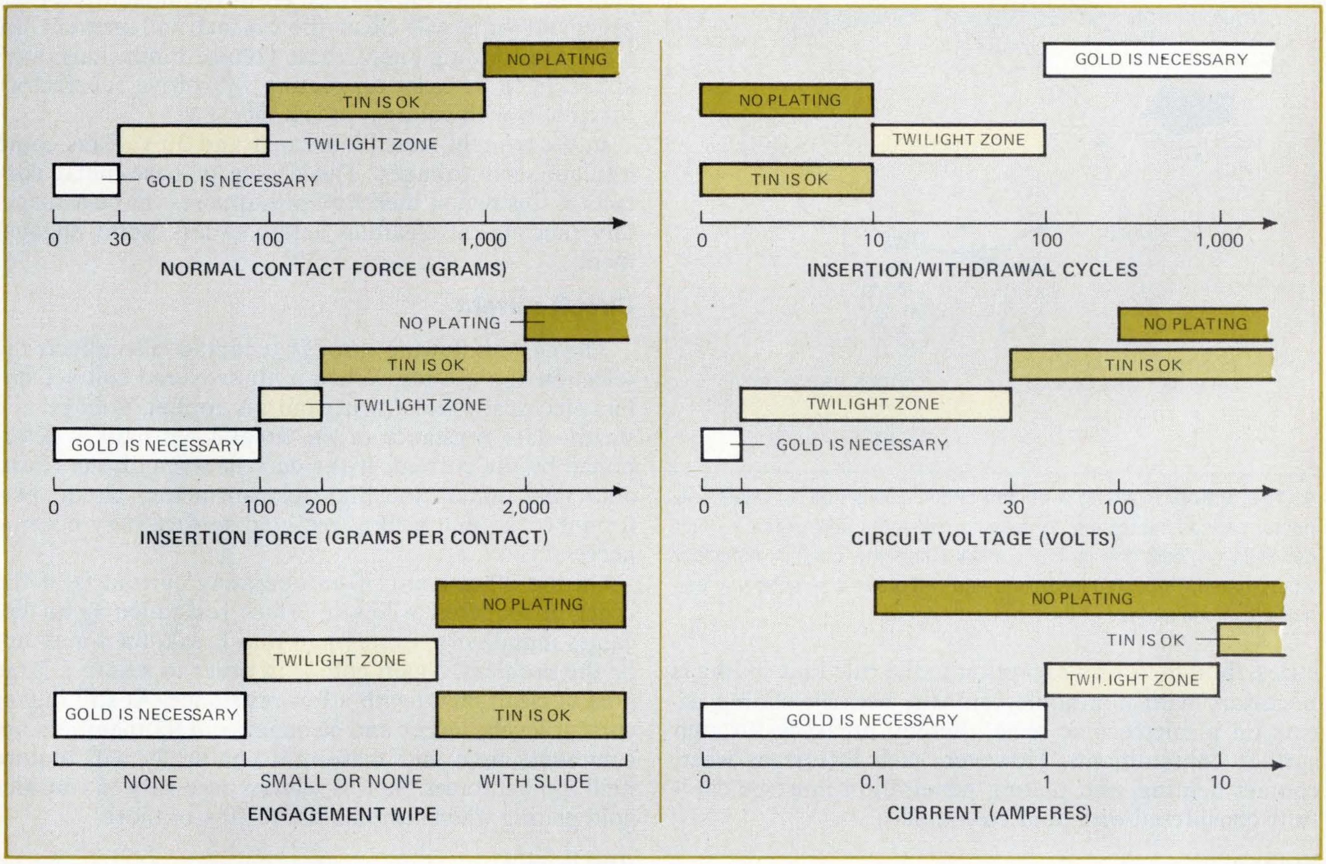
When forces are a kilogram or more, and when there is some slide during engagement, plating a base metal is probably unnecesary. With such high forces, a soft metal plating would not survive very many insertions anyway. When plating is used in such cases, it is intended to inhibit corrosion, to enhance the cosmetics or, in high-current applications, to achieve the lowest possible contact resistance to prevent overheating.

Insertion force

The human force available to engage and/or disengage the contacts usually sets a limit on the maximum number of contacts in a multiple-circuit connector. The engaging force, which is generally greater than the withdrawal force, is determined by the contact-system geometry, the normal contact force, and the friction coefficient. For instance, the insertion force is often minimized by the process of gentle lead-in tapers or ramps that deflect the contact springs during engagement. Figure 4 shows the geometry of a typical contact in a printed-circuit connector—note the curved entry ramps of the contacts. A further reduction can be accomplished by decreasing normal contact force by resorting to gold plating. For, if insertion forces fall below 100 grams per contact, wiping will be insufficient to re-



2. Attacked. One problem that tin plating can develop is the fretting corrosion shown here. The black tin-oxide inclusions, shown magnified 750 times, were driven deep into the tin plate by relative motion between this surface and an identical mating contact.



3. Plate it? These guidelines will help a designer to choose gold, tin, or no plate at all, for connector contacts. The recommendations relate the plating choice to both the design of the connector and the application for which the connector is intended.

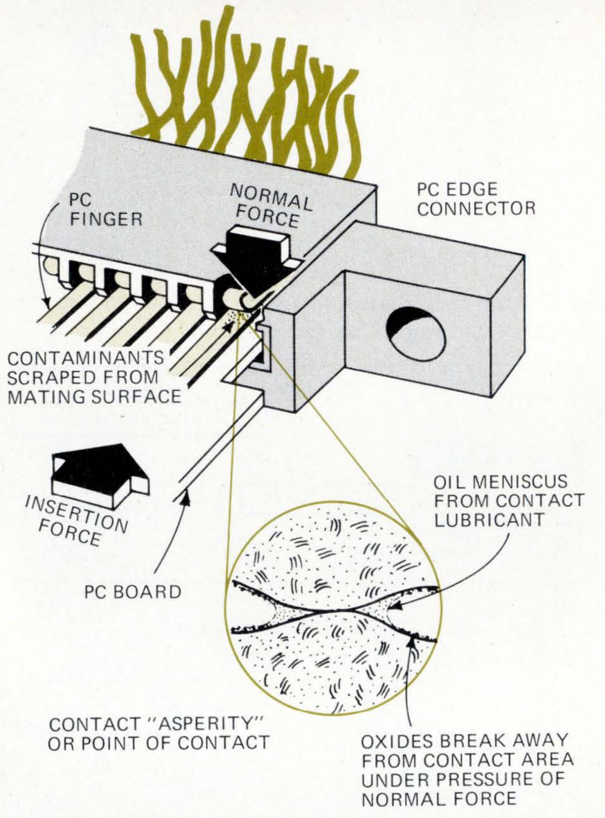
move any oxide film. Also, in miniaturized connectors, when high normal forces might otherwise be feasible, the contact retainers, usually plastic, cannot withstand the high insertion forces.

Finally, the insertion force can be further lowered by thin boundary-layer lubrication, which can reduce the friction coefficient, typically 0.5 to 1.5 in gold and tin systems, to approximately 0.1 without significantly degrading contact resistance. Thus lubrication makes it possible to operate contacts with normal forces high enough to permit tin-plated contacts at 100 grams and above, while maintaining the low insertion forces normally associated with gold-plated connectors.

The zero-insertion-force (ZIF) connector, of course, does away with insertion and withdrawal forces altogether. It incorporates a mechanism that postpones a heavy normal force until engagement is completed. Thus the severe wear problems associated with sliding under a high-normal force can be avoided. ZIF connectors have, in principle, enormous advantages. However, the expense of the added mechanical complexity in such a connector must be weighed against the savings obtainable by the use of non-noble platings. The insertion force values shown in Fig. 3 refer to good contact designs with or without lubrication, but they do not consider ZIF designs.

Engagement wipe

The combination of low normal force and absence of sliding action, as in the case of the zero-insertion-force connector, requires a film-free gold surface. But non-noble metals can be used, as Fig. 3 indicates, when higher normal forces are combined with some sliding action to clean the surface. Sharp-point contact geom-



4. The action. Inserting a printed-circuit board into an edge connector causes the mating contacts to develop a normal force which depends on both the spring constant and the contact deflection when mated. Repeated insertions and withdrawals remove tiny particles from the surface of the pc-board fingers.

etries, though, are an exception to the rule that sliding is necessary with non-noble contacts, because sliding occurs on a microscopic scale, thereby breaking through surface contaminants. However, such factors as wear, contact heating, and plating penetration must be carefully considered with pointed contacts.

Wear cycles

An application requiring many mating cycles—engagements and disengagements—often tips the decision against non-noble metals. Such metals require a large contact force and a disruptive sliding action that over repeated mating cycles are incompatible with low wear. However, it is possible to lower the wear rate by using light contract forces on special hard gold-alloy contacts.

The wear requirement should be reviewed carefully when this is the principal factor favoring the use of gold. The design engineer should avoid specifying more mating cycles than the connector could ever encounter, because it is a very expensive safety factor.

Circuit voltage

Although there is general agreement that gold is the preferred material for "dry-circuit" contacts, there is little agreement as to just what constitutes a dry circuit. A dry circuit is one in which the voltage is too low to puncture insulating films on the contact pair interrupting the circuit. Figure 3 offers some values for the circuit voltage boundaries based on theory, laboratory experiments and field experience.

Laboratory experiments disclose that about 1 to 2 volts will puncture the natural oxide films on many base metals, including tin, with the highest value at about 10 V. Therefore, if the applied voltage is less than 1 V, gold should be considered. If the voltage is 30 V or more, it is highly unlikely that any base-metal oxide could insulate the contact pair and so gold is not necessary—tin plate, or possibly no plating, will suffice.

It must be emphasized that these circuit voltage limitations assume that a film does cover the interface region and insulate the contact. However, if connector engagement wipe will clean the contact and prevent the film from forming anew, these voltage limitations don't apply. In these cases tin plating will prove satisfactory for circuits with voltages of less than 1 V.

In the twilight zone, between 1 and 30 V, films could insulate such voltages. The choice of base-metal contacts in this region therefore presupposes that a satisfactory mechanical cleaning action occurs upon engagement.

Circuit current

The current flowing through a contact also affects the selection of a plating. When a film-covered contact suffers electrical breakdown from an applied voltage, the steady-state resistance of the breakdown path is determined by the current. If the current is small, the resistance may remain too high for satisfactory circuit performance, so that a film-free gold surface may become necessary.

On the other hand, if an operating current is of the order of amperes, a low interface resistance again becomes mandatory, even when film breakdown may not be the problem. Again gold is in order to assure a large area of clean metal with a low resistance. At still higher current levels, larger and stronger contact members are commonly used and these quite naturally will require high contact forces. So it is seldom necessary to consider gold plating when currents rise to 10 A or more.

And finally . . .

Some factors which play a role in contact selection don't lend themselves to a simple graphical presentation. As an example, gold is immune to most environmental attack and should be used in corrosive environment. However, in many normal environments tin and its alloys are attacked very slowly, and will provide some protection for an underlying copper-based alloy.

There is no denying that gold delivers highest possible reliability. Moreover, in critical applications, where there is no chance to repair or remate a failed connection, gold always provides an added margin of safety.

However, the current demand for lower cost, pluggable components, and the proliferation of low, millivolt signals is indeed a heavy burden for the engineer designing interconnections. By examining each application in accordance with these guidelines, the engineer can determine if low-cost tin and its alloys can provide a satisfactory and reliable enough contact interface. □