Interconnection Evaluation Technology for Printed Wiring Boards

● Mitsuhiko Sugane ● Yoshihiro Morita

(Manuscript received December 28, 2009)

As a developer of world-class products including server and network devices, Fujitsu recognizes the printed wiring board (PWB) as a core component among the various components of those products. One basic element supporting high-quality PWBs is through-hole interconnection reliability. Existing methods for evaluating interconnections typically involve temperature cycle tests that subject the PWB to low and high temperatures. We have developed an evaluation technique that applies current to interconnections and wiring patterns to heat the PWB's interior and generate a temperature rise. This technique can apply a temperature load closer to actual conditions than temperature cycle tests can, enabling evaluation in one-fifth the time. In this paper, we introduce this new through-hole interconnection evaluation technique.

1. Introduction

Hardware products consist of various components, and the printed wiring board (PWB) ranks as a core component. The structure of a PWB is shown in **Figure 1**. A through-hole, formed by drilling a hole through a PWB, enables electrical connections to be made between inner-layer and surface-layer conductors via copper plating. For PWBs, insulation reliability and through-hole interconnection reliability are especially important as basic elements supporting PWB quality.

Fujitsu Advanced Technologies Ltd. (FATEC) develops PWB technology and PWB certification and evaluation technology and establishes specifications for PWBs procured by Fujitsu. FATEC aims to achieve a stable level of quality in PWB products received from PWB suppliers to ensure that customers do not experience problems with Fujitsu products.

This paper introduces new technology that we have developed for evaluating through-hole interconnection reliability in PWBs.

2. Outline of PWB evaluation

At Fujitsu, PWBs are evaluated through tests that conform to international and industry standards. Specific test descriptions and evaluation criteria are designed to check whether equipment lifetimes guaranteed to customers and PWB reliability (lifetime and expected failure rate) are being maintained.

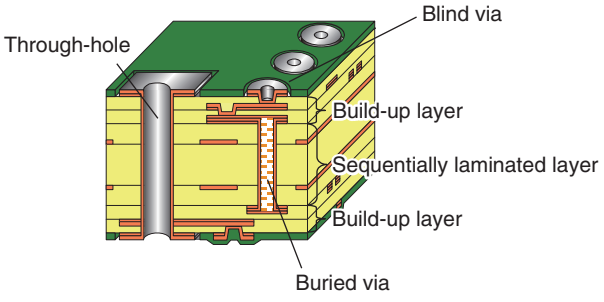

Figure 1
Structure of PWB.

2.1 Insulation reliability

The wiring pattern on a PWB is tested by applying voltage in a high-temperature, high-humidity environment using environmental testing equipment and monitoring the insulation resistance between adjacent conductors and between vias.

2.2 Through-hole interconnection reliability

As shown in **Figure 2**, thermal shock tests using temperature-cycle testing equipment are applied to PWB through-holes and wiring patterns to check through-hole interconnection reliability. In these tests, a PWB is subjected to low- and high-temperature atmospheres and accepted or rejected on the basis of:

1) the rate of change in resistance of wiring conductors and
2) through-hole cross section observations.

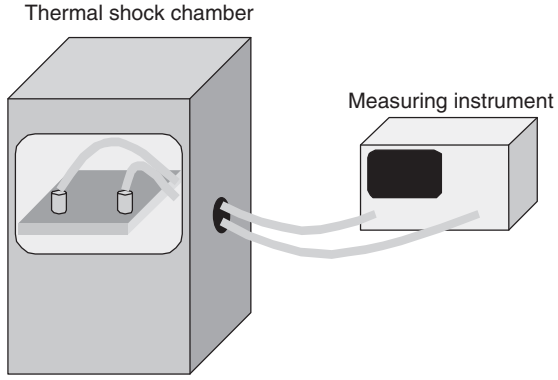

Figure 2
Thermal shock test.

Details of the thermal shock tests as prescribed by international and industry standards are given in **Table 1**. At FATEC, one cycle has been taken to range from -65°C to 125°C and the number of test cycles has been set to 100. On the above basis, two conditions for determining acceptance have been established:

1) the rate of change in conductor resistance must be within 10% and
2) FATEC-specified values must be satisfied for the extent of plating cracks, inner-layer connectivity, plating thickness, etc.

3. New evaluation technology

This section describes FATEC's use of the Interconnect Stress Test (IST) system offered by PWB Interconnect Solutions, Inc. For PWB specifications that cover multiple overlapping elemental technologies, the trend has been for increasingly longer reliability-evaluation periods lasting from half a year to one year or even longer. One reason for this is the difficulty of determining whether problems are due to the technical expertise of the PWB supplier or to the severity of the PWB specifications themselves. Therefore, the need has been felt for a technique that can determine the PWB supplier's technical expertise relatively quickly. In response to this need, we introduced the IST system into through-hole interconnection reliability tests. With IST, we investigated evaluation acceleration factors and determined optimal values, enabling us to grasp the supplier's technical expertise and establish PWB specifications that could allow a

Table 1
Details of thermal shock tests.

	IEC standards	MIL standards	IPC standards	JIS standards
Test description	61889-3 3E08 Condition A -65ºC→125ºC	MIL-STD-202-107G Test Condition B -65ºC→25ºC→ 125ºC→25ºC	IPC-TM-650 2.6.7.2B Test condition D -55ºC→25ºC→ 125ºC→25ºC	JISC5012 9.2 -65ºC→125ºC

IEC Standards: International Electrotechnical Commission Standards
MIL Standards: Military Standards
IPC Standards: Institute for Interconnecting and Packaging Electronics Circuits Standards
JIS: Japanese Industrial Standards

shorter evaluation period.

3.1 Overview of IST system

The IST system tests the reliability of PWB through-hole interconnections by applying current to the wiring pattern of a test coupon and repeatedly heating and cooling the PWB's interior by switching the current on and off. This test method has been standardized as IPC-TM-650 2.6.26. Specifically, DC current is passed through the test coupon's conductors and through-holes for three minutes to bring the PWB to the temperature designated by test requirements. The PWB is then left for two minutes to cool to room temperature. This process, which is taken to be one cycle, is repeated for a specified number of cycles, and the test coupon's resistance changes are objectively assessed by electrical evaluation of through-hole defects and the quality of conductor connections. The IST system test procedure is as follows.

1) Measure the test coupon's resistance and calculate the current needed to bring the test coupon to the designated temperature.
2) Apply DC current.
3) Monitor the test coupon's conduction.
4) Bring the test coupon to the designated temperature for the test.
5) Repeat the thermal cycle in an environment designated by test requirements.
6) Monitor the changes in the test coupon's resistance and temperature.
7) Record and analyze data.

3.2 Test coupon design

Standard data has been prepared for test coupons used by the IST system with respect to standard PWB configurations (through-hole, build-up, etc.), but data for non-standard PWB specifications has not been prepared. Therefore, at FATEC, we designed special test coupons in line with PWB specifications targeting core Fujitsu equipment. The test coupon pattern that we designed for this study is shown in **Figure 3**.

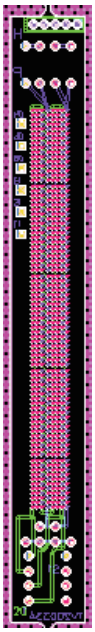

Figure 3
Test coupon.

3.3 Test items and test method

The test items and test method that can be supported when using the IST system are summarized below.

1) Through-hole interconnection reliability

A wiring pattern through which DC current is applied and a wiring pattern for testing through-hole interconnection reliability are arranged. If the through-hole resistance should exceed a certain value, the test coupon is judged to have failed and the test is terminated. Auxiliary equipment is then used to determine where the abnormal resistance rises occurred and perform cross-section observations of those locations so that through-hole defects can be examined.

2) Inter-layer peeling check

Inter-layer peeling can occur during testing due to the higher profile setting temperature associated with reflow soldering using lead-free solder. Whereas existing methods are unable to check for inner-layer peeling from external appearances, the use of a test coupon lets us arrange the test pattern so that we can observe inter-layer peeling that occurs after thermal

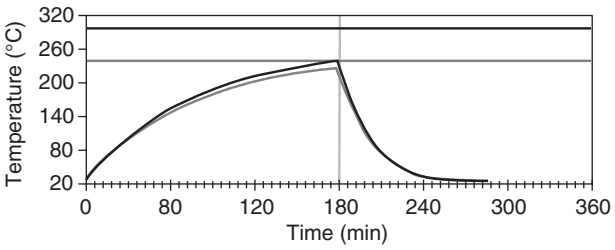

Figure 4
Preconditioning cycle.

processing or during testing. This test pattern is used to evaluate inter-layer peeling.

3) Test method

The test method has five steps: measure the glass-transition temperature, measure the electrostatic capacitance between layers (evaluate inter-layer peeling), perform preconditioning (set to correspond to the reflow solder process), measure the test coupon's initial resistance, and start the test. The glass-transition temperature is measured in sections of the test coupon that do not have any copper foil. The measurement procedure follows IPC-TM-650 2.4.24.5. Measurements are performed before the test, after prescreening, and after the test. Preconditioning consists of three cycles that reach a maximum of 230°C within three minutes; an example of one actual cycle is shown in **Figure 4**. The test coupon's initial resistance is measured using a tester. The test is conducted at three temperatures as standard test conditions: 150°C, 160°C, and 170°C. The number of test cycles is set to 500.

4. Experiment

We compared our new IST-based evaluation method with existing test methods in terms of through-hole interconnection reliability. The results are presented below.

4.1 Test coupon specifications

We used glass-fabric-based epoxy resin as the PWB material and compared multilayer PWBs prepared by the through-hole plating method. The specifications of these test coupons matched the specifications of multilayer PWBs used widely in core Fujitsu equipment. The wiring specifications were as follows.

Board thickness: 2.3 mm, number of layers: 20, hole diameter: 0.25 mm, material: FR-4.

4.2 Comparison method

1) Glass-transition temperature measurement

The glass-transition temperature was measured by thermo-mechanical analysis after the solder mask stamped on the test coupon had been peeled off.

2) Thermal shock resistance test

To add the thermal processing of the reflow solder process to the test coupon, the IEC test listed in Table 1 was performed after the IST system had been preconditioned. This test was repeated until the rate of change of conductor resistance exceeded 10%, at which time through-hole cross sections were observed.

3) IST system test

Preconditioning was performed three times at 230°C as thermal processing similar to the thermal shock resistance test. The temperature was set to 120°C, 150°C, 160°C, and 170°C as four test conditions and the test was performed until the change in conductor resistance exceeded 10%. Abnormal locations were determined using a test coupon whose resistance rate-of-change exceeded 10%. Through-hole cross sections were then observed at those locations and the state of cross-section cracks was compared with the thermal shock resistance test results.

4.3 Results

The results of this comparison test are summarized below.

1) Glass-transition temperature

Although the table of general characteristics (catalog values) for the material in question listed a glass-transition temperature of 135°C, the actual measurements revealed a temperature of 150°C.

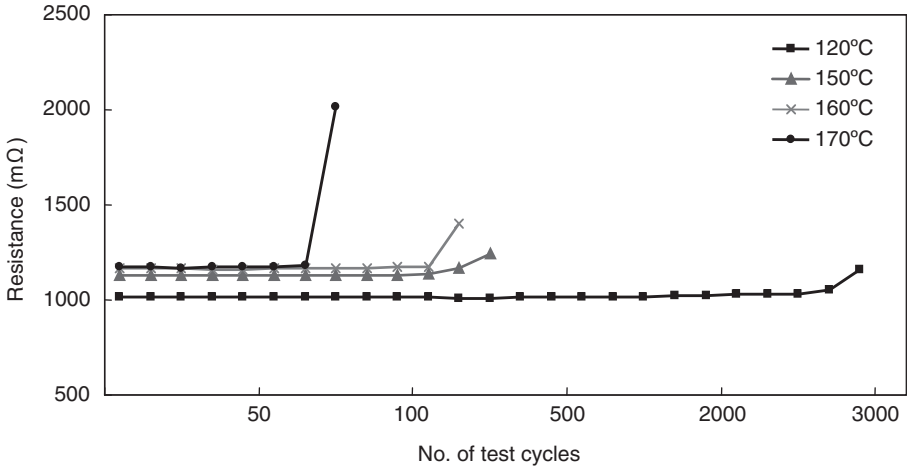

Figure 5
Test results.

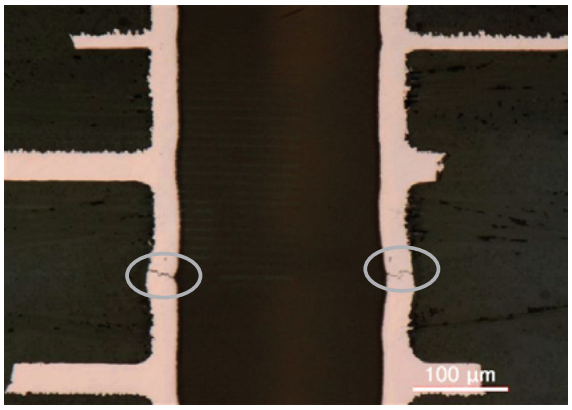

Figure 6
Cross sections of through-holes.

2) Thermal shock resistance test

It took 400 cycles to exceed a resistance rate-of-change of 10%.

3) IST system test

At a temperature setting of 120°C, a test coupon first showed a resistance rate-of-change in excess of 10% at 2595 cycles. Test results are shown in **Figure 5**. The cycle numbers corresponding to the onset of problems at the other temperatures were: 156 cycles at 150°C, 115 cycles at 160°C, and 69 cycles at 170°C.

When we observed test-coupon through-hole cross sections for which the resistance rate-of-change exceeded 10% in the IST system test, we found cracks in the plating of all such through-holes, as shown in **Figure 6**. We also found that cracks occurred in the same way in the thermal shock resistance test performed in the comparison test, indicating that the defect phenomena are the same.

Table 2
Test times.

Test	Temperature	Time
Thermal shock resistance test		about 20 days
IST system test	120°C	about 9 days
	150°C	about 1 day
	160°C	about 1 day
	170°C	about 1 day

The times required for tests are given in **Table 2**. The IST system tests enabled significantly shorter tests.

5. Proposal of new evaluation technique

Up to now, we have been examining existing PWB test methods and a new test method based on test results. We think that applying the IST system to through-hole interconnection reliability tests is an effective way to achieve stable evaluation tests in a relatively short

time and supplement a PWB supplier's quality assurance activities. In this section, we describe the effects of using the IST system and describe the test itself.

1) Shorter evaluation time

At FATEC, we have found that switching to the IST system lets us perform evaluations in about one-fifth the time required for conventional test methods. In the comparison test described in this paper, a through-hole interconnection reliability evaluation under a single test condition (temperature setting) took a total of four days: one day for the test, two days for cross-section observations, and one day for drafting a report.

2) Acceleration factor (in comparison with conventional tests)

We have concluded that compared with test methods used by FATEC in the past, the IST system corresponds to tests with an acceleration factor of more than four times.

3) New evaluation method

At FATEC, we are creating new evaluation standards using the IST system with the aim of migrating to this new evaluation technique. We would like to propose to our PWB suppliers that they use this new technique. We think that the following rules are appropriate for this new evaluation technique.

- The number of test cycles shall be 500 for testing below the glass transition temperature of the PWB material used in the test coupon.
- The number of test cycles shall be 100 for testing at the glass transition temperature of the PWB material.
- The acceptance criterion shall be a resistance rate-of-change of less than 10%.

6. Issues and future activities

Looking forward, FATEC will undertake the following activities and address the following issues:

1) Collaborate with PWB suppliers so that the IST system can be used for evaluating the quality of the PWB manufacturing process with the aim of improving PWB quality.
2) Accumulate reliability-evaluation data for various PWB materials and promote standardization of evaluation technology using the IST system so as to establish and promote the use of a new evaluation technique for through-hole interconnection reliability.
3) Improve evaluation technology using the IST system so that it can also be applied to PWB specifications for boards other than those discussed here, such as flexible PWBs and build-up PWBs.

7. Conclusion

This paper presented the ideas behind a new evaluation technique for assessing the reliability of through-hole interconnections on PWBs using the IST system and described a specific method for applying it. The quality of PWBs directly affects the quality of Fujitsu products. Fujitsu intends to achieve even higher levels of product quality by improving PWB evaluation technology by using new evaluation techniques and establishing techniques for evaluating the quality of the PWB manufacturing process in cooperation with PWB suppliers.

Mitsuhiko Sugane
Fujitsu Advanced Technologies Ltd.
Mr. Sugane joined Fujitsu Ltd., Kawasaki, Japan in 1984 and designed equipment for communication network systems. He has worked on research and development of PWB technology since 1990. He moved to Fujitsu Advanced Technologies in 2007.

Yoshihiro Morita
Fujitsu Advanced Technologies Ltd.
Mr. Morita joined Fujitsu Ltd., Kawasaki, Japan and was engaged in research and development of PCB assemblies for high-end server systems and later was involved in research and development of PWBs. He moved to Fujitsu Advanced Technologies in 2007.