"Fine Line Thick Film Circuits with High Conductivity Built on Flexible Substrates are Capable of Soldering"

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Introduction:
Previously, the general understanding about polymer-base thick film flexible circuits consisted of low density with low electrical conductivity because of the organic matrix in the conductor materials. Additionally, the organic matrix of these traditional circuits does not allow any soldering. These are the major reasons why thick film circuits did not become the mainstream technology of the industry even though the technology provides much lower manufacturing cost compared with the traditional copper-etched circuits.

Basic concept:
The major barrier for soldering of polymer base thick film conductors is the organic binder of the conductive particles. The binder resins work as pressure generators for the conductive particles. After an appropriate curing process, the binder resin shrinks and generates compression pressure that makes electrical contact among the conductive particles. This is the basic mechanism of electrical conductivity of the polymer thick film conductors. (Fig. 1) The electrical current flows through the contact points of the conductive particles. Because of the small size of the contact points between the conductive particles and longer current paths the conductivity of the traditional thick film conductors is three to four orders smaller compared to the solid copper metal conductors. As shown in Fig. 1 the majority of the surface of the traditional thick film conductors is covered with an organic polymer based binder resin. This is the major reason why thick film conductors do not get wet with molten solder. Nano pastes that use nanometer size conductive particles can improve the conductivity of the thick film circuits however; they are not effective for soldering unless organic base binders are used for the conductor traces.

The situation in ceramic based thick film circuits is basically the same for 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 toform the conductor traces without glass matrix and the traces are available for soldering. Noble metals such as gold, platinum and palladium should be used instead of silver. During 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 provides relatively larger cross sections for the conductor traces.

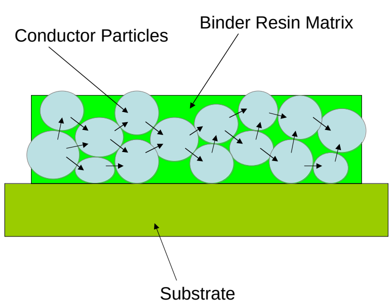

Fig. 1 Conducting Model of the Traditional Polymer Thick Film Conductors

Unfortunately, these same metals with the same firing process are not available for the polymer based thick film circuits because of the limited heat resistance of the substrate. All of the organic molecules decompose and vaporize at the firing temperature of the noble metal particles. A modified process was introduced to make thick film conductors with reduced 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 typical screen-printing processes. Under the baking process, the organic silver molecules decompose 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. The majority of the conductor surface can now be covered with metal silver that demonstrates wetting with molten solder. (Fig.3)

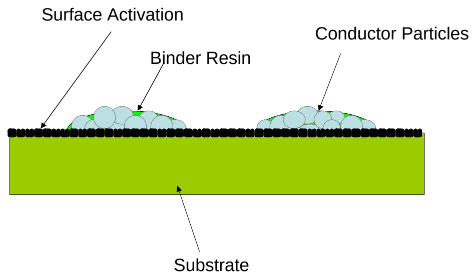

Fig. 2 Conducting Model of the Binderless Thick Film Conductors with Surface Treatment

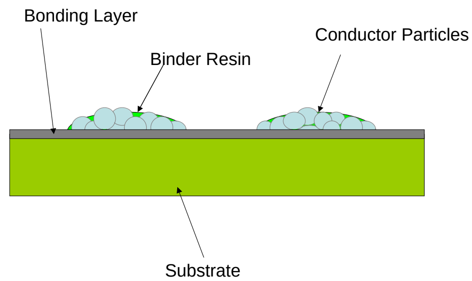

Fig. 3 Conducting Model of the Binderless Thick Film Conductors with Bonding Layer

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 screen-printing. 50micron thick polyimide films and PEN (Polyethylene Naphtalate) were employed as the flexible circuit substrates to provide enough heat resistance for soldering. Several surface treatments have been tried on the surface of the substrate films before conductor generation to promote good affinity between the substrates and traces.

Screen-printing of the conductor traces is made with a #500 mesh screen mask followed by baking at 180 degree C for 30. For a comparison, a traditional polymer base silver ink paste with binder resin was used with the same process to produce a traditional thick film circuit.

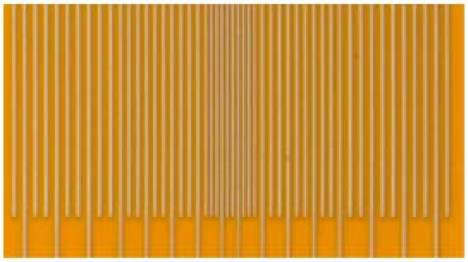

Fig. 4 Example of Fine Line Traces with Binderless Silver Paste (50micron L/S)

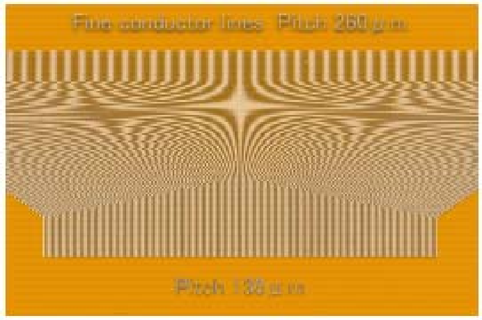

Fig. 5 Example of Fine Line Traces with Binderless Silver Paste (65micron L/S)

Fig. 4 and Fig. 5 show examples of the fine thick film traces generated on the polyimide film with the binderless silver paste. The fine screen-printing process is capable of producing 30micron line and space using a #500 mesh mask. Traditional silver paste produced 100micron line and space as the finest resolution. There were no significant resolution differences 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 requirements to produce conductor resistance of 100 mm long traces. The traditional silver paste (B) cannot generate finer traces than 100micron line & space even though a fine screen mask is used. On the other hand, the binderless silver paste (A) provides finer resolutions than 30micron line & space.

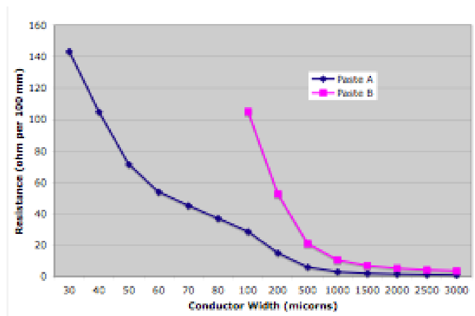

Fig. 6 Comparison of the Conductor Resistance

Several soldering tests have been conducted on the thick film traces. It is well known that thick film traces made from traditional silver paste do not exhibit wetting with molten solder under any condition. On the other hand, binderless thick film traces showed good wetting 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 covered100% with temperature controlled molten solder between 230 and 260 degree C as shown Fig. 8.

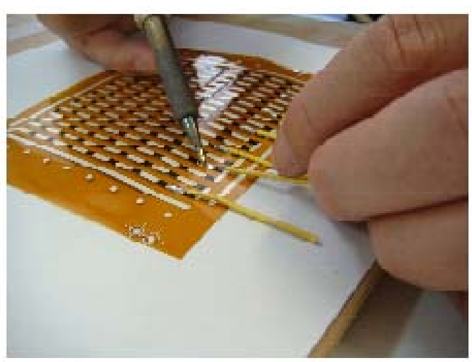

Fig. 7 Hand Soldering of the Thick Film Traces with Binderless Silver Paste

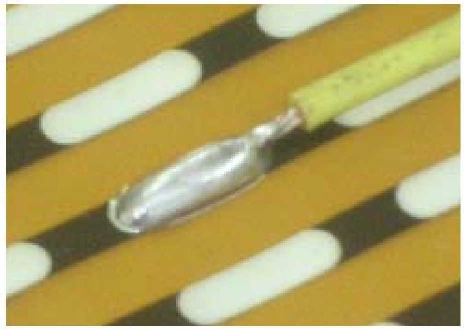

Fig. 8 Soldered Pads of the Thick Film Traces with Binderless Silver Paste

Fig. 9 Cross Section Photo of the Thick Film Conductors

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

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.

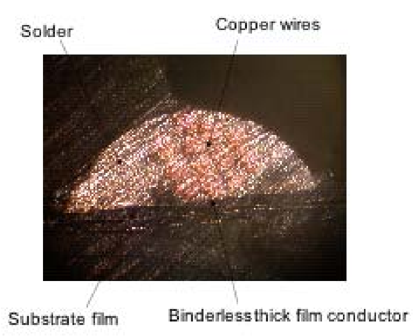

Fig. 10 Cross Section Photo of the Soldered Thick Film Conductor

Conclusion:
A series of screen printing trials have shown that binderless silver paste provides not only fine traces with high conductivity but also has a soldering capability. Collaboration with the embedded passive circuits made by screen printing process will generate a complete circuit module capability as shown in Fig. 11.

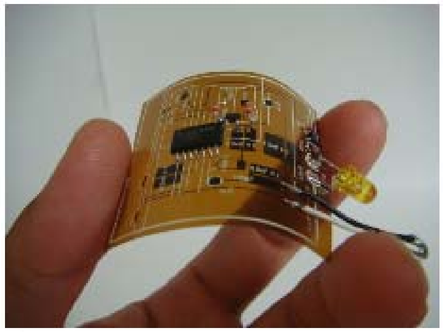

Fig. 11 Example of the Soldered Flexible Module with Embedded Passive Circuits

References
1. “Advanced Screen Printing Process” -Practical Approaches for Printable & Flexible Electronics”, Dominique Numakura**,** 3rd IMPACT and the 10th EMAP, Taipei/Taiwan, October 2008

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Conventional vs. Advanced Screen Printing

Low Density	Higher Density
Low Cost	Low Cost
Low Conductivity	Higher Conductivity
Not Solderable	Solderable

Conventional Screen Printing

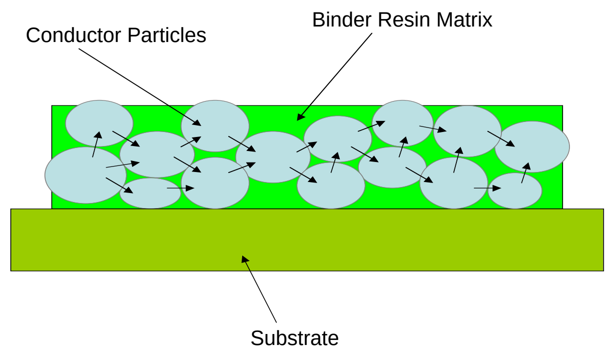
-- Organic Binders

-- Small Contact Area

-- Longer Current Path

-- Conductivity

** 3-4 Orders Lower



Ceramic Thick Film Circuits

-- Glass Matrix Over Conductors

-- Eliminate Glass

** Gold, Platinum, Palladium

** High Temp Firing

**Melting & Larger X-section

Advanced Screen Printing

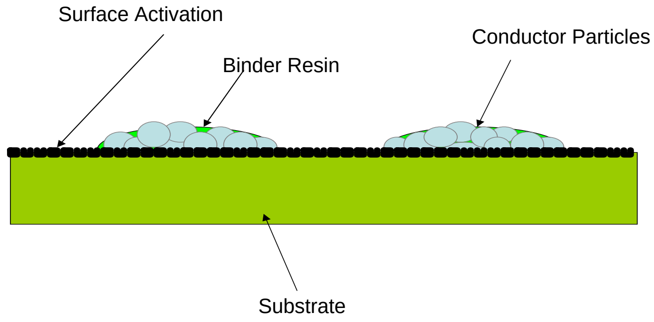
-- Not Suitable for High Temp Firing

-- Organic Silver Molecule

-- Reduced Binder Resins

-- Molecules become Particles

-- Effective X-section 1 Order Higher



Advanced Screen Printing

-- Silver Powder with 0.1-1.0 Micron Sizing

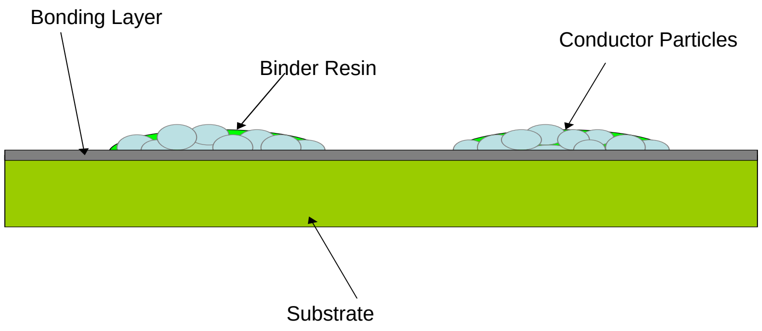
-- Organic Solvent Used

-- Base Substrate PI or PEN 50 Micron

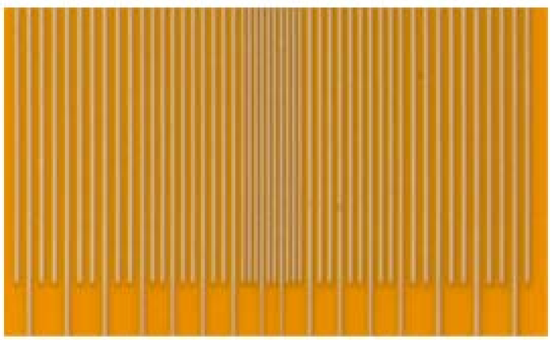
-- Surface Treatment Enhances Bonding

-- #500 Steel Mesh Screen Mask

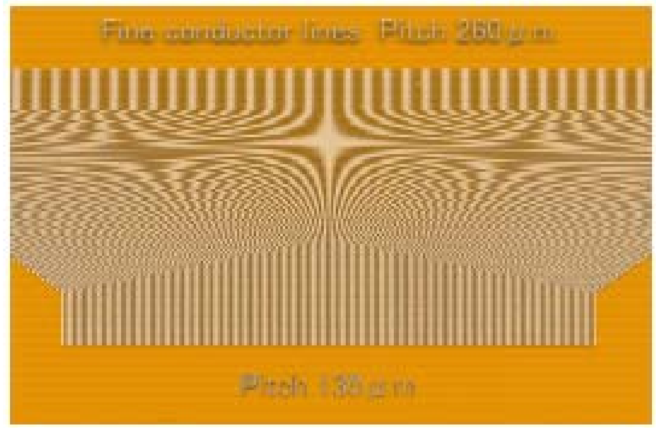
-- Bake Cycle of 180 C for 30 Minutes



Advanced Screen Printing Densities

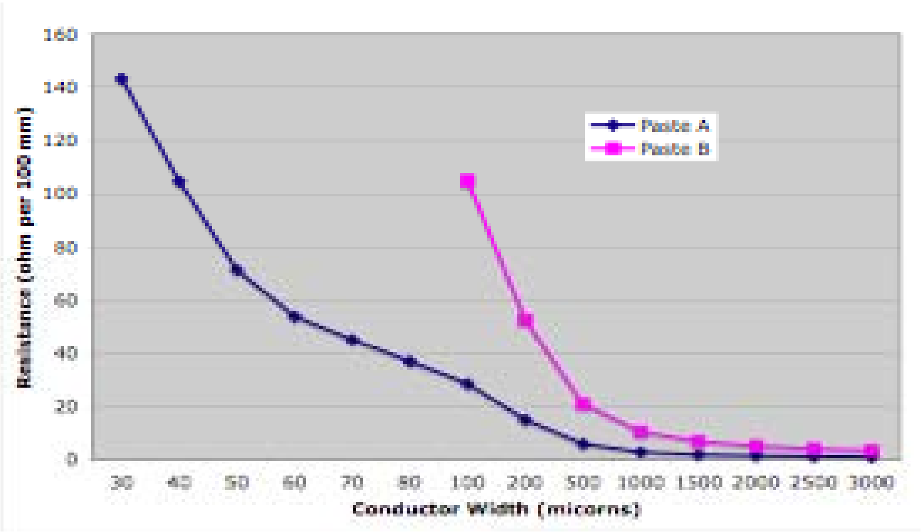


Binderless Silver Paste (50micron L/S)



Binderless Silver Paste (65micron L/S)

Comparison of Conductor Resistance



Solder Testing

Solder Testing

Analysis of Advanced vs. Conventional

-- Thickness of Conductors Lower

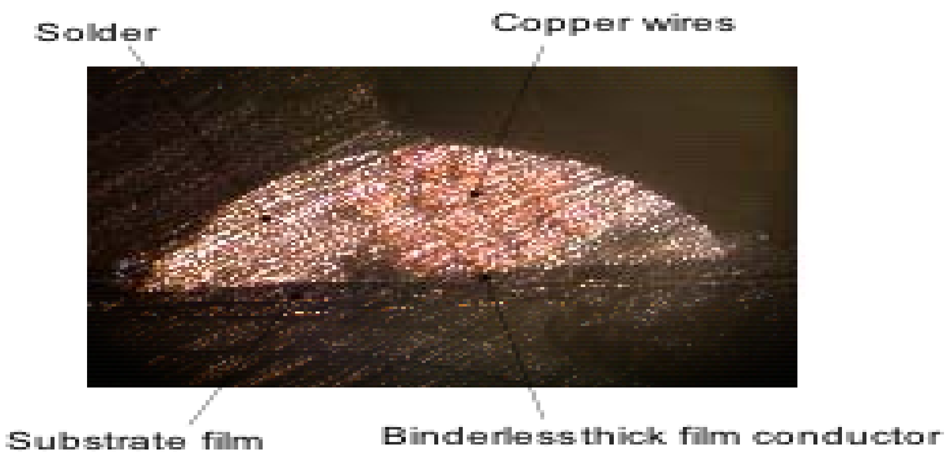
Binderless thick film conductors

Traditional thick film conductor

Analysis of Advanced vs. Conventional

-- Volume Resistance 10-6 Two Orders Higher vs. Conventional

-- Volume Resistance 10-8 of Copper Two Orders Lower



Conclusions

-- High Densities Possible

-- Low Cost Maintained

-- Solderable

-- Complete Circuit Module Capable