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All Polyimide Thin Multi-Layer Substrate

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Abstract

As a promising candidate for future substrate with high pin-count and low transmission loss at high frequency, we have developed an all polyimide multi-layered board laminated by single batch process. Compared with circuit boards of glass-epoxy and ceramics, this circuit board made from polyimide films is thin and decreases transmission loss. It makes wiring-density higher and manufacturing cost lower, because of having all-layer IVH, Inner Via Hole, structure fabricated by single batch process. It is a significant feature that the process applies new interconnection technology to formation of conductive paste via in polyimide films, by laser-drilling and screen printing. By the most suitable condition of paste volume, temperature and pressure in laminating process, we have achieved 1.0 milli-ohms in resistance for each via.

Introduction

Recently, mobile electronic instruments, such as mobile phones, digital still cameras, digital camcorders, and others are continuing to be compact and lighter while its required performance is much more functional in limited space. To meet these requirements, IC substrate thickness, its wiring density and its transmission loss at high frequency are also needed to be much thinner, much higher and much lower, respectively.

We have developed "All Polyimide Multi-Layer Substrate". Compared to the substrate made by glass-epoxy or ceramics, the substrate made from polyimide films is thinner, and it has a possibility to decrease transmission loss because of the low dielectric constant of polyimide.

To realize the new substrate, conductive paste in IVH and gang operation when laminating has been newly adopted. There are some printed circuit boards made by glass-epoxy adopting conductive paste to the IVH portion [1)2)], but there was little report made by film material adopting conductive paste to the IVH portion ever.

This paper describes feature of "All Polyimide Multi-Layer Substrate", especially concerning the influence of the compression of conductive paste to the IVH resistance.

Structure of All Polyimide Multi-Layer Substrate

The cross sectional structure of current common IC substrate is shown in Figure 1. As the inner layer, glass-epoxy board adopting through-hole is used, and on both surfaces its, there are fine pitch wirings made by the build-up method.

The prototype all polyimide substrate has 3 wiring layers of a thickness about 160 microns. The view of the front side, its back, and its cross-section are shown in Figure 2. This substrate has 3 copper wiring layers, and each layer is connected by the IVH. Its specifications are shown in Table 1. The IVH is made from conductive paste. The structure is one of the significant features of this substrate.

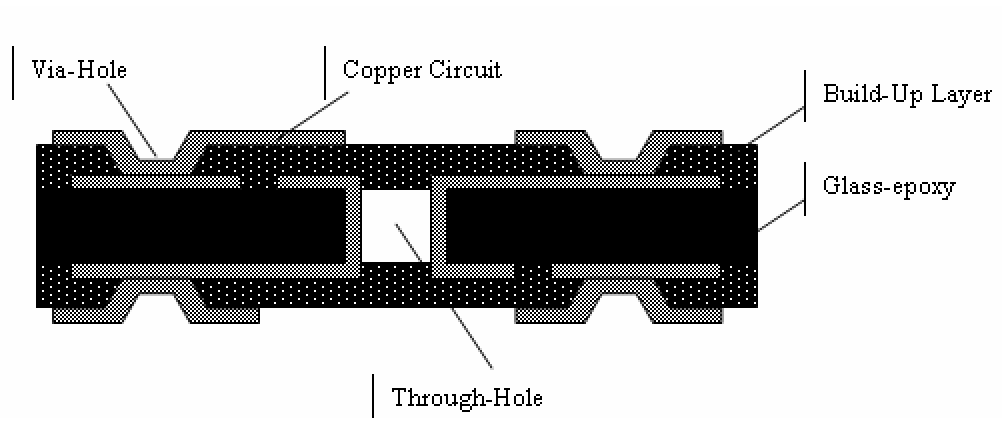


Figure 1 – Structure of Current IC Substrate

Table 1 – Specification

Number of Layers	3
Number of I/O Pads	256
Line/Space	50/50 microns
Land/via diameter	300/100 microns
Total Thickness	160 microns
Solder Bump Pitch	800 microns

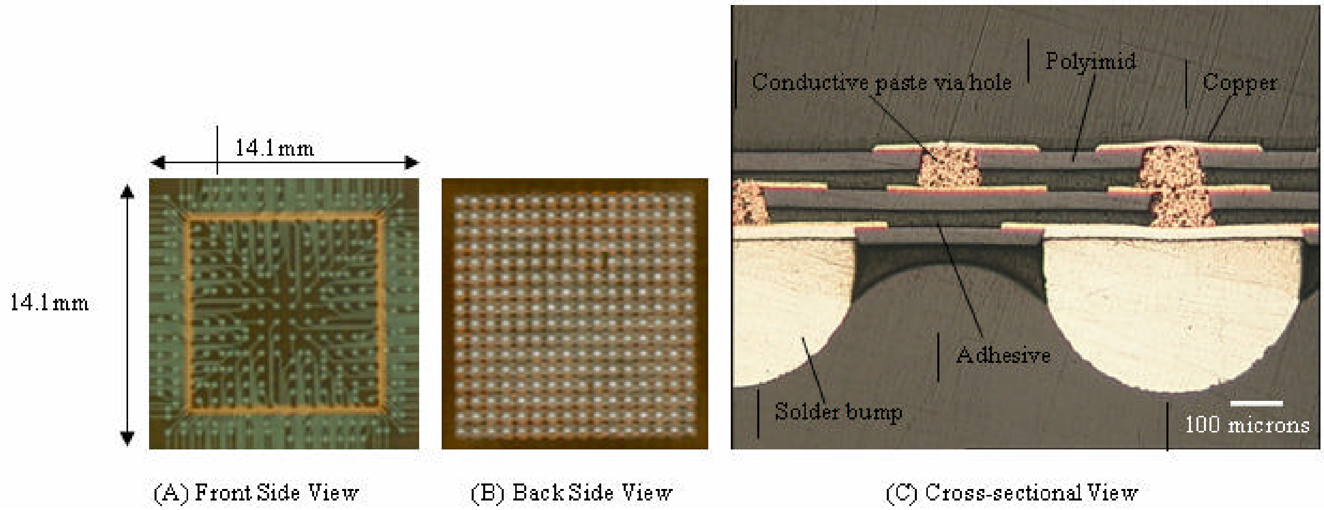


Figure 2 – (A) Front / (B) Back Side and (C) Cross- sectional View of All Polyimide Multi-Layer Substrate

The Process to Produce

The process to produce this All Polyimide Multi-Layer Substrate is shown in Figure 3. It starts from polyimide film formed on the copper layer on single-side, CCL. By etching the copper layer, the copper circuit is formed. Then adhesive material is laminated on the opposite side from the copper on polyimide. Next, on the surface of the adhesive, masking film is laminated. Then via holes are formed by laser drilling. Its diameter, of the portion in the resin consisted of polyimide, adhesive, and masking film, is about 100 microns and its diameter of the copper is from 20 microns to 30 microns. Next, the via holes are filled with conductive paste by screen-printing method. Through the process of filling the via holes by conductive paste, air is moved out from the copper hole and it prevents air from remaining in via hole. Then the masking film is removed and the boss of the conductive paste is exposed on surface of the adhesive.

Then the materials made by the same method shown above are superimposed with aligning, then they are laminated by pressurization and heating in single-batch process. This is completely different from the conventional process of producing multi-layer circuit board, called “Build Up process” that requires laminating process several times. This single-batch process of lamination is named “Gang Operation”.

Finally, gold plating, solder resist forming, and solder bump forming are applied to the Multi-layered board.

As mentioned above, this process has possibility to reduce the number of processes and failures because all the layers can be made at the same time and the failure layers can be tested and eliminated before laminating.

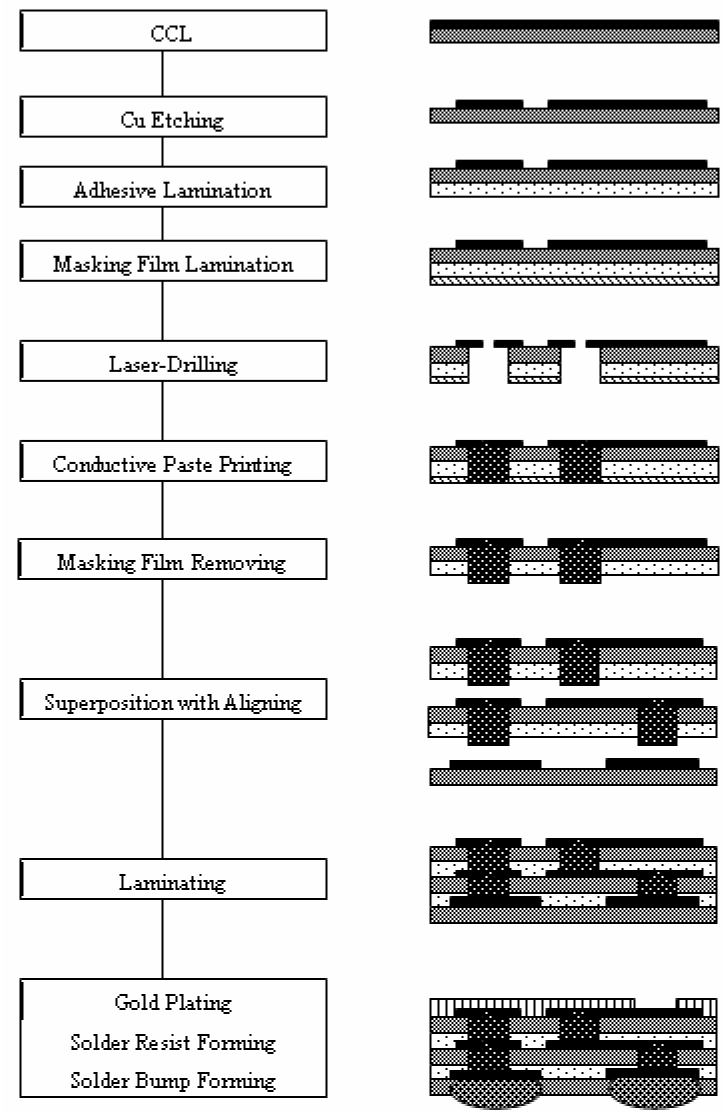


Figure 3 – Process Flow

Experimental Procedure

Using conductive paste to IVH is necessary for the Gang Operation. Conductive paste is frequently applied to the Multi-Layer Board made by glass-epoxy, but there was little precedent adopting conductive paste to the film-shape material. Therefore, experiments were carried out to obtain high connecting reliability by using conductive paste in the IVH and to clarify the influence of the process condition to the resistance of IVH. The factors that influence the resistance of IVH were found to be laminating pressure and the length of IVH, and it was the same as the thickness of the polyimide film with adhesive layer. The dependence of IVH resistance on the laminating pressure and the thickness of insulating layer were studied.

To calculate the resistance of IVH, the daisy-chain circuit shown in Figure 4 was used. Its land diameter was 300 microns and IVH diameter was 100 microns. The copper circuit was connected by 10 IVHs. To calculate the resistance of IVH, resistance of copper circuit without IVH was derived from the value of daisy-chain resistance. To measure the resistance, a Digital Multi-meter, Advantest Corp R-6551, was used and resistance was measured by the four-probe method with constant current of 1mA.

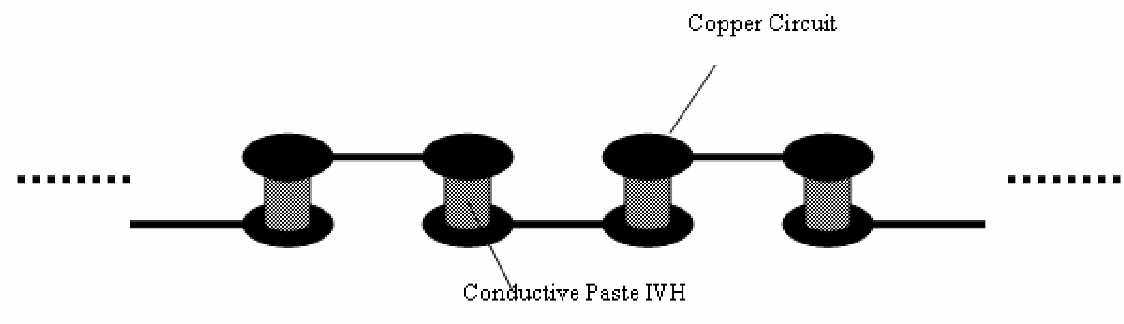


Figure 4 – Daisy Chain Circuit

Results and Discussions

Figure 5 shows the dependence of IVH resistance on laminating pressure. The thickness of insulating layer, polyimide with adhesive layer, was fixed at 63 microns in this experiment.

From 10kgf/cm^2 to 55kgf/cm^2, the resistance of IVH keeps almost constant value, but when the pressure is larger than this particular value, resistance becomes extremely large. The cross-sectional views of IVH's are shown in Figure 6. In the case of a laminating pressure of 70kgf/cm^2, adhesive material is invading into IVH and conductive paste is effusing from IVH through the small hole of copper. It is estimated that the phenomenon made the resistance large.

Figure 7 shows the dependence of IVH resistivity on thickness of insulating layer, polyimide with adhesive. Because of the results, the laminating pressure was fixed at 40kgf/cm^2.

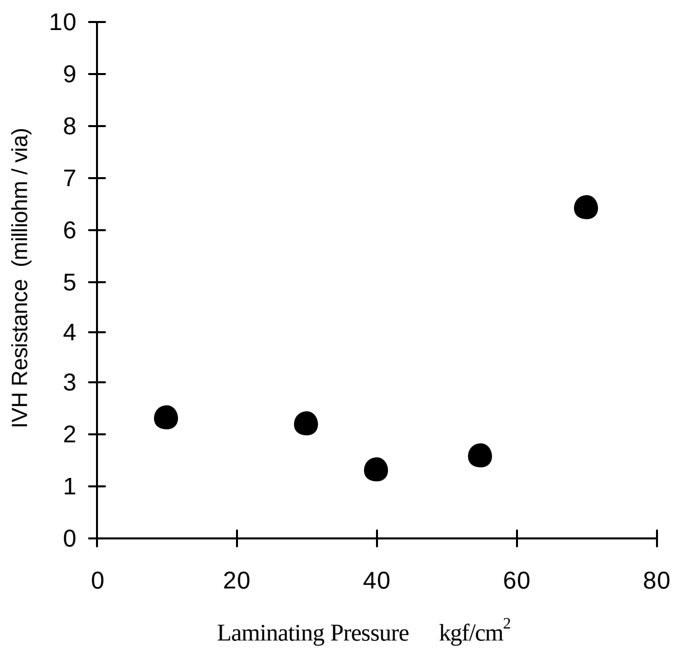


Figure 5 - Dependence of IVH Resistance on Laminating Pressure

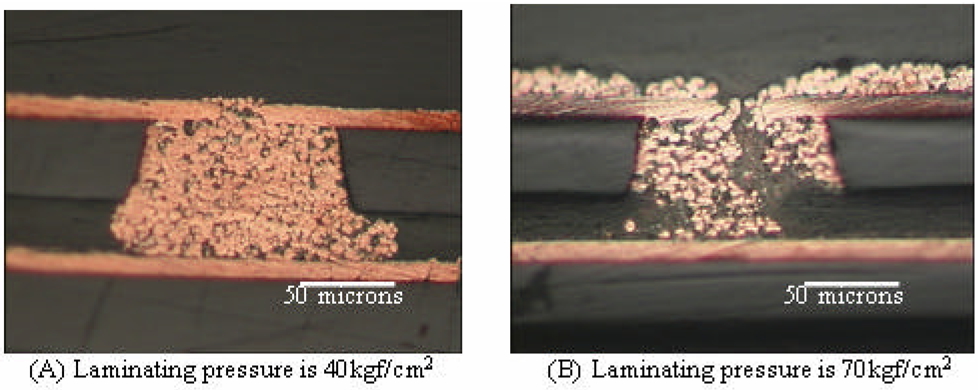


Figure 6 - The Cross-Sectional Views of IVHs

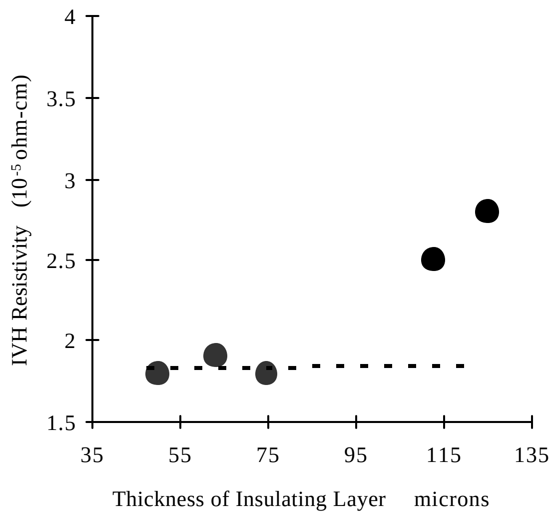


Figure 7 - Dependence of IVH Resistivity on Thickness of Insulating Layer

When the thickness of insulating layer is from 50microns to 75microns, the resistivity is almost constant. But when the thickness becomes larger than this range, the resistivity deviates from the constant linear relationship, and as the thickness becomes larger, the deviation becomes much larger.

As mentioned in the section on the production process, when masking film is removed, the boss of conductive paste is exposed on surface of the adhesive as shown in Figure 8. The height of this boss is constant at 25 microns, and the filler of this boss invades into IVH when laminating. So as the thickness of insulating layer becomes smaller, the ratio of the volume of boss against the volume of via hole becomes larger, therefore the density of filler in IVH becomes higher.

For this mechanism, the resistivity becomes larger as the thickness of insulating layer becomes larger beyond particular value.

To confirm this mechanism, we have investigated the volume ratio of filler in conductive paste in the case of compressed and non-compressed. The compressed conductive paste was sampled from IVH whose insulating layer's thickness was 63microns and laminating pressure was 40kgf/cm^2. On the other hand, non-compressed conductive paste was sampled from a painted membrane. Both cross-sectional views are shown in Figure 9.

As shown in these cross-sectional views, in the case of painted membrane, the volume ratio of filler was 46%. This Value agrees in the composition ratio of conductive paste used in this experiment. On the other hand, in the case of IVH, the volume ratio of filler is 68%, i.e. it is much larger than painted membrane.

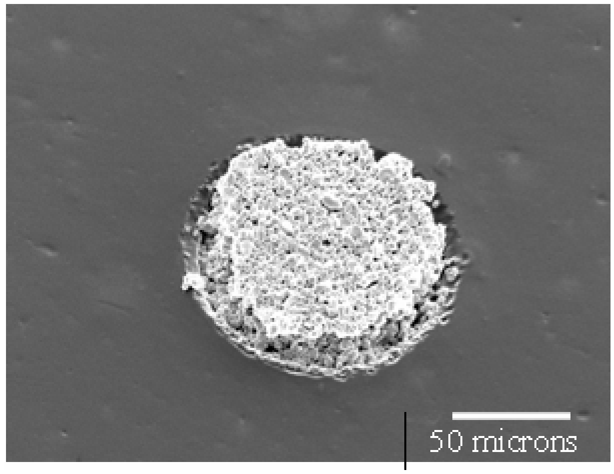
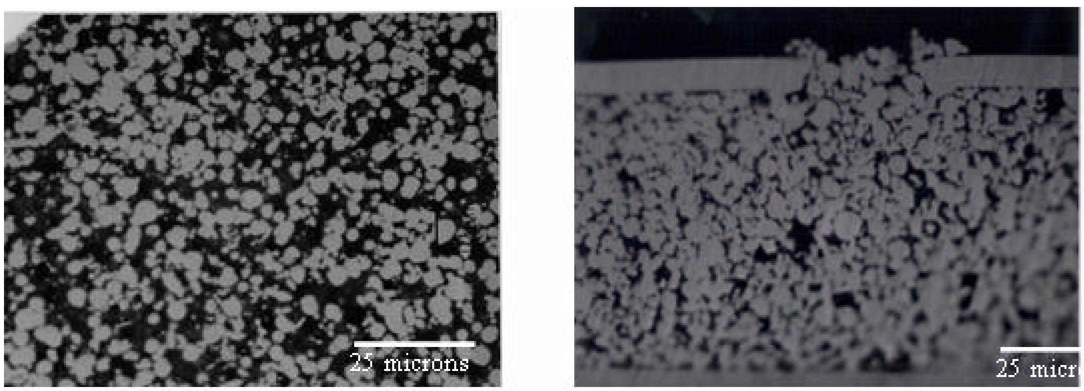


Figure 8 – Boss of Conductive Paste (SEM Image)



(A) Non-Compressed Conductive Paste (Painted Membrane)

(B) Compressed Conductive Paste (IVH)

Figure 9 – Cross-sectional Views of Conductive Paste (SEM image)

Suppose that diameter of via hole is 100 microns, the height of conductive paste boss is 25 microns, and the volume ratio of filler before laminating is 46%, and the all fillers of boss is included in the via hole, the ratio of filler after lamination is expressed below.

$pr^2 \times (T+25) \times 0.46 = p r^2 \times (T-8) \times R$

Therefore,

$R=0.46 \times (T+25)/(T-8)$ eq (1)

where, R is volume ratio of filler after lamination, and T is the thickness of insulating layer before laminating and T-8 implies that after lamination, copper circuit is buried in the adhesive, so the thickness become 8 micron smaller after lamination.

When T=77 microns, the volume ratio of filler is 68%.

Figure 10 shows the dependence of IVH conductivity, reciprocal of resistivity, on thickness of insulating layer, and the dependence of volume ratio of filler on thickness of insulating layer according to the equation 1. Right longitudinal axis, volume ratio of filler is adjusted as next. When the volume ratio of filler is 46%, electric conductivity is in the case of painted membrane, 0.2×10^{-5}/ohm-cm, and when the volume ratio of filler is 68%, electric conductivity is 0.56×10^{-5}/ohm-cm.

As shown in Figure 10, it is supposed that IVH conductivity shows the same behavior as the volume ratio of filler, but volume ratio of filler saturates at 68% and the electric conductivity does not gain from the value of its case, 0.56×10^{-5}/ohm-cm.

It is concluded that when using this conductive paste, the height of conductive paste boss is 25 microns, IVH conductivity can be maximized by setting the thickness of insulating layer less than approximately 77 microns irrespective of thickness of insulating layer.

In addition, the boundary view of conductive paste and copper is shown in Figure 11. The filler of conductive paste is stuck into the copper, and it is supposed to cause high reliability and low resistance of IVH.

The resistance per via is 1.0milli-ohms when the laminating pressure is 40kgf/cm^2, the thickness of insulating layer is 50 microns.

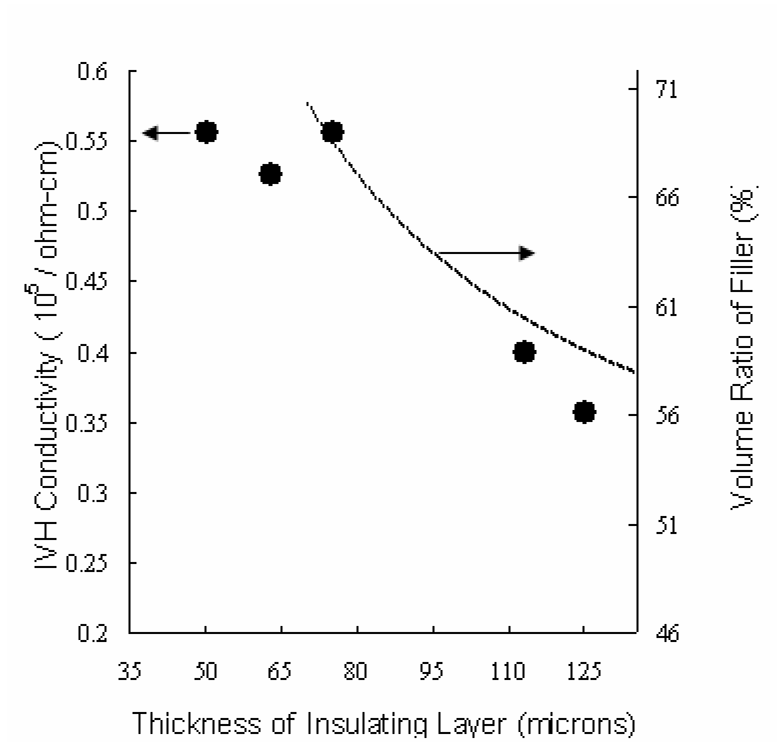


Figure 10 – Dependence of IVH Conductivity and Volume Ratio of Filler on Thickness of Insulating Layer

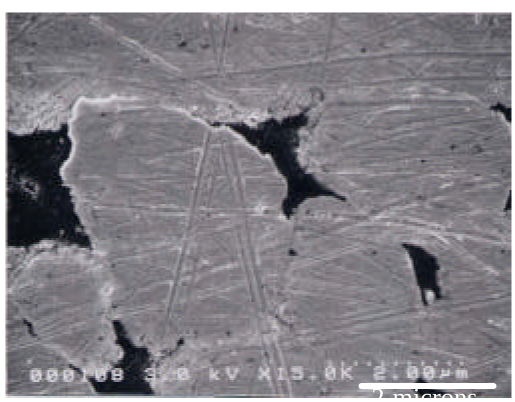


Figure 11 - Boundary View between Copper and Conductive Paste (SEM image)

Results of Reliability Test

Table 2 shows the results of reliability test against the daisy-chain circuit. The solder reflow test, thermal cycle test, and temperature-humidity-bias test are done under the conditions shown in Table 2, and it is confirmed this board has been passed all of the tests.

Table 2 – Results of Reliability Test

Item	Condition	Specification	Results
Solder Reflow Test	Hot Air Reflow (max 260 Celsius)	Resistance variance <20%	Pass
Thermal Cycle Test (hot oil)	20 Celsius 20 min/260 Celsius 10 min 200 Cycle	Resistance variance <20%	Pass
Thermal cycle Test (Air)	-65 Celsius 30 min/125 Celsius 30 min 1000 Cycle	Resistance variance <20%	Pass
Temperature-Humidity-Bias Test	85 Celsius/85 RH% 30V 1000 hour	Insulating resistance >500M-ohm	Pass

Conclusion

We have developed All Polyimide Multi-layer Substrate made by "Gang Operation". And the technology of connecting layers by conductive paste IVH has been established and succeeded to reduce the resistance of IVH.

The technology of this substrate can be applied to the mother boards and module boards, and expected to contribute to the reduction of size of electronic instruments.

References

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2) Y. Fukuoka, H. Oodaira, H. Hamano, Y. Satou, K. Shibayama, K. Sasaoka, Electronics Parts and Materials, 95-101, 1995 Nov.