Investigation of the influence of electrochemical migration (ECM) on the reliability of electronic assemblies after rework using lead-free solders and No-Clean flux mixtures

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Abstract

In the IGF-research project 17960N “Investigation of the influence of electrochemical migration (ECM) on the reliability of electronic assemblies after rework using lead-free solders and No-clean flux mixtures” the reliability of flux mixtures using different materials in inline assembling and rework has been systematically studied.

A zero defect production is still not fully realized in manufacturing of electronic assemblies, despite all efforts. Necessary rework and repair are often performed with other fluxes than used in inline reflow or wave soldering processes. They can be mixed and react with each other. Especially, if the used flux doesn’t reach soldering peak temperature or if excess flux amount remains on the assembly after soldering, a great danger of ECM is given in particular under the influence of moisture.

Using different No-clean flux materials and No-clean solder pastes for lead free application a variation of processing parameters (e.g. time, temperature) was performed. The combination of inline reflow soldering with wave soldering, selective wave soldering, manual iron soldering and rework soldering was studied with Surface Insulation Resistance (SIR) Test. Electrochemical impedance spectroscopy and electrochemical noise measurements has been performed accompanying.

Results show that if the flux doesn’t reach the soldering temperature especially in combination with flux type L1 or M1 the danger of ECM rises. These results will help assembly manufacturers to assess their production process regarding possible danger of ECM. A recommendation for a preparation procedure of SIR Test patterns to be implemented in DIN EN standards should be worked out.

Keywords:
Electrochemical Migration (ECM), Surface Insulation Resistance (SIR), Electrochemical Noise Analysis (ENA), Rework, Flux Mixtures
Introduction
A zero defect production is still not fully realized in manufacturing of electronic assemblies, despite all efforts. Necessary rework and repair are often performed with other fluxes than used in inline reflow or wave soldering processes. They can be mixed and react with each other. Especially, if the used flux doesn’t reach soldering peak temperature or if excess flux amount remains on the assembly after soldering, a great danger of electrochemical migration (ECM) [1] is given in particular under the influence of moisture.

A rework soldering process is a selective heating of the assembly in general. Only at the solder joint, the assembly must achieve the required solder joint temperature for solder joint formation. Adjacent areas on the assembly remain cold or only reach a maximum temperature notably below the soldering temperature. The introduced soldering heat may not be enough to consume the flux used in a rework process. Undefined, but often harmful residues may remain on the board.

Task
The effect of such flux mixtures on the board reliability has been systematically studied using different materials in inline assembly and rework. The project was funded in the frame of the industrial collaborative research (IGF) research project 17960N “Investigation of the influence of electrochemical migration (ECM) on the reliability of electronic assemblies after rework using lead-free solders and No-clean flux mixtures”.

With the aim to receive additional resp. earlier relevant results, the Surface Insulation Resistance (SIR) Test was supplemented with electrochemical methods as the corrosion process is of electrochemical nature. Here two methods have been investigated to evaluate their additional information content, the high ohmic impedance spectroscopy (EIS) and the electrochemical noise analysis (ENA).

Understanding how a flux works
Depending on the composition, a flux has a defined process window in which the soldering must take place (Figure 1). There is a predetermined temperature time range in which the flux is active. Only above the lower activation temperature the flux unfolds its effect; if the upper active temperature is exceeded, decomposition of the flux begins. If the soldering process is too short, no activation takes place. If the soldering process takes too long, the active ingredients of the flux are consumed before surface wetting has taken place.

![Figure 1: Solder process window of flux [2]](image-url)
Implementation

Using different No-clean flux types (L0, L1 and M1) for lead free application and No-clean SAC-solder pastes with flux type L0, a variation of processing parameters (e.g. time, temperature) was performed. The combination of inline reflow soldering with wave soldering, selective wave soldering, manual iron soldering and rework soldering was studied with SIR test.

For inline convection soldering, the process profile setting was located in the center of the data sheet settings which corresponds to the typical application in assembling with a maximum soldering temperature of about 245 °C.

With the wave soldering two conditions were studied. First, the usual process, passing through the solder wave with a temperature-time curve as it corresponds to a typical SAC soldering process (Figure 2). The second wave soldering condition corresponds to flux which has flown on top of the board as it occurs possibly during flux application, spraying flux through a hole in the PCB. This flux has no further wave contact and will not be hotter than a maximum temperature of about 150 °C (Figure 3).

![Figure 2: Typical wave soldering profile; max. temperature: PCB Bottom 216 °C, PCB Top 171 °C](image1)

![Figure 3: Incomplete wave soldering profile; max. temperature: PCB Bottom 153 °C, PCB Top 142 °C](image2)
For the selective wave soldering process, two preheating conditions were studied that represent typical preheating profiles, but also a setting that represents a higher heat transfer. This might happen when soldering large thermal masses by selective wave.

The heat transfer during manual iron soldering should be carried out by the wetted solder. This process can only be simulated with very limited reproducibility when building SIR-Test boards. Variations in the temperature profile were not realized. Instead, the manual iron soldering process was modeled with a rework station using a bonding tool. Temperatures in the range of 100 °C to 250 °C in 50-degree increments has been applied on the test boards.

During rework, the heat input has been carried out with a 40 x 40 mm² large hot gas nozzle. In order to examine the influence of flux residues that are not exposed to the working temperature, soldering profiles with maximum temperatures of 150 °C, 215 °C and 230 °C have been applied.

**Evaluation and error condition**

The SIR Test is a method to characterize fluxes by determining the degradation of electrical insulation resistance of rigid printed wiring board specimens in the presence of moisture. The test is carried out according to IPC J-STD-004 (Surface Insulation Resistance, Fluxes) [3] on standardized comb test patterns according IPC-B-24 (Surface Insulation Resistance Test Board) [4], where an individual comb structure has defined lines and spacing. The samples run through a soldering process as previously described. Experimental conditions are 85% relative humidity and 85 °C temperature for 168 hours. A voltage of 100 V is applied to the comb structures and the resistance is measured in 20 minute intervals.

Each comb pattern on each test PCB has been evaluated by the insulation resistance values during the climate testing. If the readings at the end of the measurement period are less than 100 megohm (1E8 ohm), the test is evaluated as fail. All specimens have been examined optically within 24 hours of completing the testing. Visible discoloration, corrosion or dendritic growth, which will constitute a failure, have been reported.

**Results**

The inline convection reflow soldering appears uncritical (for the examined solder pastes) regarding ECM, as shown in Figure 4.

![SAC reflow profile no abnormalities](image1)

![SIR-Test Board 5](image2)

**Figure 4: Inline convection reflow soldering**

*Left: Visual inspection of test board, right: SIR measurement*
The combination of inline convection reflow soldering with nitrogen wave soldering appears uncritical for the investigated fluxes. If not fully implemented in the soldering process (low temperature, lack of wave contact, such as flux on the board top), wave solder fluxes show some corrosion potential (Figure 5) alone and in combination with solder pastes.

If inline convection reflow soldering is combined with selective wave soldering, the examined fluxes for selective wave soldering appear uncritical with respect to ECM, providing they have sufficient preheating. An examination of the residue by SIR test when used in critical (moisture) environment seems nevertheless useful because in individual cases the used process parameters (and flux) may differ from those which have been studied here.

In manual iron soldering process, soldering flux appears to be critical when flux is only exposed to a temperature of 100 °C or below. Using process temperatures between approx. 100 °C and 250 °C, fluxes are still potentially unsafe. Flux for manual soldering application requires a temperature of at least about 250 °C to pass the SIR test.

When combining inline convection reflow soldering with a rework process, some fluxes appear critical or at least noticeable when a maximum temperature of less than 230 °C is used. After qualified automatic cleaning, all fluxes in all the studied parameters and material variations passed the SIR test.

The electrochemical impedance spectroscopy EIS could not be verified to be a valuable tool to supplement the SIR-Test. It is too sensitive concerning variations of the flux layer whilst the growth of dendrites could not be identified clearly.

On the other hand, electrochemical noise analysis ENA showed promising results concerning the determination of the active corrosion condition. As ENA could be understood as a very close look (in terms of sampling rate and resolution) to the fluctuations of the current flow during test, it can be implemented quite easily in the test system.
Summary

- Flux types with activation higher than L0 are critical and the danger of ECM rises.
- Flux mixtures can lead to electrochemical corrosion, especially when the flux does not completely decompose through the soldering process.
- Manual soldering processes are considered as potentially critical regarding ECM, especially again in case of incomplete flux decomposition in the primary soldering process (for example, flux splashes or flux excess that run in gaps).
- The amount of the applied flux should be reduced to the minimum necessary; spreading beyond the soldering area should be prevented.
- The prescribed soldering temperatures (material data sheet) for the process must be respected.
- An individual qualification by SIR test under defined conditions is recommended for use in critical environments. In order to achieve satisfactory results, the material combination should be assessed with realistic production process parameters such as the amount of flux, flux mixture, coating method and soldering profile.
- Qualified cleaning processes can minimize the risk for ECM on electronic components.

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