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RESEARCH ON GOLD PRESENTED AT MAJOR CONFERENCES

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The tempo of research on gold in electrical contacts has increased, spurred by the desire to optimize performance at least cost. This review highlights significant findings presented during 1980 at the International Conference on Electric Contact Phenomena in Budapest, the Holm Conference on Electrical Contacts in Chicago and the Annual Symposium of the Electronic Connector Study Group, Inc. held in Philadelphia.

In this past year, many publications on gold in electrical contacts have been directed at achieving a better understanding of its properties so that more efficient use could be made of the metal. It was hoped that methods would be found that would lead to reduction in its consumption. Other metals have been proposed for use in separable electronic connectors and in instrument slip rings, but none matches gold's unique combination of nobility, low contact resistance and good sliding properties. Among the results of these researches are the findings that in certain cases more gold is being used on contacts than is necessary and that merely reducing its thickness can lead to considerable savings in cost. In other cases, thin gold coatings on less expensive, but still relatively corrosion-resistant, materials may be acceptable. These underlayers range from other noble metals, such as palladium, ruthenium and even gold alloys containing a large amount of base elements, to base metals which become passive in environments of practical interest at the pores which are invariably present in thin gold coatings. Another important result is that good sliding wear behaviour can be obtained from thin gold coatings on hard substrates owing to the metal's ability to act as a lubricant.

Basic Properties

R. L. Freed of E. I. du Pont de Nemours and Co., Wilmington, DE., in 'Micro-Structural Characteri-

zation of Thick, Soft and Hard Gold Electrodeposits' (1), examined a number of gold coatings by transmission electron microscopy and by selected area X-ray diffraction, using thinned foils. The deposits were obtained from baths with and without added iron (90 ppm), thallium (12 or 42 ppm), or cobalt (50 to 1 000 ppm). Structural analysis showed striking differences in the deposits, particularly in respect of grain size, growth twins and microvoids. The causes of hardening in gold electrodeposits are primarily grain refinement and secondarily voids which are obstacles to plastic deformation. Growth twins may make a minor contribution to hardening by inhibiting plastic flow. Ductility and hardness are believed to be inversely related, although ductility measurements of the samples were not made. A deposit that was free of heavy metal impurities was hard (184 KHN₁₀₀) and fine-grained, other hard deposits contained cobalt, and the deposits from iron- and thallium-doped solutions were pure, soft and relatively coarse-grained. The hardness of deposits from baths containing cobalt reached a maximum at bath concentrations of 300 ppm, and did not increase when this level was exceeded under the operating conditions used.

An electric potential exists between two dissimilar metals and current flows in a circuit having two boundaries when one of them is at a higher temperature than the other. The potential depends on the metals and the temperature difference. A. Keil and G. Weik of INOVAN-Stroebe GmbH, Birkenfeld, Federal Republic of Germany, in 'Thermoelectric Voltages at Electrodeposited Gold Layers' (2), reported that there is no measureable thermoelectric potential with junctions between pure gold and silver, but that junctions between gold deposits containing 0.22 per cent cobalt and silver give significant voltages which increase with gold thickness in the range 0.9 to 19.2 μm . The maximum potential was about 0.6 mV at a temperature difference of 80°C, which was the limit of these authors' experiments. When an intermediate nickel layer was used between the gold and the silver substrate, a thermoelectric voltage was obtained which also increased with underplate thickness, approximating 0.18 mV with 3 μm of nickel at a temperature difference of 80°C.

The value and consistency of contact resistance are the most important characteristics which determine

whether or not a component is satisfactory. Accordingly, there has always been interest in determining contact resistance for such purposes as contact materials development, production control in manufacture and for evaluating device test procedures. M. Antler of Bell Laboratories, Columbus, OH., in 'Contact Resistance Probing: Development of a Standard Practice by the American Society for Testing and Materials' (2), reported on activities to develop the science of contact resistance measurement with probes (reference surfaces with which the contact resistances of samples are measured). A new standard, ASTM B667-80, has been published in which solid fine gold is specified as the probe metal, because it uniquely satisfies the requirements of a readily available inert reference material having well-known properties. Furthermore, in the preferred shape and size (a spherically-ended rod, rivet or ball having a radius of curvature of 1.6 mm) gold has minimal influence on the surface being probed. Lastly, the results of probing with gold are generally directly applicable to many devices, since gold is one of the most widely used contact materials.

Thermal Studies

Electrical contacts may be subjected to elevated temperatures in manufacture and in service. For example, reed relay contacts may be heated to 500°C for several seconds in the glass-sealing operation during assembly. It is therefore of interest to determine the changes in morphology and hardness which can occur under such conditions. This is especially important with cobalt-hardened gold electrodeposits, because it is well known that the polymers and other co-deposited materials in them are unstable at 150°C and even at lower temperatures — although the rate of change in this range is slow. Hardness is a controlling factor in the sticking of sealed reed contacts, the

tendency to adhesion increasing as the hardness of the gold is lowered. J. Augis and T. Paskowski of Bell Laboratories, Columbus, OH., in 'The Softening of Cobalt Hardened Gold Electrodeposits' (2), reported on the heat treatment in air and in forming gas of cobalt-containing gold electrodeposits both on molybdenum and freed from their substrates. Forming gas (90 nitrogen/10 hydrogen per cent) is an atmosphere commonly used in the glass envelope of reed relays. Ageing tests were conducted for various times and at temperatures ranging from 250 to 500°C. Microhardness measurements were made on some samples which were also sectioned. Others were powdered and then heated in a differential scanning calorimeter in controlled atmospheres.

It was found that there are significant differences according to whether the ageing atmosphere is oxidizing or reducing. In air, at temperatures as low as 250°C, pinhole features appear on the surface in a few hours, in the wake of a reaction front that advances into the interior and results in a spongy structure. The reaction is essentially an exothermic oxidation of co-deposited organics to form gaseous products. In forming gas, endothermic decomposition of the organics occurs with similar morphological and hardness changes as in air, but at a much slower rate, becoming significant in an hour only at 400°C or more. Kinetic data and activation energies for these reactions were derived which relate decomposition to time of exposure in air or in forming gas at given temperatures. These results were extrapolated to lower temperatures. For example, at 150°C, 50 per cent decomposition is predicted in about 30 days in air (see Figure 1) or 69 days in forming gas.

Hardness is affected by ageing in two ways. First the development of the spongy structure which causes an indenter to crush the sample, and secondly an actual softening (annealing) of the gold matrix. Scratch

hardness determinations under a load of 0.5 g show that loss of hardness develops more rapidly in air than in the reducing atmosphere.

Gold-Solder Interface

Although gold is the contact material of choice for most high reliability electronic connectors, other contact metals are used in certain cases. For example, if contact spring members are designed for high force connectors and only a small number of matings is required, then tin or solder coatings may be acceptable. High forces can displace insulating films on base metals, but high forces also reduce the durability of contact materials, particularly those which are soft and inherently high-wearing. The question of whether different finishes can be used on the mating parts of connectors arises occasionally and in 'Performance Characteristics of Connection Systems with Gold/Tin Interfaces' (2), J. L. Radnik and K. M. Krafthefer of Molex, Inc., Lisle, IL., discussed tests with sockets typical of those which connect to printed circuits having rigid contact pins emerging at right angle from through-holes in the board. The force was approximately 700 g per contact with members designed to touch at a single point. It was found that although contact resistance remained stable on prolonged thermal ageing at 105°C and in shock and vibration tests, it rose significantly on ageing the mated contacts at 95 per cent relative humidity (RH) in air, and especially in a 5 per cent salt fog test. Failure was caused by galvanic corrosion of the tin, accelerated because it was in contact with the more noble gold. Connectors having all tin-plated or all gold-plated contacts had satisfactory performance. From these results it can be concluded that gold-tin interfaces should be avoided in applications where moisture is likely to condense on the contact surfaces.

Effects of Plating Conditions

Dry reed relays have noble metal contacts on flat blade nickel-iron alloy spring members and are sealed in a glass envelope containing an inert or reducing atmosphere (see *Gold Bull.*, 1971, 4, (3), 42-46). They are widely used in light duty switching applications because of their speed and durability. Among the important failure modes of these relays is the onset of high contact resistance or sticking. F. M. Beeftink, J. Scheepstra, and A. Steinmetz of N. V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands, in 'Gold Bath Composition and Reed Contact Quality' (2), discussed reeds having a finish of about 3.5 μm thick electrodeposited gold overlaid with a thin coating of ruthenium.

It was found that when erosive wear of the contact finish occurs evenly over the entire surface, its life is prolonged. Early failure ensues when wear is con-

fined to a small region, which leads to pip formation on one contact and a corresponding crater on the other. In turn, this causes sticking and rising contact resistance. 'Flat' erosion is promoted by occluded carbon in the gold coating which, with cobalt-hardened gold electrodeposits is related to cobalt content. The levels of co-deposited cobalt and carbon increase with the concentration of unbound cobalt in a conventional bath made up of $\text{KAu}(\text{CN})_2$, citric acid and KH_2PO_4 , and having cobalt both as the EDTA complex and as a soluble salt (unbound to cyanide or to EDTA). A concentration of 40 mg/l of unbound cobalt in the bath is considered ideal at the plating conditions that were used, and results in a carbon content of 0.3 per cent in the deposit. The carbon is in the form of an occluded organocobalt complex and an organic polymer.

Solution contamination by nickel originating from attack of the blade substrate must be kept low because, although nickel also elevates the carbon content of the deposit, its presence promotes early failure for unknown reasons. Surprisingly, nickel does not co-deposit with the cobalt, but displaces it from the cobalt-EDTA complex. The level of nickel is kept low by solution drag-out and by replenishment of the bath with nickel-free gold and cobalt compounds.

Tribological Studies

In 'Sliding Wear of Metallic Contacts' (3), the address of the 1980 recipient of the Ragnar Holm Scientific Achievement Award of the Holm Conference, M. Antler gave a comprehensive review of current knowledge of contact wear. Emphasis was placed on gold, particularly as it is used in separable electronic connectors. Wear was discussed in terms of five mechanisms: adhesion, abrasion, brittle fracture, fretting and delamination. A new explanation was given for the large differences in rates of adhesive wear observed for gold electrodeposits from different processes; the wear of inlay and of electrodeposited golds was compared; the influence of substrate topography and mechanical properties on the rate of wear of gold was explained; and the first experimental data on the wear of gold electrodeposits during fretting were given. The key points in this paper were:

- Sliding wear of metallic contacts often limits the life and reliability of connectors and slip rings, and is significant in determining product cost when noble metals are used. Run-in phenomena dominate the wear process in many cases and the details of metal transfer and loss during running-in may be quite different from those under steady-state conditions.
- Adhesive wear is due to the formation of strong bonds at touching asperities, especially with clean surfaces. This can occur in mild or severe regimes, according to load, and the extent of surface damage can

vary significantly. The adhesive wear process called **prow formation**, which is observed with many contact metals, including gold, palladium, silver, tin and solder, entails massive transfer of material from the member having the larger surface involved in sliding, to the smaller. This material can subsequently appear as loose debris. When sliding occurs repeatedly in the same track there is a transition to a process called **rider wear** in which, in the severe regime, only the smaller member loses metal by transfer. Conditions for this transition depend on the material, load, track length and surface roughness, but it occurs usually within the expected lifetime of components, for instance after 150 to 200 passes under a load of 100 g on a 1 cm long track in the usual range of roughness for gold sliding on itself.

— Adhesion between many dissimilar contact metals, such as gold and rhodium, is so strong that the recently proposed compatibility theory appears not to be a satisfactory guide in the selection of contact material pairs. Gold prows initially form on rhodium riders with attendant high friction and wear.

— The adhesive wear of numerous types of gold electrodeposits has been examined in detail and it appears that ductility of the metal is the key to determining whether high wear by prow formation will occur. Brittle gold coatings, such as those containing cobalt and obtained from acid cyanide baths, which have a tensile elongation below 0.4 per cent, are preferred to more ductile deposits. Ductile, hard or soft, pure or alloyed gold coatings, with or without co-deposited organic polymer, are prone to adhesive wear. Thus, neither deposit hardness nor its polymer content is a reliable guide to the selection of electrodeposited golds for low adhesive wear. The common view that co-deposited polymeric materials are lubricants has not been proven and is probably incorrect, but such substances can contribute to the brittleness of deposits. Gold coatings prepared by pulse plating are generally more likely to wear adhesively than those prepared from the same bath by DC plating. Ductile wrought coatings, such as those prepared by mechanical cladding, are also prone to adhesive wear, but this tendency can be reduced if they are hard and contact lubricants are used. The relationship between ductility and adhesive wear results from 'junction growth' whereby the area of contact increases during sliding, which in turn promotes the subsequent formation of large transfer prows and of coarse wear debris. Junction growth is illustrated in Figure 2.

— Abrasive wear is caused by the ploughing of a surface by an opposing member that is rough and substantially harder. Fracture may occur with brittle materials. If the sliding members consist of noble metal contact finishes on base metal substrates, porosity may develop in the wear track and with it the

possibility arises that corrosion will occur in aggressive atmospheres. Ductile electrodeposits and mechanically clad finishes resist fracture wear.

— Fretting wear is the result of small amplitude oscillatory movement which occurs when mated contacts are subjected to vibration or other mechanical stresses. Wear debris accumulates between the contacts and, if of base metal, will oxidize and cause contact resistance to increase. This is a significant failure mechanism with base metals and it can occur also with gold-coated contacts if the finish wears through to the basis metal. In favourable cases, lubricants can minimize degradation due to fretting corrosion.

— Delamination wear occurs in repetitive pass sliding when voids nucleate below the surface, grow into elongated cracks which become continuous, eventually emerge at the surface and finally result in the loosening of thin sheets of debris. This process can contribute to surface damage during fretting wear for a large number of cycles, but is not significant during sliding for a small number of passes.

— Hard ductile substrates and underplates are desirable, for they can lower adhesive, abrasive and brittle fracture wear, and minimize the increase of contact resistance during fretting wear in some cases when thin noble metal finishes are used. Finishes of thin gold on less noble, hard, metals are a promising class of wear-resistant, low friction contact materials.

— Contact surfaces should be smooth when noble metal finishes are used. In addition to minimizing porosity in the as-deposited coatings, smooth surfaces resist both adhesive and abrasive wear. However, 'immobile' solid contact lubricants, such as microcrystalline waxes, are more easily removed from smooth than from rough surfaces. Thin films of fluids are more persistent on smooth surfaces and may therefore be preferred.

Fig. 2 Brittle gold electrodeposits have been found to be less prone to adhesive wear than ductile deposits, and the reason lies in junction growth which is shown schematically in this sketch. An asperity in contact with an ideal flat surface is modelled by the solid lines. When a normal load is applied, the asperity is deformed so that contact occurs along *ab*, and the surfaces adhere strongly. Then, if a tangential stress is imposed in the direction of the arrow, the junction grows as shown by the dashed lines, and the two surfaces move slightly together. Ductile materials can undergo large junction growth, but brittle materials will break before growth becomes extensive

The escalation in the price of gold has stimulated research to reduce the amount of the metal which is used in low force, multi-contact separable connectors. Such devices are required to have low contact resistance on initial mating, after repeated cycling and after simulated service in corrosive environments. A widely used finish is 2 μm of cobalt-hardened gold on both members. One approach towards cost reduction is to use thinner gold coatings on less expensive, but still relatively noble underplates such as palladium or ruthenium. Another is to use gold alloy electrodeposits containing a significant percentage of base metals, such as an 18 carat alloy of gold with copper and cadmium, either as a finish or as an underplate. A third method is to substitute a less noble material which may have a flash gold coating on its surface for one member, while retaining the normal gold deposit on the opposing contact. Examples of these approaches were reported upon by H. Grossman and M. Huck of Doduco KG, Pforzheim, Federal Republic of Germany, in 'Tribological Studies of Electroplated Sandwich Layers on Connectors' (2). Their model connector was of the spring blade type with four points of contact and a normal load of 80 g at each of these. Testing involved (a) insertion and withdrawal for up to 1 000 cycles with measurement of contact resistance after the first cycle, after 100 cycles and at the end of the test, (b) exposure of the unmated connectors in separate groups after up to 1 000 insertions, following which the parts were remated and contact resistance was measured (the connectors could also be inserted and withdrawn after exposure with monitoring of contact resistance), (c) measurement of insertion forces after increasing numbers of mating cycles. Exposures were for six days in air containing 400 ppb each of SO_2 , H_2S and NO_2 at 75 per cent RH and 25°C. These tests were intended to assess the wear and corrosion resistance of the contact materials: rising contact resistance implying that wear-through to the underlying metal (a nickel underplate or a copper alloy spring material) had occurred and/or that the surface was being corroded.

Exhaustive testing showed that performance similar to that of the control connector with 2 μm of cobalt-hardened gold on both contact surfaces could be obtained with systems consisting of 0.2 μm of gold on 2 μm of palladium, 1 μm of cobalt-hardened gold on 1 μm of ruthenium, or 2 μm of cobalt-hardened gold on the spring mated to 0.2 μm gold over 2 μm palladium on the blade. Ruthenium is brittle and prone to severe wear which accounts for the poor performance of contacts which had a 0.2 μm gold flash on this metal. Palladium on an 18 carat gold-copper-cadmium alloy electrodeposit was not a corrosion-resistant combination owing to porosity in the palladium and the reactivity of the gold alloy. A

final flash coating of gold on the palladium upgraded performance considerably.

The significance of this work is that it suggests directions that can be taken to utilize gold in the most efficient manner. It is clear, however, that extensive testing is necessary to assess the merits of proposed new systems — the results of studies such as this may be different with other connector designs and when different tests are employed. Also, since the physical characteristics of the deposits, such as their wear resistance, are affected by the plating process, their optimization is necessary before it is possible finally to decide the merits of any approach.

S. A. Barber and E. Rabinowicz of the Massachusetts Institute of Technology, Cambridge, MA., in 'Material Selection for Noble Metal Slip Rings' (3), discussed the 'noise' or variability of contact resistance during sliding between various pairs of noble metals in a simulated slip ring configuration at loads of 0.5 to 30 g. From short term tests, it was found that the least noise occurred when the ring was made of gold, irrespective of the brush material. The authors suggested that iridium and rhodium brushes are preferable to those made of gold, silver, platinum or palladium. Iridium and rhodium are immiscible with gold and therefore are expected to have reduced friction and a lower wear rate; these latter properties, however, were not measured as part of the study. Long term sliding — two weeks at 10 rpm — with an iridium brush on a gold cylinder and a gold brush on an iridium cylinder, conducted in the presence of organic vapours, showed the latter combination to become quite noisy at all loads, while the former was virtually noiseless under a load of 8 g or more. The causes of noise generation were not investigated, but it was postulated that insulating friction polymers formed on the iridium. This is a well-known problem during sliding with members of the platinum group metals. Films that develop on iridium rings have a greater effect than those which form on iridium brushes, presumably owing to the large difference in the relative areas of the contact surfaces exposed to the environment in the two configurations.

Satisfactory substitutes for gold on low force electronic connector contacts have not been developed, although new investigations reveal how the amount of the metal which is utilized can be reduced. T. Sato, Y. Matsui, M. Okada, K. Murakawa and Z. Henmi of Fujitsu Laboratories, Ltd., Kawasaki, Japan, in 'Palladium with a Thin Gold Layer as a Sliding Contact Material' (3), described the wear and friction behaviour of multi-layer coatings of electrodeposited gold (0 to 3 μm thick) on 0.5 μm palladium over 1.5 μm of Watts nickel. Their apparatus employed substrates of phosphor bronze wire, 0.9 mm in diameter, in a crossed-rod configuration such that

wear was localized to a spot on the moveable member and spread out on a 6 mm long track on the stationary member. Normal load was 300 g, and the number of passes (a forward and back traverse is two passes) was varied in increments up to a total of 200. Such specimens and testing conditions are a reasonable simulation of the service conditions in common connector systems. Wear was determined by measurement of track width, X-ray electron probe elemental analysis and by exposure to air containing 10 ppm H_2S which revealed the substrate areas exposed as a result of sliding. The coefficient of kinetic friction (μ_k) and contact resistance were also determined. The gold coating, deposited from a proprietary bath containing aliphatic amines, was quite soft (110 KHN₅) and the palladium, from a proprietary alkaline bath, had a hardness of 285 KHN₅.

The first studies with 0.5 and 10 μm palladium alone showed it to have an unacceptably high μ_k , initially about 0.55, and to wear excessively, as revealed by scar measurements and the corrosion tests. For comparison, gold was also tested at thicknesses of 0.75 and 10 μm , without the palladium underplate, and gave an initial μ_k below 0.2 and much less wear than had been observed with palladium alone, especially when the thinner deposits were compared. This result for pure gold is interesting, because such behaviour is not unlike that generally observed with the more common cobalt-hardened gold electrodeposits which are considerably harder.

The specimens having a gold coating on 0.5 μm palladium showed outstanding performance, friction and wear diminishing with increasing gold thickness, particularly in the range of 10 to 100 nm, as illustrated in Figure 3. As little as 10 nm of gold on 0.5 μm of palladium was nearly as effective as 750 nm of gold without palladium, giving a μ_k which did not exceed 0.3 for up to 200 passes and a minimal increase in scar width. Both gold and palladium debris were found to be present in the wear areas of the members. It is assumed that the effectiveness of gold is due to its acting much like a solid lubricant for the underlying metal, coupled with an ability to alloy mechanically or thermally with it. The authors proposed that a composite of thin gold on palladium be considered as a replacement for thicker gold.

Environmental Investigations

Former practice for most connectors and printed circuit boards involved plated finishes with a minimum thickness of 1.25, 2.5 μm or even more gold, so as to minimize the possibility of having significant intrinsic (as-plated) porosity in the deposit. This originated in the view that service environments are generally chemically aggressive and may generate corrosion products at pore sites which cause contact

Fig. 3 The coefficient of friction of palladium sliding on itself is reduced when a gold coating is applied to both members. In this example, from sliding studies with 0.5 μm of palladium underplate on 1.5 μm of nickel subplate on a phosphor bronze substrate under a load of 300 g, the reduction in one pass is at a maximum with only 0.1 μm of gold, although slightly greater thicknesses are required when sliding is continued for an additional period

resistance to increase, thereby contributing to the unreliability of the system. With the increase in the price of gold, it has become important to determine the actual behaviour of devices having contacts plated with gold to various thicknesses, including some much thinner than previously used. Such information could lead to more meaningful specifications and perhaps show that a reduced thickness of gold would not necessarily degrade product quality. W. Reyes, R. Currence, E. F. St. Peter, J. Liao, and G. Bolger of Xerox Corp., El Segundo, CA., in 'Performance of Thin Gold in the Office Environment' (1), described a study of printed circuit boards with gold contacts, 0.38 to 3 μm in thickness on a nickel underplate, that were mated to connectors having contacts clad with 75 gold/25 silver per cent alloy at least 2.5 μm thick. The connector contacts were bifurcated, with a force of about 100 g per tine. Contact resistance was measured after service for up to 9 years in four regions of the U.S.A. (East, Midwest, Southwest and West). Most of the operating equipment had been in typical air-conditioned business machine rooms which had a maximum temperature of 30°C and a maximum RH of 55 per cent. Copier electronics are forced air cooled, so that temperature in the vicinity of the contacts is about 45°C, with RH correspondingly lower than the room ambient. Some 10 000 contact resistance determinations were made and 20 000 junction surfaces examined under a microscope at magnifications of 10 to 50X.

From a statistical analysis of the contact resistance data it was found that there was some variability in

the values of this characteristic, the medians of which exceeded by several milliohms those of unaged 'factory' samples. The maximum changes of contact resistance were of the order of tens of milliohms. There was, however, no relationship between contact resistance stability and gold thickness, nor was there any significant ageing effect, even with thin deposits — the values for 6 to 9 year old samples were similar to those for 3 to 5 year old samples. Furthermore, the microscopical examinations showed that there was no corrosion at pores or migration of corrosion products from adjacent un-plated areas of the connector structure onto the mating surfaces. This is an important result, since the porosity of the gold coatings (determined by exposure for 2 hours to SO_2 — see ASTM B583-73) varied considerably: from 0 to 1 pore/cm² at a thickness of 1.75 μm , to 15 to 100 pores/cm² at a thickness of 0.38 to 0.5 μm . However, the worst performing samples had had an unusually high number of mating cycles (100 to 150) which suggests that wear of the gold and exposure of underlying base metal had occurred. Wear is believed to be more important than porosity and environment in determining the thickness of gold which is required for products of this type. A secondary cause of contact resistance increase, particularly for the samples for which the high values were found, was contamination by insulating particles of epoxy-glass from the printed circuit board, nickel and/or copper debris from its chamfered insertion edge, and atmospheric environmental dust. The authors concluded also that accelerated tests which cause corrosion at pores, and which are traditionally used for predicting contact performance, are unsuited to evaluating products intended for service in business offices.

Although gold is unaffected by even the most severe environments, thin coatings of it on corrodible substrates such as copper, copper alloys or nickel may degrade due to corrosion of the underlying material at pores in the gold. The traditional approach to the solution of this problem has been to use gold coatings so thick as to assure virtual freedom from porosity, and this has often required electrodeposits 2.5 μm or more in thickness. An alternative approach to ensure corrosion resistance has been to utilize substrates which are inert, or at least corrode only slowly. Such materials develop passive films, and are therefore unsatisfactory as contact materials by themselves because of the electrically insulating characteristics of these films. Thin, inherently porous gold coatings may, however, provide the required low, stable contact resistance, while passivation of the substrate alleviates the problems of corrosion at pore sites. This principle in materials selection is used to a limited extent with thin gold coatings on electrodeposited equiatomic tin-nickel alloy coatings in applications

where the part is not significantly deformed, and in which possible fracture of the finish due to the low ductility of the underplate is avoided.

W. H. Abbott of Battelle Laboratories, Columbus, OH., in 'Field and Laboratory Studies of the Contact Resistance of an Amorphous Metal Alloy' (3), discussed the $\text{Ni}_{63}\text{Fe}_4\text{Cu}_{12}\text{B}_{13}\text{S}_8$ alloy as a substrate for gold. This alloy is prepared by rapid solidification from the melt to impart chemical homogeneity and an amorphous structure, both of which contribute to good corrosion resistance, and is reasonably ductile. Coupons coated with a 60 nm thick gold strike or with such a strike plus 250 nm of an acid hard gold were compared with samples of nickel with coatings of 1.25 μm of the acid hard gold. The finish of the nickel substrate was rough so as to ensure that the gold deposit on it would be highly porous. Samples were then exposed to a variety of environments for different lengths of time, following which contact resistance was determined with a gold probe according to ASTM B667-80 (see above). The environments ranged from a benign laboratory air exposure in covered containers to severely aggressive ambients such as 10 per cent SO_2 at 85 per cent RH for 24 hours, a flowing mixed gas containing fractional ppm levels of H_2S , SO_2 , NO_2 and Cl_2 at 75 per cent RH, and field exposure in a paper mill, a steel plant and an oil refinery. As expected, it was found in almost all cases that contact resistance of the thicker gold deposits on nickel degraded more rapidly than that of 60 nm of gold on the amorphous alloy. The finish consisting of 250 nm of hard gold on 60 nm of the gold strike on the amorphous material was either better than, or equivalent to, the strike alone. However, a disadvantage of the substrate is that it is a relatively poor conductor. Its contact resistance (20 milliohms at 100 g for a thinly gold-plated material) is higher than that of gold on nickel (2 milliohms) when tested under the same conditions.

Conclusion

The recent escalation in the price of gold has in general not resulted in its replacement in electrical contacts. The researches to which it has given rise have, however, made it clear that gold can be used in conjunction with other metals having suitable chemical and mechanical characteristics in ways which provide excellent performance at reduced cost.

References

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- 2 'Proceedings, 10th International Conference on Electrical Contact Phenomena', Budapest, Hungary, August 25-29, 1980.
- 3 'Proceedings, 26th Annual Holm Conference on Electrical Contacts', Chicago, IL., September 29 - October 1, 1980.