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# Mateability of Tin to Gold, Palladium, and Silver

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## ABSTRACT

Fretting corrosion is a major failure mechanism for tin-to-tin connections. This work shows that fretting corrosion is also a serious concern when tin is mated to gold, palladium, or silver. Material transfer and oxidation of tin wear debris (produced as a result of micromotion) leads to rapid and dramatic increases in contact resistance. While antifretting lubricants retard contact resistance increases during fretting motion, the long term stability of tin-to-gold and tin-to-palladium combinations is questionable. The tin-to-silver interface behaves similar to tin-to-tin.

## INTRODUCTION

A low and stable value of contact resistance is essential in electrical connectors. Understanding the failure processes which contribute to contact degradation is basic to the correct selection of contact materials and component design, and to characterize conditions in which they can be expected to assure reliable performance. One important failure mechanism, especially for non-noble contact finishes, is driven by fretting—small amplitude relative motion at the contact interface.[1-4] This micromotion generally falls in the 10–200 micrometer range, and is caused by either mechanical disturbance (vibration) or differential thermal expansion effects.

Fretting causes metal transfer and wear. If the contact is made of a base metal, oxidation of the surface and the wear debris occurs leading to a process defined as fretting corrosion. This sequence of events often leads to rapid and dramatic increases in contact resistance. Noble metals, such as gold, do not oxidize and are not susceptible to fretting corrosion.

The mechanism for fretting corrosion is schematically illustrated in Figure 1. Figure 1a shows the initial contact spot. In Figure 1b the contact spot has moved to a new location, and a new contact spot established. At the original location the exposed tin reoxidizes. If such motions are repetitive, the buildup of oxides (fretting corrosion) can result in the formation of an insulating film at the contact interface. Figure 2 gives the results of an analysis conducted on a tin contact subjected to a fretting test (in this case, forced translational motion). Figure 2a is a trace showing the functional relationship between contact resistance and position along the fretted track. Note that resistance is highest at the extremities of the track. Figure 2b shows a photomicrograph of the track along with an x-ray line scan for oxygen. Note the strong correlation between high resistance and oxygen (tin oxide).

Questions often arise concerning the performance of tin mated to noble, or semi-noble metals such as gold, palladium, or silver. The purpose of this work is to report on the fretting corrosion susceptibility of those materials in combination with tin, and the effectiveness of contact lubricants as a countermeasure to the development of contact resistance increases.

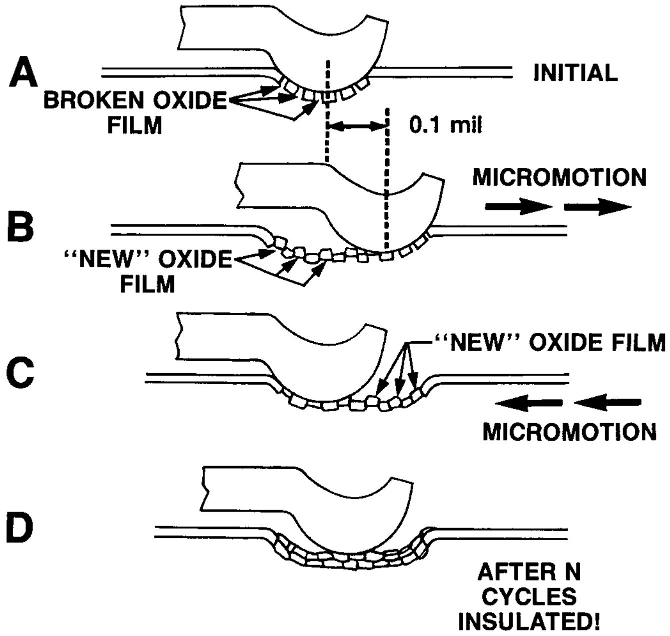



Figure 1. Schematic illustration of the process leading to contact resistance increases during fretting.

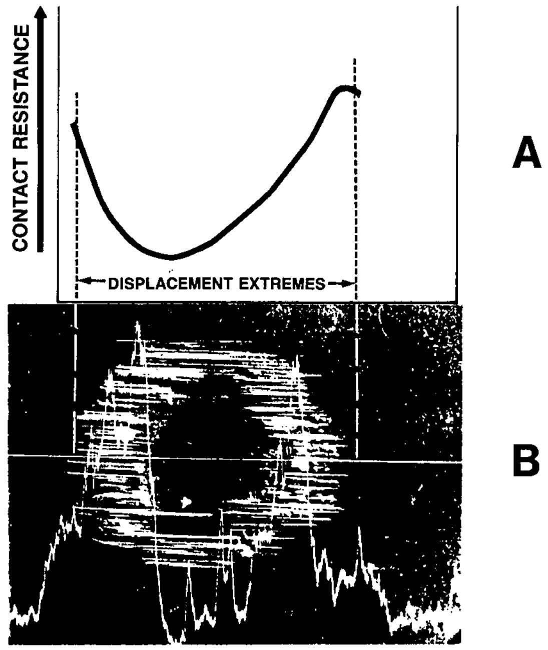



Figure 2. Illustration of the correlation between oxide and increased contact resistance during fretting. Figure 2a (top) shows contact resistance variations along the fretted track shown in Figure 2b (bottom). Figure 2b also shows an x-ray line scan superimposed on the photomicrograph of the fretted track. Note the coincidence of increased oxygen content with increased contact resistance.

## EXPERIMENTAL PROCEDURE

The extent of fretting degradation depends upon the method to produce motion and on the apparatus employed. The contact resistance changes which result may depend upon the current/voltage levels and on the procedure for measuring contact resistance. A test program in which micromotion is forced (as in this program) is useful in determining if the contact materials are susceptible to fretting corrosion. One should be aware that the results of such a test should not be used as an indication of the susceptibility of a particular connector design to fretting, and cannot provide pertinent reliability information on connector performance.

Results are given for contacts tested under three conditions: unlubricated (degreased), lubricated with an antiwear formulation, and lubricated with a proprietary antifretting formulation. The fretting tests were conducted on an apparatus which produces translational motion. This apparatus has proved useful in earlier work. Fretting motion is produced through the use of a single axis translation stage driven by a DC stepping motor. A schematic of the device is illustrated in Figure 3. The average velocity, translation, and dwell times are microprocessor controlled. For the purpose of this program, the velocity was set to 0.005 cm/second, the translation/pass adjusted to 0.005 cm, and the dwell time set to 2 seconds. Generally, faster cycling rates have been shown to increase the number of cycles necessary for degradation. A stationary rider, in the form of a 0.635-cm-diameter hemisphere, was dead weight loaded against a flat coupon mounted on the stepping motor driven stage. The normal force was set at 100 grams.

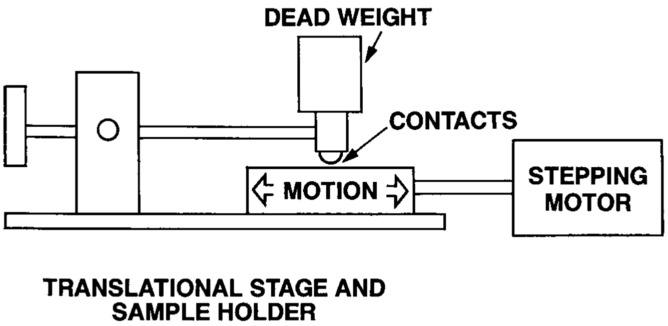



**Figure 3. A schematic of the fretting device. Motion is introduced through the use of a microprocessor controlled stepping motor.**

Contact resistance measurements were conducted with a Keithley Model 580 Micro-ohmmeter. The dry circuit mode was utilized; that is, open circuit voltage was limited to 20mv and the maximum current to 100ma. This assured that the act of measuring the resistance did not modify the interface through film fritting phenomena. Resistance was measured with contacts in the static mode (rest position) at the extremes of the translational motion. Experience has generally indicated that the highest values of contact resistance as a function of displacement along the fretted track are associated with these end positions.

The material finishes included in the program are described in Table 1.

**Table 1. Contact Material Finishes**

| Material | Thickness (μm) | Underplate (Nickel) (μm) |
|---|---|---|
| Bright Tin | 3.75 | 1.25 |
| Matte Silver | 3.75 | 1.25 |
| Gold (Cobalt hardened) | 1.25 | 1.25 |
| Palladium | 1.25 | 1.25 |

## RESULTS

### The Unlubricated Condition

Test results for degreased contact pairs subjected to fretting motion produced by the stepping motor driven device are illustrated in Figure 4. Results were somewhat similar in that ohmic values were reached in all cases within the range of 500 to 1,500 cycles. The tin-to-gold and tin-to-palladium systems are judged slightly worse, and the tin-to-silver combination, slightly better than tin-to-tin.

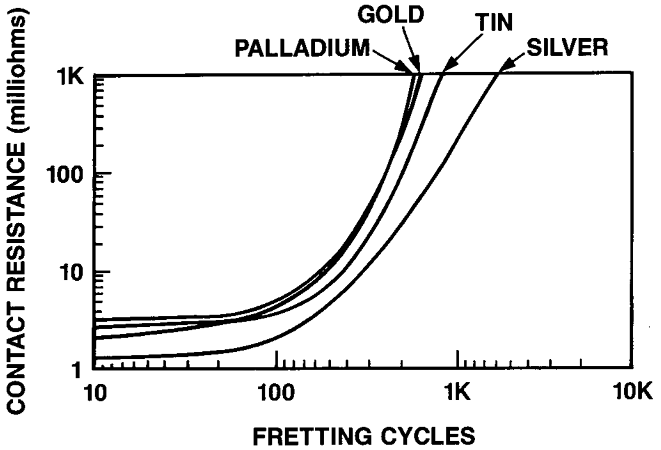



**Figure 4. Results of a fretting test conducted on degreased tin, gold, palladium, and silver contacts mated to degreased tin contacts.**

The buildup of oxidized wear debris on tin contacts due to fretting produces a contact spot appearing black.

Figure 5 shows spots developed on tin, gold, palladium, and silver contacts which were mated to tin and subjected to a fretting test. A characteristic "black spot" associated with fretting corrosion is indicated on each.

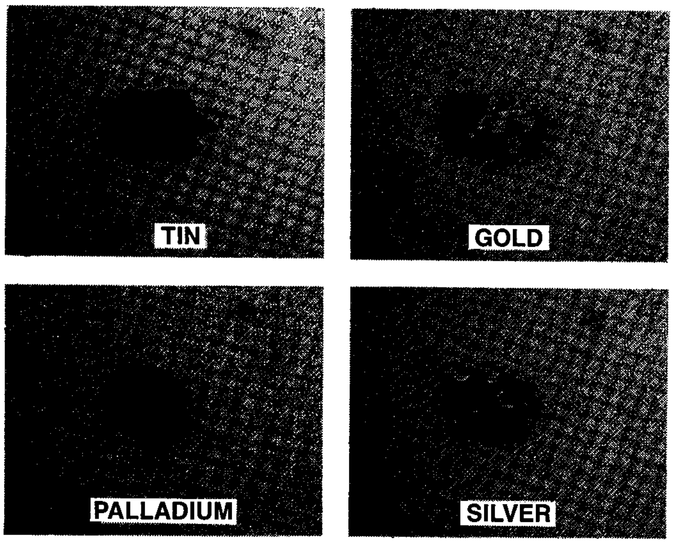
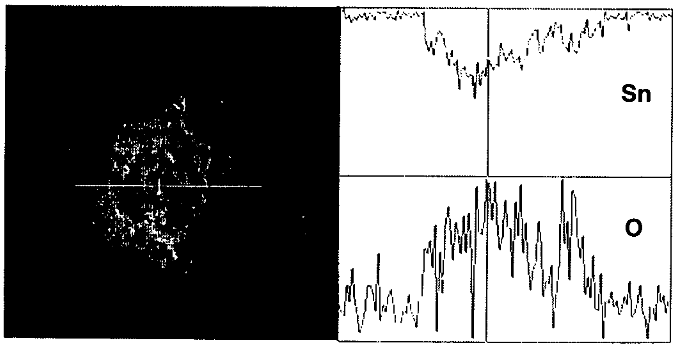


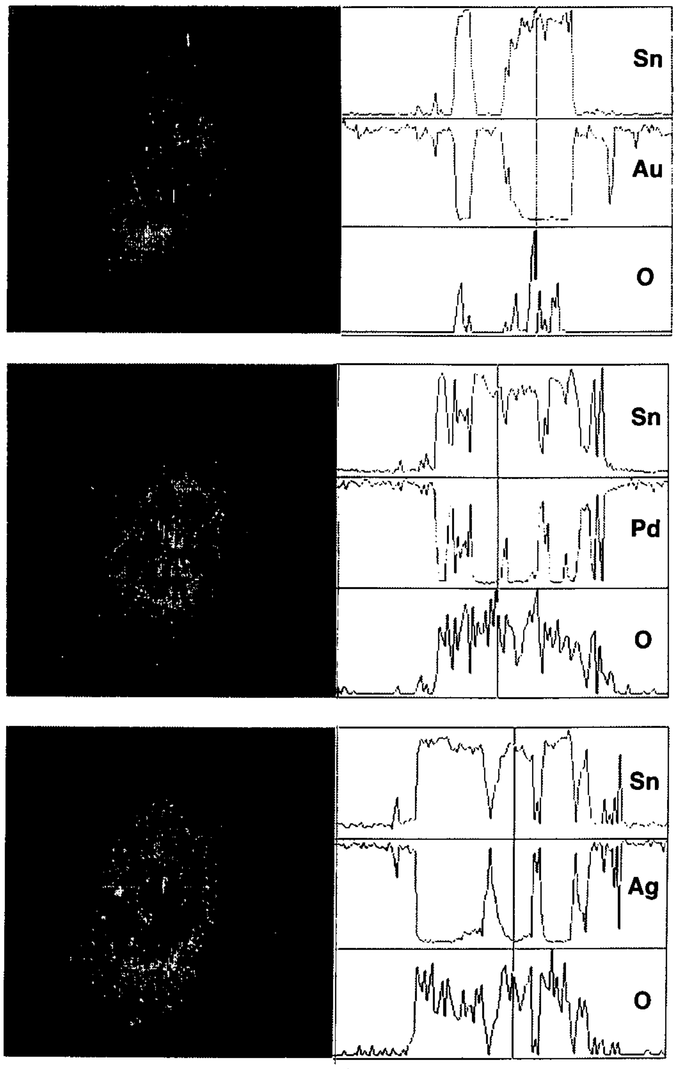

**Figure 5. Optical micrographs of tin, gold, palladium, and silver contacts which were mated to tin and subjected to a fretting test. The characteristic "black spot" normally associated with fretting damage is noted.**

When fretting corrosion is the failure mechanism, scanning electron microscope elemental analysis techniques can identify oxides at the interface of the contact. Tin oxides were identified at the interface of all contact combinations. The results of the analysis are shown in Figures 6 and 7. Transfer of tin and oxidation of the transferred tin, is indicated for each of the dissimilar metal interfaces.




**(a) Image showing contact spot and location of elemental line scan.** **(b) Results of elemental scan.**

**Figure 6. Oxidation of tin is indicated in a scanning electron microscope elemental analysis. The tin contact was mated to tin and subjected to a fretting test.**




**(a) Image showing contact spot and location of elemental line scan.** **(b) Results of elemental scan.**

**Figure 7. Gold, palladium, and silver contact surfaces show tin transfer and oxidation of transferred tin in scanning electron microscope elemental analysis. The contacts were mated to tin and subjected to a fretting test.**

The relatively poor performance of tin-to-gold and tin-to-palladium interfaces results from oxidation of the transferred tin. This leads to the formation of an oxidized tin layer on a hard substrate, and mechanical disruption of such a composite is more difficult than for the case of an oxide on a soft substrate—as an example, tin oxide on tin. Tin surfaces are always covered with a natural oxide. Despite this oxide, it is relatively easy to establish electric contact to the surface. The reason for this performance is the different mechanical behavior of tin and tin oxide. Tin oxide is hard and brittle. Tin is soft and ductile, the difference in hardness promotes cracking as the tin is plastically deformed during mating. Disruption of the oxide and extrusion of tin through the cracked oxide layer allows establishment of good electrical contact. A hard substrate, in this case cobalt hardened gold or palladium, is more able to support a corrosion film (oxidized tin) and minimize or eliminate cracking and subsequent extrusion of underlying material.

The tin-to-gold interface has been discussed in the literature.[1,2] Abbott and Schrieber comment that exceptionally poor contact performance had been noted for the tin-to-gold interface. They attribute the degradation process to surface films, oxidized wear debris, and interface motion. Mottine and Reagor have investigated fretting behavior of tin-to-tin and tin-to-gold interfaces of socketed IC devices.[2] Their conclusion was essentially that all interfaces of tin and tin-lead mated to themselves, or to gold, fail by fretting corrosion. These failures were observed both in field applications and in the laboratory.

## Lubricated With an Antiwear Formulation

The lubricant chosen for this portion of the study was a 6-ring polyphenyl ether. This lubricant has been widely recommended as an antiwear lubricant for gold contacts.[5,6] Test results for contacts lubricated with this material are shown in Figure 8. Fretting motion was provided by the stepping motor driven device. The test was continued to 10,000 cycles of operation. In all cases, contact resistance degradation was noted. However, the tin-to-gold and tin-to-palladium combinations degraded faster than tin-to-tin or tin-to-silver.

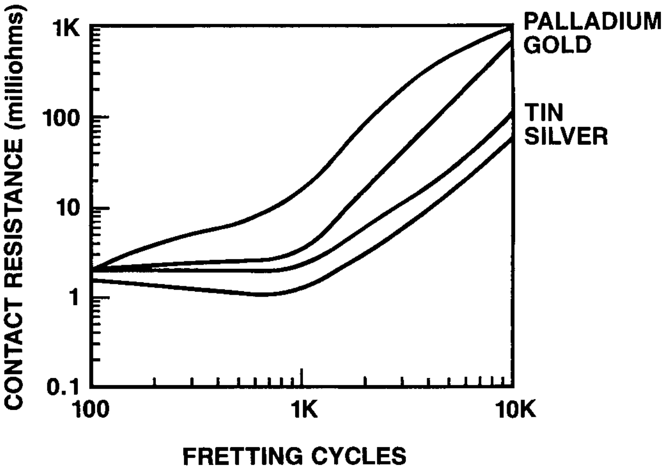



**Figure 8. Results of a fretting test conducted on tin, gold, palladium, and silver contacts mated to tin and lubricated with an antiwear formulation—a 6-ring polyphenyl ether.**

Mottine and Reagor reported on the effect of lubrication on fretting corrosion on tin-to-tin and tin-to-gold interfaces.[3] In that study, lubricated socketed IC devices were subjected to low-level vibration. The lubricant studied was a mixture of an oil and a wax. Resistance data shows that the tin-to-gold interface failed repeatedly. No such failures were noted for lubricated tin-to-tin or for gold-to-gold matings. They stated that "lubricant did not eliminate fretting related failures for the tin-to-gold interface, but did increase the threshold time to failure." Our results are in agreement and indicate that such lubricants lengthen the threshold to failure, but that the process is not materially affected.

## Lubricated With an Antifretting Formulation

A variety of synthetic and natural oils have been found to be effective in minimizing fretting corrosion.[4] Generally, it has been our experience that liquid or semi-liquids are more effective than solid lubricants. The self-healing qualities of a lubricant appear to be very important. AMP has developed a lubricant which offers very good antifretting properties.[7] The formulation is proprietary and contains special ingredients which have been shown to stabilize contact resistance increases promoted by fretting motion. This lubricant has been shown to be very effective for tin-to-tin systems.

The results of the proprietary antifretting lubricant are shown in Figure 9. Testing was continued to 100,000 fretting cycles. Throughout this test the antifretting lubricant was able to maintain low and stable values of contact resistance for the tin-to-tin and tin-to-silver combinations. However, contact resistance increases on the order of 5 to 10 times the initial values were noted with the tin-to-gold and tin-to-palladium systems. For critical applications, such increases could be unacceptable. In all cases, results for the antifretting formulation were superior to those obtained with the antiwear formulation tested.

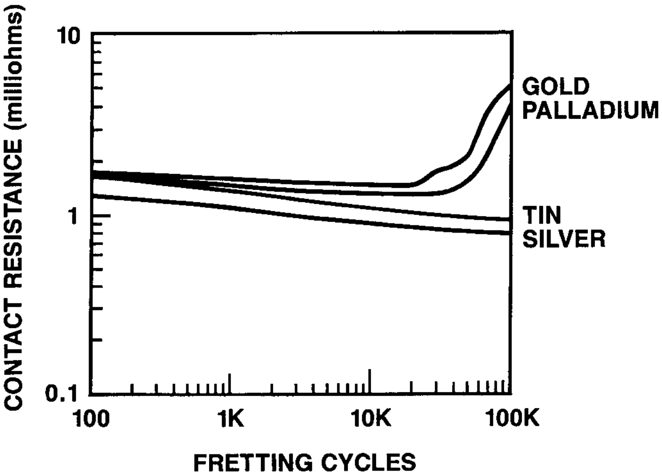



**Figure 9. Results of a fretting test conducted on tin, gold, palladium, and silver contacts mated to tin and lubricated with an antifretting lubricant.**

The increases in contact resistance for the tin-to-gold and tin-to-palladium combination are probably a consequence of fretting wear, as contrasted to true fretting corrosion. A build-up of wear debris—equivalent to a loss of contact area—is responsible for the resistance increases. The relative hardness of gold and palladium (with respect to tin and matte silver) modifies the ease with which debris may be displaced or disrupted at the contact interface. This hypothesis is currently being investigated. Testing is now being conducted on hard silver deposits—with hardness values that are comparable to cobalt hardened gold (~200 Knoop).

## CONCLUSIONS

This work shows that tin in combination with itself, as well as with gold, palladium, or silver is susceptible to fretting corrosion. Rates of degradation depend upon the metals in contact, and upon the state and type of lubrication. In both the clean and lubricated state, the degradation of tin-to-gold and tin-to-palladium would be considered worse than tin-to-tin. The performance of tin-to-silver is slightly better than tin-to-tin.

Antifretting contact lubricant formulations are preferred to antiwear contact lubricants. A proprietary formulation has been shown to be very effective in stabilizing contact resistance for the tin-to-tin and tin-to-silver combinations. However, contact resistance increases (on the order of 5 times the initial values) for the tin-to-gold and tin-to-palladium interfaces demonstrate that such combinations should not be encouraged for critical circuit applications in environments where fretting reactions are likely.

The connector applications engineer should be aware of the problems that may arise when mating tin to gold, palladium, or silver, especially when fretting conditions are known to exist. Where fretting corrosion has been shown to be a problem, substituting another metal for one half of the tin-to-tin interface could worsen the situation. Even where lubricated tin systems have been shown to operate satisfactorily, lubricated tin-to-gold and tin-to-palladium systems may not provide suitable performance (although tin to silver would be acceptable). However, if mating tin to gold or palladium is unavoidable, an antifretting lubricant is a necessary, though imperfect, solution.

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