Thermal Stress Failures: A New Experimental Approach For Prediction and Prevention

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THERMAL STRESS FAILURES:
A NEW EXPERIMENTAL APPROACH FOR PREDICTION AND PREVENTION

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ABSTRACT

A new experimental tool for analyzing the topography and deformation of electronics components under thermo-mechanical stress is presented. Application examples are shown for a great variety of components, for localizing and quantifying deformations of electronic assemblies.

Cooling and heating cycles following JEDEC type thermal profiles have been applied on different components, both before and after assembly. Simultaneously, real time topography and deformation measurements are obtained. These capabilities constitute a powerful tool for failure prediction, risk evaluation, and accelerated development.

The high resolution optical setup allows analysis of deformations in the micrometer range, even for very irregularly shaped surfaces.

1. INTRODUCTION

Decreasing the number of component failures like delaminations or BGA ball ruptures is a constant concern for electronics development engineers. Thermal stress induced by CTE mismatch between the multiple laminated materials or by increasing solder temperatures as consequence of the RoHS standard is the physical reason for a great number of damages. Additional damage risks are induced by hygroscopic stress, which is out of the scope of the present paper.

Failure analysis is often done by numerical modeling [1]. However, the modeling of the thermo-mechanical behavior of electronic assemblies, whether soldered or not on a PCB, encounters many difficulties. These difficulties are mainly due to the rapid increase of the number of layers and the fact that the characteristics of the materials and the interfaces under thermal and mechanical stresses are partially unknown.

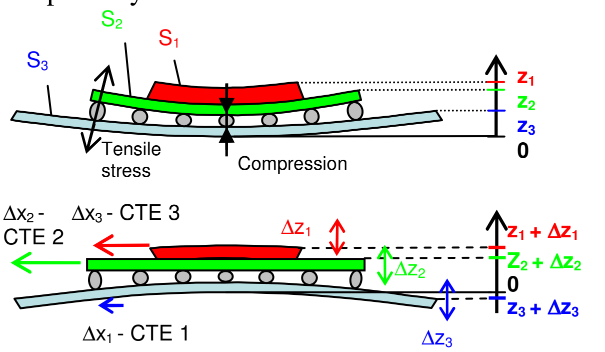

Fig. 1: Schematic view of the variation of a BGA's topography with temperature. Top: BGA on PCB at room temperature. Bottom: Same assembly at 300°C.

Reliable experimental tools are therefore required for detection of risks related to thermo-mechanical stress of the components [2]. Several conditions apply in order to obtain relevant results (Fig. 1):

- The measurement has to be non destructive, in order to analyze real components without any obligation of cutting, drilling, or mechanically deforming them;
- The possibility to take measurements with a large field of view and to permit the simultaneous acquisition of all surfaces (S_1, S_2, S_3 in Fig. 1) of an electronic board has to be given;
- Measurements have to be done under thermal stresses like those encountered by the component during its assembly and product life time: reflow profiles, on/off cycles, external thermal solicitation, and others;

- Real time measurements simultaneously in plane (x, y) and out of plane (z) are necessary [3];
- Finally, the setup has to be flexible enough to allow analysis for a great number of different applications, like package development, CTE evaluation, in service stress evaluation, RoHS consequences analysis, reliability tests.

The scope of the present paper is to introduce TDM, a new tool developed for ***T***opography and ***D***eformation ***M***easurement under thermo-mechanical stress. After a description of the experimental set-up, a large section is reserved for application examples in thermal management development in various fields of today's electronics.

This setup allows absolute and relative deformation measurements both in plane (xy) and out of plane (z). The in plane resolution is 5×10^{-5} times the sample length, the out of plane resolution is 10^{-4} times the sample length.

In comparison to Moiré interferometry [4], the present set-up features two main benefits. First, there is no need for a reference grating or any other movable part, simplifying noticeably the entire alignment and acquisition procedure. Second, the measurement procedure works independently for each voxel of the measurement volume. Therefore, large height variations (Δz steps) or even holes in the sample do not affect at all the measurement at the surrounding voxels.

2. SET-UP

The experimental setup is shown in Figure 2. The electronics assembly to be studied is illuminated by a light source, which projects a structured light field on the sample surface. The light's intensity pattern is more or less deformed by the sample's surface structure. The resulting image is captured by a CCD camera.

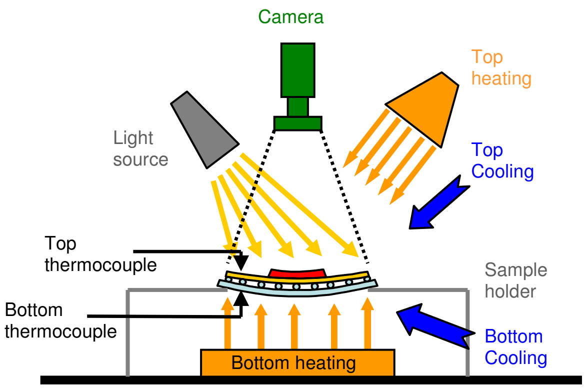

Fig. 2: Sketch of TDM setup.

Real thermal stress is available by top and bottom heating and cooling elements. The current sample temperature is monitored by several thermocouples. Thus JEDEC type temperature profiles with gradients up to +/-3°C/s may be imposed to the component, within a temperature range from -40 up to +300°C.

3. RESULTS

3.1. Power device: Al_2O_3 brazed on Cu plates

When alumina (Al_2O_3) is deposited on copper (Fig. 3), for power components for example, the difference in the coefficients of thermal expansion between the two materials creates a deformation of the assembled parts and results in stress at the interface when the component returns to room temperature.

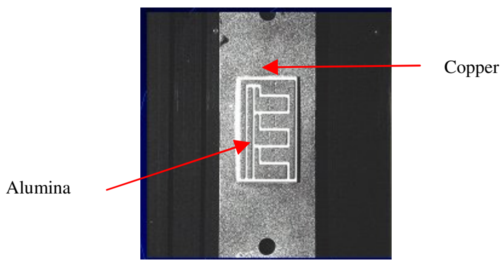

Fig. 3: Video Image of the Alumina part brazed on copper.

At the brazing temperature (400–600°C) both the alumina and the copper part are plane. During cooling, both materials will retract differently due to CTE mismatch, and strong deformation occurs. At room temperature the alumina part becomes convex, while the copper part is concave (Fig. 4). The space in between the two parts is filled with brazing alloy.

However, the interface is subjected to strong stress, both in plane (shear stress) and out of plane (tensile stress). When submitted to thermal cycling this configuration contributes to premature aging and significantly increases the failure risk.

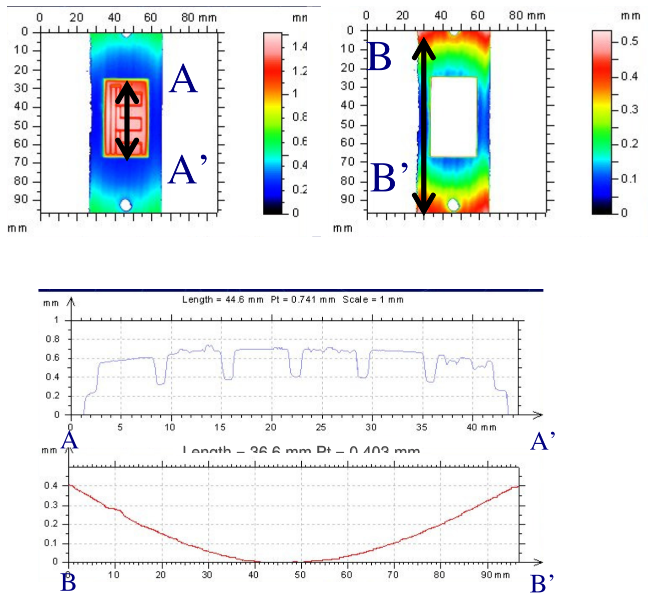

Fig. 4: Characterization of the alumina and the copper surface in one single measurement, at room temperature. A software zoom is possible on each surface, for a high resolution image of the surface topography.

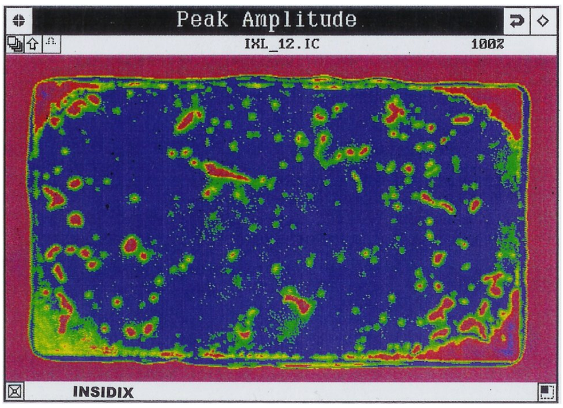

Fig. 5: SAM analysis of the alumina – copper interface. Crack initiation is observed in all 4 angles of the brazing area.

Additional investigation [5] of the part by scanning acoustic microscopy (SAM) confirmed crack initiation in the four angles of the brazing area (Fig. 5).

Introducing TDM measurements in the development cycle of this product allowed to optimize the characteristics of the part (like the exact dimensions and the solder characteristics), in order to minimize the effect of opposite bending of the alumina and the copper part.

3.2. Lead free JEDEC thermal profile effect on BGA deformation and damage

New JEDEC type temperature profiles for soldering under lead free conditions attain sensibly higher peak temperatures than classical reflow profiles, with strong incidence on damage risks due to CTE mismatch or other stress induced deformations.

If such a high temperature profile is used for soldering a BGA, then both the BGA and the PCB will strongly bend during the soldering process. The final form of the balls will be fixed at more than 200°C, when the solder becomes solid. However, the final geometric form of BGA and PCB is determined only when the assembly is back at room temperature. Therefore, some balls will see compressive, others tensile stress (Fig. 1).

TDM allows following in detail the topography of the parts to be soldered during a JEDEC type reflow profile (Figures 6 and 7).

The topography images show several incidents:

- The initial topography at room temperature is slightly concave. Up to 150°C, the BGA changes its topography only slightly, to become flat at this temperature. Between 150 and 200°C, the topography changes slowly, and the BGA becomes convex.
- Above 200°C, a dramatic topography change takes place, with a final amplitude of the convex deformation of about 220 µm. Fast changes of topography, especially from concave or flat towards convex, are in most cases related to delamination. Indeed, for this BGA delamination has been confirmed by SAM. By multiplying the number of images between 200 and 245°C, it is therefore possible to determine the exact temperature where delamination occurs.

- After cooling down to room temperature, some convex deformation remains. This hysteresis effect is the second characteristic observation when delamination occurred.

This kind of measurement has several direct benefits for the thermal management developer: The temperature where delamination occurs can be determined, and if possible the applied reflow profile adapted accordingly. The amplitude of deformation allows an estimation of the failure risk of the component in future applications, even if no direct delamination occurs. And successive measurements with the same temperature profile allow an evaluation of the componenet behavior under future cyclic load, like on/off cycles or for fatigue control.

3.3. Accuracy control on very small components

With increasing miniaturization, quality control on very small components becomes an issue in all fields of electronics. Parts manufactured by subcontractors needs to be controlled before being integrated in complex assemblies.

Figure 8 shows the photograph of a standard module for SIM cards in mobile phones. Critical dimensions are the height and the parallelism of those parts of the module which will be soldered onto the PCB.

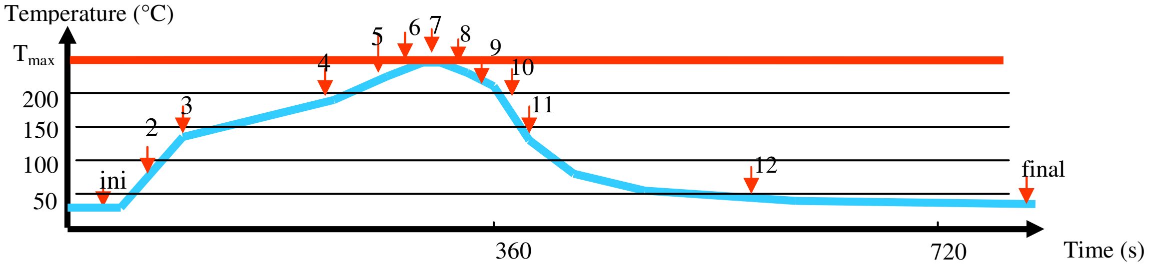

Fig. 6: JEDEC type reflow profile generated and monitored by TDM. The arrows indicate temperatures where deformation measurements are automatically triggered. These temperatures may be defined by the user.

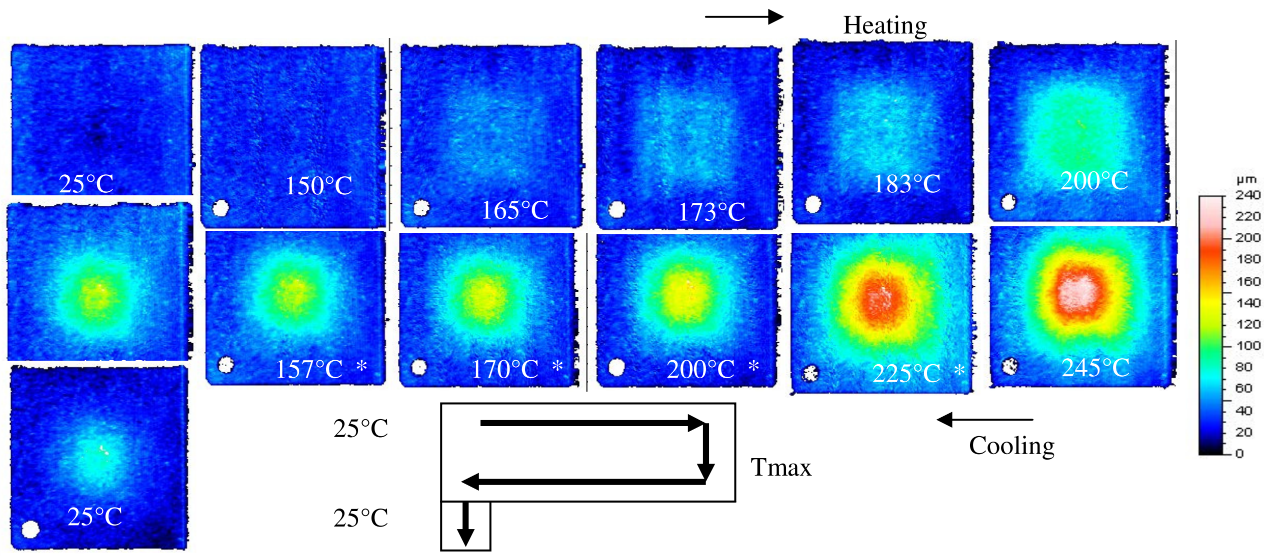

Fig. 7: Deformation measurements performed on a BGA at different temperatures during the temperature profile shown in Figure 6. Strong deformation occurs between 200 and 245°C. Note the hysteresis in deformation when the component is back at room temperature.

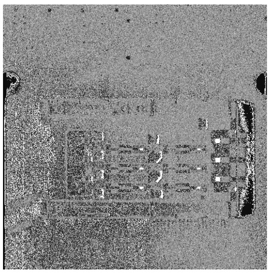

Fig. 8: Photography of a SIM card module. Dimensions of the component: 25 x 15 x 2 mm (l × w × h).

Figure 9 shows the topography of the bottom side of the component, measured with TDM. The height and the parallelism of the parts to be soldered are clearly identified, and may be compared to manufacturing specifications. Note that TDM is able to obtain high resolution topography even for components with very strongly structured surfaces, even in presence of multiple holes.

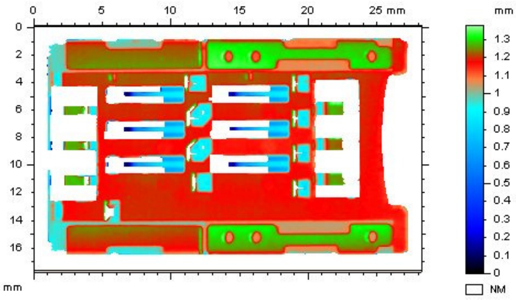

Fig. 9: Height profile of the bottom side of the SIM module. The most prominent parts (green) are used for soldering the component onto the PCB.

A 3D representation of the component is given in Figure 10. This view, which is calculated on the basis of the 2D bottom view acquisition shown in Figure 9, allows detailed verification of the dimensions of further critical parts, like the springs in the centre of the module.

Overall, application of TDM measurements to this part allowed a big step forward towards total quality control of pieces delivered from subcontractors, manufactured following specifications defined in the order.

Fig. 10: 3D view of the SIM module, calculated from the image given in Fig. 9. Note that one single 2D bottom side measurement of the component is sufficient for generating this view.

3.4. Quantitative deformation measurement on BGA after assembly on PCB

In this application, we compare, for the same component/PCB set, the assembly process with a Pb/Sn profile, Figure 11, and with a lead free profile, Figure 12. These Figures show diagonal warpage profiles measured on the BGA while soldering on a PCB. In each Figure, the top diagram corresponds to the time interval where temperature increases, the lower diagram to the interval where temperature decreases.

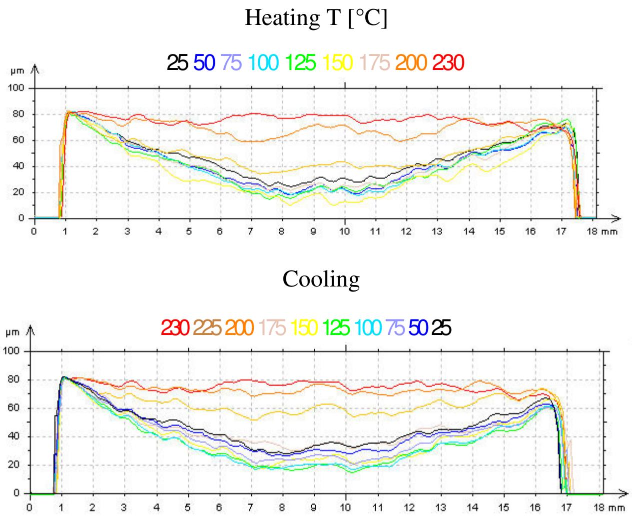

Fig. 11: Diagonal warpage profile on a BGA during soldering on a PCB. Analysis for a Pb/Sn temperature profile (maximum temperature 230°C)

During the two different reflow profiles, the topography changes with temperature strongly differ. This situation induces different effects on the interface integrity, which might be seen afterwards using acoustic microscopy, and ball interfaces, which might be seen by X-ray tomography.

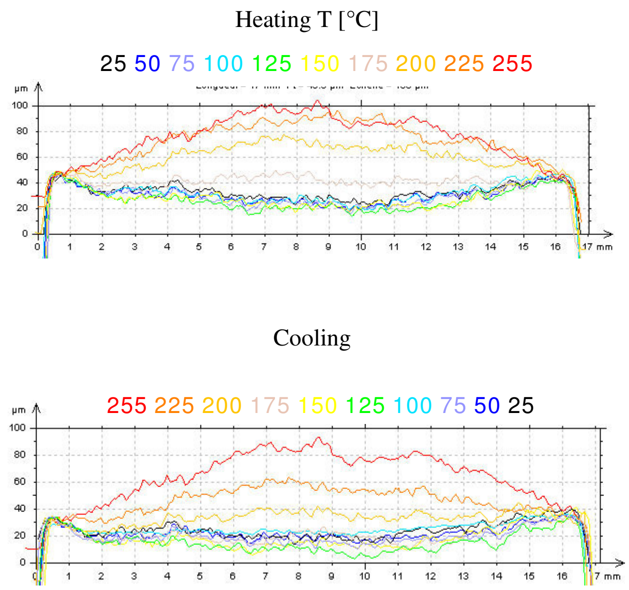

Fig. 12: Diagonal warpage profile on a BGA during soldering on a PCB. Analysis for a lead-free temperature profile (maximum temperature 255°C)

After assembly on the PCB, the same BGA component has different remaining warpages depending on the reflow profile.

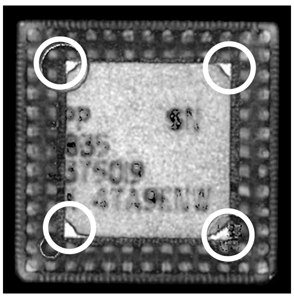

Fig. 13: SAM image of the BGA soldered on PCB using a lead-free reflow profile. White circles: crack initiation

Additional measurements by scanning acoustic microscopy confirmed the different behaviors of the BGA under Pb/Sn and lead free profiles: Figure 12 shows the initiation of cracks in the case of the lead free profile. No cracks are detected in the BGA soldered with the Pb/Sn profile.

4. CONCLUSIONS

A new experimental tool, TDM, has been developed for topography and deformation measurement under thermo-mechanical stress. This tool enables high resolution absolute 3D imaging of warpage (z) and in plane (xy) deformation.

Four examples have been discussed for application of TDM in prediction and prevention of failures in electronics. In each example, analysis of the different components in an early stage of the development and production cycle allowed an early failure risk analysis, successive design changes, and thus shorter time to market as well as lower risk of customer returns.

In future, the results obtained by TDM will be coupled with modeling, which will allow easier definition of boundary conditions and validation of modeling results by experimental values.

5. REFERENCES

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