RELIABILITY AT THE CORE OF PRODUCT DEVELOPMENT

THERMAL CYCLING ANALYSIS

C2MI

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INTRODUCTION

The purpose of this article is to highlight the importance of reliability testing for identifying weaknesses in a microelectronic component during its various development cycles. Emphasis will be placed on thermal cycling, which, combined with electrical readings and failure analyses, allows the detection of marginal parts and helps understand their failure modes. Based on this information, necessary modifications can be made to make the modules more robust.

LAB TEST: THERMAL CYCLING

Thermal cycling involves subjecting samples to a temperature change. The primary goal is to simulate the power-on and power-off cycles of various electronic systems. When the systems operate, the temperature rises, and when stopped, the component returns to ambient conditions. The objective is to simulate these changes in the laboratory but in an accelerated mode. Important parameters of thermal cycling include: thermal ramp rates, dwell times at extreme temperatures, and minimum and maximum temperatures.

The "ramps" refer to the rate of thermal transfer experienced by the component when transitioning from one extreme temperature to another. For example, a dual-compartment chamber uses an elevator system to transfer the parts being tested from a cold room to a hot room, allowing the modules to quickly reach the desired temperatures. In such cases, the thermal transfer is aggressive, and the term "thermal shock" is used. In contrast, the same temperatures can be reached using a single-compartment chamber. Unlike a double chamber, thermal transfer is much slower since the same chamber must be used to reach the extreme temperatures.

Generally, the term thermal cycling refers to single-chamber tests. Figures 1 and 2 illustrate the difference between these two types of chambers and the profiles obtained in each.

The "dwell time" represents the duration for which components are maintained at extreme temperatures. Typically, materials (especially solder) tend to stabilize (relax) over longer durations, making acceleration factors more significant.

The minimum and maximum temperatures represent the extreme temperatures to which the components are exposed. The greater the difference between the two, the more significant the acceleration factor.

Generally, thermal stresses occur in air, but they can also be done in a liquid to increase thermal transfer, resulting in a more intense thermal shock than in air.

It is crucial to identify stress conditions carefully and avoid overly aggressive conditions that create "artifacts," i.e., failures that are not representative of the product's actual application.

THERMAL SHOCK AND THERMAL CYCLING TEST

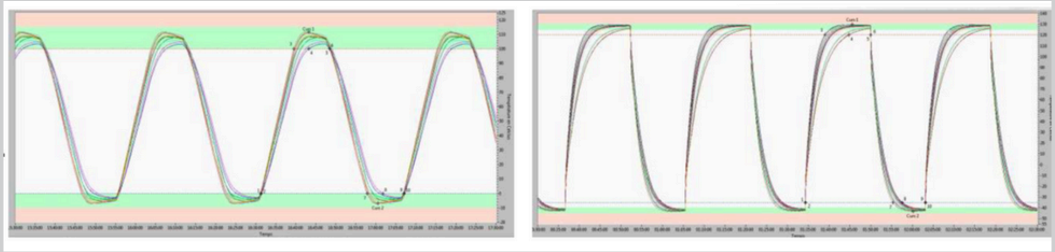
Double-compartment chamber

Single-compartment chamber

Figure 1 : Thermal shock and thermal cycling equipment - C2MI

Profile by type of equipment used

Temperature



Profile obtained in a single-compartment chamber

Time

Profile obtained in a double-compartment chamber

Figure 2 : Comparison between the profile otained in a single and double compartment - C2MI

Thermal Cycling Involves Thermal Expansion Phenomena of Various Materials "CTE Mismatch".

The differences between the coefficients of thermal expansion create stress that can lead primarily to delamination or cracking at the interfaces or directly in the materials. This type of defect is detected by an increase in electrical resistance. In Figure 3, it is possible to see that the solder joint must accommodate the difference in thermal expansion between the microchip and the substrate. With the increasing number of cycles, the solder joint deteriorates.

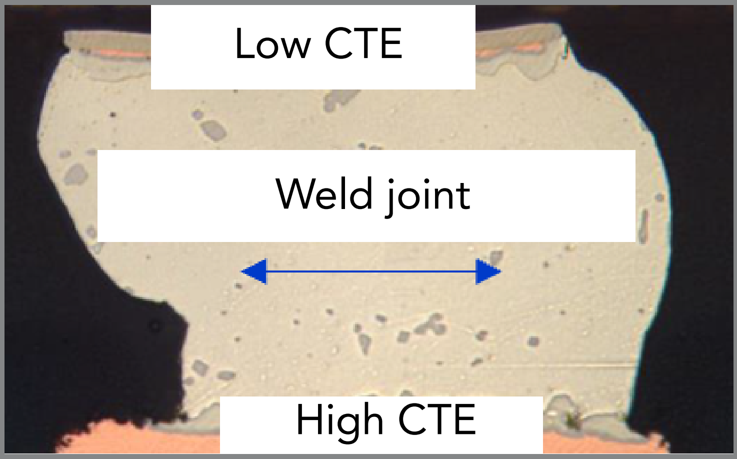


Figure 3: Diagram showing the movement of solder to accommodate the difference in thermal expansion coefficients - C2MI

Different types of modules, often microelectronic boards, can be subjected to stress. However, the key is to be able to take readings during or after the stress to detect potential damage. A "Test Vehicle or TV" allows the creation of electrical chains between the module's various components to link certain sections. This makes it easy to take an initial reading at T0 (before stress) and subsequent readings during stress. A variation in resistance is often the sign of early degradation.

Following the abnormal detection of electrical resistance, the module can be removed from the stress for failure analysis. C2Mi has several analytical techniques, including some commonly used ones: Acoustic Microscopy, Infrared Microscopy, X-Ray Microscopy, Scanning Electron Microscopy (SEM), Optical Microscopy, and Cross-Sectional Analysis.

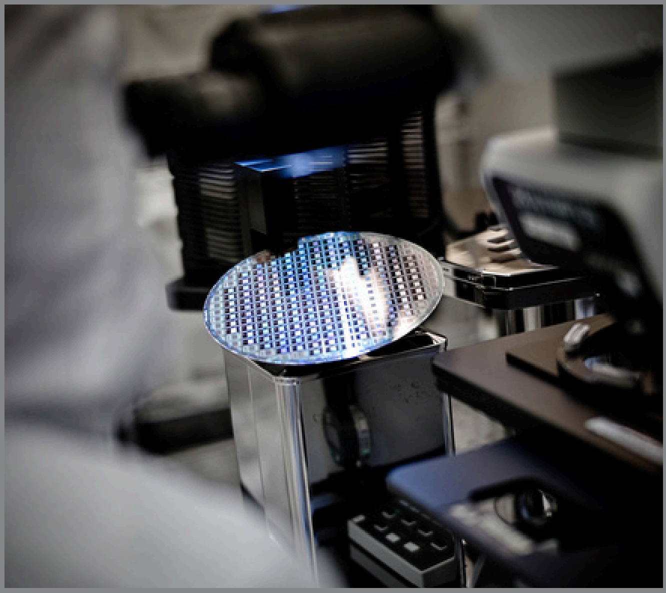
Scanning Acoustic Microscope – SAM): This technique involves sending a sound wave through a medium (usually water). Depending on the interfaces encountered by the wave, some of it is reflected while the rest is transmitted. The system processes these signals to visualize the internal structures of the component, primarily detecting the presence of air associated with porosity, delamination, or cracking.

Infrared Microscopy Technique ("IR Microscope"): Silicon (the material of the microchip) is transparent to infrared rays. This advantage reveals metallization structures in the active portion of the microchip and, in turn, can potentially reveal defects.

X-Ray Microscopy Technique: This technique allows imaging in 2D or 3D of certain internal structures of components.

Cross-Sectional Analysis (often called "cross-section"): Unlike the previous non-destructive techniques, the cross-section is a destructive method. The component is molded in resin and polished to obtain a cut for observation of its interior.

Optical Microscopy and Scanning Electron Microscopy (SEM): It is possible to observe the components or micro-sections using optical or electron microscopes. SEM allows high magnification with excellent resolution and, when coupled with an energy-dispersive detector, enables elemental analysis.



Figures 4 to 8 illustrate the electrical and analytical results obtained after the thermal shock test of the modules. Electrical anomalies were detected during thermal cycling at extreme temperatures of either -40°C or -55°C and 125°C. Following these results, some parts were removed from the stress for failure analysis.

Electrical Results:
Figure 4 shows the resistance reading, in ohms, at T0 (before stress) and during the thermal shock test, after 250 and 500 cycles. A significant increase is observed in the chains linking the solder joints on the four sides of a test module, indicating a problem.

Module	Net type	T0	Criteria	T250	Criteria	T500	Criteria
1	South side	26.01	Good	150.22	Fail	200	Fail
1	North side	26.53	Good	33.29	Fail	200	Fail
1	West side	26.7	Good	40.15	Fail	200	Fail
1	East side	23.12	Good	23.2	Good	200	Fail

Figure 4: Electrical results in ohms, before stress and after 250 and 500 cycles of thermal shock - C2MI

When this has been established, it is important to remove one or more modules from the test in order to identify the failure mode and thus the source of the weakness.

Acoustic Microscopy Technique: Once an electrical anomaly is detected, failure analysis can begin. Figure 5 shows an example of acoustic inspection. The image below demonstrates the presence of delamination at all four corners of the module.

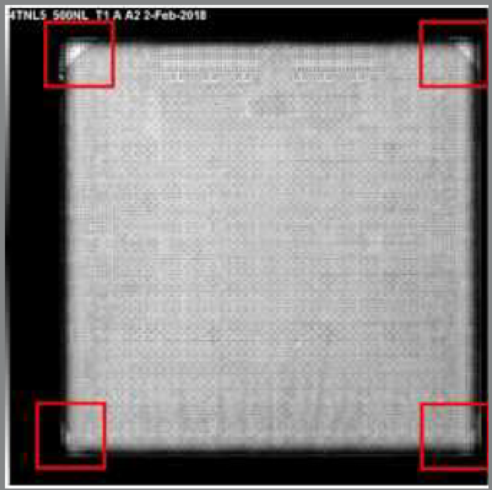


Figure 5: Image obtained with SAM, with the white areas in the red boxes showing the presence of air (delamination)

Infrared Microscopy Technique: Infrared microscope inspection allows the detection of defects within the microchip. The image below shows the circuitry of the microchip and an abnormal dark region indicating a break in the chip.

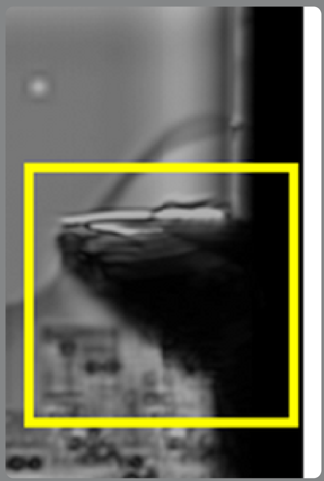


Figure 6: Image obtained with an infrared microscope, with the yellow box highlighting an anomaly

X-Ray Microscopy Technique: 2D X-ray inspection detected the cause of an electrical failure.

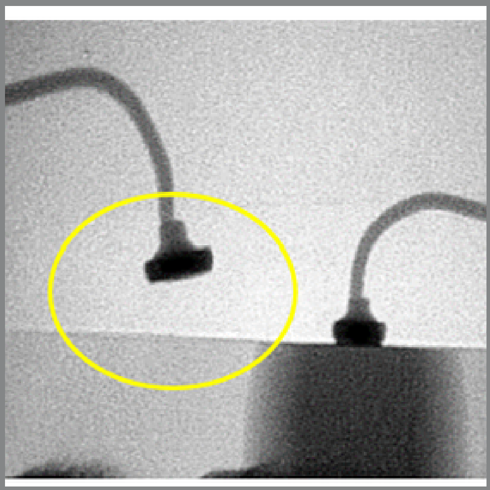


Figure 7: Image obtained with an X-ray microscope, with the yellow circle showing the anomaly

Cross-Sectional Analysis, Optical Microscopy, and Scanning Electron Microscopy (SEM): After non-destructive analyses are completed, it is often necessary to perform a cross-section to better illustrate the defect and aid in understanding the failure. The images below show the same solder joint: the left image was taken with an optical microscope, while the right one was taken with a scanning electron microscope. A crack in the solder joint is visible, explaining the rise in electrical resistance.

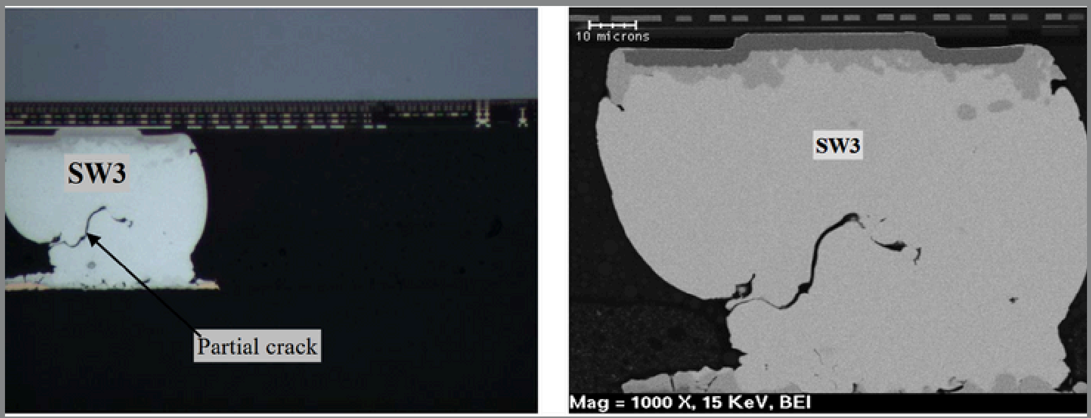


Figure 8: Left image obtained with an optical microscope, and the right one taken with a scanning electron microscope

CONCLUSION

Thermal cycling is a crucial stress test for validating the reliability of a component. Various conditions are possible, and it is preferable to use a more aggressive condition than normal operating conditions to minimize stress time. However, it is essential to avoid overly aggressive conditions that may lead to failures not representative of the module's actual application.

During the stress, resistance readings are taken to detect changes compared to the initial reading before stress. If anomalies are detected, laboratory analyses are required to understand the failure mechanism and make the necessary corrections to increase the robustness of the module.
Reliability is a guiding principle to follow throughout the product development cycle: from design to final application.

The C2MI team offers expertise and execution of stresses compliant with industrial standards, along with advanced laboratory analyses to validate component reliability and ensure compliance with the most stringent requirements. Our experts can design a customized testing plan to validate the reliability of your products, whether in development or production. Contact our team to learn more.

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