

Thinner Flexible Printed Circuits with Nano-conductive Paste

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Recently, the miniaturization and high functionalization of electronic devices have been progressing increasingly. Therefore, flexible printed circuits (FPC) are also required to be thinner and to realize finer pitch pattern formation. Regarding interlayer connection technology, a key technology for these factors, we have developed a new interlayer connection technology with our original nano-conductive paste, "paste via technology," an alternative to traditional plating through hole technology (PTH). The newly developed technology allows formation of interlayer connection part with no increase of copper thicknesses associated with PTH, thereby enables production of thinner FPCs with fine pitch formation. Now we have started mass production of these FPCs. This paper describes our novel "paste via technology."

Keywords: FPC, conductive paste, nano particle, thinner FPC, interlayer connection

1. Introduction

Because of their small sizes, thin thicknesses, and high flexibilities, FPCs are an essential part of electronic devices. Since we first started developing FPC technology in the R&D department in 1965, we have produced many products meeting the needs of the electronics market with flexible creativity and original technology based on the manufacturing technology of copper electric cables⁽¹⁾.

Recently, the miniaturization and high functionalization of electronic devices, as represented by wearable devices, have been progressing increasingly. Therefore the FPC is also required to be thinner and to realize finer pitch pattern formation. With the needs of high functionalization of FPCs, the ratio of double-sided and multi-layer FPC production is increasing, and interlayer connection technology is a key technology to meet the needs of thinner FPCs and finer pitch pattern formation. We have developed a new paste interlayer connection technology made from our original silver nano particles, and demonstrated high connection reliabilities between this conductive paste and the metal covered with a passive layer⁽²⁾. Now we applied this paste technology to normal substrates, where circuits and bottom of via are copper, and started mass production of thinner FPCs or FPCs with finer pitch formation.

2. Paste Via Technology Development

There are three categories of FPCs, depending on the number of copper conductive layers that consist of copper foil, or copper foil and plating copper, single-sided FPC for one conductive layer, double-sided FPC for two conductive layers, and multi-layer FPC for three or more conductive layers (**Fig. 1**).

FPCs can demonstrate higher performances with more conductive layers. With the rising needs of high functionalization of FPCs, the ratio of double-sided and

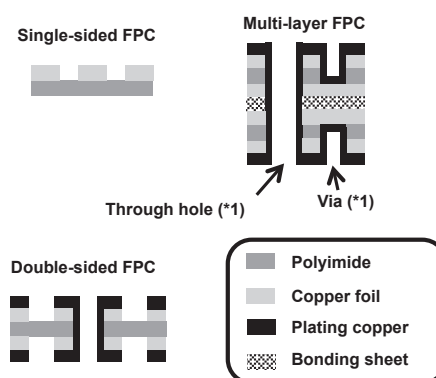


Fig. 1. Cross-section structures of FPCs

multi-layer FPC production is increasing. Double-sided FPCs and multi-layer FPCs need to connect to each conductive layer through interconnecting holes, which are called "through hole"*1 or "via"*1. The traditional interlayer connecting technology is the plating through hole technology (PTH). Through holes are drilled by drills or laser drills, and interlayer connections are made by electroless plating and electroplating, and then circuit patterns are formed. However, electroplating increases the whole copper thicknesses, there was therefore a limit to making thinner FPCs or FPCs with finer pitch pattern formation.

In response to this situation, we have developed original conductive paste technologies and have already started mass production of jumper FPCs where circuit patterns are formed by the conductive paste only on necessary parts on single-sided FPC, or shield FPCs that are covered with a shield layer by highly flexible conductive paste (**Fig. 2**).

Furthermore, we have developed a new interconnection technology, named "paste via technology,"

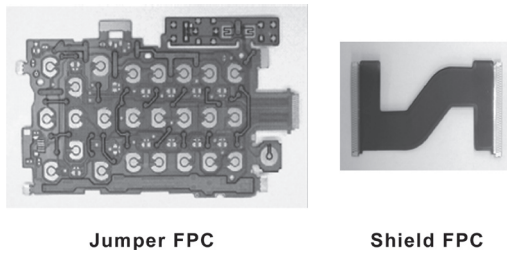


Fig. 2. Jumper FPC (left), Shield FPC (right)

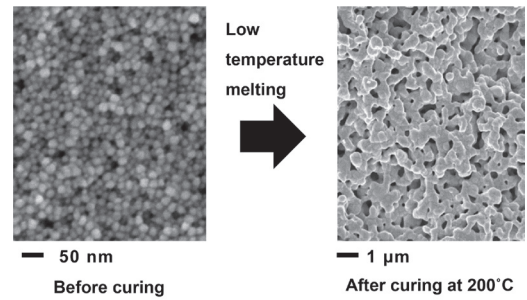


Fig. 4. Low temperature melting effect of nano silver particles

where only interconnecting holes are connected by the conductive paste to accommodate the needs of thinner double-sided FPCs. In paste via technology, we make vias with laser drills on the substrate where circuit patterns have already been formed. Then we print on the vias the conductive paste of which conductive particles are dispersed in resin. We can form circuit patterns first in this method, so the original copper thicknesses are kept, and we can make thinner FPCs or FPCs with finer pitch formation (Fig. 3).

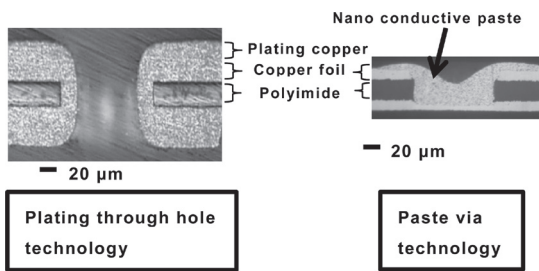


Fig. 3. Thinner FPC by paste via technology

2-1 Feature of nano-conductive paste

We have established a unique nano particle production method with our original liquid phase reduction technology without vacuum process, thereby providing low-cost and with uniform-sized nano particles⁽³⁾. We have already put into use nano nickel particles as anisotropic conductive films (ACF)⁽⁴⁾, as well as nano silver particles as conductive inks⁽⁵⁾ to practical use.

The conductive paste, called “nano-conductive paste,” for paste via technology coordinates nano meter and micron meter order silver particles as conductive particles. Nano silver particles are highly activated and melted at a lower temperature than the melting point of bulk silver (about 1,000°C), so they take an important role in decreasing the connection resistance and in enhancing the connection reliability (Fig. 4).

2-2 Via filling with nano-conductive paste

To enhance the connection reliability with paste via technology, it is necessary to print nano-conductive paste on the vias without position gaps and to fill the

vias without voids. We had confirmed filling the vias properly when polyimide thickness is 10 µm thus far. In addition, we optimized the conductive particles, resins, and additives in nano-conductive paste and developed a screen printing technology. Now we can also fill the vias without voids when polyimide thickness is 12 or 25 µm (Fig. 5).

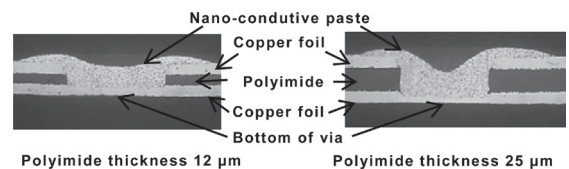


Fig. 5. Via filling with nano-conductive paste

Nano-conductive paste and the copper foil become integrated at the bottom of the vias with forming metal junctions with high-activated nano silver particles, thus enhances the connection reliability (Fig. 6).

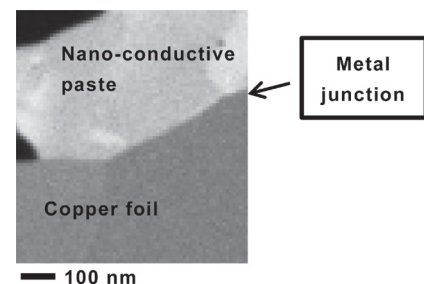


Fig. 6. Metal junction at the bottom of the vias

3. Substrate Performance

We carried out a connection reliability test and an anti-migration test of double-sided FPC by paste via

technology in the same condition required to pass in mass production by traditional plating through hole technology, and confirmed the mass production stability.

3-1 Connection reliability

(1) The heat cycle test of ten million vias

We measured the via connection resistance change in the heat cycle test after repeating 1,000 cycles, where the low temperature side is -40°C and the high temperature side is 125°C . We evaluated 1,000 pieces of 10,000 vias daisy chain, i.e. ten million vias connection reliabilities. After the passage of 1,000 cycles, the resistance change was just below 4%. We confirmed the connection reliability on the level of mass production (Fig. 7).

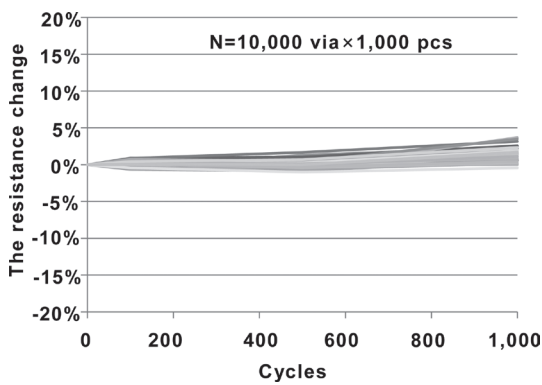
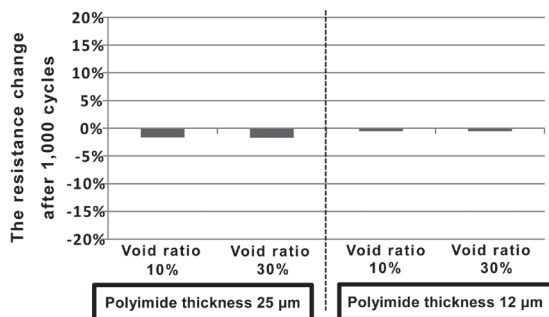


Fig. 7. The heat cycle test of ten million vias

(2) Reliability against void intrusion

As mentioned before, nano-conductive paste is superior in terms of filling the via. In the case of existing voids in vias, we carried out the heat cycle test by making voids in vias on purpose. With 30% of voids in vias, the result of the heat cycle test showed that the connection resistance was very stable and did not increase significantly (Fig. 8). This indicates that the connection breaking from voids rarely occur and the



*Void ratio: ratio of voids in the volume that should be filled with paste

Fig. 8. Void intrusion test in paste via

paste via technology is a highly reliable connection technology.

3-2 Anti-migration test

We measured the insulation resistance under $85^{\circ}\text{C}/85\%RH$ with applying 50 V to circuits having minimum space of $50\ \mu\text{m}$ and including paste via connection holes with via diameter / land*2 diameter = $\phi 100\ \mu\text{m} / \phi 300\ \mu\text{m}$ (Fig. 9). The insulation resistance kept high enough after 1,000 hours, we showed that the paste via technology did not undermine the insulation property (Fig. 10).

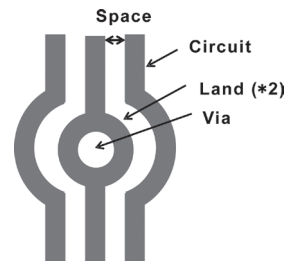


Fig. 9. The circuit pattern of anti-migration test

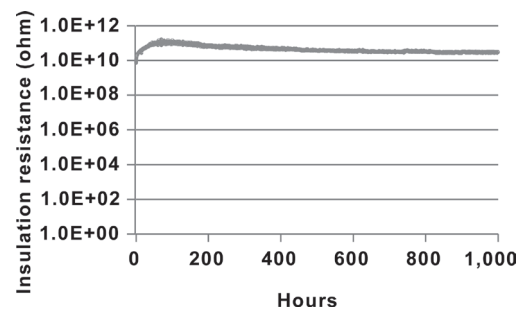


Fig. 10. Anti-migration test

As described above, showing strong results in the connection reliability test or anti-migration test, paste via technology has the connection reliability at the level of mass production. And also, it showed high connection reliabilities even with vias intentionally added to voids. We confirmed that the paste via technology has enough margins for mass production.

The paste via technology has enabled provision of thinner FPCs or FPCs with finer pitch formation. Following the successful development, we started mass production of the paste via technology in 2013⁽⁶⁾.

4. Conclusion

We have developed a nano-conductive paste, applying our original nano metal particle producing technology and material compounding technology, which allow filling the via well in thicker polyimide than

ever before. Metal junctions are formed at the bottom of the vias with nano-conductive paste. We, therefore, confirmed the connection reliability and anti-migration property at the level of mass production and started mass production of the paste via technology.

Technical Terms

- *1 Through hole, Via: Interlayer connection holes in double-sided or multi-layer FPCs. The through hole without bottom is called “through hole,” and hole with bottom is called “via.”
- *2 Land: Circuits around through hole or via, mainly circle shaped

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