Interconnections for Thick Film Circuits

SCREEN PRINTED NOBLE METAL CONDUCTORS

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A complete range of noble metal screen printing inks for thick film circuits has been developed that can be co-fired within the same time-temperature cycle with the object of simplifying and reducing the cost of circuit production. The resistor compositions have been described earlier; this article outlines the development of the conductor inks in the range.

In an electronic circuit, provision must be made for interconnecting and terminating the components. Where discrete components are used, such connections are usually made by soldering wires to the body of the components and using these wires as the terminals or for interconnections, often by way of a printed circuit board. In thick film integrated circuits the component elements, such as resistors and capacitors, are screen printed and fired in close proximity on substrates of relatively small surface area. Where terminal wires need to be connected to component elements they cannot be attached directly to them, and associated contact areas must be provided for the wires. To overcome these problems in thick film circuits, conducting paths and contact "lands" are produced by screen printing and firing appropriate inks in the same way as are the component elements themselves.

Where conducting paths have to cross, they are insulated from each other by a glaze film produced by screen printing and firing a crossover ink between them.

A network of thick film elements is usually produced by printing and firing each type of ink in sequence on the circuit substrate, which could entail at least three firing cycles. This is necessary because the resistor, conductor, crossover and capacitor inks available are not fully compatible, and require different firing cycles to develop satisfactory physical properties. Clearly, if the inks could be fired in a single cycle, the operation would be a considerable simplification and would save time and money. The main difficulty in attaining this objective has been the sensitivity of resistor inks of the silver-palladium type to firing temperatures and the necessity, therefore, to fire these inks to a closely restricted profile for fear of obtaining unpredictable resistivity changes that occur with quite small variations in firing time and/or temperature. However, the new range of ruthenium-based resistor inks that have been developed by Johnson Matthey (1) are more stable in this respect and offer more latitude in firing. This provides the basis for a system that requires only one firing operation.

Advantages of a Single-firing Cycle

A compatible range of resistor, conductor, crossover and capacitor inks has now been developed in the Johnson Matthey Research Laboratories that, after sequential printing and drying, can be co-fired in one operation to produce thick film circuits. By this means, as many as six or seven sequential prints can be co-fired. For example the process

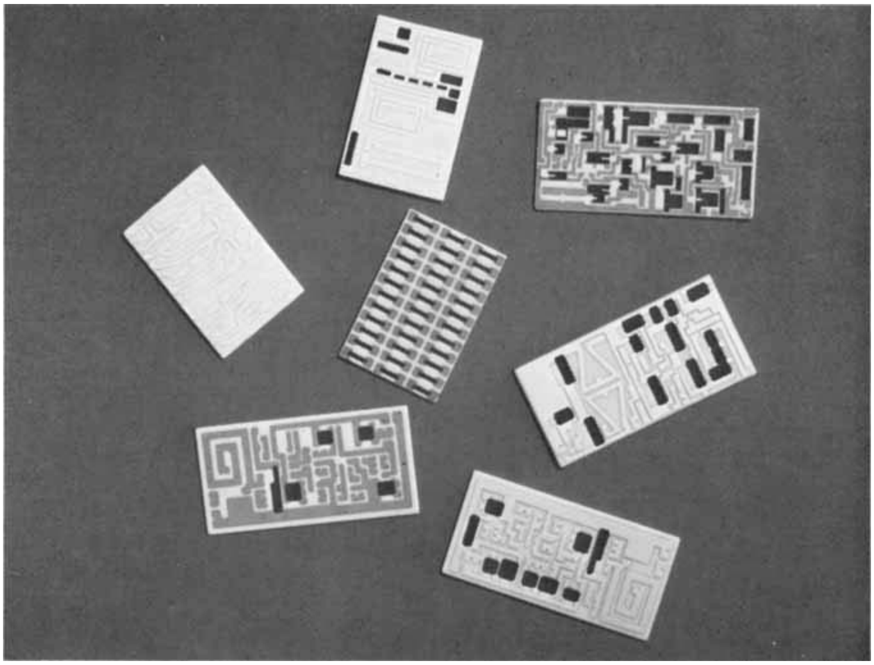


Fig. 1 Thick film circuits on alumina substrates in the course of preparation, showing a few of the wide range of circuit configurations that can be produced by the screen printing and firing technique. The dark areas are ruthenium-based resistors interconnected with various noble metal conductors *Courtesy of Ether Engineering Ltd*

could be as follows:

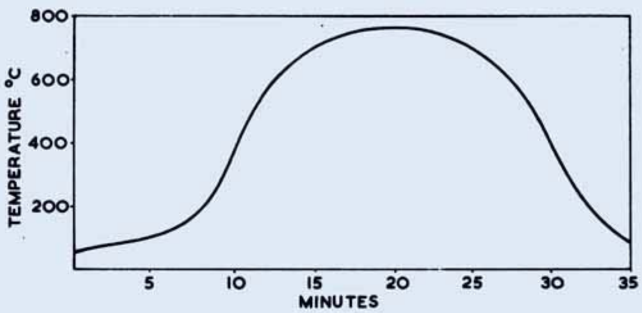
First print	Conductor paths and contact lands or resistor tracks
Second print	Resistor tracks or conductor paths and contact lands
Third print	Crossover areas
Fourth print	Second layer of conductor paths and associated contact lands
Fifth print	First capacitor dielectric areas
Sixth print	Second capacitor dielectric areas
Seventh print	Conductors for top capacitor electrodes and contact lands

Each print would in turn be allowed to level and then be dried. The profile illustrated in Fig. 2 shows a typical time and temperature cycle in which all these elements develop satisfactory properties.

Conductor Properties

Circuit interconnections should conduct electricity permanently between other elements without modifying the properties of these elements or the circuit as a whole. They

Fig. 2 Johnson Matthey conductor inks can be co-fired with resistor, crossover and capacitor inks within the wide time/temperature limits established for ruthenium-based resistors. This is a typical firing profile to give satisfactory properties with all these elements



should therefore have a low, uniform resistivity throughout their length, adhere firmly to the substrate and make good electrical contact with other circuit elements. In addition they should be readily solderable so that terminal wires and components such as capacitor chips, can be incorporated in the circuit.

Conductor inks to provide interconnections must have good screen printing properties, and in particular must be capable of depositing extremely fine, sharply defined lines. The inks should not deteriorate within a reasonable storage period, and should require no time-consuming preparation before use.

Metal Compositions

The noble metals in general are eminently suitable for conductor compositions because of their stability, low specific resistivity, good soldering properties, and freedom from oxidation during the firing process necessary to dispel and burn off organic constituents of the inks and to cause the metal layer to adhere to the circuit substrate.

Silver is the obvious first choice because of its relatively low cost, low density and high electrical conductivity. Its ions, though, are very mobile and can migrate under a polarised electrical load in the presence of moisture, leading to tracking across gaps between unprotected conductor paths that are closely spaced. This is a disadvantage where a combination of such conductors arises. A fired silver contact land will tin readily with a soft solder but, because silver dissolves at a relatively high rate into molten tin-lead solder, the time and temperature of the soldering operation must be closely controlled or a weak joint will result. To ease the operation, tin-lead solders containing a small percentage of silver are generally recommended, particularly for initial tinning of contact lands.

It has been established that the properties of silver conductors are improved by the addition of 15 to 25 per cent of palladium (2), but the addition of as little as 10 per cent of palladium to silver significantly retards its rate of dissolution in molten solders and its rate of migration. Therefore, where silver may prove marginally unsatisfactory, a silver-palladium conductor ink should be used.

Mixtures of gold and palladium and of gold and platinum powders provide valuable alternatives to silver and silver-palladium conductors in circuits where no possibility of silver migration can be tolerated. When fired, the mixtures form alloys by thermal diffusion, such as have been used for many years to provide silver-like tarnish resistant films on glass and ceramics. They have very good soldering properties, and components can also be bonded to them by compression and thermal bonding techniques. Gold-platinum mixtures give slightly the better conductivity and adhesion in some conditions.

Gold can be used alone as a conductor, but it dissolves more rapidly in soft solder than do some of its palladium and platinum diffusion alloys. Furthermore, it forms intermetallic compounds with solder constituents that can embrittle and adversely affect the bond strength of circuits during storage. It is used mainly when transistor or diode chips are to be eutectically bonded into the

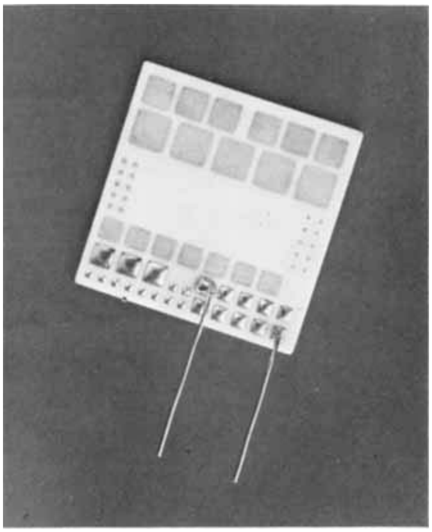


Fig. 3 A test pattern of conductor areas used in assessing the solderability and adhesion of fired inks

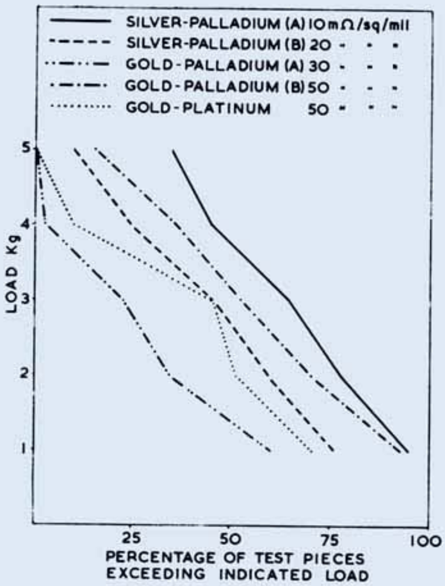


Fig. 4 Comparison of the bond strengths between various fired conductors and alumina substrates. The results shown were determined on 300 test pieces

circuit and for multi-layer conductor networks.

From these considerations, conductor inks were based on silver and gold powders and on silver-palladium, gold-palladium and gold-platinum powder mixtures, and this range has now been made available.

Adhesion

Metal powders require the addition of a fusible glass frit to form an adherent conducting layer on the ceramic substrate and other circuit elements. The composition of the glass, its particle size distribution, and the amount used were found to be governing factors in the adhesion of the metal powders at various temperatures. They also had a significant effect on other conductor properties. Many of the glasses that promoted good adhesion were found to impair the soldering properties of the film, and some increased its resistivity to an unacceptable degree. Others were not fully compatible with the glass used in the ruthenium-based resistor inks, generating electrical noise at the resistor conductor interface. Some glasses with otherwise satisfactory properties penetrated the dielectric of the capacitors printed into the circuit, reducing the insulation resistance of the dielectric layers.

These difficulties were overcome by developing low-melting glasses having a very high viscosity when molten, and using these in quantities and particle size distribution ranges to suit the various metal compositions. The resulting conductors, fired in the time-temperature cycle recommended for ruthenium-based resistors, gave bond strengths of between 1 and 5 Kg in tension on a 0.06 inch square conductor land, using a silver-containing soft solder. The type of specimen used in determining solderability and adhesion is shown in Fig. 3, and the consistancy of the results obtained is well illustrated in Fig. 4.

Printing and Co-firing

The increasing trend towards miniaturisation, and the consequent necessity for printing very fine, closely spaced and sharply defined lines was taken fully into account in the development of the inks. Printing properties were found to be largely governed by the rheology of the liquid organic vehicle, and the particle size distribution and degree of dispersion of the metal and glass powders in the vehicle. By establishing these parameters individually for each ink, a range was developed having uniformly good printing properties, and capable of depositing lines of 0.003 inch wide, at similar spacings, with precision screen printing equipment.

By combining adhesion-promoting glasses of suitable composition with the appropriate noble metal powders, and controlling the particle size distribution of these constituents, the objective was fully achieved that all the conductor inks should be compatible and capable of being co-fired with ruthenium-based resistors and other thick film elements.

References

1 G. S. Iles and M. E. A. Casale, *Platinum Metals Rev.*, 1967, **11**, (4), 126
2 L. F. Miller, U.S. Patent 3,374,110