The stacking of via holes is used effectively in the development of high density circuits on build-up printed wiring boards (PWBs). However, when micro via holes (MVHs) are repeatedly stacked, they can cause open circuits due to the difference in the thermal expansion of the Copper and the glass epoxy base material. In order to verify the reliability of the stacked via hole connections, a range of test boards with different numbers of stacked via hole layers, material types (FR-4, high-Tg FR-4, low thermal expansion material, etc.), and via hole diameters (0.100 mm and 0.075 mm) was produced and tested.

The boards were examined through DC current induced thermal cycling tests to determine the reliability of the various samples. With regards to anti-migration properties, the pitches and base material types of micro via holes were also studied. As a result of the evaluation, it was verified that first the MVH, then the interstitial via hole (IVH) and lastly the plated through hole (PTH) achieved, respectively, the most reliable connections. As for base materials, a high-Tg material with low thermal expansion qualities is recommended. It would seem that a MVH diameter of 0.100 mm is preferable to prevent voids due to a high aspect ratio. No problems with the reliability of the insulation were found on any base material, as long as the MVH pitch is 0.35 mm or more (or 0.25 mm between the hole walls).

Due to higher pin counts and narrower pitches, the density of the printed wiring boards required by the market today is higher than ever. As a result, the adoption of

‘build-up printed wiring boards’ has become widespread, particularly in the areas of communication station infrastructures (which require a high level of reliability) and industrial devices such as IC testers.

The method used for manufacturing build-up printed wiring boards generally employs the prepreg process to produce the build-up material and Copper plating to ensure electrical connection. In the case of filled via holes, excellent reliability of the electrical connection is provided by the MVH. Moreover, an advantage of adopting filled via holes is the via-on-via structure (stacked via hole). This structure, in which filled via holes are stacked, provides more flexibility in the design of circuits and makes it possible to achieve higher density circuits.

In our research on the reliability of these types of connections as a function of base materials, the
number of build-up layers and the MVH diameter, it was found that certain design rules had to be established to ensure the reliability of the test results. As a comparative study, further research was also conducted on PTHs and IVHs. Therefore the connection reliability of the entire range of build-up printed wiring boards was addressed.

Furthermore, as it is becoming necessary to make MVH pitches even narrower in line with the narrowing pitch on surface mount components, it was decided to evaluate also the insulation reliability of PWBs with fine-pitched MVHs by using test patterns on which the distances between MVH and MVH are gradually changed.

**The manufacturing process**

The manufacturing process used for the evaluation is shown in Figure 1. As for the IVH, it was filled with epoxy resin after plating and after a build-up layer was formed. The build-up layer was formed with a thermal press, applied on the prepreg material and Copper foil after the formation of circuits. A CO₂ laser was used to make the MVHs. Since it is generally difficult to work Copper foil using a CO₂ laser, partial etchings on the Copper foil were made prior to drilling the holes with the laser. After plating the filled via holes, a circuit pattern was formed on both sides and then a lamination layer was applied, onto which another circuit pattern was formed to achieve three build-up layers. Stacked via holes were produced by repeating this MVH formation process as required.

**Connection reliability**

One cause of long-term failure that may occur in printed wiring boards is an open circuit resulting from a crack of a PTH. When a printed wiring board is repeatedly subjected to thermal stress, the difference in thermal expansion between the Copper plate and the base material causes a distortion of the board, which can lead to an open circuit if a crack forms in the Copper plate. The failure mode for similar mechanisms on stacked via holes must therefore be studied as well. In order to determine the extent of influence of the difference in thermal expansion between different base materials, besides FR-4, materials with low thermal expansion coefficients were selected for the test. Table 1 shows the characteristic values of base materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Classification</th>
<th>Tg (°C)</th>
<th>α1 (&lt;1g)</th>
<th>α2 (&gt;1g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>FR-4</td>
<td>131</td>
<td>860g/°C</td>
<td>264g/°C</td>
</tr>
<tr>
<td>b</td>
<td>Halogen-free</td>
<td>152</td>
<td>420g/°C</td>
<td>200g/°C</td>
</tr>
<tr>
<td>c</td>
<td>High Tg FR-4</td>
<td>171</td>
<td>780g/°C</td>
<td>273g/°C</td>
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<tr>
<td>d</td>
<td>Low CTE</td>
<td>163</td>
<td>300g/°C</td>
<td>150g/°C</td>
</tr>
<tr>
<td>Hole filling</td>
<td>Low CTE</td>
<td>151</td>
<td>300g/°C</td>
<td>150g/°C</td>
</tr>
</tbody>
</table>

**Table 1 – Characteristic values of the base materials**
For the evaluation, 16-layer boards with a total thickness of 2.0 mm were used. The boards consisted of three build-up layers on each side of a 10-layer IVH. The board thickness of the IVH layer (layers 4 - 13) was 1.3 mm, while the thickness between the build-up layers was 0.06 mm per layer.

The evaluation method

The evaluation method consisted of a DC current induced thermal cycling test according to IPC-TM-650: 2.6.26 - three minutes of heating followed by two minutes cooling (maximum temperature 150°C). Pretreatment consisted in 3x3 cycles from ambient temperature to 230°C. The number of cycles of the test was 2,000 cycles and the criterion was a change in conductive resistance 10%. Six samples were produced. The test pattern consisted of a daisy chain pattern for PTH, IVH and MVH. The design rules are shown in Table 2.

The mean time to failure (MTTF) obtained for each type of base material used in this evaluation is shown in Table 3. Failures occurred first for PTHs, then IVHs and then MVHs, in that order. The failure results of the base material (a) in the PTHs, IVHs and MVHs (three-step stack) are plotted on Weibull probability paper and shown in Figure 2. Comparing the results for various base material types, it was confirmed that the combination of high-Tg materials with low thermal expansion specifications does not cause more failures than when using FR-4 material. Furthermore, in the stacked via hole area, it is assumed that cracks tend to be caused by the increase in distortion resulting from the difference in thermal expansion between the base material and Copper. When the failure modes were checked, barrel cracks and corner cracks were detected on PTHs and IVHs (Figures 3 – 6). In the case of failure on MVHs, corner cracks were also detected (Figures 7 and 8).

Results of the evaluation

As a result of this evaluation, it was verified that the connection reliability was superior for MVHs, then for IVHs and least reliable were PTHs. In order to enhance the total connection reliability, we believe that it is necessary to improve the connection reliability of PTHs and IVHs in particular. For both the PTH and the IVH processes, it is generally accepted that a thinner board causes fewer problems. To verify this, PTH boards with a 1.6 mm board thickness were produced for evaluation purposes. These thinner boards were obtained by making the prepreg thinner for the substrates (a) and (c) (Table 4). It was ultimately verified that a thinner board provided superior connection reliability.

In order to determine the extent of the failures as a function of smaller MVHs, three-step stacked via holes were produced using base materials (a) and (c), and using two different types of laser fabrication conditions. The average value of MVH diameters obtained is given in Table 5. The evaluation revealed that the first failures occurred during the 10th cycle on base material (a) and during the 58th cycle on base material (c). The results of the evaluation of the base material (a) are shown in Figure 9 as an example. Comparing the “m” values (i.e., shape parameters) on a Weibull distribution, we can see that under laser fabrication conditions (ii), when m < 1, failures
occur early. In the case of type (i) laser fabrication conditions, with \( m > 1 \), the occurrence of failures is related to the elapsed time. Checking the failure mode under the laser fabrication condition (ii), it was found that the Copper plated walls of the hole became thinner as a void occurred within the MVH (Figure 10). The root cause was the difficulty in circulating the foaming solution and Copper plating solution within the MVH during the Copper plating process due to the higher aspect ratio resulting from the decreased MVH diameter. In promoting smaller diameters of MVH, attention must be paid to the MVH diameter and the dielectric thickness. To achieve a stable volume production, it is also necessary to establish a quality assurance process aimed at eliminating voids within MVH. In order to satisfy the 200 cycle requirement of the DC current induced thermal cycling test, it is necessary to ensure the reliability of PTHs or IVHs and use either a high-Tg material or a low thermal expansion material. With regards to MVHs, a diameter of approximately 0.100 mm is desirable in correspondence of a thickness of 0.06 mm between build-up layers. The manufacturing specifications of chip carrier applications require careful examination since their design rules and base materials are different from those of general printed wiring boards.

### Insulation reliability

In line with the trend towards narrower pitches for surface mount components, distances between MVHs are also becoming shorter. A study was carried out to determine how the reduced distance between MVH and MVH affects insulation. We used the test pattern that combined MVHs in a comb-type pattern as shown in Figure 11, in accordance with the design rules described in Table 6. Four types of base materials were used for the evaluation, namely base materials (a), (b), (c) and (d), as shown in Table 1. The thickness between build-up layers was 0.06 mm.

The evaluation method for moisture and insulation resistance (IR) was Printed Board IPC-TM-650, 2.6.3F, Class 2, 50°C +/-5°C, 85–93% RH, DC 100V, for 7 days (168 hours). The test was conducted in accordance with all of the above conditions except for the test duration, which continued for up to 500 hours. The IR of the samples was measured every 10 minutes under the test conditions. Pre-treatment consisted in maintaining the samples at 50°C for 24 hours. As for the failure criteria, no measing, blistering, delamination, etc. is allowed. Insulation resistance should be at least 500 x 10^6 ohms. The number of samples was six.

The results of this evaluation are provided in Table 7. No failures occurred on any of the samples for the 168 hours of testing that is the standard requirement for the IPC-TM-650 Environmental Test Method 2.6.3F. However, our longer test duration found that 1 out of every 6 samples of base material (a) with a 0.35 mm MVH pitch (a distance between hole walls of 0.25 mm), had a failure after 434 hours. When the defective portion was examined, a conductive anodic filament (CAF) was discovered (Figure 12). Because the results satisfy the standard 168 hour requirement, it was concluded that there is no problem with an MVH pitch of 0.35 mm or more (or a distance of at least 0.25 mm between hole walls) on any of the base materials examined (Figures 13-16).

Insulation reliability apparently varies depending on the type of resin and glass cloth within the base material. It is therefore important to select an appropriate base material in consideration of the customer’s requirements and the design rules.

### Conclusions

The evaluation verified that the connection reliability was highest...
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For MVHs, followed by IVHs, and then PTHs. For the base material, a high-Tg material with low thermal expansion properties is recommended as no failure was found after completing a total of 2000 cycles.

In general, the thicker the board, the more problems occur in IVHs and PTHs. To improve the reliability in products with a higher layer count, it is desirable to use base materials with both high-Tg and low thermal expansion properties. Assuming there is no restriction on the impedance specification or the like, we suggest, to improve connection reliability by reducing the total thickness, using a 0.06 mm thick inner layer material and a 0.06 mm thick prepreg.

In promoting smaller diameters of MVH, the aspect ratio of MVH becomes higher, increasing the risk of a void on the Copper plate. Thus greater care is required in the setting of the thickness between the build-up layers. To allow for volume production, an MVH diameter of 0.100 mm is desirable if the thickness between the build-up layers is 0.06 mm. In order to realise a higher aspect ratio of MVH, consideration must be given to de-foaming during Copper plating, the method for circulating the Copper plating solution within MVH, and the reduction of glass projections from the hole walls.

With regards to the insulation reliability, care is required in the selection of base materials even though no problem was found for an MVH pitch down to 0.35 mm. To further enhance the reliability of high layer count build-up printed wiring boards, it is necessary to optimize the base materials in regard to the board thickness, PTH diameter, IVH diameter, MVH diameter and Copper plate thickness.

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