The Wettability and Dissolution Behaviour of Gold in Soft Soldering

H. Heinzl and K. E. Saeger

DODUCO KG, Pforzheim, West Germany

Even though an increased cost consciousness on the part of the manufacturers of electronic equipment has become noticeable during the last few years, gold continues to be one of the important metals for the electronics industry. To a large extent this is due to the excellent contact properties exhibited by gold and by gold-rich alloys. Other arguments for the use of gold in this field of application include its high resistance against atmospheric corrosion and the resulting ability to protect silver and base metal parts during inevitable periods of storage. Furthermore, it appears extremely difficult to find a substitute for gold in certain types of printed circuits and micro-electronic devices.

As soft soldering is a method of joining very much used in the assembly of electronic devices, it is quite often necessary to solder gold and especially thin gold coatings. This has not always been without its problems, and for this reason a great many papers on this subject have been published. The observations on the solderability of gold and the conclusions drawn from them, however, differ widely. Several authors (1, 2 and 3 for example) have maintained that gold coatings will aid the soldering process, others (4, 5) argue that problems with the solderability of gold coatings are mainly due to inadequate surface preparation. Disque (6) and Barber (7) advise against the use of gold coatings if solderability is of importance because the tin-lead-gold alloys formed in the soldering process with tin-lead solders have a high surface tension, which, in turn, leads to poor wetting. Furthermore, dewetting and "balling" of the solder has been observed with electrodeposited gold layers of 1.2 μm thickness (8). According to Harding and Pressly (9) sound solder joints are only possible with coating thicknesses below 1.2 μm . Harmsen and Meyer (10) advocate the use of a very thin gold flash only, i.e., coating thicknesses below 0.5 μm . On the other hand, it has been stated by Thwaites (11) that with thin gold coatings (1 μm), because of their porosity, solderability deteriorates quite rapidly. Probably the most impor-

tant problem with soldering gold arises from the fact that gold not only dissolves quite readily in tin and in the customary tin-lead solders but also forms a number of intermetallic compounds which may cause rough surfaces and embrittlement of the solder joint if the gold concentration reaches about 5 weight per cent (12).

The problems mentioned occur mainly if the customary tin-lead solders are used. According to the literature (13, 14 and 15) it should be possible to overcome them by applying solders containing indium. The joint strengths obtained with solders of this type appear to be lower than those observed on joints made with the more usual tin-lead-type solders (4, 15); for a great number of applications, however, this will not pose any problems. The indium-bearing solders have a lower tendency towards embrittlement because the formation of the gold-tin intermetallic compounds is suppressed (13, 14). The wetting behaviour of these alloys should also be better than that of tin-lead solders (16). Quantitative data are not, however, given by the authors men-

Fig. 1 The dissolution of fine gold in various solders as a function of the temperature of the solder bath

Fig. 2 Micrographs showing the differences in severity of attack on gold wires for different compositions of solder

- (a) (top) Sn-40Pb, 240°C
 (b) (middle) Sn-33Pb-18Cd, 260°C
 (c) (bottom) Sn-29Pb-17.5In-0.5Zn, 245°C × 60

tioned above. As the interest in these problems continues to be considerable it was thought useful to carry out an investigation into the wetting and dissolution behaviour of a number of different solders, part of which has been published elsewhere (17).

Dissolution of Gold in Soft Solders

The dissolution behaviour of gold in different solders was determined by dipping annealed pure gold wires into a number of solder baths. The wires

had a diameter of 1 mm, and were fluxed with rosin dissolved in butyl acetate. The samples were moved downward into the solder bath for 15 seconds and then retracted with the same speed so that the lower part of the wire was in contact with the solder bath for 30 seconds. After the dipping procedure, that part of the wire which had been submerged was cut off and analysed. By repeating this test at different temperatures of the solder bath it was possible to determine the amount of gold that went into solution as a function of bath temperature. This procedure corresponds to the testing method used by Harmsen and Meyer (10). Gold is dissolved most rapidly in pure tin, and this behaviour is changed only insignificantly if the solder bath is alloyed with 7 weight per cent gold. In both cases the curves for the quantity of gold dissolved away from the dipped wire rise noticeably with temperature and show a very steep rise at approximately 260°C, as may be seen from Figure 1. The curve for the eutectic tin-lead alloy rises rather slowly for temperatures up to 200°C. For temperatures above 200°C, i.e., in the region interesting for practical purposes, the rate of

Table I
The Dissolution of Electrodeposited Gold in Soft Solders

Solder	Type of Electro-deposit	Coating Thickness After Test μm
Sn	(1)	0
	(2)	1.5
	(3)	0
	(4)	0
	(5)	1.5
Sn-40Pb	(1)	0
	(2)	0
	(3)	0
	(4)	0
	(5)	5
Sn-29Pb-7.5In-0.5Zn	(1)	3
	(2)	3
	(3)	0
	(4)	4
	(5)	4.5
Sn-33Pb-18Cd	(1)	2
	(2)	4.5
	(3)	1
	(4)	5
	(5)	4.5

dissolution increases very markedly, and at 240°C the steep rise is observed. If 4 weight per cent of the lead in the tin-lead solder bath is substituted by gold the rate of dissolution is lowered again to some extent; the temperature of the steep rise, however, remains nearly unchanged.

Quite a different behaviour is shown by the soldering alloy described by Braun (18), which contains 17.5 weight per cent indium and 0.5 weight per cent zinc in addition to 53 weight per cent tin and 29 per cent lead. At temperatures up to 250°C practically no gold is dissolved in this alloy although this temperature lies 105°C above the melting temperature of the alloy. For temperatures in excess of 250°C, however, the rate of dissolution also becomes very high.

With the tin-lead-cadmium solder the extremely high rates of dissolution are reached only at temperatures in the vicinity of 260°C. Figure 2 shows the differences in severity of attack for three different types of solder in micrographs prepared from wires which had been used in the wetting test on solid gold wires already described.

As most of the soldering to gold is done on thin electrodeposited coatings, our study was extended to include the influence of the type of plating bath on the dissolution behaviour. In practice the electrodeposits are fairly thin ($< 5 \mu\text{m}$), and the soldering times are in the vicinity of 3 to 5 seconds. So the conditions of our dipping test were modified for the study of the electrodeposited golds. The results described below were achieved with a time of submersion of 3 seconds, the bath temperature being kept at 240°C. The deposits had a thickness of $6 \pm 1 \mu\text{m}$. They were deposited on 1 mm diameter nickel wire and had the following compositions:

- (1) 99.99 per cent Au; neutral type bath.
- (2) 99.8 per cent Au, 0.2 per cent Co; acid type bath.
- (3) 99.6 per cent Au, 0.4 per cent Co; acid type bath.
- (4) 99.8 per cent Au, 0.2 per cent Ni; acid type bath.
- (5) 67 per cent Au, 33 per cent Cu; neutral cyanide-free bath.

Table I gives the results for the dissolution behaviour of these electrodeposits. The coating thicknesses after test given in the table are mean values. The measurements show a considerable amount of scatter and thus the values shown here can only indicate certain trends. Nevertheless, it can be seen that the tendencies observed in the first part of the dipping tests are repeated here. Again the tin-lead-indium-zinc and the tin-lead-cadmium solders attack the gold less severely than the tin-lead eutectic. Furthermore, quite a remarkable influence of the

Fig. 3 Differences in severity of attack on gold coatings deposited on nickel wire $\times 600$

- (a) Sn-40Pb, gold coating type 2; gold completely dissolved
- (b) Sn-40Pb, gold coating type 5; practically no signs of attack
- (c) Sn-29Pb-17.5In-0.5Zn, gold coating type; 4 negligible attack

Table II
Wetting of Gold by Soft Solders as a
Function of Temperature

Solder	Melt- ing Point °C	Tempera- ture of Bath °C	Height of Climb mm
Sn	232	232	0
		250	2
		270	4
Sn-40Pb	183	183	0
		200	1.5
		220	6.7
		240	7
Sn-7Au	217	217	0
		240	2.6
		260	7.3
Sn-36Pb-4Au	185	185	0
		200	3.8
		220	8
		240	9
Sn-33Pb-18Cd	145	145	0
		160	0
		180	0
		200	0
		220	1
		240	5
Sn-29Pb-17.5In-0.5Zn	145	145	0
		160	0.3
		180	0.7
		200	3.8
		220	5
		240	9

type of electroplate is observed. With all solders tested the 67 per cent gold deposit proved to be quite resistant; rather low rates of dissolution were also found for the hard gold deposit with 0.2 per cent nickel when tin-lead-indium-zinc or tin-lead-cadmium solders were used. Figure 3 shows micrographs of nickel wires coated with different types of gold electrodeposits after having been submerged in tin-lead and tin-lead-indium-zinc solder respectively.

Wetting Behaviour

The wetting power of the different types of solder was studied with the aid of the twisted-wire test as described by Schumacher et al. (19). Great care was

taken to ensure that the samples were given the same pitch in twisting. The testing time was 30 seconds. Table II gives the heights of climb as a function of the temperature of the solder bath. The measurements of the heights of climb were taken at 20°C intervals from the melting point of the solder in question up to that temperature at which the rate of dissolution became so high that the greater part of the gold wire disappeared. The climbing of the solder began approximately 20°C above the liquidus point. An exception to this rule was observed only for the tin-lead-cadmium alloy. Here the melt began to rise only if its temperature was about 80°C above the melting point. This, of course, narrows quite considerably the temperature range in which this solder can be used, as the gold is wetted very poorly for temperatures below those at which the liquid solder begins to climb. For tin, tin-lead eutectic and tin with 7 weight per cent gold, the comparatively low heights of climb are probably due to the fact that very large amounts of gold are dissolved away. Thus the viscosity of the melt is increased and the spreading is impeded although the solder actually wets the gold surface. The best performance was shown by the tin-lead-indium-zinc alloy, which has a temperature interval of 80°C in which good wetting power is combined with a very low rate of dissolution of gold in the solder.

For the reduced times of immersion as used in the tests with the electroplated wires the heights of climb were too small to show characteristic differences in wettability of the deposits. The longitudinal micro-section (Figure 4) shows, however, that all the

Fig. 4 Longitudinal microsection through a wire plated with 6 μ m of gold coating type 4, showing the wetting behaviour for Sn-29Pb-17.5In-0.5Zn solder × 700

gold electrodeposits are wetted quite well by the tin-lead-indium-zinc solder. Similar results were also found for the other solders. The observation that pure gold deposits are wetted best, which has been reported before (4, 9), was again confirmed.

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Wear Properties and Structure of Gold Alloy Deposits

In applications of gold plating to sliding contacts high wear resistance of the deposit is an essential requirement. This property is clearly influenced by the surface condition and the mechanical properties of the coating, but hitherto little attention has been directed to the relationship between wear properties and the structure of deposits, and for this reason a paper recently published by Samuel Steinemann of the University of Lausanne and W. Flühmann and W. Saxer of W. Flühmann, Zürich, (1) is of particular interest. This is concerned specifically with a ternary gold alloy electrodeposit of nominal composition 75 per cent gold – 22 per cent copper – 3 per cent cadmium which is produced under the trade name GALVATRONIC by the Flühmann company, and for which much information is already available concerning its properties and wear performance. In the present paper it is shown how the high strength and low wear of the coating can be explained in terms of the structural features revealed by the X-ray studies.

The authors begin by briefly reviewing modern ideas concerning the nature of the wear process, and an analysis is then made of the wear profiles and other data obtained in the earlier work. The results are expressed in terms of the "representative wear number", Z , a dimensionless quantity proposed by Holm as a numerical description of wear, and having a clear physical significance as an indication of the approximate number of atomic layers corresponding to the smeared-out wear volume. In the present case the wear number for 10^6 revolutions of the slip ring was in the order of 10^{-2} for the unlubricated gold coating, which compares with that typical of a lubricated bearing. With the above significance, this result indicates that one atomic layer would be removed in 100 revolutions if wear remained proportional to sliding distance throughout; however, taking into account the observed increase in wear with sliding distance, the authors conclude that the actual number of revolutions corresponding to the removal of one atom layer is 10^4 to 10^5 . Up to this stage the electrodeposit remains practically free from wear (with brush loading of 140 g), after which accelerated abrasion begins, with visible roughening of the surface.

X-ray structural determinations were made on 20 micron deposits on a base of a 75 per cent gold-copper alloy. The results show a very pronounced fibrous orientation of the coating, with crystallites in over 90 per cent of the volume being oriented with octahedral faces lying parallel to the surface. The deposit is completely single-phase, homogeneous and disordered, in contrast to other alloy deposits where separation of copper-rich regions or of less noble compounds with other alloying components is observed.

Fourier analysis of diffraction line profiles permits the determination of the exact centre of gravity of the line, from which can be derived the exact lattice parameter, mean lattice strains, and density of twinning or stacking faults. The results indicate extraordinarily small apparent average grain sizes of 25 to 30 Å, with a high density of lattice defects. In discussing the wear properties in relation to structure, the authors refer to hardness and strain measurements made by Gane (2) in the electron microscope which showed that if the indenter were covered by the contaminant film normally present under these conditions, hardness reached the so-called theoretical value, but otherwise narrowly localised stresses in the contact points produced massive plastic slip at reduced force. This latter process, which could lead to deformation and fracture in small contact areas, is apparently absent in the case of the electrodeposit under investigation, because, owing to the very fine grain size, the electrodeposit metal is hard and strong for any dimension of contact, even the submicroscopic. This, according to the authors, is the true explanation of the high wear resistance.

The authors further suggest that the process of electrodeposition offers a subtle "tool" for the production of metals with properties not achieved by conventional metallurgical procedures.

F. H. R.

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