Stress Analysis and Accelerated Evaluation of Tin Whisker under Thermal Shock Stress

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Abstract

Though it is generally known that whisker often springs from tin, the tin plated film on nickel does not provide the tin whisker growth under high temperature storage. But under thermal shock stress tin whisker grows even if the nickel film is formed under tin plated film. Then we have investigated the trend of growth and reliability evaluation about the tin whisker under thermal shock stress. As a result, we confirmed that the tin whisker under thermal shock stress did not cause short-circuit failure in field.

Key words : tin whisker, thermal shock stress, lead-free.

1. troduction

With the promotion of lead-free solder in these years, the conversion of solder-plating technology of electronics components from current methods to pure Sn or Sn-system plating is widely pursued. It is generally said that Sn is a metal easily generating whiskers in high temperature atmosphere, and each concerned manufacturer, etc. has made research about this type whickers[1] . We have also conducted the 50°C high temperature storage test of products with Sn plate on Ni under-plate and confirmed that this type of whiskers are not generated on our products for a time period of 18 years [2].

However, it has been lately found that, if a thermal stress shock is charged on a product with Sn plate on Ni under-plate, it generates lint-like deposition products (i.e. we call them "whiskers ")[3]. As these whiskers have lint-like sinuous shape, some of which grow to few score micrometers, there is a concern that they may cause short-circuit failure between electrodes on electronics components.

Therefore, we have performed stress analyses in order to investigate, in what conditions, these whiskers generated under the thermal shock stress grow and how they affect product reliability, and estimated the reliability level of electronics components used in the market environment in respect of the whisker generation. This paper reports the results of these research.

2. Experimental Conditions

2.1. Samples

Our ceramic chip products with Ni under-plate and Sn surface plate on sintered Ag electrode were used as experimental samples.

These sample were soldered using a hot-plate method and fixed on alumina substrates. The influence of soldering heat on the samples was minimized by removing them from the hot-plate at the moment when Sn-Pb eutectic solder (melting point about 183°C) got started wetting.

2.2. Evaluation Method

In this experiment, we used a SEM (Scanning Electron Microscope) for the observation of whisker shape, also we observed the whiskers using a laser microscope in order to quantitatively evaluate whisker lengths, which were measured using laser microscope images obtained as shown in Fig. 1. In addition, we compared whisker length levels generated in each test condition by calculating the average of most grown ten (10) whiskers among measured whiskers in that condition (hereinafter referred to as "worst 10").

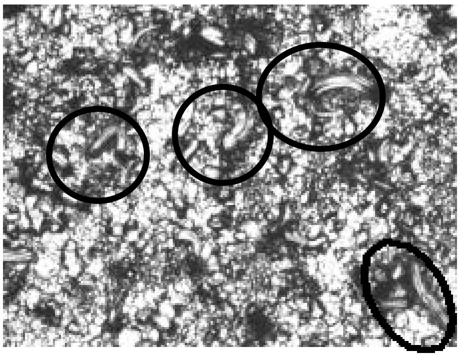


Fig. 1 Laser microscope image of tin whisker
[-40↔85°C,1000hrs]

3. Experiment Results and Consideration

3.1. Observation of Whisker Shape

SEM image of a whisker generated under thermal shock stress (test condition : – 40 ↔ 85°C, 800 cycles) is shown in Fig. 2. Whiskers generated under thermal shock stress have sinuate shapes and, as their nature, do not grow vertically to sample surface but grow crawling alongside the surface.

3.2. Analyses of Thermal Shock Stresses

We conducted thermal shock stress analyses in order to learn which of temperature test steps, high side or low side, or temperature difference (ΔT) are most affecting the whisker growth. The applied test conditions and whisker length measurement results are shown in Table 1. We have figured out the following facts from these results :

1. The whisker length does not solely depend on the temperature difference (ΔT) (comparison between test results $\boxed{1}$ and $\boxed{2}$).
2. When the low temperature side is – 40°C, whiskers more grow in 85°C high side temperature than in 125°C (comparison between test results $\boxed{1}$ and $\boxed{3}$).
3. When the high side temperature is 125°C, the

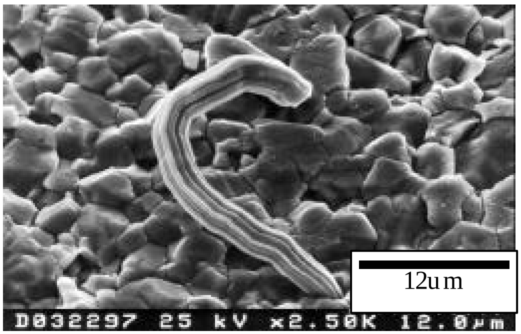


Fig. 2 SEM image of tin whisker under the thermal shock stress

relation between low side temperature and whisker growth length is unclear (comparison between test results 2 and 4).

Based on these results, we further investigated the effects of high side and low side temperatures in order to clarify the condition in which whiskers most rapidly grow.

3.3. Effect of High Side Temperature

We measured whiskers' growth length in various conditions with fixing the low side temperature to – 40°C and changing the high side temperature condition. The test conditions and resulted whisker length measurements are shown in Table 2. As the whisker growth was most active in Test 6 [– 40 ↔ 85°C] in Table 2, it is inferred that the whisker growth is most activated in the condition of high side temperature around 85 °C.

Table 1 Thermal shock test conditions and whisker's length

No.	Test condition (500cycle)	Whisker's length(um) (mean of worst 10)
1	-40↔ 85°C (ΔT =125°C)	34
2	0↔125°C (ΔT =125°C)	19
3	-40↔125°C (ΔT =165°C)	18
4	-55↔125°C (ΔT =180°C)	15

Table 2 Thermal shock test conditions and whisker's length
(Effect of high temperature)

No.	Test condition (300cycle)	whisker's length/(um) (mean of worst 10)
5	-40↔ 65°C (ΔT =105°C)	17
6	-40↔ 85°C (ΔT =125°C)	24
7	-40↔105°C (ΔT =145°C)	17

Table 3 Thermal shock test conditions and whisker's length
(Effect of low temperature)

No.	Test condition (300cycle)	whisker's length(um) (mean of worst 10)
8	-40↔ 85°C (ΔT =125°C)	24
9	0↔ 85°C (ΔT = 85°C)	11
10	25↔ 85°C (ΔT = 65°C)	9

3.4. Effect of Low Side Temperature

Next, we measured whiskers' growth length with fixing the high side temperature to 85°C and changing the low side temperature condition. The test conditions and resulted whisker length measurements are shown in Table 3. From these results, we have confirmed that, in the conditions of 85°C high side temperature, the lower the low side temperature is (the greater the ΔT is), the more actively the whiskers grow. It can be understood that this occurs because Sn plate Inside strain becomes greater as the thermal shock stress loaded on tested product and whiskers are generated in a course to alleviate the strain. However, as the whisker generation has been observed in the condition of low side temperature 25°C (room temperature level), the whisker generation / growth in the market conditions is apprehended. Therefore, we have tried to estimate whisker growth length in the using market environment relatively to the three test conditions shown in Table 3.

3.5. Estimation of Whisker Growth Length in Market Environment

In order to estimate whisker growth length in the market environment, we performed additional thermal shock tests using three conditions in which the high side temperature was fixed to 85°C and the low side temperature was changed to – 40, 0 and 25°C(i.e. ΔT was 125, 85 and 60°C respectively). The number of cycle times and whisker length (mean value of worst 10) obtained in each test conditions are plotted on a diagram with common logarithm X and Y axes, of which results are shown in Fig. 3. These results suggest that, in the thermal shock condition of [– 40 ↔ 85°C], the whisker growth has come to stop after 2000 cycles (The research results about whisker growth limit are later mentioned).

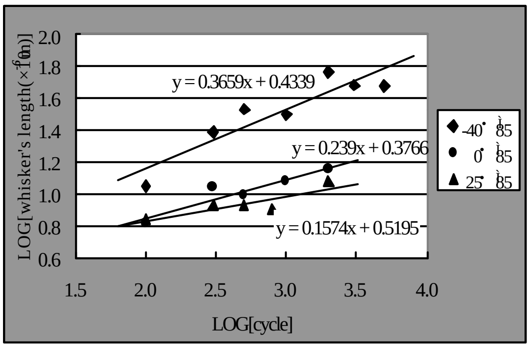


Fig. 3 Estimation of whisker's length

However, under an assumption that those whiskers ceaselessly grow by successive thermal shock stresses given in the market environment, we tried to estimate the whiskers' growing length in the market. Assuming an acceptance criterion for whisker-generated failure to be 100 m whisker length (i.e. assuming 200um as minimum electrode interval on circuit boards), we have determined the estimated values extrapolating the approximated curve obtained in Fig. 3. Product life estimation in each test condition is shown in Table 4.

Next, Fig. 4 diagram is shown on which the results in Table 4 are plotted using Eyring model. If we assume thermal shock stresses (switch ON and OFF) charged on products in the markets to be ΔT = 60°C and 10 times (cycles) per day, 36,500 cycles of the thermal shock stresses are charged on the products in a time period of 10 years. Meanwhile, required thermal shock cycles for whiskers to grow to 100um are estimated to be 2.2×10^9 cycles (more than sixty thousand years) from Eyring model in Fig . 4.

Therefore, we can conclude that these whisker do not reach 100um length in the actual using environment.

Table 4 Estimation of life

Condition(°C)	ΔT =125	ΔT =85	ΔT =60
Life(cycle)	1.91×10^4	6.20×10^6	2.55×10^9

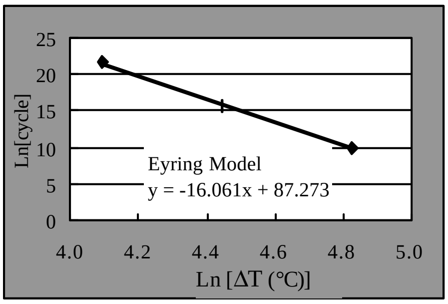
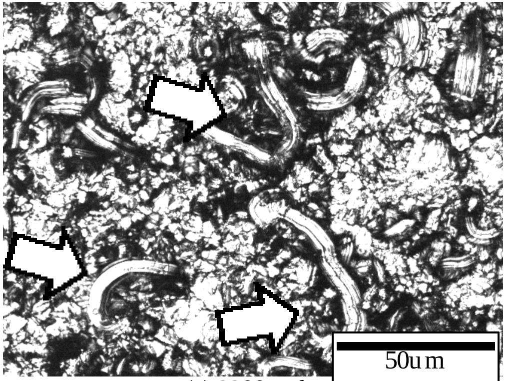


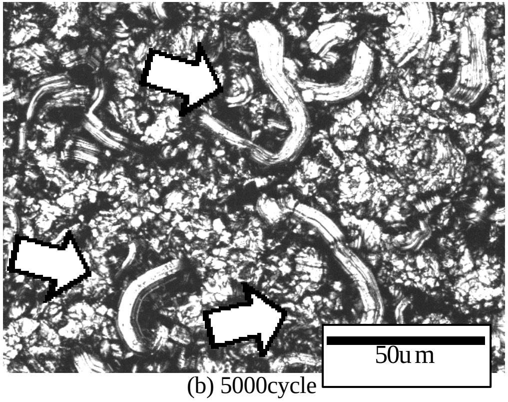
Fig. 4 Analysis by Eyring plot

3.6. Research of Growth Limit

We have investigated how far these whiskers grow by repeatedly charging a thermal shock stress (– 40 ↔ 85°C, each 30minutes keeping). Two photographs observing the same microscopic view field for a Sn plate after 2000 cycles and 5000 cycles are shown in Fig. 5 (a) and (b), in which the stop of whisker growth has been clearly recognized. From these observations, it is estimated that the whiskers do not endlessly grow also in the market environment and they have a growth limit.



(a) 2200cycle



(b) 5000cycle

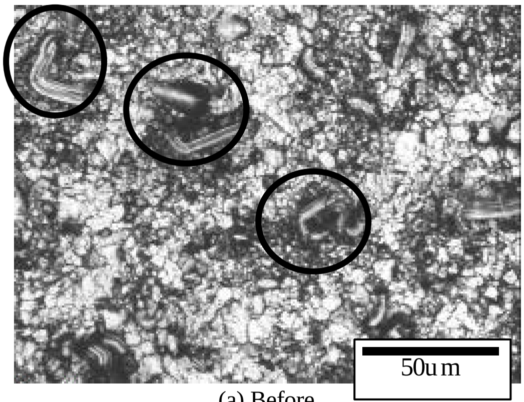
Fig. 5 Laser microscope images of tin whisker at 2200cycle and 5000cycle[–40↔85°C]

3.7. Evaluation of Strength against Vibration and Mechanical Shock

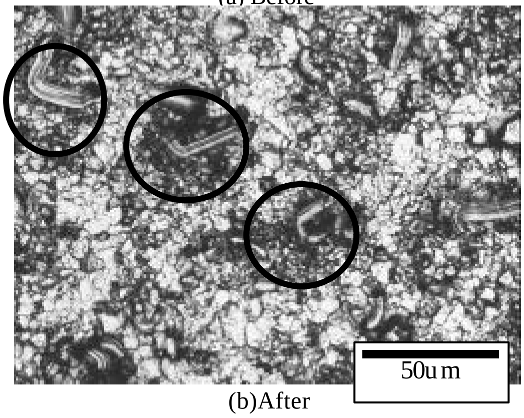
In this evaluation, we performed vibration test and mechanical shock test (series test) of the samples in order to check whether whiskers generated depart from electrode surface by vibration / mechanical shock. The test conditions are shown in Table 5 and the laser microscope images of Sn plate surface before and after test are shown in Fig. 6. From these results, we can see that no change has been occurring in the shape of these whiskers after the vibration / mechanical test and they hardly depart from Sn plate surface. Therefore, we can say that it is improbable that grown whiskers depart from electrode by vibration / mechanical shock even in a specific using environment (such as mobile phone) and a fall-off causes into short circuit failure.

Table 5 Vibration test and Shock test conditions

Vibration test	Frequency range:10~2000Hz Maximum acceleration : 20G Maximum amplitude : 3.0mm 1octave/min 2 directions, 10cycle
Shock test	Maximum acceleration : 3000G Duration : 0.3msec 6 directions,3 times



(a) Before



(b)After

Fig. 6 Laser microscope images of tin whiskers before and after vibration and shock test

3.8. Effect of Reflow Soldering

Assuming actual product use, we performed thermal shock test (- 40 ↔ 85°C, 1000cycles) on samples pretreated by reflow soldering (maximum reflow temperature : 240°C). A laser microscope image of tin whiskers after the test is shown in Fig. 7. The whiskers on this sample grew only about 10um. From these results, we have confirmed that the reflow soldering at 240°C represses Sn whisker growth. The reason is inferred that internal stress inside Sn plate is alleviated by Sn plate melting in soldering operation.

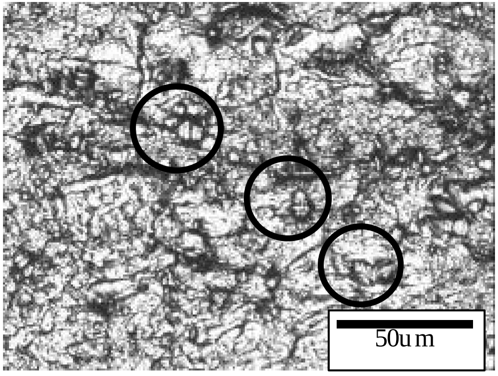


Fig. 7 Laser microscope images of tin whiskers in the case of reflow soldering at 240°C[–40↔85°C, 1000cycle]

4. Summary

The following results have been obtained from this research :

1) Tin whiskers do not endlessly grow by thermal shock stress and have their growth limit. Even if assuming they grow endlessly, we can say that they do not actually reach 100um estimating from thermal shock stress levels in actual using environments (for example, 25 ↔ 85°C).
2) As the whiskers have convoluted shape and grow crawling on electrode surface, there is little possibility that they cause short-circuit failure with adjacent electrode.
3) The whiskers do not easily removed from electrode by a vibration / mechanical shock.
4) Reflow soldering on electrode represses whisker growth.

From the above results, we can say that Sn whiskers generated by thermal shock stress make no trouble in usual using environments.

References

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