Evaluation Method for Ion Migration Using Dew Cycle Test (Part 1)

Yuuichi Aoki[*1]/Hirokazu Tanaka[*1]/Shigeharu Yamamoto[*1]/Osamu Obata[*2]

Ion migration has customarily been evaluated through high-temperature, high-humidity testing. However, due to ever-widening application of electronic equipment resulting in use under a variety of conditions, the need for evaluation based on dew condensation has greatly increased.

In view of this, we have developed a dew cycle test chamber. This equipment can reproduce a uniform level of dew condensation, making it possible to quickly evaluate ion migration caused by dew condensation, a feat that has until now not been possible. In this paper, we shall present a technical examination of the dew cycle test chamber and actual examples of the evaluation process. We shall also report our findings on the effectiveness of the test chamber.

The material in this paper was presented at the 24th Symposium on Reliability and Maintainability sponsored by the Union of Japanese Scientists and Engineers, and was awarded the R&MS Award for Recommended Best Paper. This report contains some revisions to that paper.

1. Introduction

In recent years, miniaturization of electronic equipment and high density mounting of parts has resulted in minute spacing between semiconductors. At the same time, freon regulations have resulted in parts not being rinsed with freon, causing flux residue to remain. These factors are behind the scourge of ion migration (hereafter called migration) causing shorts between conductors and resulting in equipment failure.

In particular, changes in operating environment for portable equipment and mobile on-board machinery often cause dew condensation, resulting in migration. Test methods and test equipment to evaluate migration caused by dew condensation have been under study, but as yet have left a lot to be desired. In an attempt to fill this breach, we have developed a prototype dew cycle test chamber for evaluating migration caused by dew condensation. We shall report on our evaluation of the technology and the testing methods.

2. Migration

Migration occurs when moisture adheres between electrodes made of materials such as copper, solder, or silver. As voltage is applied, the electrons carrying the Coulomb charge created by the ionization of the positive electrode flow toward the negative electrode. The charged electrons is reduced at the negative electrode and extends back toward the positive electrode. Photo 1 shows migration of copper and of solder.

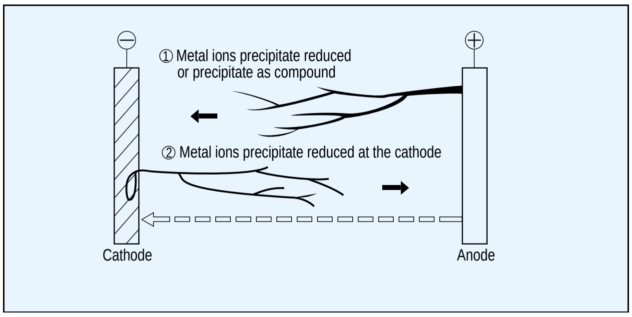
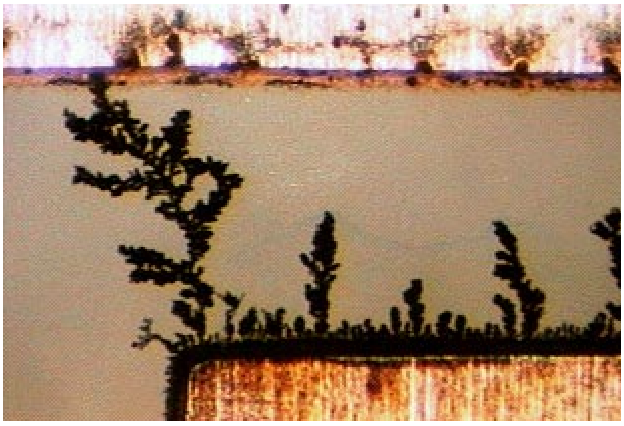


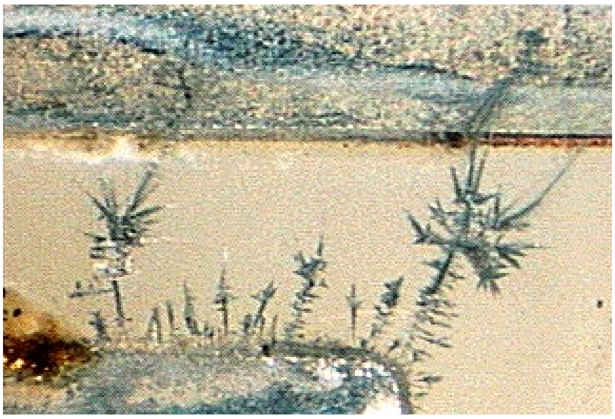
Fig. 1 Pattern of ion migration

From the "Insulation Reliability of Printed Circuit Boards: the Insulation Reliability Research Group Technology Report" (1994) Japan Institute for Interconnecting and Packaging Electronic Circuits

*1 Environmental Test Technology Center
*2 Product Design Department



a. Copper migration



b. Solder migration

Photo 1 Examples of migration

3. Conditions Required for Dew Cycle Test

Little progress been made in quantitatively determining the condition of dew condensation, and the mechanism producing it. Because of this, it is vital that the conditions for dew condensing test be both reproducible and in uniform quantities.

- The major conditions for dew condensing test are: reproducibility and quantitative uniformity.

1) Reproducibility: Must be able to constantly reproduce the same conditions inside the test chamber.
2) Quantitative uniformity: Must be able to quantitatively determine conditions of dew condensation (moisture quantity and duration).

Functions required by the dew cycle test chamber are noted in Table 1.

Table 1 Functions required by the dew cycle test chamber

1	**Temperature, humidity**	Allows accurate control (stability, uniformity, and control accuracy)
2	**Dew condensation**	Able to form and dry uniform dew condensing quantity on specimen surface for uniform duration
3	**Wind speed**	Allows suitable control of wind speed that can be considered to exert an influence on condensation adhering to the specimen
4	**Instrumentation**	Able to measure temperature of dew condensation on specimen and to connect a cable to apply voltage to specimen, and measure electrical characteristics
5	**External influence**	Avoids excess stress to specimen from shock or vibration causing dripping or disturbance to dew condensation

4. Dew Condensation Process

Migration in the dew cycle test can be assumed to be related to the quantity and duration of dew condensation. Fig. 2 shows the relationship of quantity and duration of dew condensation to specimen temperature when ambient temperature and humidity are abruptly raised.

4-1 The Process of Dew Condensing and Evaporating

a. Dew Condensing

When the temperature of the specimen is lower than ambient temperature, the surface of the specimen cools moisture from the air, forming dew condensation.

b. Dew Evaporating

After the temperature of the specimen has reached equilibrium with the ambient temperature, dew condensation will begin to evaporate unless the ambient temperature is at 100%RH.

c. Heating

After the dew condensation has evaporated, the temperature of the specimen reaches equilibrium with ambient temperature.

4-2 Evaluating the Dew Condensation Process

a. Changes in Specimen Temperature

Theoretically, the temperature of the specimen rises in steps in the above process, but in reality the change is more gradual as represented by the dotted line in the middle graph in Fig. 2. This gradual change is due to such factors as the conductivity and heat capacity of the specimen as well as response to heat transfer with the atmosphere.

b. Effect of Wind Speed

A high ambient wind speed during the process of dew condensation causes greater heat transfer between vapor and the specimen, so one might suspect that dew condensation would form more rapidly. However, such a sweeping statement is not possible, due to influences such as heat transfer, thermal capacity of the specimen, and heat transfer due to sensible heat and hydrophilic property. In addition, in the process of evaporating, a large amount of heat is transferred between atmosphere and dew condensation, speeding up evaporation time and shortening the duration time of dew condensation. Since other factors exert influence on conditions for forming dew condensation (such as layer condensation and drip condensation), great care must be taken regarding test chamber wind speed.

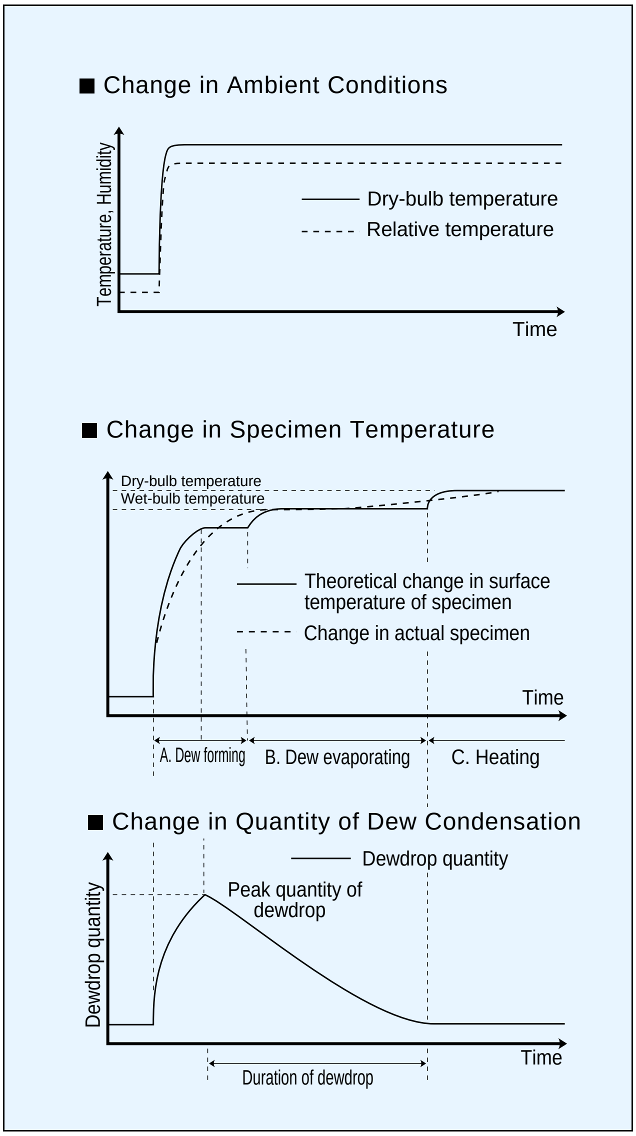
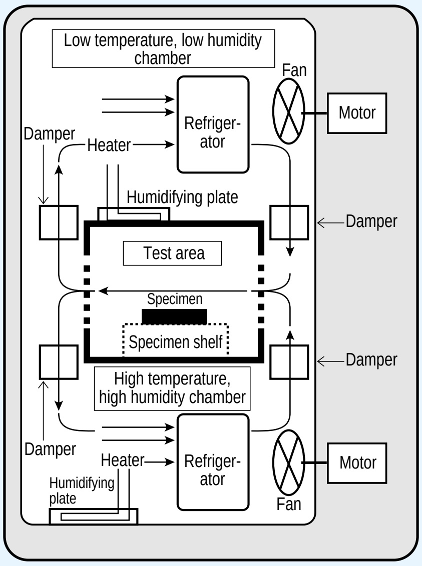


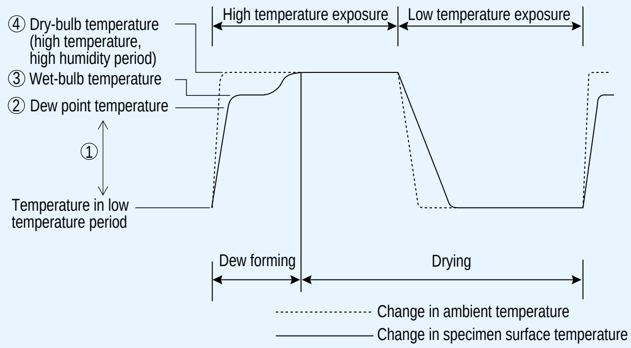
Fig. 2 Relationship between quantity and duration of dew condensation

5. Dew Cycle Test Chamber

Various means can be devised to reproduce dew condensation in the dew cycle test chamber. The method we have used in this design shown in Fig. 3 utilizes a damper changeover to switch the air in the test area between the low- temperature,low-humidity chamber and the high-temperature, high-humidity chamber.



■ "Dew Condensing" and "Drying" Processes



① When temperature and humidity are abruptly raised inside the test chamber, the thermal capacity of the specimen is greater than air so the temperature of the specimen rises more slowly than ambient temperature. The difference in temperature during this time lag causes dew condensation to form.

② Dew drop begins to evaporate when temperature reaches dew point.

③ Equilibrium is reached at wet-bulb temperature.

④ When dry-bulb temperature is reached (the high-temperature, high-humidity temperature), all dew condensation evaporates from the surface of the specimen, which dries completely. Repeatedly alternating between the low temperature conditions and the high-temperature, high-humidity conditions reproduces the conditions causing dew condensing and drying.

Fig. 3 Design of the dew cycle test chamber

Photo 2 Dew cycle test chamber produced at Tabai Espac

6. Examples of Testing

These dew cycle tests were made to determine the number of cycles required before migration occurred under the following conditions. In our opinion, the settings of dew cycle test chamber reflect actual environmental conditions and are more suitable than hasher condition such as 85°C at 85%RH.

Because of this, we selected test conditions from within the range of temperature and humidity in which general electrical and electronic appliances (excluding special production equipment) are operated. Preliminary testing indicated that 5 minutes was sufficient to allow dew condensation to form on and evaporate from the substrate board. We have added 10 additional minutes for a total of 15 minutes. On the specimen, we used a tandem compound electrode pattern corresponding to JIS type 2, as seen in Fig. 4.

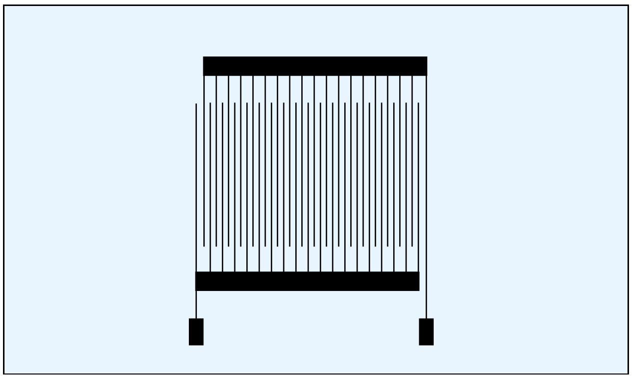


Fig. 4 Tandem compound electrode pattern corresponding to JIS type 2

6-1 Test Conditions

Table 2 presents test conditions.

Table 2 Test Conditions

Temperature, Humidity	5±2°C 60±5%RH (25 minutes) ←→25±2°C 90±5%RH (15 minutes)	
Specimen	Material	Glass epoxy substrate board
	Pattern	Tandem compound electrode pattern corresponding to JIS type 2
	Sample number	n=9
	Substrate board dimensions	50 mm x 120 mm
	Voltage applied	DC 5V

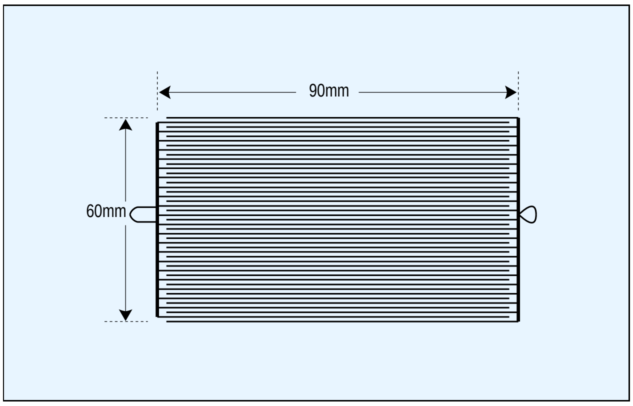


Fig. 5 Gold-plated tandem compound substrate board

6-2 Confirming Dew Condensation

We set electrical current leakage measured between electrodes on the tandem compound substrate board as an indicator of dew condensation levels. As shown in Fig. 5, we used a gold-plated tandem compound substrate board (developed by this company) to measure the electrical current leakage.

6-3 Measuring Migration

To measure migration, we moved the specimen during the test and checked for migration using a stereoscopic microscope.

6-4 Test Results

Fig. 6 gives a Weibull probability plot showing the observation cycle and the rate of migration occurrence. Photo 3 (on next page) shows migration.

A Weibull analysis of the results yielded a form modulus of m = approximately 1.8, and an average wear-out failure life of 15 cycles (L50). No dispersion occurred in separate areas of the pattern.

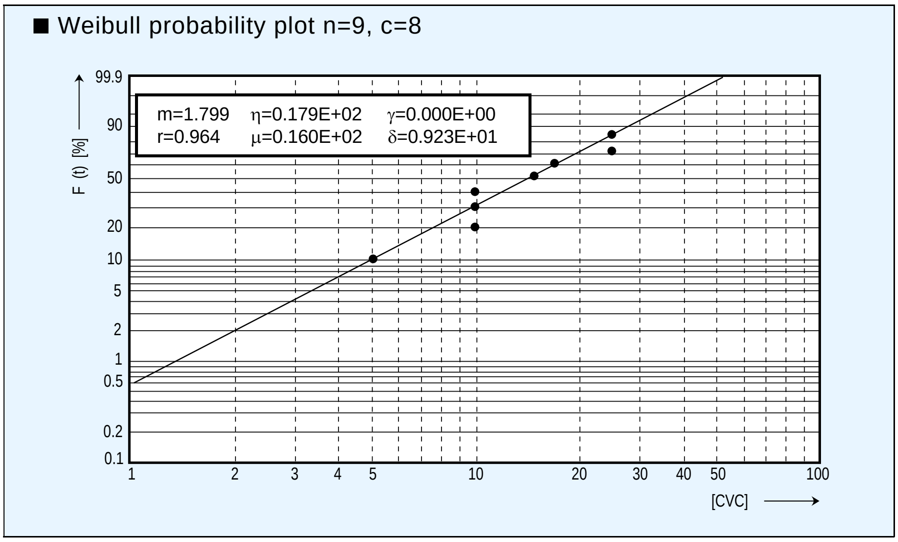


Fig. 6 Weibull probability plot data on migration in the dew cycle test

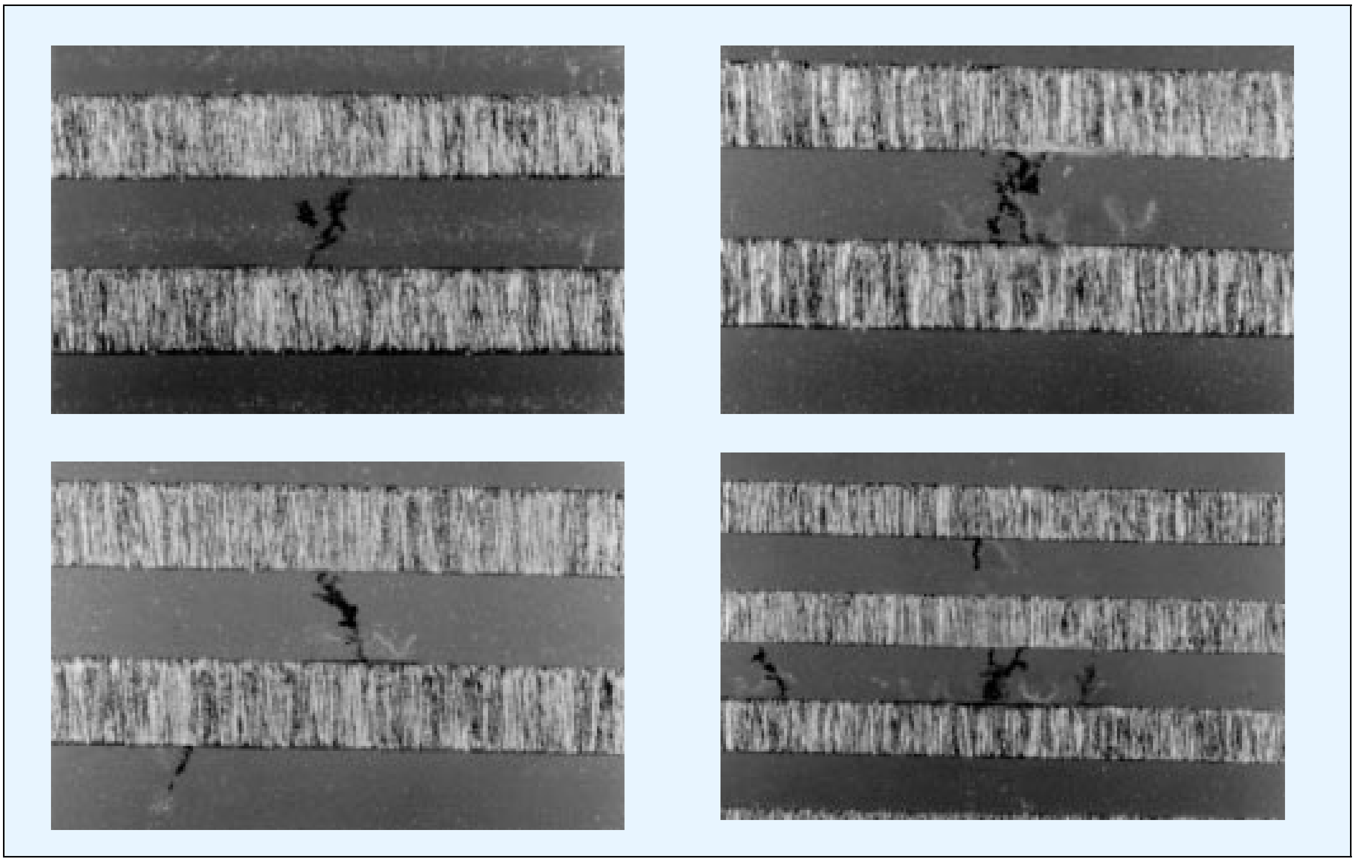


Photo 3 Migration occurrences in the dew cycle test

7. A Critique of the Dew Cycle Test

7-1 Quantity and Duration of Dew Condensation

The following tendencies were seen in quantity and duration of dew condensation in test results measuring electrical current leakage from the electrodes for measuring dew condensation. Duration of dew condensation was fairly uniform for each test cycle, but current leakage varied depending on the conductor spacing and on difference in thermal capacity due to the size of the specimen. This indicates that specimen conditions greatly influence the quantity of dew condensation. Even when test temperature and humidity conditions are uniform, different results can be anticipated according to the dimensions of the specimen.

7-2 Substrate Board Surface Elements and Wettability

Current leakage showed a gradual decline during continuous dew cycle tests. Interrupting the tests and removing the specimen in the middle of the series caused somewhat of an increase in current leakage. These changes might be due to the wettability of the surface of the substrate board with water. We can also report that migration is not as likely to occur when using organic acid flux in the dew cycle test. We surmise that this effect is due to the loss of bonding strength between water molecules and the surface elements of the substrate board when organic material exists between water and the surface of the substrate board, causing lower wettability.

Moisture absorption characteristics of the substrate board are shown in Fig. 7. Changes in current leakage are thought to be related to moisture absorption of the substrate board, but that does not seem to contribute very much to leakage. Leakage seems to be caused mainly by the wettability of the substrate board.

Cycle	Absorption Coefficient (%)
0	0.000
2	0.018
6	0.021
11	0.025
44	0.032

• Absorption coefficient =

$$\frac{\text{weight after absorption} - \text{weight before absorption}}{\text{weight before absorption}}$$

Fig. 7 Absorption coefficient of the glass epoxy substrate board in the dew cycle test

7-3 Critique of the Method of Measuring Migration

In evaluation testing, measuring was rated in general as inadequate to measure insulation resistance for conductor spacing using tandem compound electrodes for high-temperature, high-humidity testing. However, a different method of measuring can be applied in the dew cycle tests. Continuous measuring of insulation resistance is possible with a high resistance test chamber applicable even to dew cycle tests. Because of severe leakage when dew condensation is on the substrate board, measuring is limited to periods when dew condensation has evaporated. A crucial means of evaluation in the dew cycle test is to observe the growth of migration, especially up to the point that insulation resistance deteriorates. To make this observation, this specimen must be removed during the test.

8. Summary

The following observations were gleaned from this test.

(1) In technically examining the dew cycle test chamber to check migration caused by dew condensation, we found vital factors necessary for obtaining reproducibility.

(2) A tendency was noted for interdependency between quantity of dew condensation and current leakage from the tandem compound electrodes. This interdependency made possible a method of monitoring the dew cycle test.

(3) Using the dew cycle test makes it possible to cause migration to occur within a short time frame.

However, the effects dew condensation has on various conditions in the dew cycle test chamber are not fully understood, so technical matters are still under study and need to be clarified. In addition, further development of the sensor measuring the quantity of dew condensation by measuring current leakage is required to resolve instability in such areas as sensitivity, reproducibility, and sensor accuracy.

9. Acknowledgments

We would like to take this opportunity to express our gratitude for the great variety of advice we have received from everyone in the Quality Assurance Group, Quality Management Department at Matsushita Communication Industrial Co., Ltd. as well as everyone in the Electron Devices Division Device Functions Section, Electro Technical Laboratory, Agency of Industrial Science and Technology, Ministry of International Trade and Industry.

[Reference Bibliography]

1) Nobuyuki Nakamura/Tsutomu Tsukui:
"The current Status of Evaluating Insulation Reliability and Current Topics Involved" 1993 National Convention Record I.E.E.Japan (1993)

2) Tadaaki Kurosaki/Muneaki Nakai/Akira Shimizu/Tamotsu Ishii/Masataka Nishiura/Mika Nakamori/Hiroyuki Tokumasu/Masako Murao/Satoru Morimoto:
"SMT Reliability Research (5) on Solder Contact Areas, and an Analysis of Ion Migration of Solder Materials" Proceedings of the 23th. Union of Japanese Scientists and Engineers Symposium on Reliability and Maintainability (1993)

3) Nobutoyo Tsutsumi/Katsuya Takeda/Akihiko Takemura/Kenji Kawamura:
"Actual Examples of Product Malfunction During Reliability Testing (Solder Migration)" Proceedings of the 15th. Union of Japanese Scientists and Engineers Symposium on Reliability and Maintainability (1985)

4) Yukio Asami/Atsuko Kikuchi/Hiroyuki Fukazawa/Tomoshi Ooide/Akira Kojima:
"Package Crack Resistance by Washing the Surface of Semiconductor Components" Proceedings of the 22th. Union of Japanese Scientists and Engineers Symposium on Reliability and Maintainability (1992)

5) Japanese Automobile Standard:
"General rules of environmental testing methods for automotive electronic equipment JASO D 001-94" (1994) Society of Automotive Engineers of Japan,Inc.