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Stability of Solder Joint Resistance After Multiple Aging Processes. Repeatable Multiple Measurements of Solder Joint Resistance

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Abstract: The value of solder joint resistance depends on many factors such as constitution of used alloy, pad coating, metallization, formed IMC, defects within joint structure, dimensions etc. In respect of equipment reliability, stability of solder joints within a period of time that covers usage time predicted by producers is a crucial issue. The main aim of this study was to evaluate stability of solder joint resistance. The study is a part of wide experimental investigations performed by the author and devoted to reliability of the solder joints. Within the frame of this study three solder alloys and three pad coatings were selected and evaluated. The selection was based on the previous wider investigations. Multiple measurements were performed for statistical analysis. The test specimens were subjected to two aging processes in climatic chamber. The multiple measurements of the solder joint resistance were performed after each process. In order to reduce time, ensure repeatability and accuracy of the measurement dedicated, fully automatic measuring stand was designed and manufactured. The microcontroller is main control unit of the stand. Applied solutions such as the UDP communication protocol, the Ethernet interface makes it modern and flexible. Within the frame of this paper both the control stand and the results of performed experimental investigations are presented. Obtained results will be the base for next investigations.

Key words: measurement, solder joint, automation, resistance, stability

1. INTRODUCTION

Nowadays development of the electronic and electrical industry strives for minimization, efficiency increasing, ecological products and cost reducing. All the directions have a great impact on a design of products, used materials and technology of the manufacture leading also to reliability problems.

Solder joints on printed circuit boards are crucial parts of most electrical and electronic equipments. The most important function of the solder joints is to ensure electrical contact between joined pads and connectors (pins, lead frames, bumps etc.). Its other functions that should be fulfilled in specific conditions and time are thermal conductivity and constructional function.

The producers are interested in selling up-to-date products as well as in reducing amount of defective devices that come back from the market within warranty period. The failures are mostly caused by solder joint defects such as cracks, electromigration, whisker growth etc. During usage time devices are subjected to many hazards that have a great impact on the reliability of the solder joints. The most damaging are mechanical shocks, vibrations and cyclic changes of working temperature. The solder joint subjected to stress loading inducted by vibrations, mechanical shocks, thermal shocks or thermal cycling can crack easily.

Cracked solder joints can cause temporary or permanent opening of the electrical circuits. The tin whiskers, that grow from the surface of pure metal can lead to shorts between adjacent patches or lead-frames causing shorts between electrical circuits. Opens, shorts or resistance changes of the joints lead to incorrect work of analogue and digital parts of the systems. The consequences of the failures are different in case of household equipment and medical equipment, military equipment, avionic or space equipment such as space shuttles, space probes. Apart of the destination, the equipment should be reliable at least within the usage time specified by the producers.

In the respect to the reliability the most important parameters of the solder joint are its resistance and its mechanical strength. Within the warranty period the solder joints should not crack, the resistance should not change significantly, its mechanical resistance to shear forces should be as high as possible.

Within the paper the results of performed evaluations devoted to stability of the solder joints resistance will be presented. In order to accelerate the aging effect of the solder joints three test specimens were subjected to two aging processes (300 h at 150 ºC each). To perform the evaluations, dedicated control stand that ensured high repeatable measurements and the measuring system had to be designed and manufactured. Capability of both the control stand and the measuring system will be also shortly described within the paper. Presented study is a part of wide experimental investigations performed by the author and devoted to the reliability of the solder joints. The test specimens were chosen on the basis of results of the complex evaluations performed previously. The evaluations covered different solder pastes and pad coatings. The chosen configuration (solder paste-pad coating) was the most interesting because of solder joint resistance stability after the aging processes.

The aging temperature was not accidental. According to literature review many researchers subject solder joints to heating process at temperature 150 C deg. during their investigations [1-2] Some of them evaluate influence of aging processes on mechanical strength of solder joints [3], others evaluate changes of intermetallic compounds structure. In most cases the temperature and the duration of aging process is determined by activation energies of evaluated intermetallic compounds [4]

2. TEST SPECIMEN AND EVALUATION PROCEDURE

Standard FR-4 PCBs were used as the test specimens. The thin film of chemical Au/Ni was used as a pad coating. Forty 0 Ohm SMD resistors (20 pcs of 1206 and 20 pcs of 0805) were mounted on each test board. The resistors were soldered using Sn96.5Ag3.0Cu0.5 solder paste during reflow process. The reflow process was performed in nitrogen atmosphere in multi-zone professional oven. The test specimens were designed in respect to multiple measurements of solder joints resistance using 4-probe method. The view of the test specimen with measuring header is presented in fig. 1.

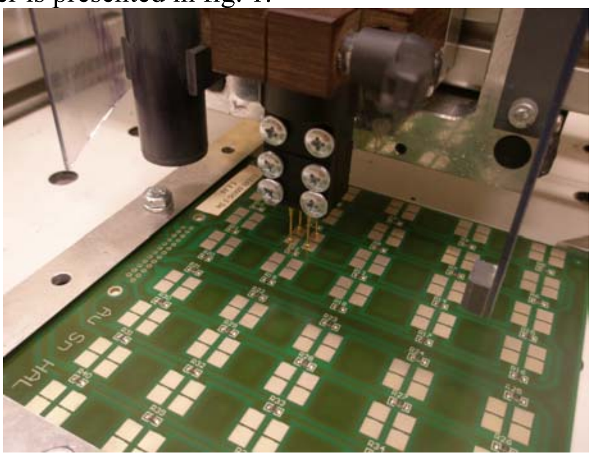

Figure 1. View of the test specimen and measuring header during measurement procedure

After the reflow process three test specimens were chosen randomly from the group of mounted PCBs. The test specimens were subjected to multiple measurements of solder joint resistance. The measurement procedure was fully automatic. The motion of the measuring header, the multimeter settings and readings are fully controlled by the microcontroller. In order to avoid deviation the header with the measuring probes was lowered three times in case of each resistor. Every time the probes touched measuring pads the resistance was measured three times. The measuring data was collected by PC to perform statistical calculations.

After the measurements the test specimens were subjected to the aging process (300 h at 150 ºC) in the climatic chamber. After the aging process consecutive multiple measurements of the solder joints were performed. To avoid the influence of measurement conditions (temperature, humidity) on the evaluated resistance changes calibrating procedure was performed before the measurements. The measurement system was calibrated using the master PCB (that was not subjected to any consecutive treatment). The correction was not significant as occurred, nevertheless it was taken into the consideration in the final analyses.

The aging and the measuring procedure was repeated once again. The collected data was used to perform statistical evaluations and analysis of variance (Anova). Anova is a statistically based decision tool for detecting any differences in average performance of groups of item tested. It enables to detect factors and correlations that influence on measured object. Within the frame of this study the Anova analyses were used to confirm if the control stand is enable to detect such low level changes of the resistance as during aging process and if the resistance of the solder joints is stable during the aging process.

The measured resistance was a serial resistance of two pads, two solder joints and resistor with the metallization (as presented in fig. 2). To avoid incorrect conclusions several resistors (not soldered) were subjected to the aging processes to determine how the resistance of the resistors changes during the aging process. Before and after the processes the resistors were subjected to resistance measurements using the control stand. It helped to determine if detected changes of the resistance are caused by the solder joints or the resistors. The results were used in the final analysis.

3. CONTROL STAND

One of the aims of the evaluations was to develop a control stand that would enable to detect changes of solder joints resistance after multiple aging processes. Measurements of solder joint resistance and its changes cause problems because of its low level. The value of the solder joint resistance depends on many factors such as constitution of the alloy, pad coating, metallization, formed IMC, defects within its structure, dimensions etc. It is much more difficult to measure resistance of single solder joint than to measure resistance of single patch or resistance of single resistor. In the practice measured resistance is the sum of serial resistance of pads, solder joints, resistor metallization and resistor. The equivalent circuit diagram is presented in fig.2

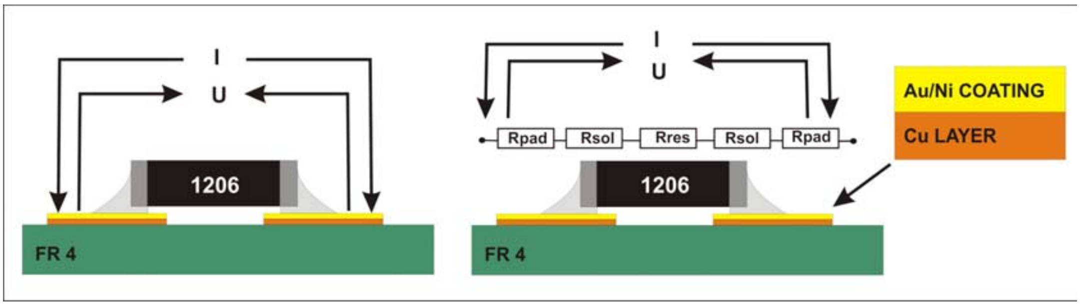

Figure 2. Test resistor soldered to the surface of Au/Ni. The equivalent circuit of measured resistance

In order to perform the statistical evaluations multiple measurements had to be performed. To ensure multiple and high repeatable measurements dedicated control stand was designed and manufactured. The control stand enables full automation of the measurement procedure. The schematic diagram of the control stand is presented in fig. 3a. The control stand consists of CNC machine tool with measuring header, commercial precision multimeter, the microcontroller and PC computer.

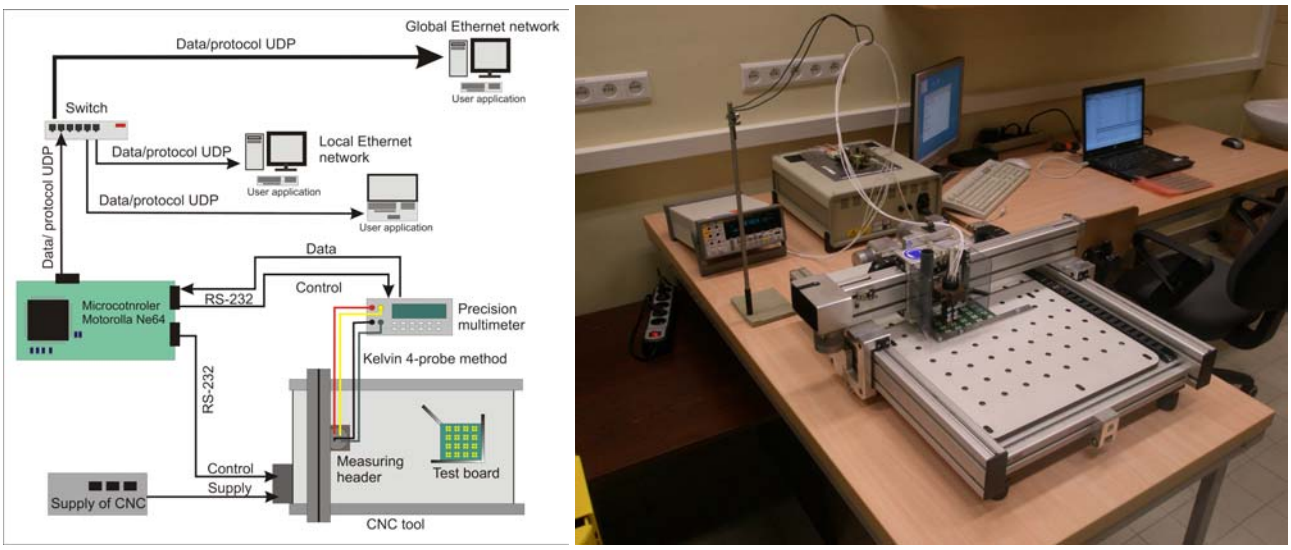

Figure 3. Schematic and view of control stand that enables fully automatic measurements of solder joints resistance

The CNC machine tool with measuring header ensures both fully automation and repeatable measurements. The header is being lowered at the same height during each measurement. Complete control of the header movement as well as application of commercial gold plated test probes with spring guarantee that all four tips of test probes press the pads with the same pressure during each measurement. The shape of the tips have a great influence on repeatability of measurements. Before proper investigations several various tips were tested. As the result the tip which ensures the best repeatability was chosen to the investigations.

The movement of the header in all three dimensions is fully controlled by the microcontroller. The microcontroller also controls settings and readings of used precision multimeter. Used 16-bit commercial microcontroller Freescale NE64 with embedded MAC+PHY layer can be connected to standard Ethernet network. The microcontroller sends measuring data to computers via UDP protocol. The hosts that collect measured data (PCs) work independently and can be replaced in any time. The data can be collected by any host connected to the same local network as the system. Hosts do not have to be in the same place as the system. Remotely controlled system makes control stand more flexible. The view of the control stand is presented in fig 3b. The NE64 microcontroller is commonly used in the authors' measuring systems [5-8].

The resolution of used precision multimeter is 6,5 digits (10 μΩ). According to the documentation delivered by the producer the accuracy of used multimeter is ± 0,3 mΩ. The accuracy depends on temperature of measurement, the time that expired from calibration, range and value of measured resistance. In case of measurements of resistance changes standard deviation of measurements (repeatability) is more important parameter than the accuracy. In purpose To evaluate the standard deviation 100 measurements of the same resistor were performed using elaborated control stand. The standard deviation calculated at the basis of 100 measurements was about 0,01 mΩ. The preliminary analyses indicate that control stand could be adequate stand for measuring low-level resistance changes of solder joints after aging process. The analysis of variance (Anova) was calculated to confirm the assessment and evaluate the stability of tested solder joints.

4. RESULTS AND ANALYSIS OF VARIANCE (ANOVA)

Firstly it should be determined how the resistance of the resistors changes during the aging processes. A group of 15 resistors (not soldered) was divided into three groups. The first group was measured after the reflow process, the second one was measured after one aging process and the third one was measures after two aging processes. The resistance of each one of 15 resistors was measured 72 times. Results obtained during the measurements were used in the one-way Anova analysis. There is only one controlled parameter in this experimental situation. The A factor is an aging process A1- after reflow process for 0 h at 150 ºC, A2- after first aging process for 300 h at 150 ºC, A3- after second aging process for 600 h at 150 ºC). The summary of the one-way Anova results is shown in table 1.

Table 1. Results of Anova calculated for not soldered resistors

	SS Sum of squares	ν Degrees of freedom	V Variance	F F ratio	SS' Expected SS due to factor	P Percent contribution
A (factor)	1,73E-007	2	8,65E-008	0,17	-8,31E-007	-13
e (error)	6,03E-006	12	5,02E-007		7,03E-006	113
T (total)	6,20E-006	14	5,89E-007			100
e*pooled	6,20E-006	14	5,89E-007		6,20E-006	100

The results of Anova indicate that heating process (A factor) has no effect on the resistance changes of evaluated resistors. The percent contribution (P) due to error is much higher than 50 % that means that some important factors were omitted from the experiments, the conditions were not precisely controlled or the measurement error was excessive [9]. The Percent contribution due to factor A is less than 0, that means that the sum of squares due to the factor A is much less than to error. The analyzes of the measurements confirmed results of the Anova. The standard deviation of the resistance calculated for tested resistors was more significant than the changes of their resistance after the aging processes. No significant change of the resistors resistance after aging processes was detected.

The next step was determination how resistance of solder joints changes after aging processes. Each of three test boards was subjected to the measurement procedure three times (after the reflow process, after the first aging process and after the second aging process). The resistance of each test specimen (soldered resistor) was measured nine times during each procedure. On the basis of first measurements results (before the aging processes) three resistors of each test board were chosen for further analysis. In order to to avoid incorrect conclusions, the choice was not accidental. The resistors were chosen and separated in respect to the least standard deviation of measured resistance. The resistors were finally divided into three groups (each group included three resistors) to simplify the Anova analysis.

The summary of the two-way Anova results is shown in table 2, 3 and 4. There are two controlled parameters in this experimental situation. The A factor is a resistor, while the B factor is an aging process. Both A and B are 3-level factors (A1 – resistor soldered on the first test PCB, A2 – resistor soldered on the second test PCB, A3 – resistor soldered on the third test PCB, B1- after reflow process for 0 h at 150 ºC, B2- after one aging process for 300 h at 150 ºC, B3- after two aging processes for 600 h at 150 ºC, A x B – correlation between factors).

Table 2. Results of Anova calculated for the first group of resistors

	SS	v	V	F	SS'	P
A* **	2,28E-007	2	1,14E-007	44,51	2,23E-007	7
B* **	**2,58E-006**	**2**	**1,29E-006**	**503,21**	**2,58E-006**	**83**
AxB* **	1,11E-007	4	2,78E-008	10,82	1,01E-007	3
e	1,85E-007	72	2,56E-009		2,05E-007	7
T	3,10E-006	80				100
e*pooled	5,24E-007	78	1,44E-007		5,29E-007	17

***at least 99 % confidence **bolded-significant factors**

Table 3. Results of Anova calculated for the second group of resistors

	SS	v	V	F	SS'	P
A* **	1,79E-007	2	8,94E-008	35,94	1,74E-007	6
B* **	**2,40E-006**	**2**	**1,20E-006**	**483,42**	**2,40E-006**	**82**
AxB* **	1,50E-007	4	3,75E-008	15,06	1,40E-007	5
e	1,79E-007	72	2,49E-009		1,99E-007	7
T	2,91E-006	80				100
e*pooled	5,08E-007	78	1,29E-007		5,13E-007	17

***at least 99 % confidence **bolded-significant factors**

Table 4. Results of Anova calculated for the third group of resistors

	SS	v	V	F	SS'	P
A* **	1,31E-006	2	6,53E-007	151,82	1,30E-006	26
B* **	**3,35E-006**	**2**	**1,67E-006**	**389,61**	**3,34E-006**	**67**
AxB* **	5,33E-008	4	1,33E-008	3,10	3,61E-008	1
e	3,10E-007	72	4,30E-009		3,44E-007	7
T	5,02E-006	80				100
e*pooled	3,63E-007	76	1,76E-008			8

***at least 99 % confidence **bolded-significant factors**

The results of Anova indicate that the aging process (factor B) has significant effect on the resistance changes of evaluated test specimens. Percent contribution (P) indicates the relative power of a factor to reduce variation. The Percent contribution indicates that the aging process contributes the most toward the variation observed in the experiment. The percent contribution varies between 67 and 83%. In each case the percent contribution due to error is low, less than 15% (when pooled increased to 17), it is assumed that no important factors were omitted from the experiment [9]. The graphs of measured resistance as a function of the factor level and the aging time is presented in fig. 4. As presented measured resistance changes after aging process.

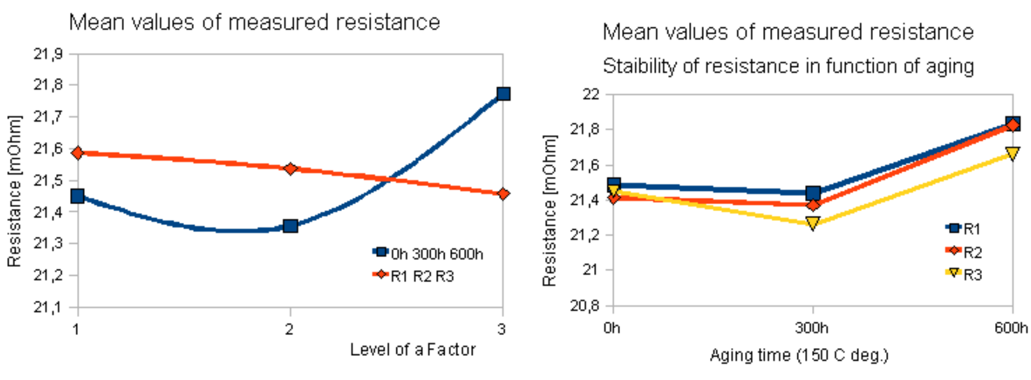

Figure 4. Mean value of measured resistance as function of a factor level and aging time (table 2.)

5. CONCLUSIONS

The presented evaluations are the part of the author's wide study connected with the reliability of solder joints. Within his study author compares many solder pastes and pad coatings looking for the most reliable configuration. To compare the configurations and detect resistance changes influenced by various factors, dedicated control stand was developed. Within the paper construction with the test procedure of the control stand, and the results of performed evaluations were presented. Very flexible method of solder joint resistance evaluation is investigation of soldered SMD 0 Ohm resistors. Nevertheless separation of single solder joint from other serial resistances (resistance of pads, resistor, metallization etc.) and measurements of low level resistance changes offered the most difficulties within this evaluations. To reduce influence of serial resistance, the design of the PCBs provided usage of 4-probe method to measure resistance. In purpose to confirm if the resistance of the solder joints changes after the aging process and if developed control stand is able to detect such low changes, the experiment was designed and the results were analysed using analysis of variance (Anova).

In purpose to ensure a lot of repeatable measuring data the control stand was designed as a fully automatic stand, controlled by the microcontroller. Precise movement of the measuring header with dedicated gold plated pins ensured high repeatability, while the precise multimeter ensured high accuracy of measurements. As occurred during preliminary tests the standard deviation of 100 measurements (the same resistor) was much less than accuracy of the multimeter. In this study (detection of resistance changes) standard deviation is more important parameter than accuracy.

In order to be sure that measured changes of the resistance are connected with changes of the solder joint, the stability of the resistors was tested. The resistors were subjected to the aging process and their resistance was measured using control stand. As occurred after one-way Anova calculations the resistance of the resistors did not change after the aging processes significantly. Moreover gold plated pads are rather resistant to such aging process.

The test boards were subjected to the aging processes. The multiple measurements of the resistance were performed after each aging process. The results of two-way Anova calculated independently for three groups of the resistors, indicate that the detected resistance changes were caused by the aging. Moreover, low level of percent contribution due to error indicates that no important factors were omitted in the experiment.

Taking into account the accuracy and repeatability of the control stand, usage of 4-probe method and the fact that the resistance of the resistors did not changed significantly, it can be said that the developed control stand is able to detect low level changes of solder joint resistance caused by aging processes. The system can be used to evaluation of solder joint stability. The thesis was confirmed experimentally. To explain detected changes of solder joints resistance, following evaluations are required (scanning electron microscopy and X-ray fluorescence analysis of cross-sections). Although detected changes, tested configuration (SAC-Au/Ni) can be treated as stable after 600 h, but the diagrams suggest that after next aging processes, the resistance would probably increase. Also in this case following evaluations are advisable.

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