“Advanced Fine Line Thick Film Conductors with High Conductivity and Soldering Capability Built Via Screen-printing”

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Abstract

Previously, the common understanding with traditional polymer-base thick film flexible circuit is its low circuit density with low electrical conductivity because of an organic matrix in the conductor materials. The organic matrix does not allow any soldering for the polymer thick film circuits. It is the major reason why the thick film circuits could not be the mainstream technology in the printed circuit board industry and semiconductor substrate industry even though the technology provides a much lower manufacturing cost and high productivity without wet chemical waste compared with the traditional copper-etched circuit. However, the advanced screen-printing process using new conductive materials is making remarkable improvements to overcome technical barriers, and is generating application opportunities as the new electronic packaging technologies.

Introduction

Low electrical conductivity of the polymer thick film traces is caused by the basic construction and materials as shown in Fig. 1. The conductive inks, mixtures of conductive particles, binder resins and organic solvent, are printed on the substrates through appropriate printing process. After the printing process, the solvent is removed by low temperature drying process.

The binder resins work as the pressure generators for the conductive particles. After an appropriate curing process, the binder resin shrinks and generates compression pressure that makes electrical contacts among the conductive particles. It is the basic mechanisms of the electrical conductivity of the polymer thick film conductors. The electrical currents flow through the contact points of the conductive particles. Because of the small sizes of the contact points between the conductive particles and longer current paths, the conductivity of the traditional thick film conductors is three to four order smaller compared to the solid copper metal conductors.
The resolution of the thick film conductors depends on the total balance of the ink materials, substrate materials, capabilities of the printing equipment. Recent screen-printing process and ink jet printing process are capable to generate finer lines than 20 microns. Affinities between ink materials and surface conditions of the substrate have been becoming the bottleneck to generate finer line conductors for thin flexible substrates.

![Conductor Model](image)

**Fig. 1 Conducting Model of the Traditional Polymer Thick Film Conductors**

The major barrier for soldering the polymer base thick film conductors is organic resin binder for the conductive metal particles. As shown in Fig. 1, the majority of the surface on the traditional thick film conductors is covered with an organic polymer based binder resin. It is the major reason why the thick film conductors do not get wet with molten solder.

The nano pastes that use nanometer size conductive particles can improve the conductivity and trace resolution of the thick film circuits, however, they are not effective for soldering, unless organic base binders are used for the conductor traces.

The situation of the ceramic base thick film circuits is basically the same for the soldering. The majority of the trace surfaces are covered with glass matrix that works similar as binder resins. In the case of ceramic base thick film circuits, however, it is possible to conform the conductor traces without glass matrix and the traces are available for soldering. But noble metals such as gold, platinum and palladium should be used instead of silver. During the high temperature firing, these noble metal particles melt at the contact points and diffuse each other. This process makes metal-metal bonding between the conductive metal particles and provide relatively larger cross sections for the conductor traces.

**Basic process**

Unfortunately, the same metals with the same firing process of the ceramic base thick film circuits are not available for the polymer based thick film circuits because of the limited heat resistance. All of the organic molecules decompose and vaporize at the firing temperature of the noble metal particles. But a modified idea was introduced to make thick film conductors reducing binder resins from the silver conductor ink. An organic silver molecule was employed as the basic material of the conductive ink for the thick film flexible circuits. The ink paste can be applied by standard screen-printing equipment. Under the high temperature baking process, the
organic silver molecules decompose under reduction circumstances and become metallic silver particles. During the baking process, the silver particles contact and diffuse each other making metal-metal bonding each other as shown in Fig. 2. The effective cross section of the traces for the electrical current is one order larger compared to the traditional thick film silver conductors. An issue is bond strength of the metallic conductors on the organic substrate, therefore, appropriate surface treatment shall be conducted before the building of the conductors. Under coating of adhesive resin is another choice to have high bond strength of the conductor traces. (Fig. 3)

As they are shown in Fig. 2 and Fig. 3, the majority of the surface of the low resistance conductors could be covered with metal silver that can be gotten wet with molten solder.

Trials and results

Powder of the silver fat acid compound was prepared as the primary conductive material for the thick film traces. The powder size distribution is between 0.1 to 1.0 microns. The conductor ink paste was prepared adding organic solvent to have an appropriate viscosity for the screen-printing.

50micron thick polyimide films and PEN (Polyethylene Naphtalate) films were employed as the flexible circuit substrate to have enough heat resistance for the high temperature baking and soldering process. Several surface treatments have been conducted on the surfaces of the substrate films before the conductor generation to have good affinities between the substrates and traces.
The screen-printing of the conductor traces has been made with a #500 mesh screen mask. A baking condition of 180 degree C for 30 minutes was employed. A traditional polymer base silver ink paste with binder resin was also processed by the same process condition as the reference.

Fig. 4 and Fig. 5 show the examples of the fine thick film traces generated on the polyimide film with the binderless silver paste. The fine screen-printing process could produce 30micron line and space by #500 mesh screen mask. The screen mask could have sharp line patterns for 30 micron traces with 30 micron spaces. The traditional silver paste could produce 100micron line and space as the finest resolution. There were not significant resolution difference observed between polyimide films and PEN films. The binderless silver paste provides more than three times finer resolution compared to the traditional silver paste.

Fig. 6 shows the width dependencies of the conductor resistance for the 100 mm long traces. The traditional silver paste (B) cannot generate finer traces than 100micron line & space on the flexible substrates even though a high resolution screen mask is used. On the other hand, the binderless silver paste (A) provides finer resolutions than 30micron line & space.

Several soldering tests have been conducted for the thick film traces. As it is well known, the thick film traces made of the traditional silver paste did not get wet with molten solder by any conditions at all. On the other hand, the binderless thick film traces could get wet with both of eutectic and lead-free solder by manual soldering as
shown in Fig. 7 without any pre-treatment such as flux coating. The pad surface of the thick film traces with binderless silver paste has covered 100% with temperature controlled molten solder between 230 and 260 degree C as shown Fig. 8.

![Fig. 7 Hand Soldering of the Thick Film Traces with Binderless Silver Paste](image1)

![Fig. 8 Soldered Pad of the Thick Film Traces with Binderless Silver Paste](image2)

**Analysis**

Fig. 9 shows the cross section photo of the thick film traces made by screen printing process. The wide trace made of the traditional silver paste has a thicker thickness than 10 microns. On the other hand, the thickness of the narrow binderless conductors could be less than five microns with higher conductivities. The volume resistance of binderless conductors calculated is order of $10^{-6}$ ohm centimeter, that is one or two order smaller compared to the traditional silver paste. It is two order larger compared to the volume resistance solid metallic copper ($10^{-8}$ ohm centimeter). It means the majority of the surface of the thick film traces is metallic silver, therefore it has a good affinity with molten solder.

![Fig. 9 Cross Section Photo of the Thick Film Conductors](image3)

![Binderless thick film conductors](image4)

![Traditional thick film conductor](image5)

Fig. 10 shows an example of the cross section photo of the soldered thick film pad. The thickness of the traces is much thinner compared to solder layer. Because of the very thin thickness of the thick film conductors, the silver metal has been absorbed by molten solder at high temperature or longer soldering condition.
Fig. 10 Cross Section Photo of the Soldered Thick Film Conductor

Conclusion

A series of screen printing trials have shown that the binderless silver paste provides not only fine traces with high conductivity, but also soldering capabilities. The new thick film circuits built on the flexible substrate will widen the applicable ranges of the circuit technology.

References