The latest activities related to the passive components in JAXA

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Japan Aerospace Exploration Agency (JAXA)

Akifumi MARU, Shunji SANO and Norio NEMOTO

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Introduction of JAXA qualified passive components

- JAXA has the components qualification system for components applied to the space application.

Main purpose of this system

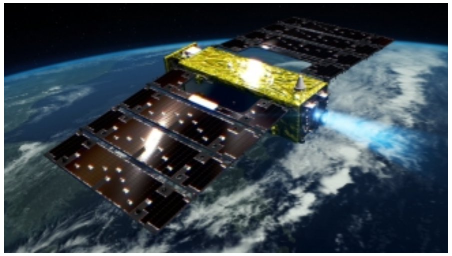
- Components which are applied for many satellites are treated as standard components.

→ Quality and reliability of standard components are totally confirmed by this system in advance.

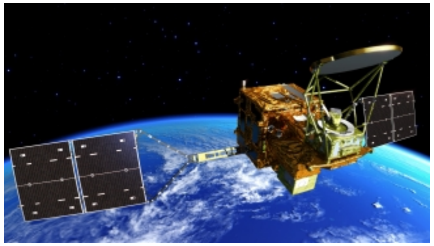
Qualification test (QT), Screening test, Stability of ML*

- Projects which plan to use such a standard components do not need any test before using.

* Manufacture line



- ESA and NASA have similar qualification system.



Introduction of JAXA qualified passive components

- There is a total of 147 models of JAXA qualified components, of which 100 models are passive components.

※ PCBs and materials such as thermal control films are also included in JAXA qualified components.

Table 1. List of JAXA qualified passive components.

Comp. family	Description	Detail spec.	Manufacturer
Capacitors	Mica	4	Soshin Electric
	MLCC	3	Murata
	Chip, Solid, Electrolytic, Tantalum EPPL	1	Matsuo Electric
Resistors	Chip, Thick Film	1	Tateyama Kagaku
		2	Hokuriku Electric
	Wire-Wound (Power Type)	2	Seiden Techno
		1	Sanada KOA
	Film	3	Sanada KOA
	Networks, Film	1	Sanada KOA
	Chip, Thin Film EPPL	1	Sanada KOA
Thermistors	Chip, Negative Temperature Coefficient EPPL	1	Tateyama Kagaku
	Lead, Negative Temperature Coefficient	1	Tateyama Kagaku
Fuses	Subminiature, Current-Limiting EPPL	2	Tateyama Kagaku
Temp. Sensors	Platinum EPPL	3	MHI*
Osc. Crystals	Quartz Crystal Units	4	Nihon Dempa Kogyo
Transformers and Inductors	Power	2	Tamura
	Others	6	Tamura
Wires and Cables	Fluoroplastic, Polyimide Insulated Wires	4	Hitachi Metals
	Differential Transmission Cables EPPL	2	Junkosha
Connectors	Rectangular, Miniature	2	JAE**
		1	Nihon Maruko
	Rectangular, Miniature, High Density	2	JAE**
		1	Nihon Maruko
	Rectangular, Microminiature	1	Nihon Maruko
	Rectangular Miniature Mixed	1	Nihon Maruko
	Coaxial, RF	3	Waka Manufacturing

* MHI=Mitsubishi Heavy Industries ** JAE=Japan Aviation Electronics Industry

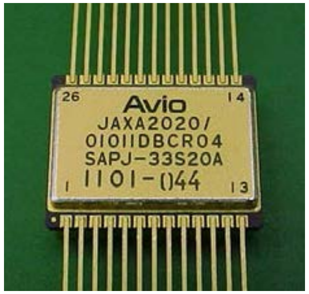
JAXA qualified components listed in EPPL

Active Components

Power MOSFET (Fuji Electric)

1) n-ch, TO254, 100-250V
2) n-ch SMD, 100-250V
3) n-ch TO-254/SMD, 500V
4) p-ch, TO-254/SMD, 100/200V
5) n-ch , Super Junction, TO-254/257/SMD, 250V
6) n-ch , Super Junction, TO-254/257/SMD, 600V

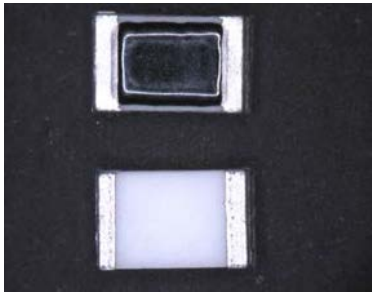
POL DC/DC converter
(Fukushima Avio)



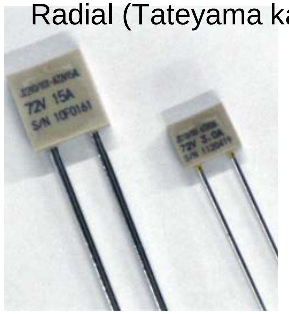
Passive Components

Platinum temp. sensors(MHI)

Chip Thermistor (Tateyama kagaku)



Current limiting fuses,
Radial (Tateyama kagaku)

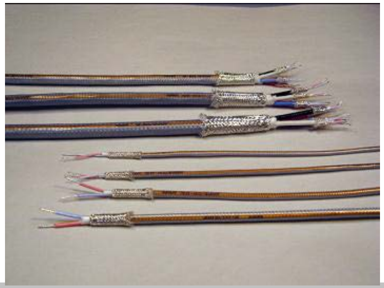


Chip Tantalum capacitors
(Matsuo Electric)

Chip resistors, metal film
(Sanada KOA)

Current-limiting fuses, SMD
(Tateyama kagaku)

Differential transmission cables
(Junkosha)



Leaded Thermistor
(Tateyama kagaku)

Red: Newly appointed after 2006

Comparison of JAXA/ESCC qualification test specification

- Like a example of JAXA qualified components listed in EPPL, JAXA and ESA conducted the activity related to the Cooperation Agreement on EEE Components for mutual usage of each components.
- Mutual usage of Japanese components in Europe / European components in Japan has been promoted by JAXA and ESA:
  - To avoid duplicated development of similar components in Europe / Japan
  - to ensure the availability of second source
- To remove the barrier of mutual usage, JAXA and ESA held joint work to compare JAXA specifications and ESCC specifications for component qualification.

Items to be compared

1. Overall difference in both qualification systems

2. Detail comparison of generic specifications

Comparison of JAXA/ESCC qualification test specification

- Document tree has been compared between JAXA and ESA qualification system.
- Same document tree from Level 2 to Level 4

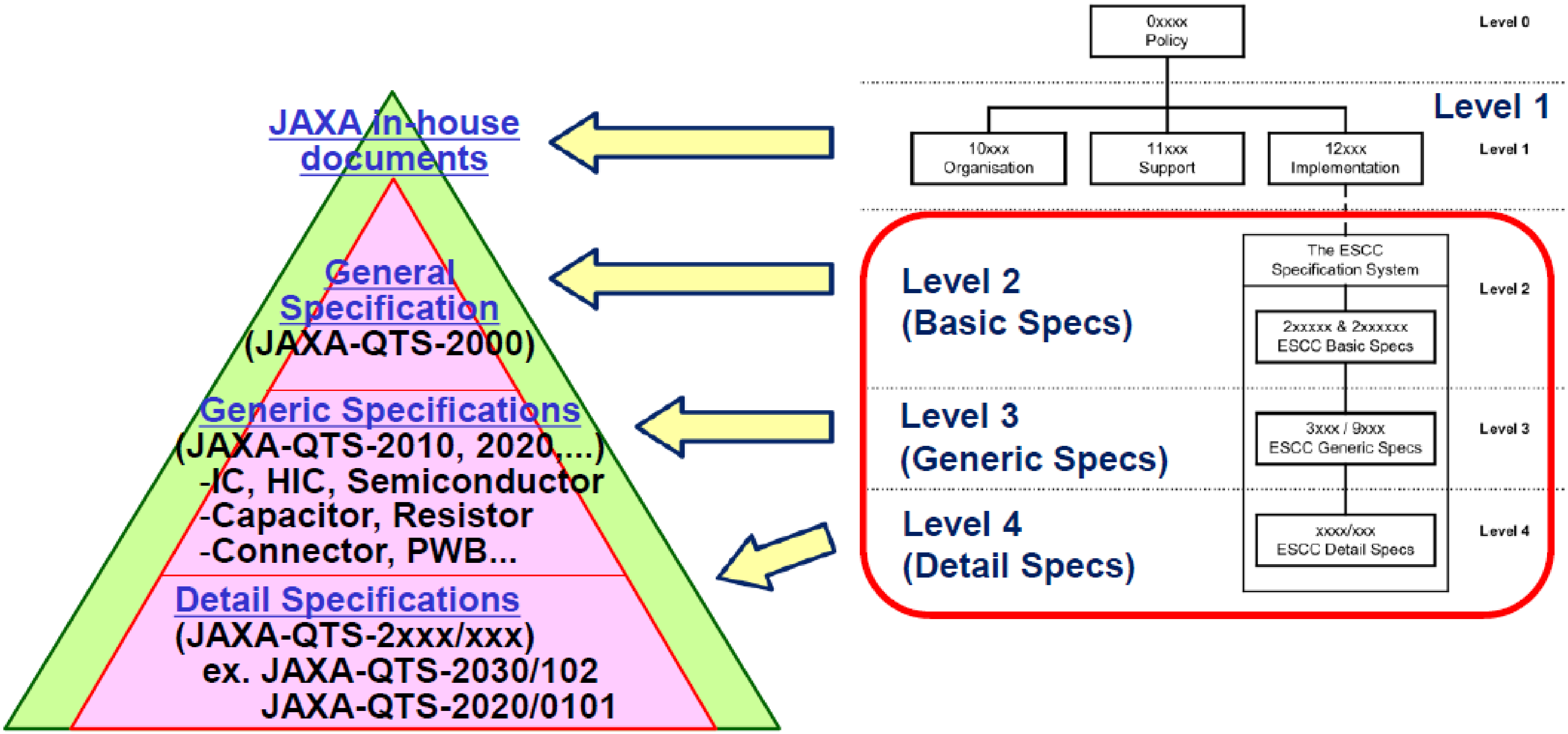


Fig. 1. Document tree of JAXA qualification system and ESCC qualification system

Comparison of JAXA/ESCC qualification test specification

- Summary of the overall comparison each qualification system are listed below.

There is no major difference when compared JAXA system with ESCC system.

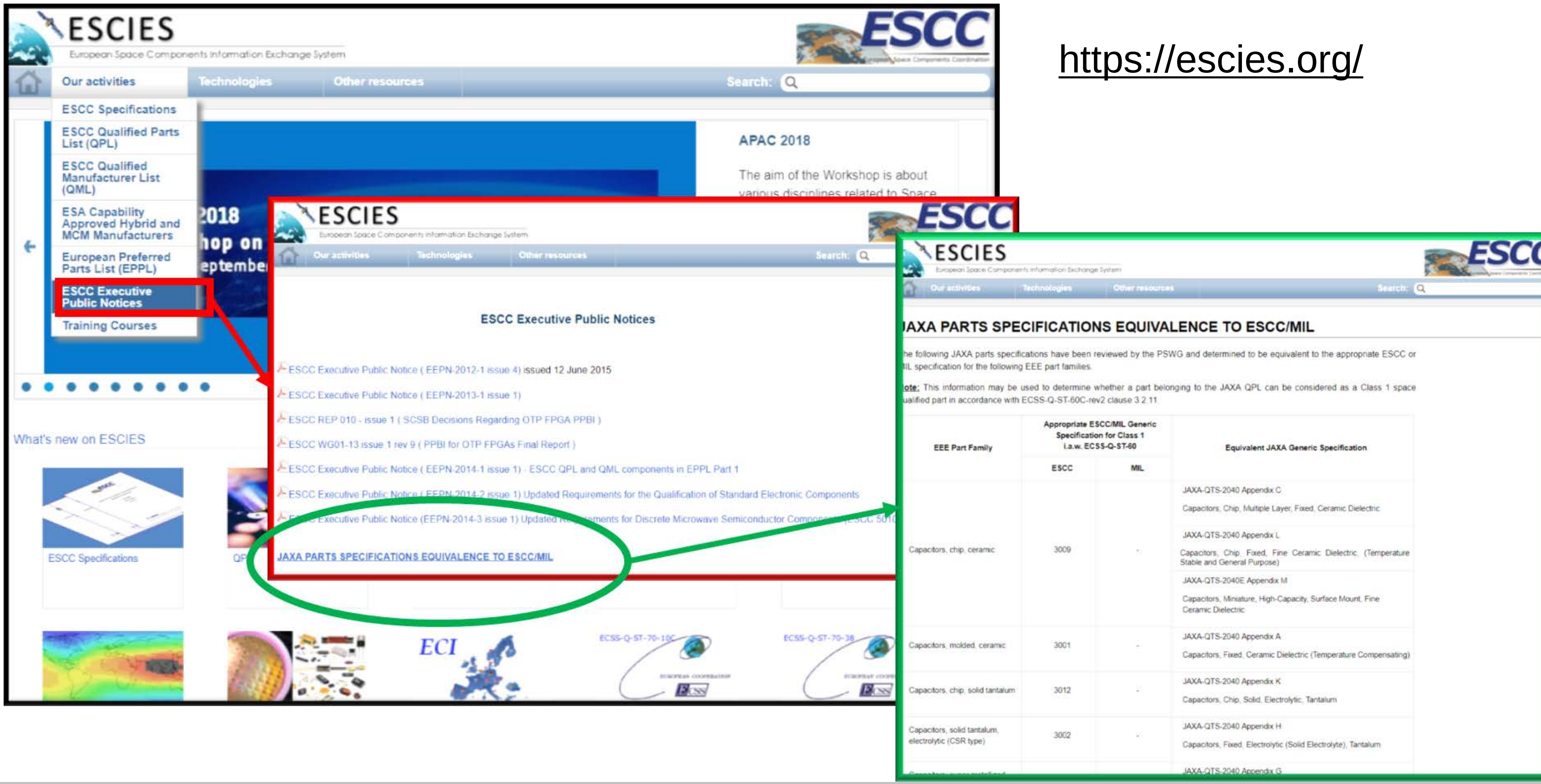
System	ESCC	JAXA
Type of qualification	- Component Qualification - Technology Flow (TF) - Capability Approval (- Process Capability Approval)	- QML (qualification of manuf. lines) - QPL (qualification of parts)
Duration	2 years	3 years (QML)
Quality management	Process Identification Document (PID) + QMS	Quality Assurance Program Plan (QAPP)
Manufacturing line	Commercial lines may be used (processes, materials and technology shall be frozen by PID)	Commercial lines may be used (processes, materials and technology shall be frozen by QAPP)
Change control of QA program	- Review / approval required by ESCC Executive - Decision can be made by TRB with limitation (TF)	Decision can be made by TRB with limitation (QML)
Required tests for MoQ / procurement	- In-process control - Screening test - Periodic tests (every 24 or 12 months) - Environmental / mechanical subgroup - Endurance subgroup - Electrical subgroup - Assembly / capability subgroup	- In-process inspection - Screening test (active parts) - Quality Conformance Inspection (test interval differ from test group) passive parts : Group A-C basic characteristics ,life test etc. active parts : Group A-E electrical tests, die related tests, package related tests, radiation test etc.
Available Docs. after certification	- Detail specification	- Detail specification - Application Data Sheet (ADS)

Comparison of JAXA/ESCC qualification test specification

- Generic specification documents of all JAXA qualified components were compared with ESCC's specification. (26 items' equivalence has been confirmed)

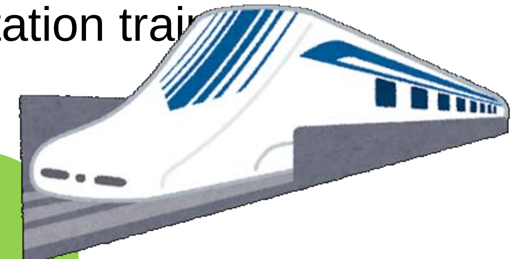
  Comparison results are indicated in ESCIES.org (ESCC Public domain website).

https://escies.org/



Recent news of passive components

- Conventionally, the PCBs for space-use were provided by almost one qualified manufacturer (Manufacturer A) for Japanese space project.
- The manufacturer A could not continue to provide their products due to shutting down of the factory since the development for magnetic levitation trai planned through their factory premises.



The manufacturer of PCBs for space-use recently transferred the qualified processes to an alternative JAXA qualified manufacturer (Manufacturer B).

Reliability test of printed circuit board for space-use

- Prior to the actual replacement, we evaluated the characteristics and reliability of the printed circuit test boards manufactured by each manufacturer under the same conditions.

Evaluation items

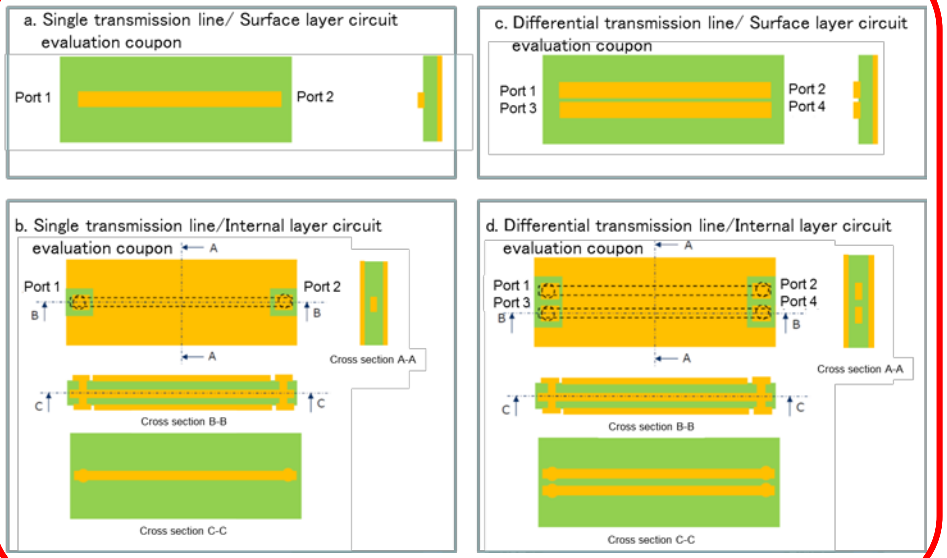
1. Electrical characteristics
   - Manufactured evaluation test coupons by each manufacturers.
   - S parameter measurements
   - Simulation based on the measured S parameters about characteristic impedance, dielectric constant and transmission loss
   - Cross-talk characteristics

1. Long-term reliability
   - Manufactured evaluation test coupons by each manufacturers.
   - Interconnect stress test (IST) & DPA

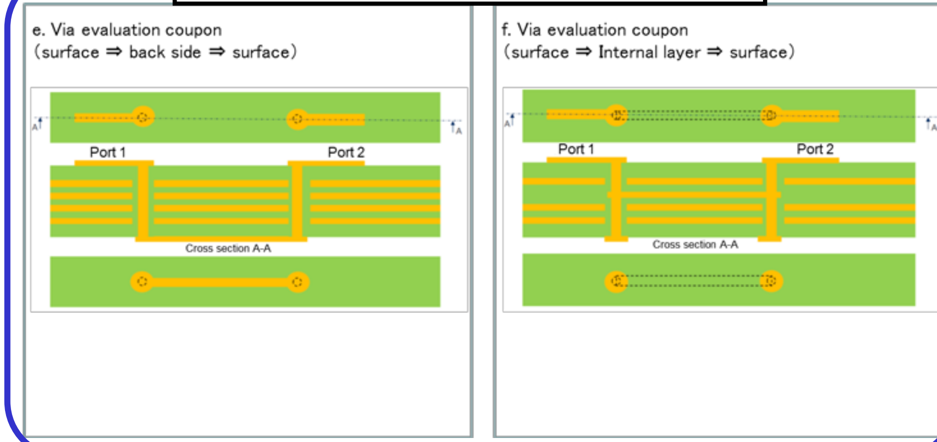
Electrical characteristics evaluation

- 8 types of test coupons manufactured by each manufacturer under the same condition were prepared.

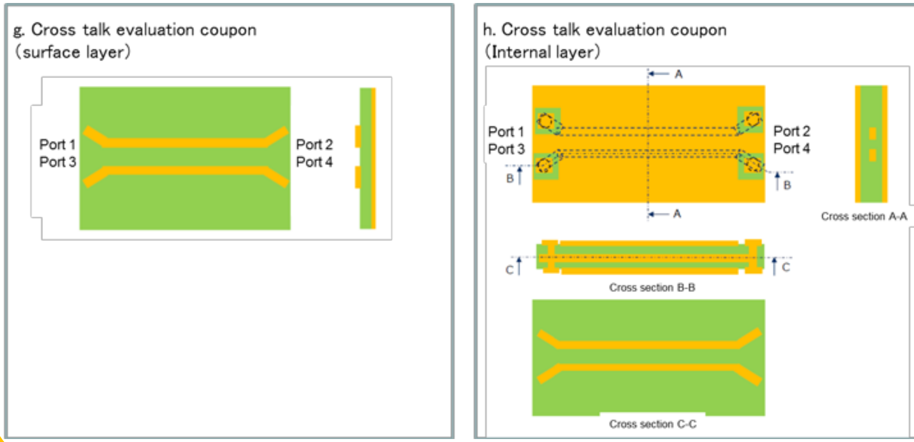
Transmission characteristics evaluation



Transmission characteristics on PCBs which have via structure



Cross-talk evaluation



Electrical characteristics evaluation

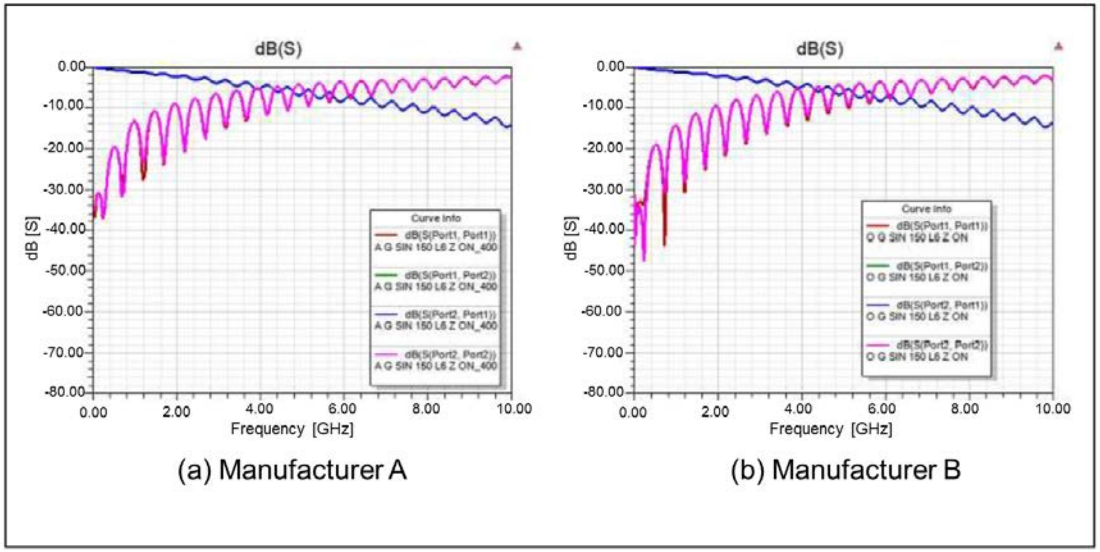


Fig. S parameter measurement results of coupons a) and b) coupons

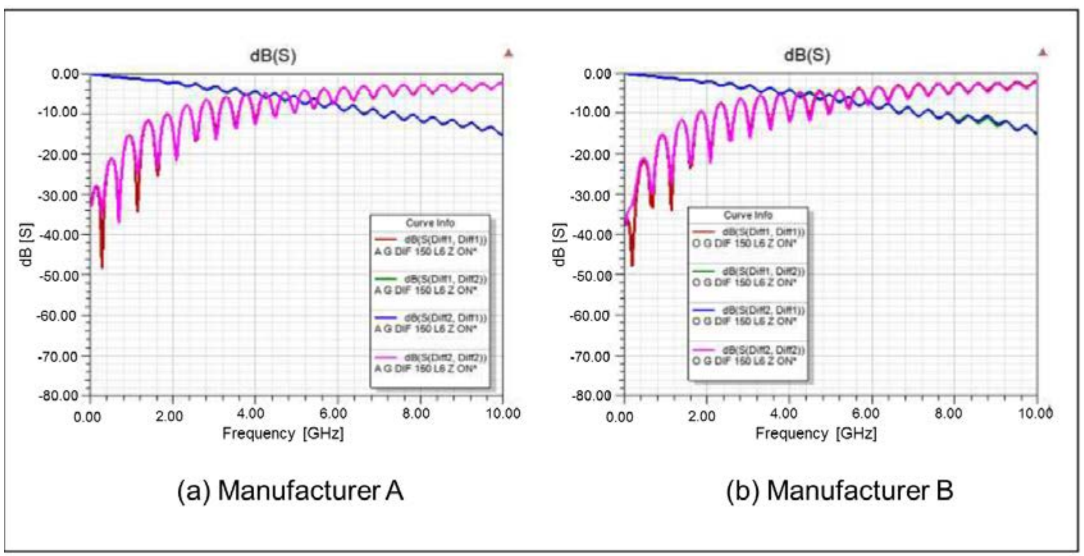


Fig. S parameter measurement results of coupons c) and d) coupons

- Although a slight difference existed on reflection coefficient below the frequency of 1 GHz between two manufacturers, the difference was less than -20 dB.

It a negligible difference for electrical characteristics.

Electrical characteristics evaluation

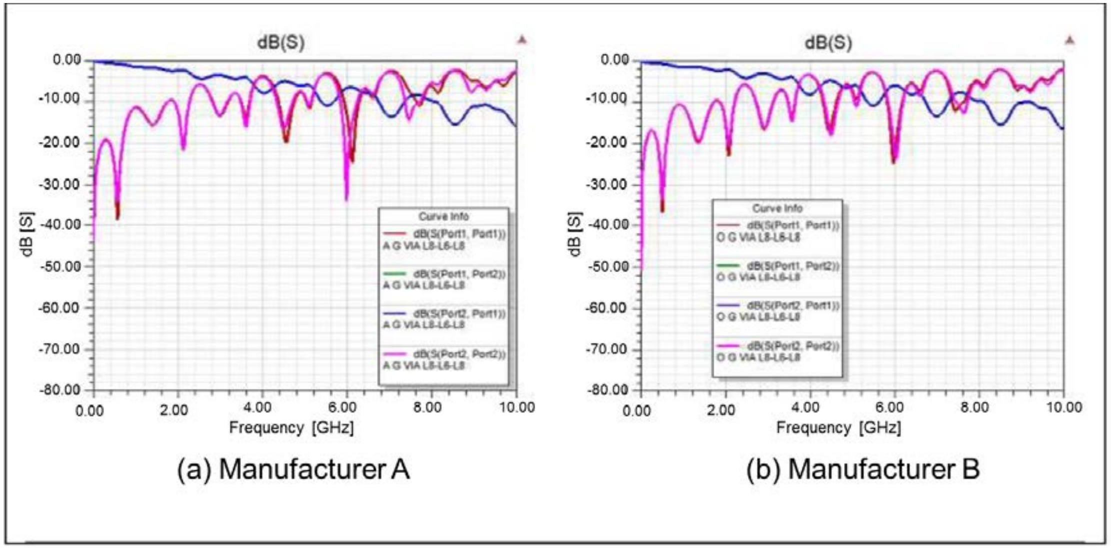


Fig. S parameter measurement results of coupons e) and f) coupons

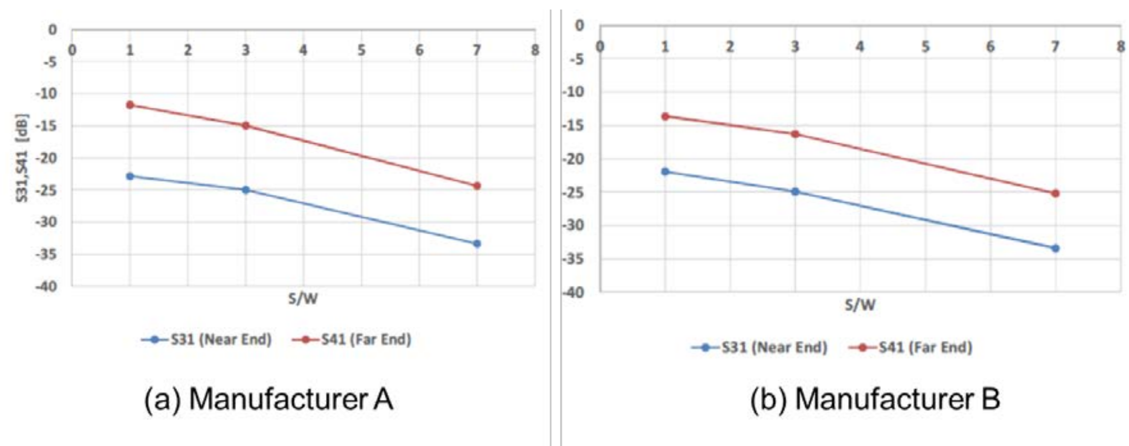


Fig. Cross-talk characteristics measurement results of coupons g) and h)

- There is a slight difference on the peak around 6 GHz, but the difference has no effect on the circuit electrical characteristics or the function.
- On the cross-talk evaluation, coupons made by manufacturer B indicated lower cross talk level than Manufacturer A's coupons.

  ⇒ The risk of switching the printed board manufacturers is low related to the cross-talk characteristics.

We concluded that there is no risks for replacing the manufacturer related to electrical characteristics.

Interconnect stress test (IST) & DPA

- In IST, the samples are heated directly by a current flowing through a self-heating circuit in the samples, and cooled by forced air cooling.
- By repeating this cycle, the temperature cycling is carried out and stress is applied to the PCBs in a short period of time.
  - ⇒ Long term reliability of PCBs can be evaluated

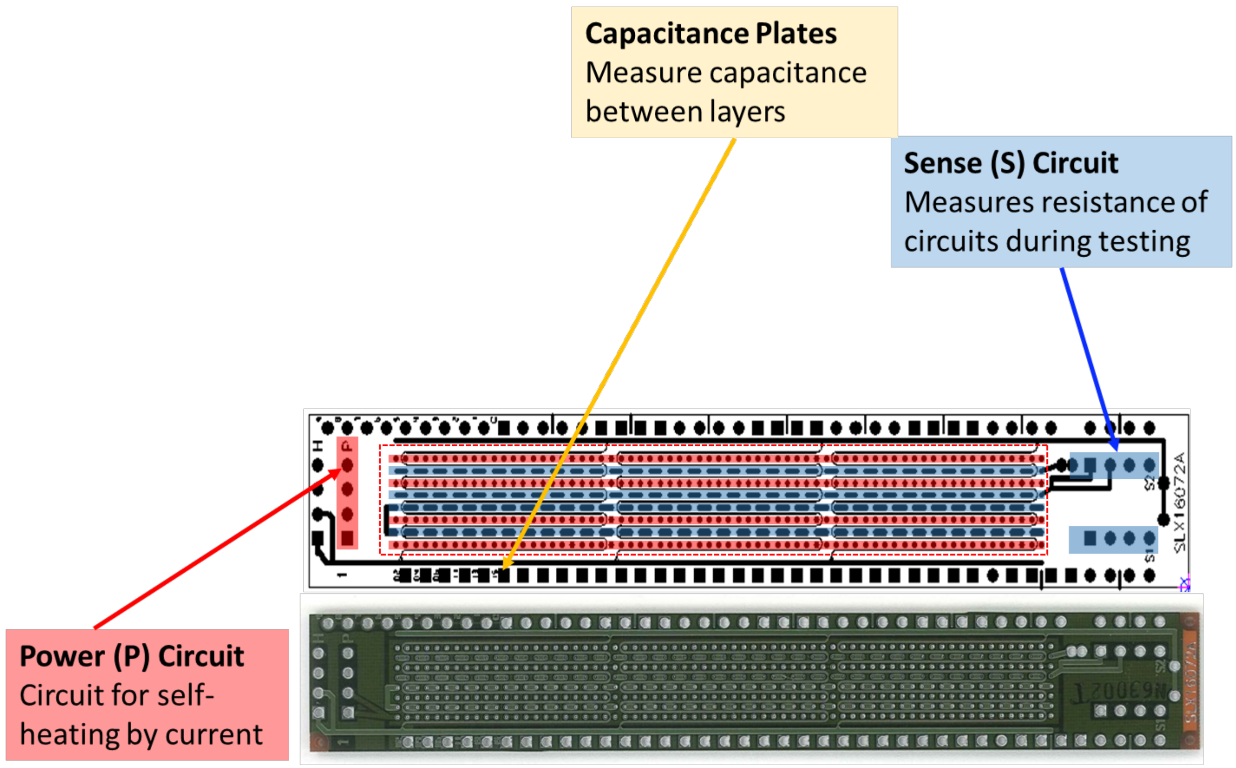


Fig. IST coupon recommended for HiRel application (18mm x 100mm)

Interconnect stress test (IST) & DPA

- IST is performed on the test coupon after pre-conditioning.
- The resistance of the circuits is measured continuously during the IST.

  10% increase in resistance is identified as a failure.

Pre-conditioning	**Delamination Test (optional)**	IST Testing	Failure Analysis
Initial measurements: -Resistance -Capacitance **Ambient~ 230 deg.C (Tin-lead)** **5-6min / cycle** **6cycles** Preconditioning to simulate assembly and rework.	Delamination is detected by the change in electrostatic capacitance between the layers after the precondition.	Thermal Cycles by electrically self-heating and forced air coolng. **Ambient~150 deg.C (Default)** **Ambient~170 deg.C (Polyimide)** **5-6min / cycle** Continuously measures resistance of circuits during testing. **10% increase in resistance is a failure.**	Cross Sectioning. Determine the Exact Failure Location with thermal camera. Failure analysis for the root cause and latent failure modes.

Fig. Test flow of IST

Interconnect stress test (IST) & DPA

- Specification of test coupons and IST results are summarized below tables.

Table. Specification of test coupons

	FR-4	Polyimide
Board Material	Epoxy(FR-4)	Polyimide(GI)
Layer count	6	12
Board Thickness	2.4 mm	3.2 mm
Drilled Hole Diameter	0.7 mm	0.35 mm
Number of samples	6 coupons (6 circuits)	6 coupons (12 circuits)

Table. Summary of the IST results

Coupon / IST Cycles	FR-4		Polyimide	
	Manufacturer A	**Manufacturer B**	**Manufacturer A**	**Manufacturer B**
Min	304	285	>2000(6.0%)	649
Max	628	400	>2000(3.6%)	859
Mean	455	352	>2000(4.9%)	786
StDev	120	39	-	72
Range	324	115	-	213

Both types of manufacturer B coupons increased resistance by 10% with fewer IST test cycles. No difference in drill condition or copper plating quality etc. were observed.

Interconnect stress test (IST) & DPA

- According to the destructive physical analysis (DPA) results, cracks on the through hole wall were observed and the shape and the position of cracks were similar.

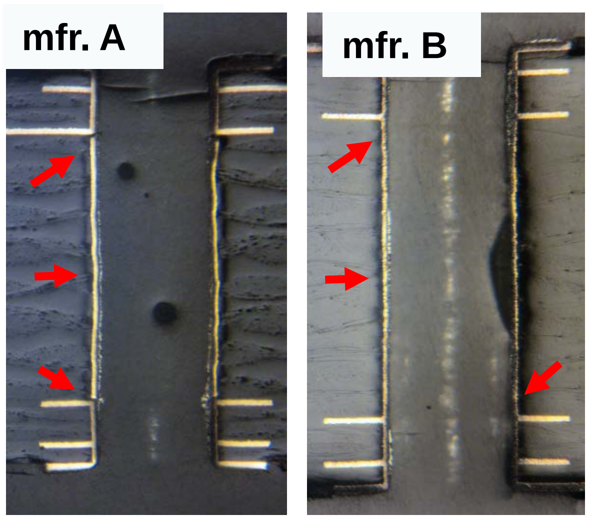


Fig. Cross-section : After IST FR-4 PCBs

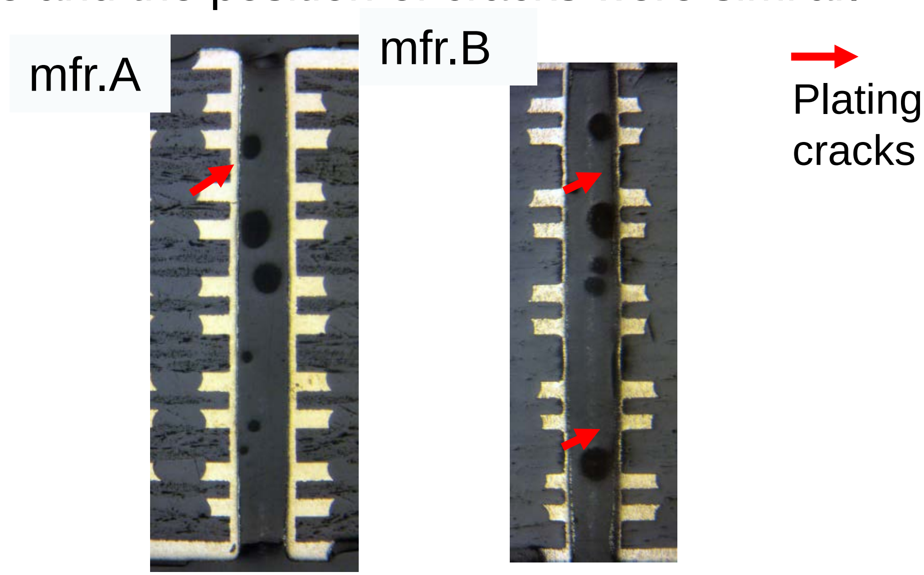


Fig. Cross-section : After IST Polyimide PCBs

Table. Copper plating thickness of each sample

	FR-4		Polyimide	
Manufacturer	A	B	A	B
Copper Plating Thickness	39μm	28μm	41μm	31μm

The difference in the number of IST cycles for 10% increase of resistance is simply due to the difference in the thickness of copper plating.

JAXA qualification test for Mfr. B

- PCBs manufactured by Manufacturer B were also provided to the JAXA qualification test which include thermal cycle test, electric characteristic evaluation test, etc..

- Manufacturer B's PCBs passed all qualification tests.

➡ It was verified that Manufacturer B's PCBs satisfied the JAXA qualification test requirements.

And these were qualified to JAXA qualification components.

Summary

- An overview of JAXA qualified passive components and their qualification requirement was introduced.
  - Currently there are 100 JAXA qualified passive components and 11 of them are listed in EPPL.
  - The qualification system in JAXA is quite similar to that in ESCC and its general requirements are outlined in comparison with those in ESCC system.
  - As the result of comparison, the qualification test requirements of JAXA qualification system are verified to be equivalent to that of ESCC system.
- As a recent news, for the replacement of PCB manufacturer, the comparison evaluation results of PCBs which made by two manufacturers were reported.
  - Electrical characteristics evaluations and IST for long-term reliability were performed and it was confirmed that the quality and performance of two products from these manufacturers are practically equal.
  - We concluded that there is no risks for replacing the PCB manufacturer.

Thank you for your attention!!

APPENDIX

1. Objectives

Thermal cycle tests have been applied as one of reliability evaluation tests for Printed Circuit Boards (PCBs) for space-use, but these tests takes a long time. (Thermal Shock Test 1000cycles : more than 1.5 month)

Recently, **Interconnect Stress Tests (IST)** have been standardized by IPC and adopted globally as a method that can evaluate the connection reliability of PCBs in a short period of time.

Therefore, we evaluated the effectiveness of IST as a test method capable of thermal cycling test in a short time.

In this evaluation, comparison between thermal shock test and IST, and comparison of two different PCBs by IST test were conducted.

2. Overview of IST

2.1 The principle of IST

In thermal cycle test of the PCBs, the difference of thermal expansion coefficients (CTE) between Copper and Substrate materials becomes a source of stress causing cracks in the through holes, resulting in failures such as resistance increase, open circuit, separation of plating from base metal etc.

In the air-to-air thermal shock test, the samples are heated and cooled by changing the temperature in the test chamber, and stress is given by the difference in CTE between Copper and Substrate materials .

In IST, the samples are heated by directly flowing a current through a self-heating circuit in the samples, and cooled by forced air cooling. By repeating this cycle, the temperature cycling is carried out and stress is applied to the PCBs in a short period of time.

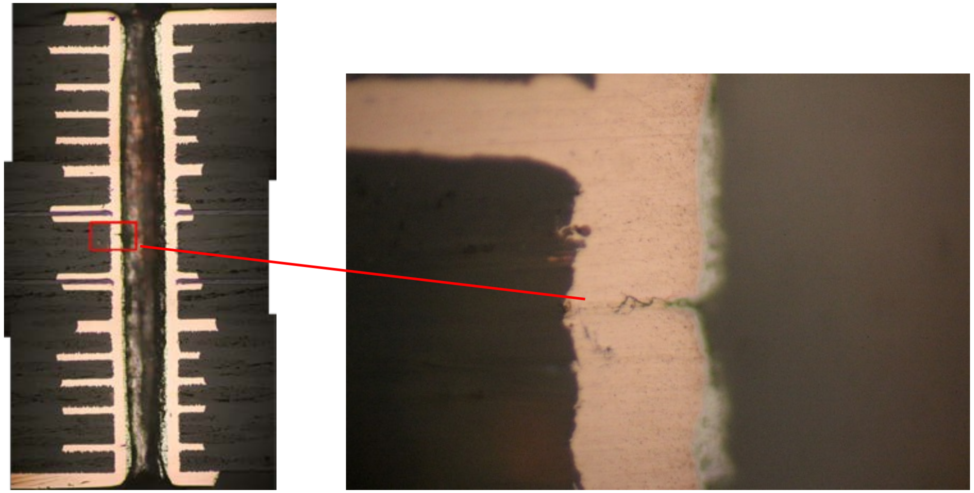
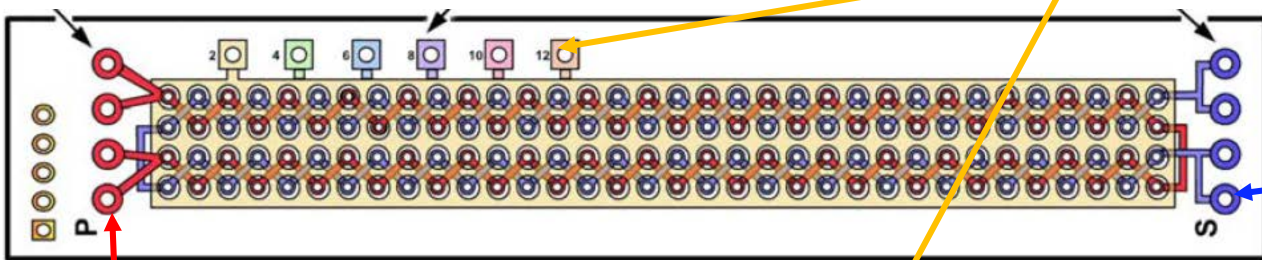


Fig.1 Through hole cracks caused by thermal stress

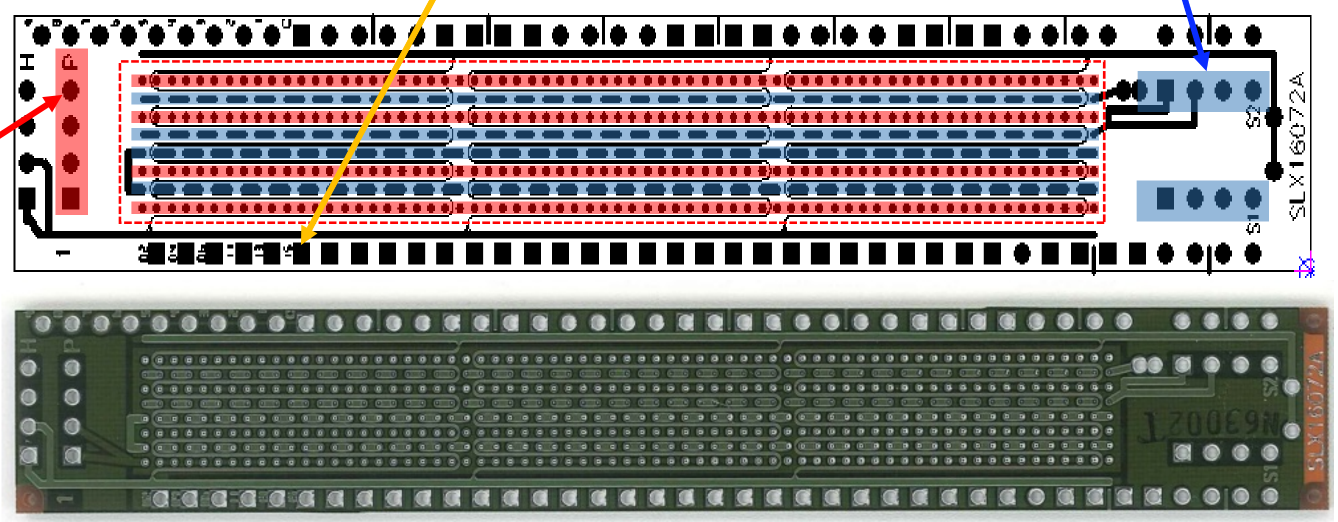
2.2 Test coupons of IST

Capacitance Plates
Measure capacitance between layers

Fig.2 IST Coupon (IPC-TM-650-2.6.26)



Sense (S) Circuit
Measures resistance of circuits during testing



Power (P) Circuit
Circuit for self-heating by current

Fig.3 IST coupon recommended for HiRel application (18mm x 100mm)

2.3 Test conditions of IST and thermal shock

A comparison of the temperature profile of **IST and** the **Thermal shock test (air-to-air)**.

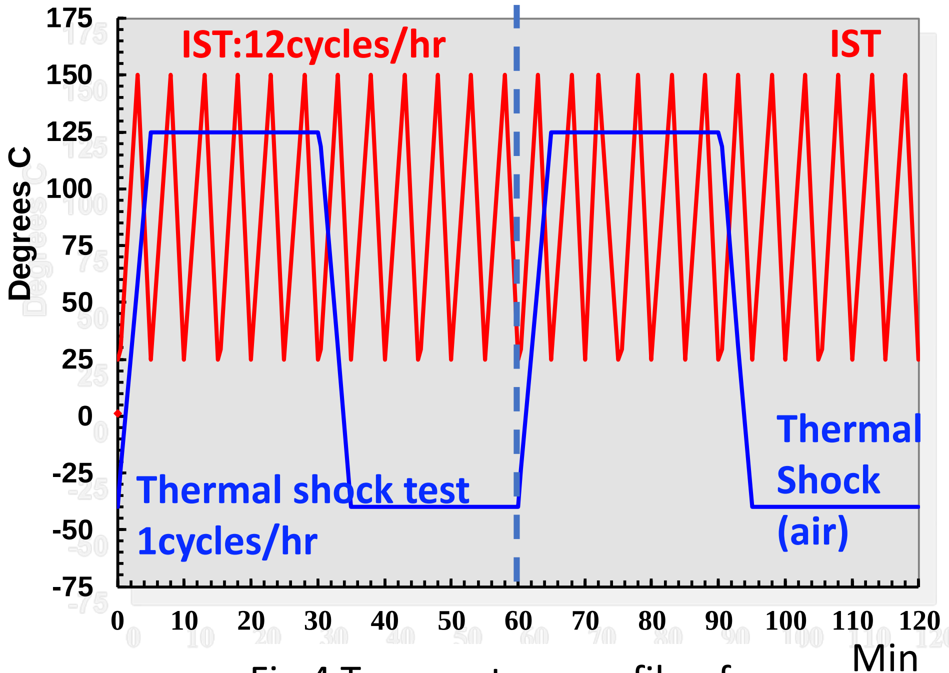


Fig.4 Temperature profile of IST and Thremal shock

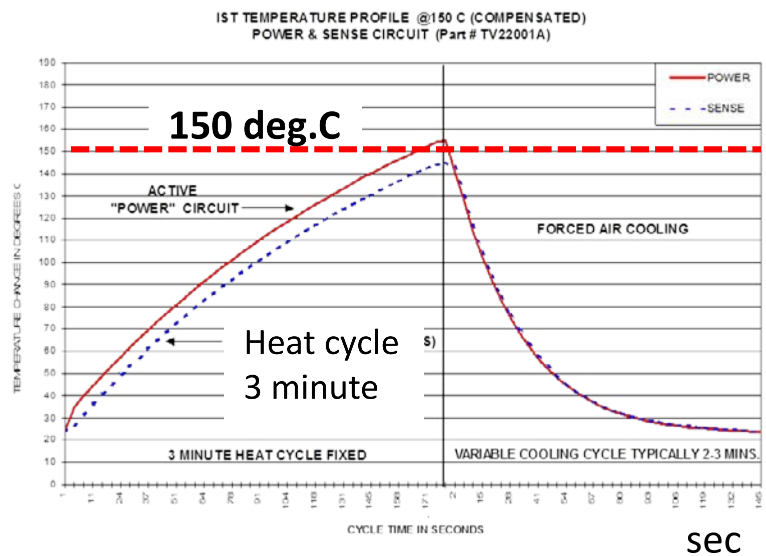


Fig.5 IST temperature profile details

Since the IST test is self-heating and forced air cooling, a short-time temperature change can be realized.

The number of test cycles of thermal shock test including soak time is 1 cycle/hr, while IST can be 12 cycles/hr.

In addition, IST is considered to be a severe stress test because the ramp-rate of temperature is larger than the thermal shock test.

2.4 Test flow of IST

Pre-conditioning	**Delamination Test (optional)**	IST Testing	Fallure Analysis
Initial measurements: -Resistance -Capacitance **Ambient~ 230 deg.C (Tin-lead)** **5-6min / cycle** **6cycles** Preconditioning to simulate assembly and rework.	Delamination is detected by the change in electrostatic capacitance between the layers after the precondition.	Thermal Cycles by electrically self-heating and forced air coolng. **Ambient~150 deg.C (Default)** **Ambient~170 deg.C (Polyimide)** **5-6min / cycle** Continuously measures resistance of circuits during testing. **10% increase in resistance is a failure.**	Cross Sectioning. Determine the Exact Failure Location with thermal camera. Failure analysis for the root cause and latent failure modes.

3. Comparative test of the IST and Thermal shock test

3.1 Comparative test

We conducted both IST and thermal shock test on PCBs which were manufactured in the same process, and compared the evaluation results.

The test conditions are shown below.

Table.1 Test condition of Theramak Shock and IST

	Thermal Shock Test	IST
Preconditioning	**Reflow 3 cycles (max temp. 240 deg.C)**	**230 deg.C 6 cycles**
Cycle Test	**-30 deg.C / 30 min ⇔ 125 deg.C / 30 min**	**Ambient~170 deg.C (Polyimide) Ambient~150 deg.C (Low-Dk)**
Number of sample	**3**	**6**
Test termination	**10% increase in resistance or at completion of 3000cycles**	**10% increase in resistance**

3.2 Test coupons (IST / Thermal Shock Test)

Table.2 Specification of test coupons

PCB specification	Polyimide PCBs	Low-Dk PCBs (Poly-phenylene-ether)
Layer count	14	18
Board Thickness	2.4mm	3.0mm
Drilled Hole Diameter	0.2mm	0.2mm

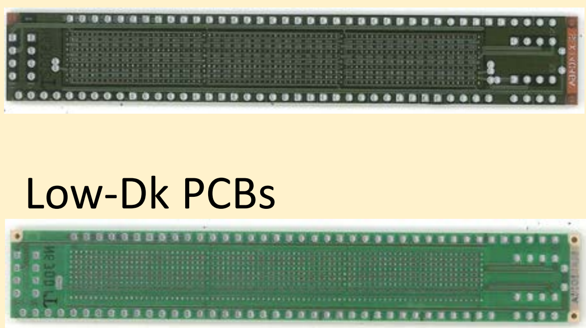


Fig.6 IST Coupons

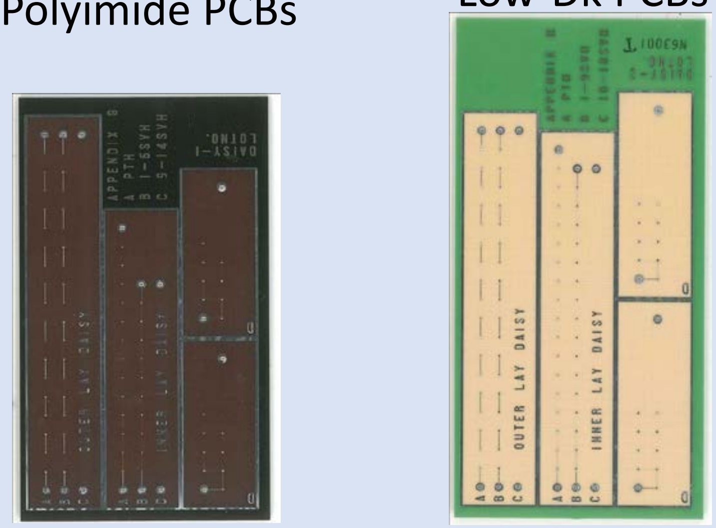


Fig.7 Thermal Shock Test Coupons

These test coupons were manufactured by the same manufacturer and the same production conditions such as plating thickness.

3.3 Results (1/4) Resistance Change of Polyimide PCBs

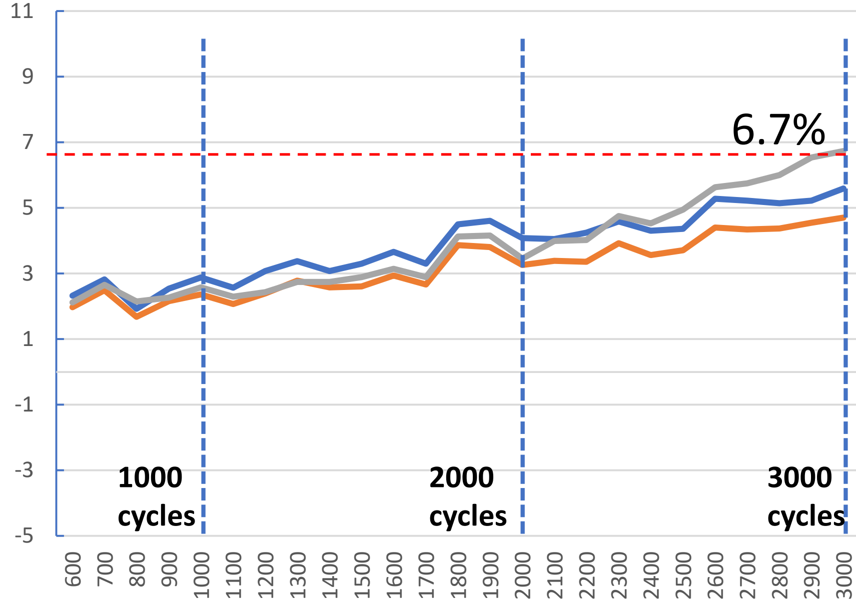


Fig.8 Thermal shock test
Resistance Change

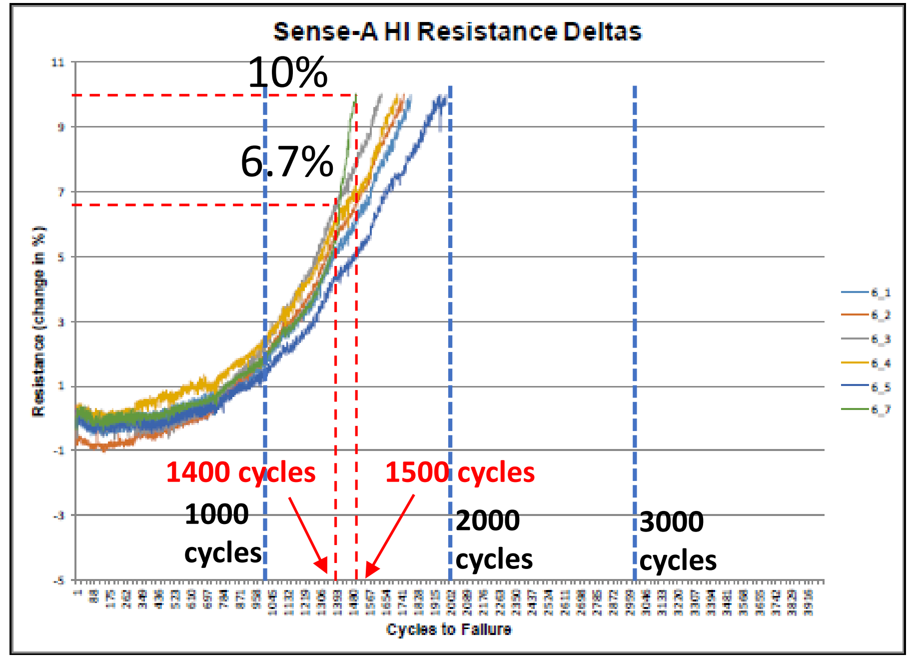


Fig.9 IST Resistance Change

The number of cycles at which the resistance change reached 6.7% was compared:

Thermal shock test: 3,000cycles (about 3,000 hour)

IST: 1,400cycles (about 116 hour)

As you can see, the IST was completed in a much shorter period of time.
The same resistance increase occurred in IST in 1/20 the time shorter and 1/2 cycle less than thermal shock test.

3.3 Results (2/4) Cross section of Polyimide PCBs

Fig.10 Thermal shock
Resistance Change 6.7%
at 3000cycles

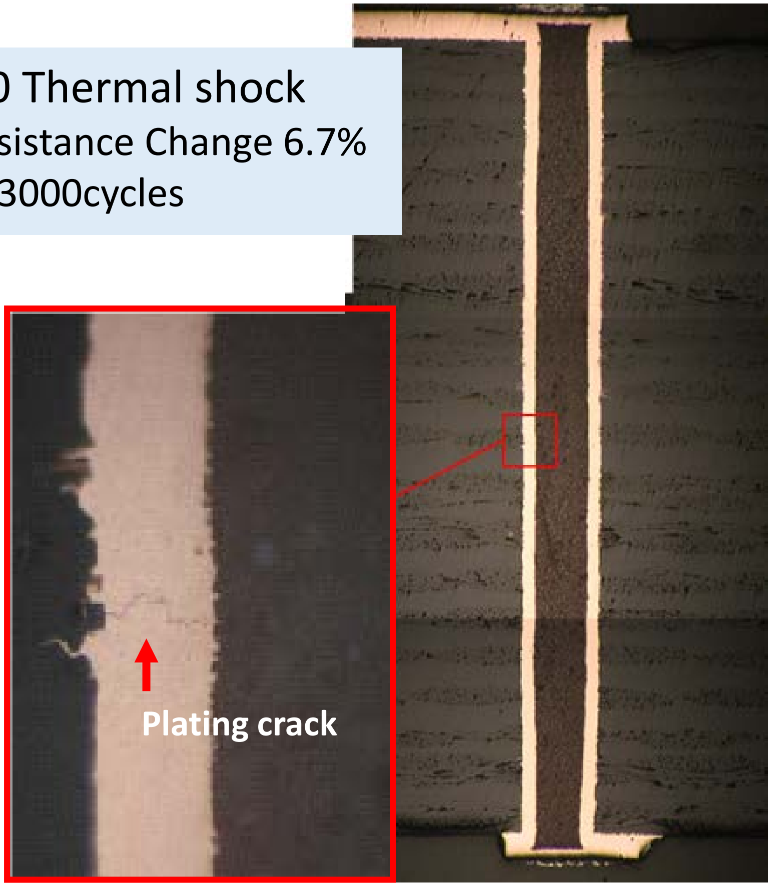
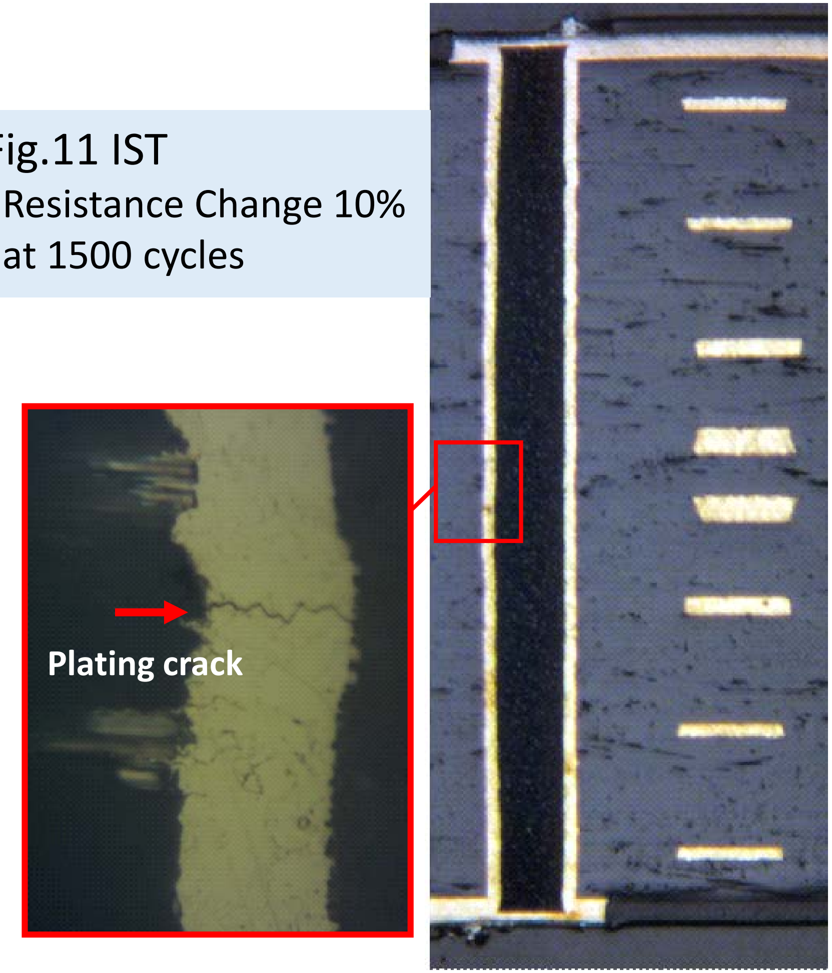


Fig.11 IST
Resistance Change 10%
at 1500 cycles



The cross section of the through-hole where resistance increased were observed. As a result, in both thermal shock test and IST, the through hole plating cracks (barrel cracks) were occurred at similar positions and these failure modes were the same.

3.3 Results (3/4) Resistance Change of Low-Dk PCBs

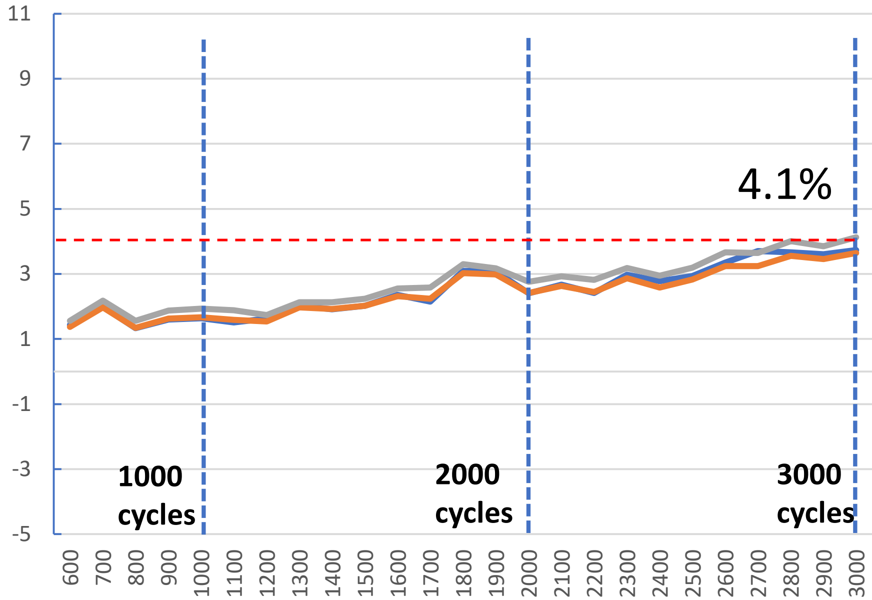


Fig.12 Thermal shock test Resistance Change

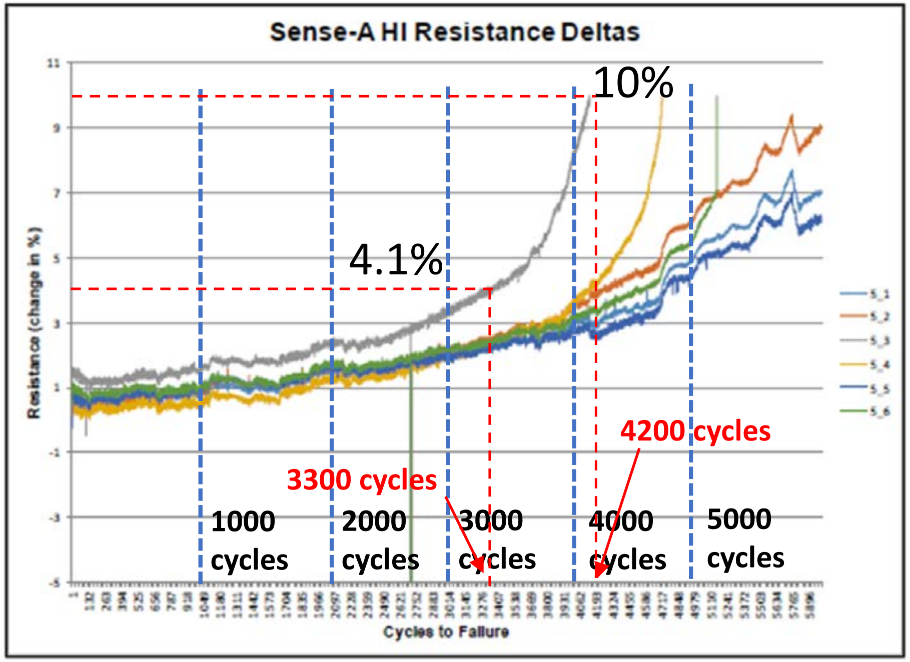


Fig.13 IST Resistance Change

The number of cycles at which the resistance change reached 4.1% is compared:

Thermal shock test:3,000 cycles (about 3,000 hour)

IST: 3,300 cycles (about 275 hour)

The IST was completed in a much shorter period of time.

Unlike polyimide PCBs, IST did not accelerate cycle number, but the same resistance increase occurred at about 1/10 or less time.

3.3 Results (4/4) Cross section of Low-Dk PCBs

Fig.14 Thermal shock
Resistance Change 4.1%
at 3000cycles

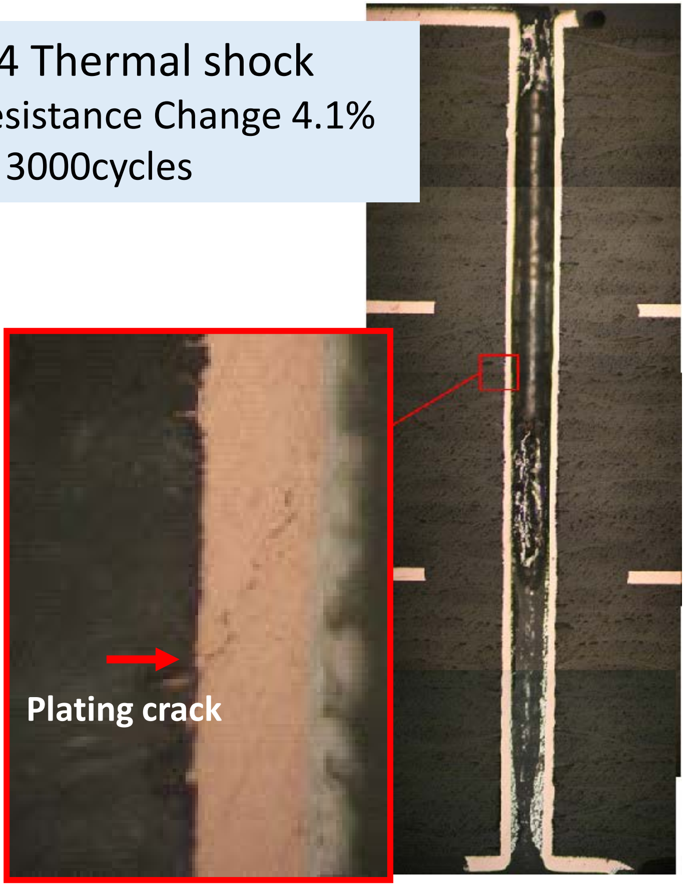
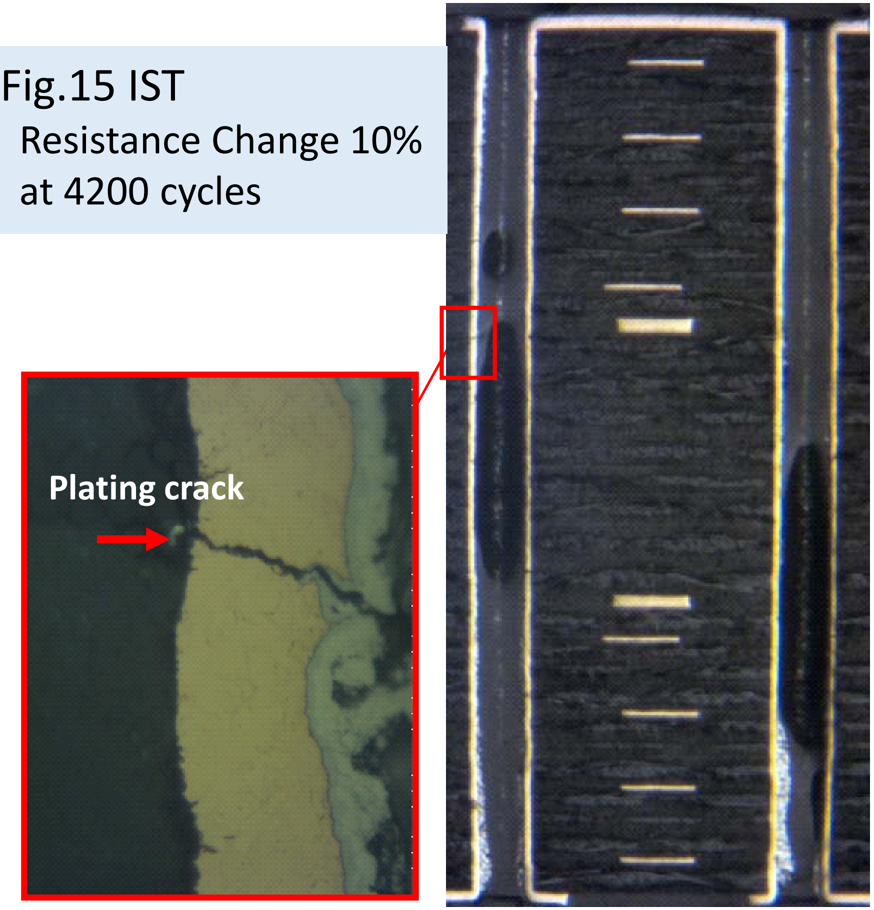


Fig.15 IST
Resistance Change 10%
at 4200 cycles



Through-hole cracks (barrel cracks) of the same mode occurred at similar positions. Although cracks of thermal shock test are small, if the test cycles is continued to reach the same resistance change as the IST, the cracks are most likely to grow to a similar size.

3.4 Discussion(1/2)

As a result of the comparative test, the failure modes of both IST and Thermal shock were through-hole plating cracks.

As the position and shape of the plating cracks in through-hole were similar, we believe that IST and thermal shock test are equivalent reliability evaluations.

As a result, we consider it possible to conduct the thermal cycle test in a short time by using the IST.

3.4 Discussion(2/2)

As a result of the evaluation, for the Polyimide PCBs, the IST showed an accelerated cycle number of the resistance increase compared to the thermal shock test. But for Low-Dk PCBs, the acceleration was different from polyimide PCBs.

One of the reason why the acceleration was different between the differences in the materials in the PCBs of under the same manufacturing condition is considered to be the difference of the z(thickness direction)-CTE of the materials.

In IST, the ramp-rate of temperature is large, stress due to the CTE difference is large and it is applied in a short time, so cracks are generated in fewer cycles.

Table.3 IST cycles and CTE

PCBs	Thermal shock cycles	IST cycles	Tharmal shock/ IST	z-CTE(ppm) material	z-CTE(ppm) Copper	ΔCTE (ppm)
Polyimide	**3000 (Resistance Increase 6.7%)**	**1500 (Resistance Increase 6.7%)**	**≒2.0**	**70**	**17**	**53**
Low-Dk	**3000 (Resistance Increase 4.1%)**	**3300 (Resistance Increase 4.1%)**	**≒1.0**	**45**		**28**

It is difficult to directly compare the tests with different materials of PCBs in IST because they have different accelerations.

However, in the comparison of the tests with the same materials, the same failure mode occurs in a short period of time, so IST is considered to be effective as a thermal cycle test.

4. Comparison of PCBs of two different manufacturers

4.1 Purpose of comparison

In the IST test, it is considered that thermal cycling tests can be conducted in a short period of time between the same material PCBs.

So samples with the same design and materials manufactured by two manufactures (manufacture A and B) with different manufacturing processes were tested using IST.

Table.4 Specification of test coupons

	FR-4 PCBs	Polyimidel PCBs
Board Material	Epoxy(FR-4)	Polyimide(GI)
Layer count	6	12
Board Thickness	2.4 mm	3.2 mm
Drilled HoleDiameter	0.7mm	0.35mm
Number of samples	6 coupons (6 circuits)	6 coupons (12 circuits)

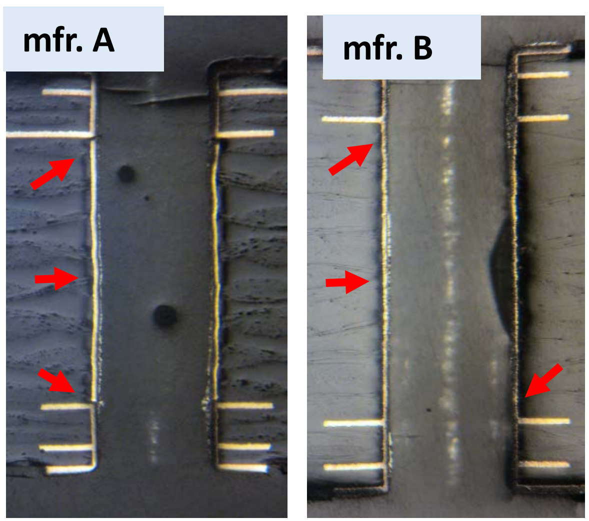
Table.5 Test condition of IST

	IST condition
Temperatures	Ambient~150 deg.C(#1.FR-4) Ambient~170 deg.C(#2.Polyimide)
Test Time(min/cycles)	5min
Test termination	Max. 2000 cycles or Resistance Change10%

4.2 Results　Comparative test by IST

Table6. IST cycle

Coupon / IST Cycles	FR-4 PCBs		Polyimide PCBs	
	mfr.A	mfr.B	mfr.A	mfr.B
Min	304	239	>2000(6.0%)	509
Max	628	354	>2000(3.6%)	788
Mean	455	292	>2000(4.9%)	657
StDev	120	40	—	93
Range	324	115	—	279



Plating cracks

fig.16 Cross-section : After IST
FR-4 PCBs

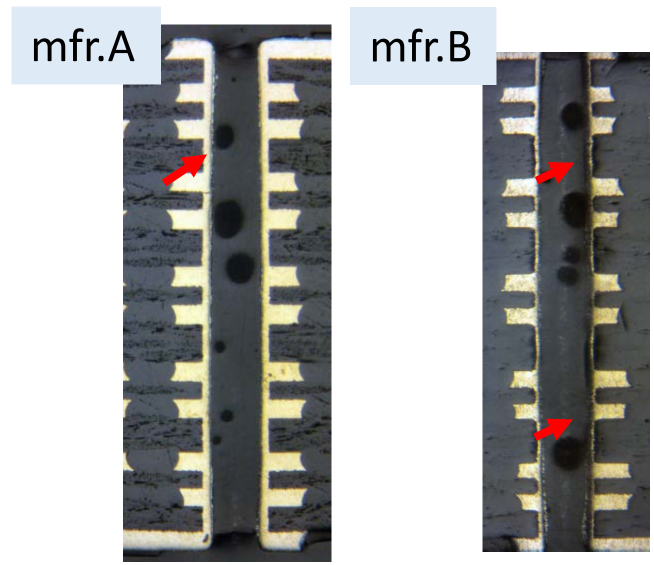


fig.17 Cross-section : After IST
Polyimide PCBs

On both types of PCBs, mfr. B reached 10% resistance increase with fewer IST test cycles.
No difference drill condition or copper plating quality etc. were observed.
Both of the failure modes were barrel cracks of through holes.

4.3 Discussion(1/2)

The result of the comparison between the two manufactures showed that the increase in resistance of mfr. B requires less cycle numbers than mfr. A.

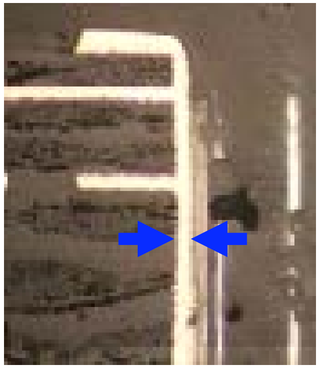
DPA showed there was no difference in the roughness of the through hole wall, the particle of the copper plating, and the state of the inner layer connection with the PCBs between these manufactures' samples.

However, there was a difference in through hole copper plating thickness; mfr. B's was thinner. It is considered that the difference in the number of cycles of the IST depends on the copper plating.

Table.7 Copper Plating Thickness of each sample

	FR-4 PCBs		Plyimide PCBs	
Manufacture	A	B	A	B
Copper Plating Thickness	39µm	22µm	41µm	28µm

Manufacturer A
39µm



Manufacturer B
22µm

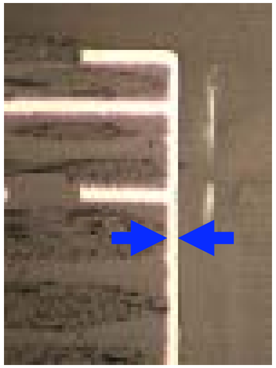


Fig.18 Cross section :Through hole FR-4

4.3 Discussion (2/2)

In order to confirm the influence of the copper plating thickness on the IST test cycles, the through hole plating was thickened on the substrate of company B and evaluated again. The manufacturing conditions other than the plating thickness were the same.

The numbers of IST cycles at resistance increase of 10% are shown in the table 8.

Table.8 IST cycle for Each Plating Thickness

Coupon	FR-4 PCBs		PolyimidePCBs	
Plating Thickness	22µm	28µm	28µm	31µm
Min	239	285	509	646
Max	354	400	788	859
Mean	292	352	657	786
StDev	40	39	93	72
Range	115	115	279	213

As the thickness of copper plating became thicker in any of the board materials, IST cycle number has increased.

From this result, it is concluded that the number of cycles at resistance increase of 10% changes as the copper plating thickness changes.

However, there is concern that if the IST test result is evaluated only by the number of cycles, it may lead to an incorrect conclusion.

Thus, It is important to implement DPA in order to determine whether failure factors other than plating thickness exist.

5. Conclusion

As a result of evaluation on IST, the effectiveness found is as follows.

In the IST, the failure mode was similar to the thermal shock test. I believe the stress was being applied to the sample by the same mechanism as the thermal shock test.

By IST, the thermal cycling can be carried out in a shorter period of time than the thermal shock test.

In addition, the issue involved with IST is as follows.

Although the faults become apparent with a smaller number of cycles in IST than in the thermal shock test, the acceleration of the test cycle is assumed to be different depending on the PCBs material (difference of CTE with copper).

It was found that the test results of IST are affected by plating thickness of samples. If evaluated under different conditions of plating thickness, through hole reliability due to other factors (drill condition and copper plating quality etc.) may not be correctly evaluated. Therefore, it is important to conduct failure analyses such as DPA.