Report 1

Evaluation Method for Ion Migration Using Dew Cycle Test (Part 3)

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The growth of Dendrites due to Ion Migration is intimately related to water present, and thus obtaining reproducible test results requires a uniform supply of moisture. In a previous issue of this magazine (April '96), we looked at dew condensation conditions as a method of supplying that moisture. We also reported on Dew Cycle Test Chambers that use both a uniform quantity of dew condensation and uniform dew condensing time in a cycle repeatedly alternated with drying. For our report this time, we have designed prototype experimenting equipment enabling us to directly observe dew condensation conditions, thus allowing us to investigate the causes of Dendrites growing in the Dew Condensation Cycle Test. We have performed experiments to confirm changes in dew condensation conditions and also to confirm the relationship between dew condensation and the growth of Dendrites. At this time, we would like to report on the results of repeated test cycles confirming that water from dew condensation covering the gap between electrodes causes the substrate surface to become subject to wetting and causes Dendrites to grow.

The authors announced the research details that form the basis of this report in [The third International Conference on Reliability Maintainability and Safety in China] presented at Guangzhou, China from November 12 to 15, 1996.

1. Introduction

The degradation and failure of printed circuit board (hereafter, PCB) insulation due to the effects of dew condensation and moisture absorption has become a well-known problem. Changes in lifestyle have promoted the miniaturization of electronic equipment and also have contributed to the diversification of environments in which such equipment is used. The miniaturization of electronic equipment has increased the mounting density of PCBs and made the distances between electrodes minute. On the other hand, the changes in usage environments has placed a great variety of environmental stress on the PCBs. The occurrence of dew condensation at the minute distances between electrodes causes the degradation and failure of insulation due to such phenomena as Ion Migration. At Tabai Espec, to evaluate tolerance of dew condensation, we have developed Dew Cycle Test Chambers that simulate actual environmental conditions. (Photo 1)

Using this test equipment we are able to evaluate Dendrite growth due to Ion Migration, and do so with reproducible test results. In parts 1 and 2 of this report we examined the development of the test equipment and the methods of testing, but until now we had not yet elucidated the mechanism of Ion Migration caused by dew condensation.

Photo 1 Dew Cycle Test Chamber (Model DCTH-70, produced by TABAI ESPEC)

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In this report we shall discuss the causes of Dendrite growth on the surface of PCBs in tests using Dew Cycle Test Chambers and we shall analyze the results. First of all, we used a TV camera to observe the dew condensation conditions (time, size and quantity of dew condensing) during tests using Dew Cycle Test Chambers. Next, we performed experiments on the relationship between water from dew condensation and the growth of Dendrites. Finally, the results of analyzing the surface of the tested specimens confirmed the process leading to degradation and failure of insulation. Water from dew condensation caused changes in the surface of the PCBs: the surface became subject to wetting and Dendrites grew due to water from dew condensation covering the gap between electrodes.

2. Test Conditions and Test Results

The samples used were tandem compound electrode pattern, corresponding to JIS type 2 as specified in Japan Industrial Standard (JIS)-Z-3197. Materials used were glass cloth epoxy (JIS: GE4) for the substrate boards, and copper was used as the electrode metal. Table 1 shows test conditions and Fig. 1 shows specimens. The test equipment used was the Tabai Espec Dew Cycle Test Chamber shown in Photo 1. Failure was determined by removing specimens after every tenth cycle and observing under an optical microscope. Specimens with Dendrites that grew between the electrodes and resulted in breakdowns were judged as failures. Fig. 2 gives a Weibull probability plot of test results, and Photo 2 shows Dendrites grew during testing. The shape parameter from the results yields a wear-out failure of m = 2.7.

Table 1 Test conditions

Temperature and humidity conditions	5°C 60% RH ↔ 25°C 90% RH at 20 minute intervals
Number of cycles	200 cycles
Voltage applied	5V DC
Specimen quantity	30 specimens
Prior processing	Ultrasonic cleaning in alcohol (IPA), then heat treatment at +100°C for 30 minutes

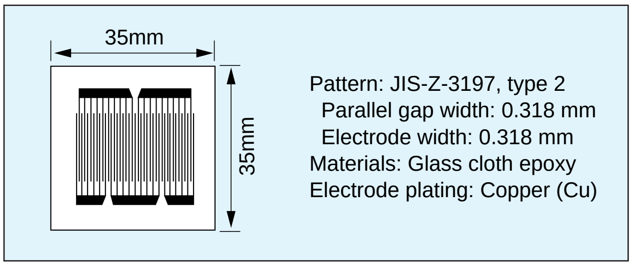


Fig. 1 Specimens

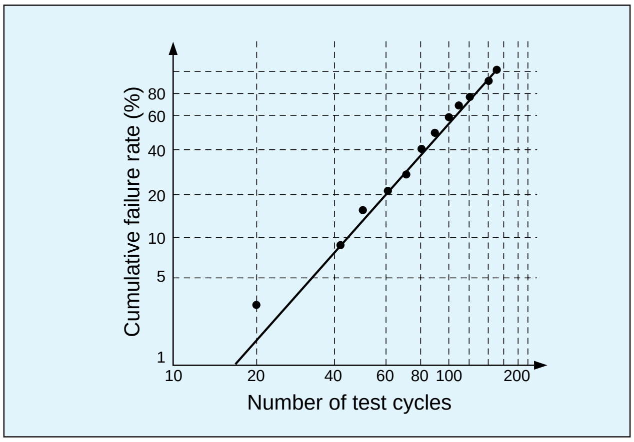


Fig. 2 Weibull probability plot of test results

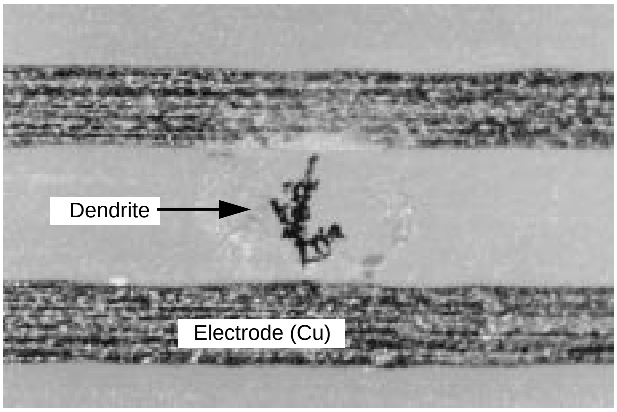


Photo 2 Failure condition

3. Observing dew condensation conditions during the dew cycle test

3-1 Cnfirming the quantity of dew condensing

We measured the amount of water (quantity of dew condensing) adhering to the surface of the PCB during the Dew Cycle Test, and we measured the dew condensing time. We found the quantity of dew condensing by measuring changes in weight, and we found the dew condensing time by measuring the current leakage between electrodes. Fig. 3 shows the results. Dew condensation approaches its peak about 1 or 2 minutes after changes are made in the temperature and humidity, after that drying gradually begins, and after about 10 minutes drying is complete. There was no change in quantity of dew condensing in different cycles, and we repeated cycles with reproducible results of dew condensation and drying.

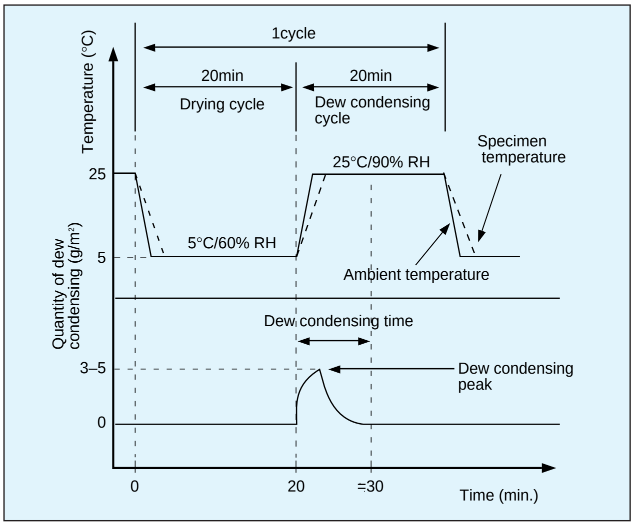


Fig. 3 Quantity of dew condensing and dew condensing time during test cycles

3-2 Changes in dew condensation conditions during the test

We set up a TV camera inside the test chamber and continuously photographed the dew condensation conditions during the Dew Cycle Test. Photo 3 shows the condition of water adhering due to dew condensation during the test. In the initial condition, the size of dew condensing is about 5 to 10 µm, easily small enough compared to the gaps between electrodes. As test time passed (repeated cycles) the water lost the shape of round droplets. After that, water formed a continuous film spreading out from both electrodes, and in some areas covered the entire gap.

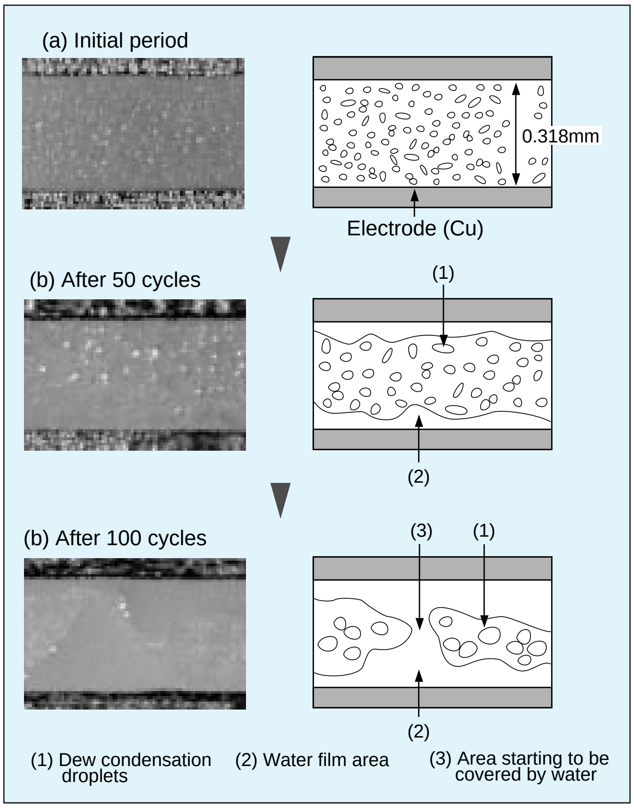


Photo 3 Changes in dew condensing conditions during testing

4. The relationship between dew condensation and failure

To clarify the relationship between dew condensation and failure, we devised prototype experimenting equipment to do nothing but cause dew condensation. This experimenting equipment accurately controls the quantity of dew condensing, and at the same time allows the process of the phenomenon to be observed. Fig. 4 shows the configuration and Fig. 5 shows the capacity of the equipment. Using this experimenting equipment, we tested the relationship between failure and the size and quantity of dew condensing, as well as at what dew condensation cycle the failure occurred. Specimens and test cycle conditions used in the experiment were the same as those given for the previously mentioned test (Item 2).

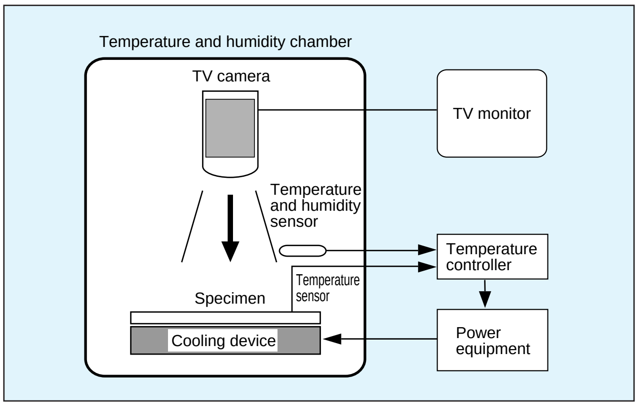


Fig. 4 Configuration of dew condensation experimenting equipment

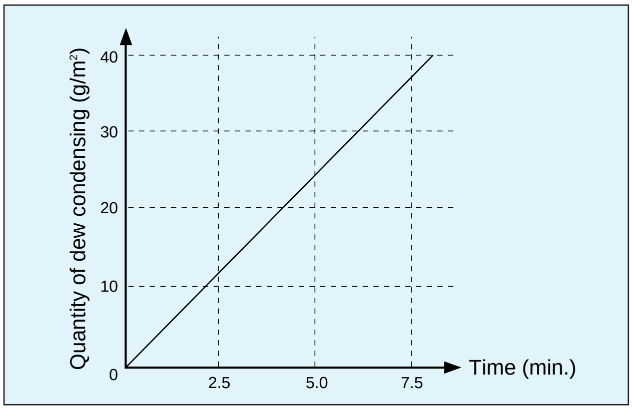
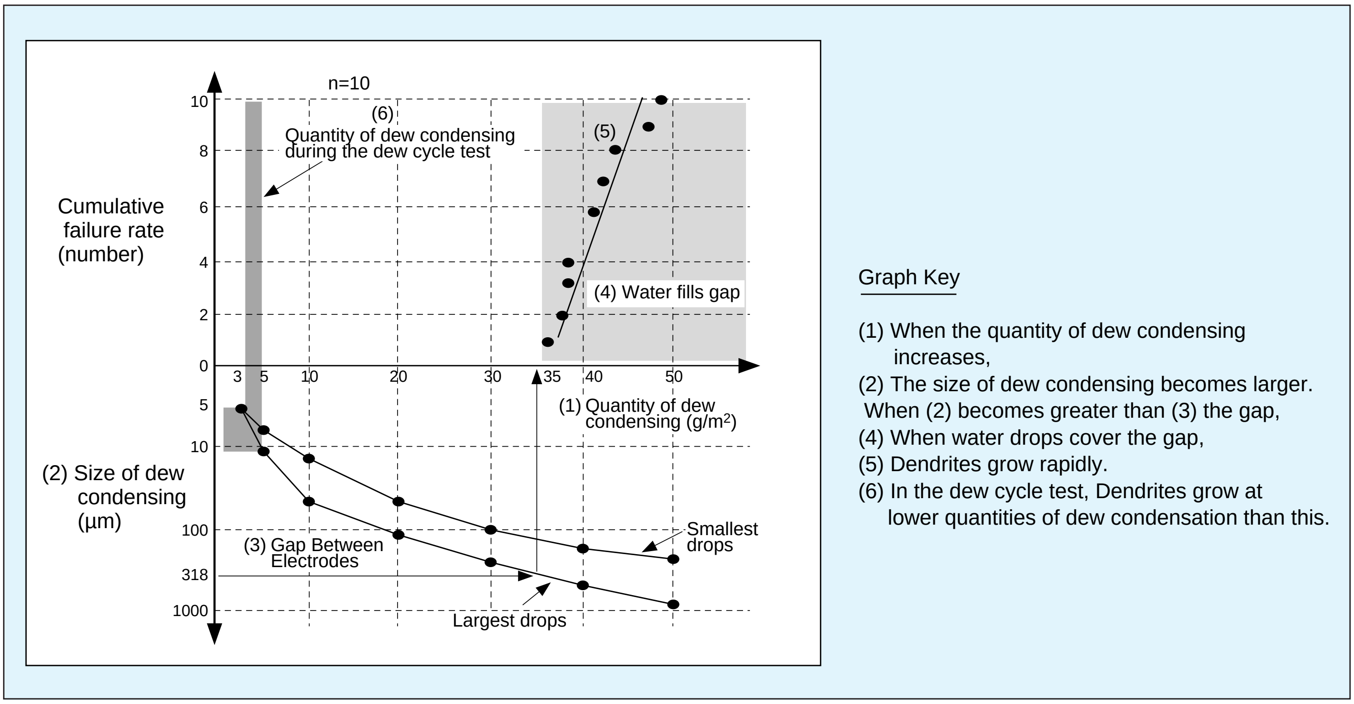


Fig. 5 Capacity of dew condensation experiment equipment

4-1 The relationship between failure and the size and quantity of dew condensation (Experiment 1)

One report states that Dendrites grow in a short amount of time when the gap between electrodes is covered with water.(3) This result is obtained using the experimenting method called the water drop method.(4) We obtained the same results using our prototype equipment. Fig.6 shows the results. When the quantity of dew condensing exceeds 35 g/m^2, the size of dew condensing becomes larger than 0.3 mm and the water begins to cover entire areas between the electrodes. From that time, Dendrites grow rapidly. Specimens have been cleaned and heat-treated, and measurements of the size of the dew condensing is the value measured from the camera images.



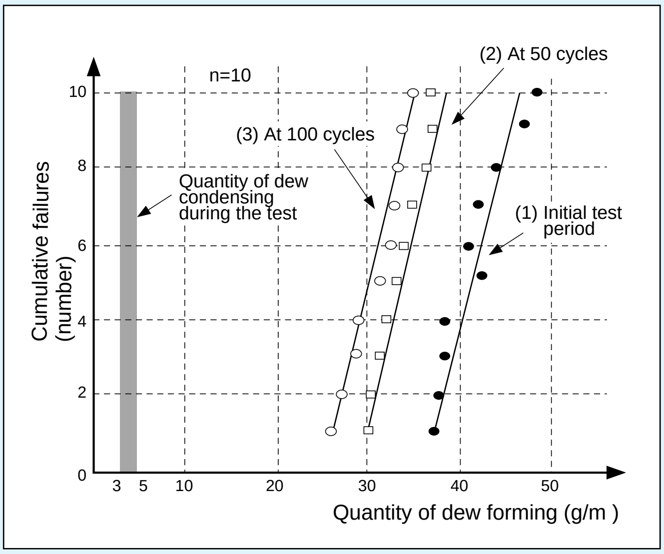
Graph Key

(1) When the quantity of dew condensing increases,
(2) The size of dew condensing becomes larger.
When (2) becomes greater than (3) the gap,
(4) When water drops cover the gap,
(5) Dendrites grow rapidly.
(6) In the dew cycle test, Dendrites grow at lower quantities of dew condensation than this.

Fig. 6 Relationship between failure and the size and quantity of dew condensation

4-2 Confirming the relationship between failure and the quantity of dew forming due to the test cycles (Experiment 2)

Using our prototype experimenting equipment, we gradually increased the quantity of dew condensing on the specimens used in the Dew Cycle Test. Fig. 7 shows the results of our investigation into the relationship between the quantity of dew condensing and the growth of Dendrites. Water spreads more easily as the number of cycles increases, and Dendrites covering the gap between the electrodes grow with less quantity of dew condensing. The quantity of dew condensing in the Dew Cycle Test is from 3 to 5 g/m^2, but failure occurred in this experiment at a lower quantity of dew condensing. Specimens used in this experiment were first put through a uniform cycle in the Dew Cycle Test then removed from the test equipment and let stand at room temperature. However, specimens in the Dew Cycle Test are not removed but are continuously tested, so we hypothesize that the moisture from repeated forming and dissipating of dew condensation was absorbed into the PCB, and the influence of that moisture caused the failure at lower quantities of dew condensing in the experimenting equipment.



Graph Key

(1) Tandem compound substrate boards not completing the dew cycle test
(2) Tandem compound substrate boards after 50 test cycles
(3) Tandem compound substrate boards after 100 test cycles

This graph shows the relationship between failure and the quantity of dew condensing when the amount of adhering dew condensation is increased in the various specimens. These results show that the greater the number of dew test cycles, the less dew condensation required for Dendrites to grow.

Fig. 7 The relationship between failure and the quantity of dew forming at different test cycles

5. Surface analysis

We can hypothesize that substances responsible for changing the wetting characteristics of the PCB surface are hydroxides from the electrode metal, impurities from the air, and (mainly) organic substances that have been eluted from the PCB materials (Fig. 8). We used an SEM (scanning electron microscope) to observe the surface of the PCBs. (Photo 4)

We were able to confirm substances adhering around the minute holes in the surface of the PCBs used in the Dew Cycle Test. An elemental analysis of these adhering substances detected copper. We can assume that this matter is copper that was little by little ionized and eluted from the repeated dew condensation and drying in the Dew Cycle Test. Also, in the area around where the Dendrites grew, the analysis detected bluish white copper hydroxide ($Cu(OH)_2$). The minute holes in that area were completely covered by copper hydroxide. We can presume that the cause of the water from dew condensation making the surface of the PCB conducive to wetting is mainly due to the effect of the ionization of the metals from the electrode, but we can also presume that a complex relationship exists with other substances.

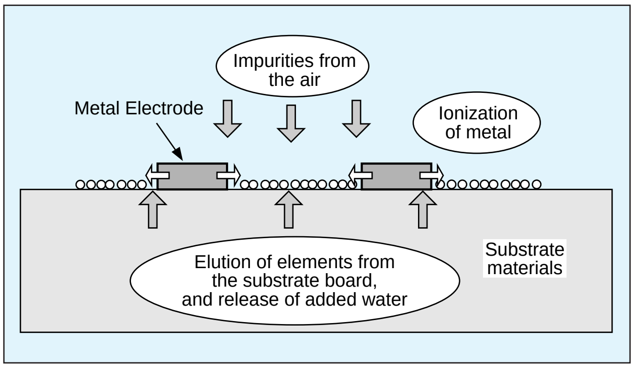
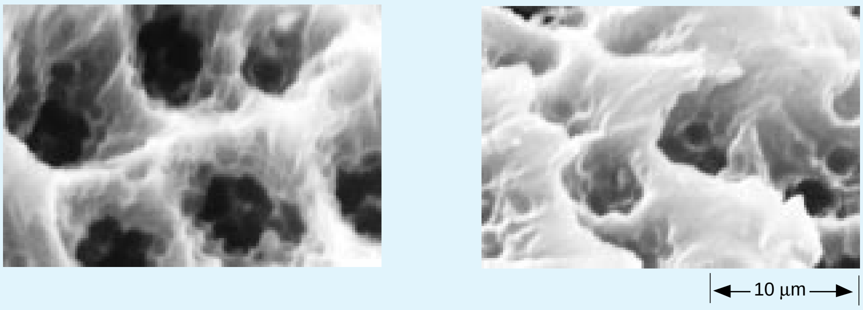


Fig. 8 Cause of changes in wetting characteristics



(a) Initial period

(b) After 100 cycles

Photo 4 Observation with SEM (2000×)

6. Conclusion

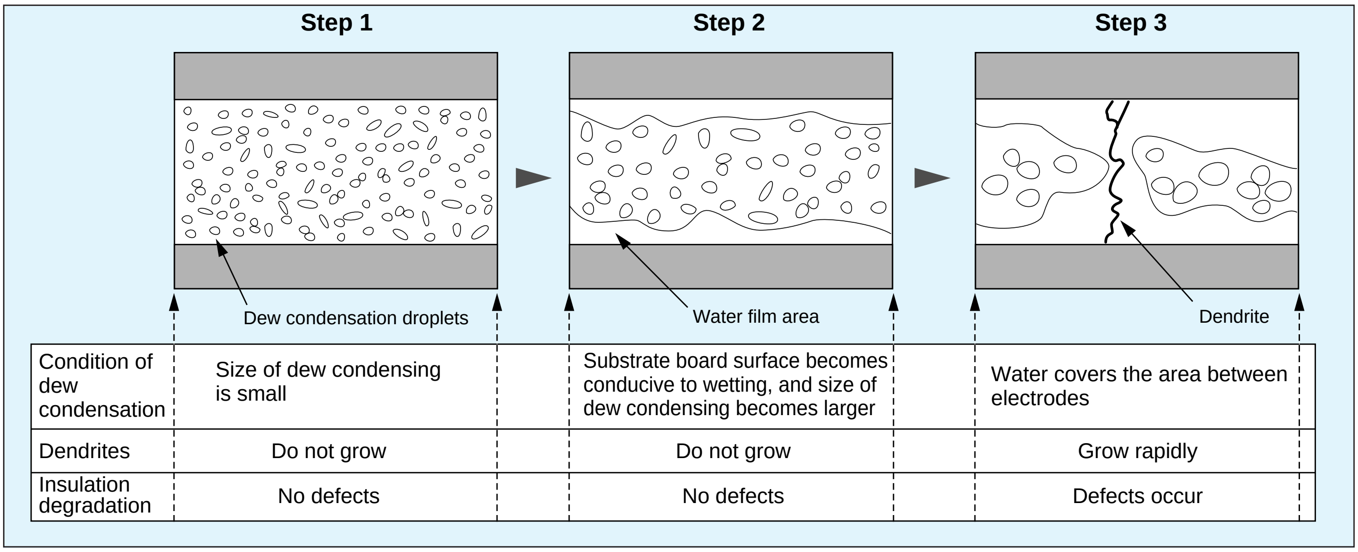
Analysis through observation of dew condensing conditions and using dew condensing experimenting equipment has confirmed the following about results of the Dew Cycle Test.

(1) The size and quantity of dew condensing during the test is well within the size allowable compared to the gaps between electrodes.
(2) The greater the number of test cycles, the more conducive to wetting the surface of the substrate board becomes.
(3) When the gap between the electrodes is covered with water, Dendrites grow rapidly.
(4) The greater the number of test cycles, the more conducive to wetting and the lower the quantity of dew condensing that is required for Dendrites to grow.

From the above, we can assume the following about Dendrites growing in the Dew Cycle Test. Repeated dew condensing and drying result in elution and adhering of electrode metals and other substances, and the surface of the substrate board becomes conducive to wetting. This condition results in water covering the gap between electrodes. When this has occurred, failure occurs fairly shortly afterwards. We can hypothesize the process up to degradation of insulation in the Dew Cycle Test as follows. (Fig.9)

Step 1: Small droplets of dew condensation water adhere, but no degradation of insulation occurs.
Step 2: Areas of wetting on the surface of the substrate boards gradually increase, but no degradation of insulation occurs.
Step 3: Areas between electrodes covered by water rapidly cause degradation of insulation.

Changes in the wetting characteristics in steps 1 and 2 can be presumed to be major causes affecting the life cycle in the Dew Cycle Test.



	Step 1	Step 2	Step 3
Condition of dew condensation	Size of dew condensing is small	Substrate board surface becomes conducive to wetting, and size of dew condensing becomes larger	Water covers the area between electrodes
Dendrites	Do not grow	Do not grow	Grow rapidly
Insulation degradation	No defects	No defects	Defects occur

Fig. 9 Process of insulation degradation in the dew cycle test

7. A final word

Ion Migration is intimately related to the water present, and obtaining reproducible test results requires uniform amounts of water. In the tests performed for this report, the size of dew condensing was easily small enough compared to the gaps between electrodes. When the quantity of dew condensing caused the size of dew condensing to become wider than the gap between electrodes, water covered the gap between electrodes and Dendrites grew rapidly. Because of these results, this test did not serve as a test of life expectancy. Care must be taken with this point when conducting a reproducible evaluation of life expectancy with the Dew Cycle Test.

The purpose of environmental testing is to cause the same characteristic changes that occur to a product during usage and to be able to evaluate the product quickly. The Dew Cycle Test method conforms to this purpose not only for Ion Migration, but can also be considered suitable for evaluating insulation degradation.

[Reference Bibliagragphy]

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2) Yuuichi Aoki/Hirokazu Tanaka/Shigeharu Yamamoto/Osamu Obata/Yoshiki Saito: “Evaluation Method for Ion Migration Using Dew Cycle Test (Part 2)” ESPEC TECHNOLOGY REPORT NO.1 (1996)

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4) Toshiyuki Ohtori: “Mechanism and Suppression of Ion Migration in Printed Circuit Boards” The Journal of Japan Institute for interconnecting and Packaging Electronic Circuits, Vol.10-No.2, 80-86 (1995)