THE SIR RELIABILITY OF FINE PITCH QFN COMPONENTS UNDER HARSH TEST CONDITION

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ABSTRACT

In the past decade, Quad Flatpack No Lead (QFN) components were widely used in a variety of electronic products and their long term reliability was highly concerned by the industry.

Compared with other package type components, such as Quad Flat Pack (QFP), the solder joints of QFN are under its body, and the standoff between component and Printed Circuit Board (PCB) is very low, and it will hinder the escape of solder paste flux at reflow stage. After reflow process, evaporation of ingredients of flux is not fully completed and the flux residue underneath QFNs, especially for large size ones, is always "gooey", and the stage of this flux residue is quite different from that reflowed in open air, whose Surface Insulation Resistance (SIR) reliability is usually evaluated according to IPC standard.

In this paper, the factors that affect SIR reliability of "gooey" flux residue underneath QFNs will be discussed. A variety of dummy QFNs that made of PCBs are assembled on PCBs whose surface finish is OSP by reflow in air, then they are tested under 5V bias voltage and 85℃, 85%RH test condition for 168 hours. After the test, the dendrites of tested QFNs are checked and measured by X-ray. Further, two solder paste fluxes from different vendors are chosen, their SIR performances of "gooey" flux residue and the properties that may affect their SIR performances are studied.

Key words: QFN, "gooey" flux residue, SIR, dendrites

INTRODUCTION

In the past decade, the increased use of QFN (Quad Flatpack No Lead) package components, also named as MLF (micro-lead frame)/BTC (bottom termination component), had been driven by their application in consumer products with the drive to miniaturization and lower costs [1].

Compared with other package type components, all the solder pads, with no solder spheres, of QFN are totally rowed underneath component body. For some QFNs, there is a large soldering ground pad on center, as shown in Figure 1.

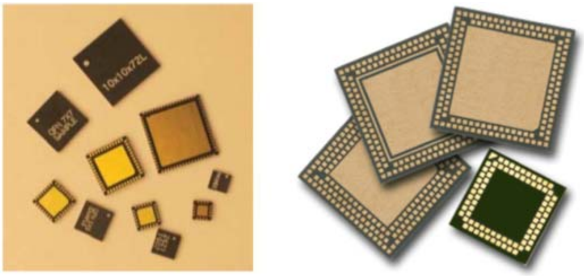


Figure 1. Common single and multi-row QFN components [1]

For its special package designs, according to long term application experiences of industry, the main issues of QFN component are [1]:

1. For the QFNs with a center ground pad, a large volume of solder paste is printed. When soldering, the solder paste is 100% covered by component body. The volatiles of flux cannot escape easily and will be trapped in molten solder, so oversize voids in the center ground pad, which may affect thermal transmit and reliability, could be a concern.

2. For the peripheral functional pads, always fine pitch and without solder balls, the standoff of solder joints is quite low, which fully depends on the volume of solder paste printed by the stencil for QFN. The low standoff will reduce the thermal cycling reliability of the QFN.

3. For the sake of low standoff, the cleaning ability of flux residue under QFN, if needed, may be also a concern, especially when using water-based cleaners.

However, in terms of flux residue underneath QFN, the researches on its SIR reliability are very little. Because the escape of volatiles in flux is greatly hindered by QFN component body, the flux residue always shows as "gooey" state. It is very different from the one reflowed in open air, which is always dry and hard.

Obviously, now widely used IPC-TM-650 method 2.6.3.7 and corresponding IPC-B-24 test vehicle which are designed to test SIR reliability of flux residue reflowed in open air do not fully apply to the "gooey" one.

Until now, there is no standard test method and corresponding vehicle for "gooey" flux residue. In order to evaluate its reliability, one idea is to design a new test structure according to QFN layout [2]. The other is to print paste flux, instead of solder paste, on IPC-B-24 coupons and then it is reflowed when covered with glass slides[3][4].

In this paper, first, the designing factors that may affect SIR reliability of QFN were studied under the test condition of 85□ and 85% RH by the specially designed test vehicle and dummy components. Second, the SIR of the "gooey" flux residues made from paste flux A and B were also tested under the same test condition. The "gooey" flux residue was made by printing paste flux on IPC-B-24 SIR boards and then placing glass slides on the boards when reflow. Final, the properties that may affect the SIR performances of these paste fluxes were studied.

EXPERIMENT PROCEDURE

Reliability Test of QFNs

Among all the QFN package components, single and dual row QFNs are the most common and widespread used ones. The positions which have ion migration risk are where the "gooey" flux residue may exist.

For single row QFNs, the "gooey" flux residue may exist at:
1. The airgaps between Outer Functional Pads (OFPs) or
2. The airgaps between Outer Functional Pads (OFPs) and Central Ground Pad (CGP)

A sketch map that shows where these airgaps are for single row QFNs is shown in Figure 2.

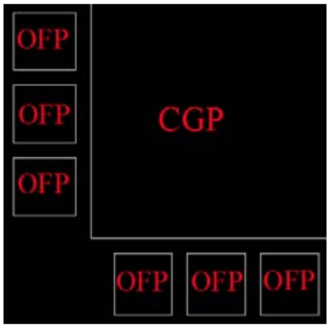


Figure 2. Sketch map of airgap locations for single row QFNs

However, for dual row QFNs, it will be more complicated and the "gooey" flux residue may exist at:
1. The airgaps between Outer Functional Pads (OFPs) or
2. The airgaps between Outer and Inner Functional Pads (IFPs) or
3. The airgaps between Inner Functional Pads (IFPs) or
4. The airgaps between Inner Functional Pads (IFPs) and Central Ground Pad (CGP)

A sketch map that shows where these airgaps are for dual row QFNs is shown in Figure 3.

In this test, in order to evaluate the ion migration risk of these positions where the "gooey" flux residue may exist, various dummy single and dual row QFN components with different factor levels were designed, according to their developing trends and real applications. The design factor levels of these dummy components were shown in Table1-5.

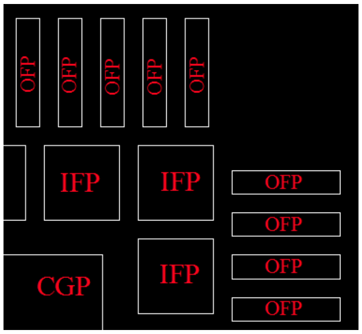


Figure 3. Sketch map of airgap locations for dual row QFNs

Because the OFPs are very similar for single and dual row QFNs, it is not necessary to repeatedly test the ion migration risk for both components. In this test, it was only tested by single row QFNs.

Table 1. Components for evaluating risk of OFPs

Components	Design Parameters	Design factor levels			
Single Row QFNs	Component size	15*15mm		15*15mm	
	OFPs size	**51*18mil**		**32*30mil**	
	airgap of OFPs	**8mil**	**10mil**	**8mil**	**10mil**
	airgap of OFPs&CGP	6mil	6mil	6mil	6mil

Table 2. Components for evaluating risk of OFPs&CGP

Components	Design Parameters	Design factor levels			
Single Row QFNs	Component size	15*15mm		15*15mm	
	OFPs size	**51*18mil**	**51*18mil**	**32*30mil**	**32*30mil**
	airgap of OFPs	8mil	8mil	10mil	10mil
	airgap of OFPs&CGP	**6mil**	**10mil**	**6mil**	**10mil**

Table 3. Components for evaluating risk of OFPs&IFPs

Components	Design Parameters	Design factor levels			
Dual Row QFNs	Component size	15*15mm		15*15mm	
	OFPs size	**46*10mil**	**46*10mil**	**24*10mil**	**24*10mil**
	airgap of OFPs	8mil	8mil	8mil	8mil
	airgap of OFPs&IFPs	**8mil**	**10mil**	**8mil**	**10mil**
	IFPs size	32*32mil	32*32mil	32*32mil	32*32mil
	airgap of IFPs	8mil	8mil	8mil	8mil
	airgap of IFPs&CGP	15mil	15mil	15mil	15mil

Table 4. Components for evaluating risk of IFPs

Components	Design Parameters	Design factor levels			
Dual Row QFNs	Component size	15*15mm		15*15mm	
	OFPs size	46*10mil	46*10mil	46*10mil	46*10mil
	airgap of OFPs	8mil	8mil	8mil	8mil
	airgap of OFPs&IFPs	8mil	8mil	8mil	8mil
	IFPs size	**32*32mil**	**32*32mil**	**20*20mil**	**20*20mil**
	airgap of IFPs	**8mil**	**10mil**	**8mil**	**10mil**
	airgap of IFPs&CGP	15mil	15mil	15mil	15mil

Table 5. Components for evaluating risk of IFPs& CGP

Components	Design Parameters	Design factor levels			
Dual Row QFNs	Component size	15*15mm		15*15mm	
	OFPs size	46*10mil	46*10mil	46*10mil	46*10mil
	airgap of OFPs	8mil	8mil	8mil	8mil
	airgap of OFPs&IFPs	8mil	8mil	8mil	8mil
	IFPs size	**32*32mil**	**32*32mil**	**20*20mil**	**20*20mil**
	airgap of IFPs	8mil	8mil	8mil	8mil
	airgap of IFPs&CGP	**15mil**	**18mil**	**15mil**	**18mil**

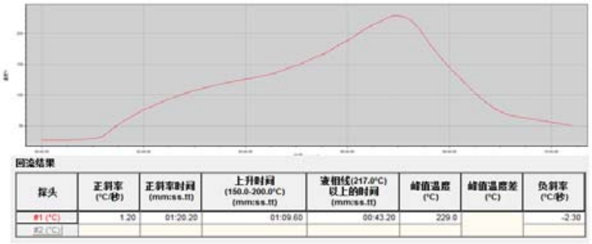
As the dummy QFNs mentioned above could not be obtained from open market, and they had to be made in the form of PCB panelizations, whose surface finish were Electroless Nickel Gold (ENIG), and thickness were 0.079 inches, and then the PCBs were divided through the milling cutter. It needs to be note that for the convenience of PCB manufacturing, the length of OFPs for all the QFNs is shorter than design value 8mils, but this will not affect horizontally comparing results and final conclusions.

The printed circuit board test vehicle which the dummy QFNs would be assembled on, is an 4 layer board with dimensions 11.7 inches x 10.9 inches x 0.079 inches, and the surface finish was organic solderability preservative (OSP). Independent traces, which were used to apply voltage bias during test, were designed to link to each component site on the board.

The PCB laminate for both dummy components and test vehicle was FR4 with middle glass transition temperature (Tg) of 150°C.

Solder paste A with SAC305 alloy was selected and all the boards were pasted by a 0.12mm thick stainless stencil. The apertures of the stencil for both OFPs (design value) and IFPs of all the components was 1:1 but 70% for CGPs.

When reflow, the temperature underneath components is measured by locating the measuring thermocouple on the center of CGP through the drilled hole of PCB bottom, and then the boards were assembled with reflow profile developed to close to the lower limit of reflow window (230℃) , as shown in Figure 4.


回流结果

探头	正斜率 (°C/秒)	正斜率时间 (mm:ss.ff)	上升时间 (150.0-200.0°C) (mm:ss.ff)	液相线(217.0°C)以上的时间 (mm:ss.ff)	峰值温度 (°C)	峰值温度差 (°C)	负斜率 (°C/秒)
#1 (°C)	1.20	01:20.20	01:09.60	00:43.20	229.0		-2.30
#2 (°C)							

Figure 4. Reflow profile of dummy QFNs

The outline of assembled boards was shown in Figure 5.


Figure 5. Outline of assembled boards

All the boards were putted into the 85 ℃, 85%RH environmental chamber. After the environment was stable, the 5V bias voltage was applied and it lasted for 168 hours. In the end, the dendrites (Figure 6) of all the tested components were checked and measured by X-ray, the length of the longest dendrite for each components was recorded according to the following 6 levels as shown in Table 6.

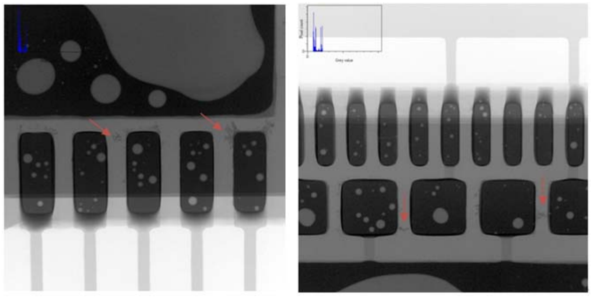


Figure 6. Dendrites morphology underneath QFNs, a) single row QFN; b) dual row QFN

Table 6. Dendrites recorded levels

Level No.	Length Range
0	100%
1	75-100%
2	50-75%
3	25-50%
4	0-25%
5	0%

SIR Test of "gooey" Flux Residue

For the purpose of investigating the effect of different solder paste formulations on SIR of "gooey" flux residue, solder pastes with SAC305 alloy named A and B, from two different vendors, that have passed IPC standard SIR test were chosen. For the convenience of printing enough flux without bridging after reflow, paste fluxes rather than solder pastes were used. The samples of "gooey" flux residue were prepared by the following steps:

1. Printed the two paste fluxes on the standard IPC-B-24 SIR boards, the thickness of stencil was 0.12mm and the apertures ratio was 1:1 compared with the lines of comb patterns.
2. Put a piece of glass slide that its size was 29*16*2mm on the center of comb pattern on which paste flux had been printed.
3. It should avoid the movements of glass slides through fixing it with Kapton tapes when reflow. The reflow profile is shown in Figure 7. For the SIR boards, the temperature of the comb patterns with glass slides could reach the peak temperature of 242.5 ℃ , while the temperature of the comb patterns without glass slides could reach the peak temperature of 252.2℃.

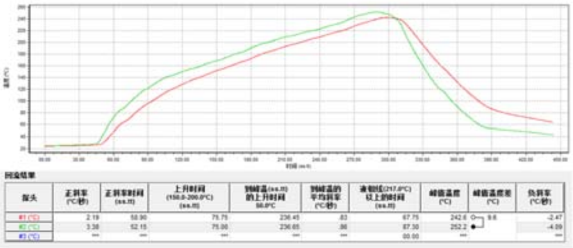


Figure 7. Reflow profile of SIR covered by glass slides

After reflow, all the samples were horizontally put into the chamber set at 85℃, 85%RH. As environment was stable, the SIR was tested for 168 hours by 12.5V bias and measurement voltage. During testing, the resistance and electrical shorting were regularly monitored by Ion Migration Evaluation System. At last, without moving glass slides, all the tested samples were checked by a optical microscope after SIR test.

Solder Paste Flux Properties Analysis

The same paste fluxes as above, A and B, were chosen. By following the same procedures above, the "gooey" flux residues were made at the reflow peak temperature of 240 ℃.

First, the standard testing solvent was made by putting 0.01g new paste flux or "gooey" flux residue individually into 20ml alcohol and solving for 24 hours, and then the conductivities of these standard solvents were tested respectively by a Conductivity Measurement Instrument.

Second, the change in compositions for paste flux A and B, when reflow at 240℃, was analyzed by In-situ FTIR. The paste flux was put on the salt pad in a heater and then the temperature was set to 240℃ and held for 10 minutes. When testing, the sensitivity of FTIR was 4cm-1.

RESULTS AND DISUSSION

Reliability Test of QFNs

After reflow, the flux residue state must be checked by pulling out the dummy components that have been mounted on test vehicles. As shown in Figure 8, the "gooey" flux residue does exist at the airgaps of components.

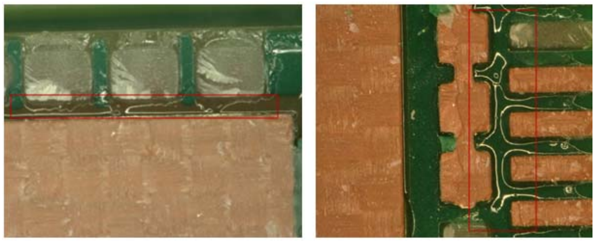


Figure 8. "Gooey" flux residue underneath QFNs, a) single row QFN; b) dual row QFN

After 85□, 85RH% test for 168 hours, the test results of single and dual row QFNs are as shown in Figure 9-13. For all the groups, two results of dendrites are shown in these figures, one is length distribution of dendrites, and the other is cumulative percent of all recorded level. Because the longer dendrites are more concerned, all the results as below are analyzed in descending order. In all the figure legends, the descriptions of the dimensions are listed in Table 7.

Table 7. Descriptions of the dimensions in the figure legends

Figure No.	Dimensions	Descriptions
Figure 9	51*18mil or 32*30mil	sizes of OFPs
	8mil or 10mil	airgaps between OFPs
Figure 10	51*18mil or 32*30mil	sizes of OFPs
	6mil or 10mil	airgaps between OFPs & CGP
Figure 11	46*10mil or 24*10mil	sizes of OFPs
	8mil or 10mil	airgaps between OFPs & IFPs
Figure 12	32*32mil or 20*20mil	sizes of IFPs
	8mil or 10mil	airgaps between IFPs
Figure 13	32*32mil or 20*20mil	sizes of IFPs
	15mil or 18mil	airgaps between IFPs & CGP

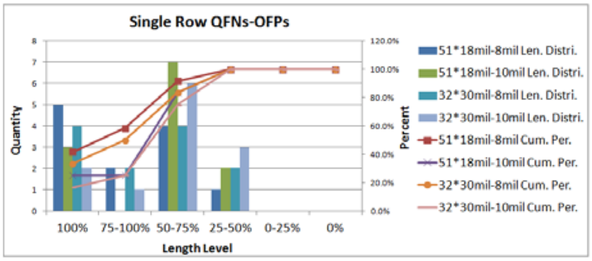


Figure 9. Test results of OFPs for sing row QFNs

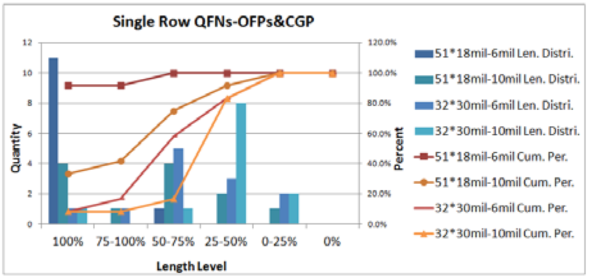


Figure 10. Test results of OFPs&CGP for sing row QFNs

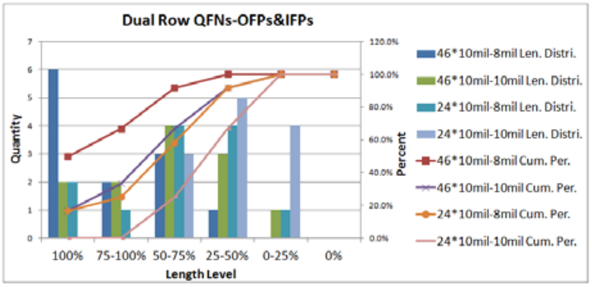


Figure 11. Test results of OFPs&IFPs for dual row QFNs

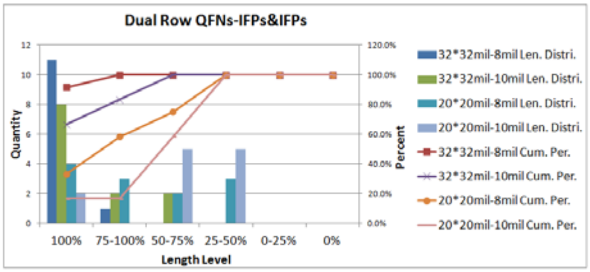


Figure 12. Test results of IFPs&IFPs for dual row QFNs

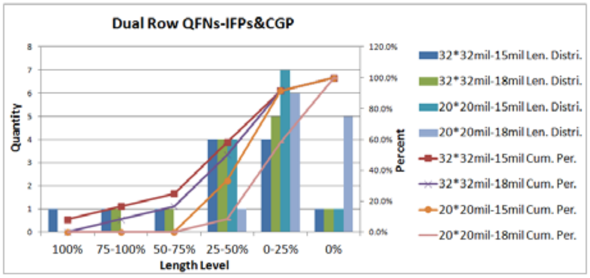


Figure 13. Test results of IFPs&CGP for dual row QFNs

Under the harsh test condition (85□, 85% RH), all the groups in this test, whether single or dual row QFNs, have the risk of ion migration. In general speaking, both the airgap and size of functional pads have the effect on dendrites growth. However, according to the results above, they are not exactly the same. Obviously, the factor of functional pads size is the major one when comparing with corresponding airgap between OFPs or OFPs & CGP or OFPs & IFPs or IFPs or IFPs & CGP. Because the aperture of the stencil for both OFPs and IFPs is 1:1, it is easy to understand that the size of functional pads is equal to printed solder paste volume. In addition, when the reflow profile is fixed, the more solder paste volume there is, the more "gooey" flux residue after reflow process. As to the airgap, when the corresponding functional pads are the same, the smaller the airgap, the more seriously the dendrites grow.

Finally, based on the above conclusions, for the sake of reducing ion migration risk of QFNs, first, when the pads are designed, the size of functional pads and corresponding airgaps between functional pads or functional pads and CGP should be optimized in advance; second, when reflow, under the premise of ensuring assembly quality and solder joint reliability, the apertures of stencil and reflow profile should also be optimized in order to reduce the "gooey" flux residue as less as possible.

SIR Test of "gooey" Flux Residue

The monitored results of resistance for paste flux A and B are shown in Figure 14-15. The resistance of both paste fluxes is lower than the baseline of IPC standard, 100M ohm, however, the resistance of paste flux B is 1-2 orders of magnitude higher than paste flux A. After168 hours, when the test is finished, for paste flux A, only 2/12 of the samples have passed this test, but for paste flux B, except for one abnormal comb pattern (paste flux B-5), 9/11 of the samples have passed it, obviously their SIR performances are consistent with the corresponding resistance at the beginning.

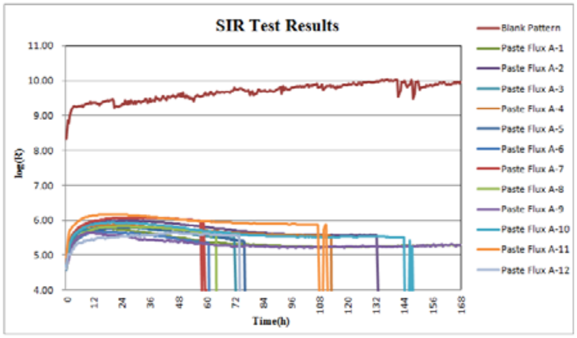


Figure 14. SIR test results of "gooey" flux residue for paste flux A

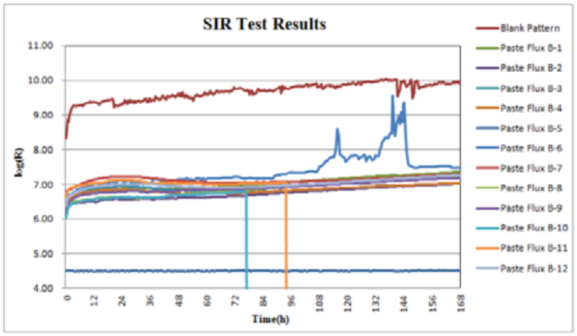


Figure 15. SIR test results of "gooey" flux residue for paste flux B

At last, all the tested samples of both paste flux A and B are checked by optical microscope, it is clearly seen that there are a lot of dendrites for the failed samples, and their features are consistent with ion migration failure mode, as shown in Figure 16.

In summary, using the test method above which is not fully mature, the SIR test results of "gooey" flux residue are much different between Paste Flux A and B, even though both of them have passed IPC standard SIR test.

Figure 16. Dendrites morphology after SIR test

Solder Paste Flux Properties Analysis
The conductivity test results are shown in Figure 17.

Whether for new paste fluxes or "gooey" flux residues, obviously, the conductivity of A is higher than B. it is well known that the conductivity is the reciprocal of resistance, so the conductivity order of paste fluxes or "gooey" flux residues is very consistent with the order of the initial resistance tested in SIR of "gooey" flux residues. This means the conductivity of paste fluxes or "gooey" flux residues is strongly related to SIR results, and conductivity test may be a quick method to evaluate SIR results of "gooey" flux residues.

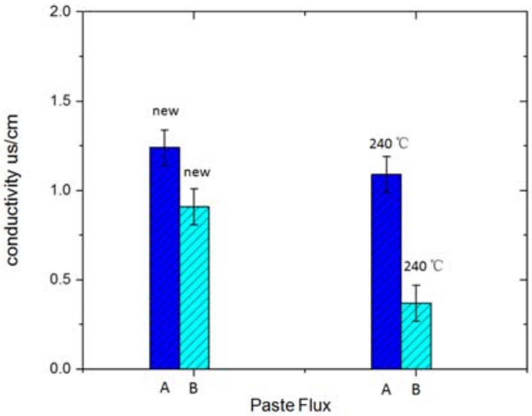


Figure 17. Conductivity of paste flux in different status

It is also well known that the carboxylic acids are always as the activators, and various ethers are always as the solvents in solder paste flux [5]. On a typical FTIR curve (Figure 18), the carboxylic acid is represented by the peak 3500cm-1 which is the absorbance peak of v(-OH), and the ether solvent is represented by the peak 1100cm-1 which is the absorbance peak of v(C-O-C).

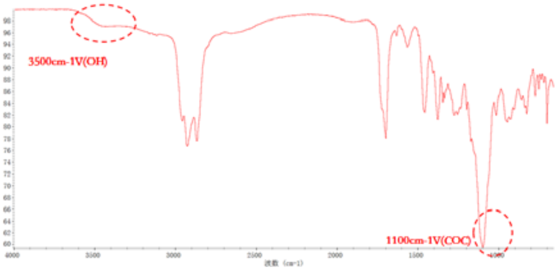


Figure 18. Absorbance peak of v (-OH) and v(C-O-C) on a typical FTIR curve

After the new paste fluxes are tested at 240℃ for 10 minutes, the changes in amount of activators in fluxes are shown in Figure 19. It is seen that the content of activators in flux A is always higher than in flux B, which is reflected by the absorbance value. According to the experience in industry, excessive amount of activator in flux residue will lower its resistance and increase the risk of ion migration.

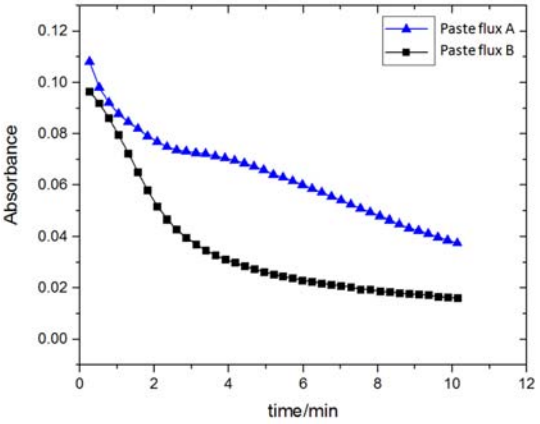


Figure 19. Changes in amount of activators when mimicking reflow at 240℃ for 10 minutes by In-suit FTIR

As to the content of ethers in flux residue, the similar regularity is not found, however, as long as the solvent exist, when there is a bias voltage, the ions in “gooey” flux residue will move more easily than in hard and dry flux residue. Further, these ethers, which are strong polar, will prefer to absorb moisture when tested in high humidity environment. For “gooey” flux residue, this will aggravate the corrosion and the risk of ion migration.

CONCLUSIONS

Under extreme design levels and harsh test condition, the SIR reliability issue of QFNs should be concerned. In order to avoid the failure of QFNs when they are used, the full cooperation in industry is needed.

When a QFN component is designed, if the pads always have bias voltage when the component is in normal operation, the size of these pads should be as small as possible while the airgap should be as big as possible.

When a QFN component is assembled on PCB, under the premise of ensuring assembly quality and solder joint reliability, the “gooey” flux residue between the pads those always have bias voltage should be reduced as less as possible by properly optimizing the apertures of stencil and reflow profile.

In addition, before a QFN is assembled on PCB, a solder paste that has better SIR reliability of “gooey” flux residue should be chosen. Of course, the premise is to establish a standard method and corresponding test vehicle that could effectively evaluate the SIR reliability of “gooey” flux residue, such as IPC-TM-650 method 2.6.3.7 and IPC-B-24 test vehicle for dry flux residue. In this test, a test method is optimized but it is not fully mature yet and should be optimized further.

As to the paste flux itself, the SIR reliability of “gooey” flux residue may be related to its conductivity and the content of activators after reflow.

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