Gold Thick Film Conductors

DEVELOPMENTS IN REACTIVELY-BONDED MATERIALS

M. V. Coleman and G. E. Gurnett
Standard Telecommunication Laboratories Limited, Harlow, England

Conventional thick film conductors rely for their adhesion on the formation of a glassy layer which keys them both chemically and mechanically to the substrate surface. A newer type of conductor contains no glass frit but is reactively-bonded to the substrate, resulting in different properties which may be advantageous for certain applications. This article is based upon a contribution presented to the International Hybrid Microelectronics Society's European Conference held at Bad Homburg, West Germany, in May.

In the fired condition conventional thick film conductors consist of the metallic phase and between 1 and 5 per cent, by weight, of a glass frit. The substrate, usually a debased alumina, is keyed to the conductor by glassy rivet headed fibres which penetrate between the conducting particles (1). A newer type of conductor—variously referred to as reactively-bonded, fritless or molecular bonded—probably adheres to the substrate through the formation of a crystalline compound at the surface. Since there is no glass phase there can be no glass penetration to the surface, and the conductivity of the film should also be greater. In addition high alumina substrates can be used successfully.

Conductor Composition

In the investigation reported seven reactively-bonded gold conductors were examined and compared with a typical fritted conductor. The seven were grouped into three categories, on the basis of the major constituents other than gold. These constituents were identified by mass spectroscopy on fired and unfired samples while atomic adsorption (2) was used to establish the copper and cadmium content. The composition and many of the physical properties of the conductors are given in the Table. With the materials grouped in (a) and (b) the adhesion takes place primarily with the alumina of the substrate, and they may be said to be reactively bonded. However with (c) there is adhesion with the alumina and also with the glasses formed at its surface with the minor constituents present in the substrate, thus these may be described as mixed bonded.

Scanning electron microscopy established that the gold powders used in the conductor inks consisted of two distinct shapes of particle. In two of the materials, and also in the fritted standard, spherical particles 0.2 to 0.5μm diameter predominated. However in the other materials similar spherical particles were mixed with hexagonal platelets 2 to 6μm diameter but only a few tenths of a micron thick.

Properties of the Conductors

The conductors were each printed on to 96 per cent alumina substrates and fired through the manufacturer's optimum profile after which various examinations were carried out. Many of the results are given in the Table. Surface topology measurements established that one conductor was significantly smoother, and one much rougher, than the others.

While the bulk resistivity of gold is approximately 2.4μΩcm at room temperature the value for the fritted standard is 3.6μΩcm, which is similar to the reactively bonded golds with the lowest resistivities. It would appear therefore that the bulk resistivity depends upon the gold porosity of the bulk film rather than upon the glass content.

A visual examination of the definition of a 0.125 mm line and space pattern showed considerable variation from one conductor to another. Some inks gave well defined lines but others spread out, in some cases to the extent of shorting out adjacent conductors, while two contracted, one to such an extent that the lines become discontinuous.

The adhesion of the gold conductors to three types of substrate, two being debased alumina, were determined. The adhesion strength of the fritted conductor was much lower than the reactively bonded conductors on both the debased aluminas and was even lower on the 99.5 per cent alumina, a not unexpected result when so very little substrate glass is present.

Composition and Physical Properties of Gold Conductors

Conductor			Major Elements	Composition Per Cent		Thickness Microns	Surface Roughness Microns	Resistivity		Adhesion Strengths kgf of 2.5 mm sq. pads		
										Substrate		
Group	Source	Reference		Copper	Cadmium			Sheet mΩ/sq.	Bulk μΩcm	Alsimag ADS 614	Coors ADS 995	A & R 974
(a)	Plessey	C5700	Cu	0.67	—	11.6	0.65	3.90	4.6	3.38	3.76	2.32
(b)	E–O	E06990	Cu,Cd	0.70	0.34	7.1	0.25	5.18	3.7	3.96	3.77	1.34
	Cermalloy	S4399	Cu, Ge	0.32	—	7.8	0.55	4.36	3.4	2.45	2.60	1.50
	Du Pont	9500	Cu, Cd	0.83	0.18	9.2	0.52	4.54	4.2	3.98	4.94	1.45
	E.S.L.	8880	Cu, Cd	0.49	0.30	9.8	0.70	3.38	3.3	3.53	3.13	1.07
(c)	E.M.C.A.	3264	Cu, Cd, Bi	0.70	1.23	9.1	1.60	5.09	5.2	2.03	1.83	1.42
	Engelhard	T2888	Cu, Cd, Bi	0.62	0.50	8.5	0.75	4.45	3.8	3.35	3.70	2.79
Fritted	Du Pont	9260	Pb, Si	—	—	7.7	0.75	4.66	3.6	1.26	0.78	1.11

When the adhesion strengths of the gold conductors were examined on one of the substrates after 40μm had been removed from the surface by lapping it was found that they were lower than on the as-received materials. In all cases ground substrates have a higher proportion of the glassy phase on the surface, compared to unground ones.

As copper oxide readily dissolves in the substrate glass forming a copper depleted zone at the gold/substrate glassy interface the gold, which relies on the copper to form a bond to the substrate, is more easily detached. However mixed bonded systems, which contain bismuth oxide, are less sensitive to grinding of the substrate.

Although no silicon was detected in the group (c) inks, S.E.M. found evidence of increased silicon concentration beneath conductor pads which must have resulted from extraction of silica from magnesium silicate in the substrate. This silicon, in the form of a copper-cadmium-bismuth silicate, and the copper-cadmium-aluminate which forms at the substrate as in the case of the pure copper-cadmium systems, are the major bonding agents for as-received substrates.

Conclusions

The properties of reactively bonded gold conductors are, in general, comparable with the best fritted golds. However, although the reactively bonded golds contain over 99 per cent gold the electrical conductivity is no better than for the fritted sample, which contains approximately 90 per cent gold and 10 per cent glass. This suggests that the number of voids is an important consideration and the mixing of gold spheres and platelets, in both the reactively bonded and the fritted materials, is an attempt to increase the density of packing.

The adhesion strength of all the reactively bonded conductors is superior to that of the fritted standard. It has been shown that both copper and cadmium, when present, are alloyed to the gold. Both the oxidation of the copper and the ease with which it dissolves in the substrate glass suggest that processing could result in reliability hazards.

Although no dramatic improvements in characteristics have been found for these reactively bonded gold conductors applications may occur where stronger adhesion or sharp interfaces between conductor and substrate are required.

Acknowledgements

The authors wish to thank S.T.L. for permission to publish this paper which reports work carried out with the support of the Procurement Executive, U.K. Ministry of Defence, sponsored by D.C.V.D. Thanks are due to the S.T.L. Materials Evaluation Centre for help with the analytical work.

References

1 L. Hailes and W. A. Crossland, *Int. Elec. Pack. Prod.*, July 1972, 25

2 M. V. Coleman, *Radio Electron. Eng.*, 1975, **45,** (3), 121