Thermo-mechanical characterization and integrity checking of packages and movable-structures

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ABSTRACT.

The paper presents two methods for measuring the dilatation resulting from thermal expansion. The contact based stylus measurement method and the contact less heterodyne laser interferometry have been compared to prove their effectiveness in measuring small dilatations. The paper presents shortly the application of both methods for measuring thermal expansion, and compares their applicability for thermo-mechanical characterization and integrity checking of packages and movable structures.

Keywords: *package void detection, thermal dilatation, stylus method, heterodyne laser interferometry, MEMS characterization, thermal transient testing.*

1 INTRODUCTION

In recent years considering and extending the reliability of **M**icro **E**lectro **M**echanical **S**ystems' (MEMS) and chip packages became a very important issue. The reliability of these devices strongly depends on the quality of the heat removal from the packages. If the heat dissipated within the package can not leave the package seamlessly, the temperature of the chip or the MEMS element within the package increases, and in worst cases may lead to burn down the entire device. In order to avoid this, checking the quality of the heat flow path of the package is a very important step in increasing the reliability of packages. Although the general knowledge in this field is still incomplete, considerable efforts are continuously devoted to reliability studies in order to get better understanding of the relations between the device design and the reliable operation. A frequently encountered problem of the packaging technology is the testing of the die attach quality, as the die attach is usually the weakest element of the heat flow path. Any void or delamination in the die attach results in increased thermal resistance.

To test this, we intend to measure the thermal time-constant of the chip/die attach structure. This can be done by thermal transient measurements. [1] In these measurements we heat the device by electrical excitation, and measure the resulting temperature in the function of time. The obtained so called heating curves are characteristic features of the structure. The change in the temperature caused by a given power excitation is a good characteristic not only of properties of packages but also of etching quality of MEMS. If the device is packaged, electrical methods can be applied for heating and temperature sensing, as e.g. using of a built-in temperature sensor for recording the heating curves.

To avoid packaging badly attached devices, the right place of the die attach qualification were in a much earlier phase of the manufacturing, before the bonding and encapsulating process begun, immediately after the die attaching. In this case however non-electric methods can only be considered for measuring the heating curve. For this purpose a fast, contact less, precise measurement of the temperature, or as a function of this, the displacement is required.

By measuring the mechanical displacement or the expansion of different MEMS structures or packages, these structures can be characterized, several important data of different material which are included in MEMS can be determined – mainly for simulation purpose – and error analysis can be done. By measuring the heat expansion the thermal transient of the investigated structure can be determined indirectly. For this aim we used two methods, one was the contact stylus method the other the non-contact heterodyne interferometry. The appropriateness of these methods for package measurement was compared.

A heterodyne displacement measuring laser interferometer (DMI) [2,3] was used for the contact less method. By using DMI only in the z axis, (vertical) displacement of the investigated structure can be recorded. This method is convenient for measuring the precise displacement of movable MEMS structures – eg. cantilevers – as well, or to determine the heat expansion map on the surface of different packages, structures. Experiments are in progress in order to prove the feasibility of this idea. The first results of these experiments are presented in this paper, as well. Our future aim is to investigate the die attach quality by using this type of fast contact-less measuring method.

2 THE CONTACT METHOD

For contact temperature dilatation measurement the so-called stylus method was used. The unit using this method is named Talystep [4], see Fig.1

Fig. 1. The measuring stylus kit of Talystep

The instrument has a built-in sharp stylus that is originally used for surface scanning and for the detection of surface steps or roughness. The accuracy of this equipment is 10 nm, this is acceptable accuracy in the range that we needed. The time resolution is about 0.1 seconds, it is far from the demand of thermal transient measurement needed 10 µs. Because of the inappropriate time resolution and the contact disadvantage that can influence the dilatation we measured the devices also with the non-contact Laser Interferometery method. This method has a low influence to the structure, so it is very useful for crosschecking the results.

3 THE CONTACTLESS METHOD

In our laser interferometer measurement set-up we use a sophisticated arrangement: a Heterodyne Displacement Interferometer as shown in figure 2. In the measurement arrangement two laser beams of a thermally stabilized HeNe laser source (632nm) are directed to the interferometer. The two beams are orthogonally polarized and have 3.65MHz frequency difference. These laser beams (one is the reference and the other is the measurement beam) are directed to the PBS. In this assembly the High Stability Plane Mirror (HSPMI) acts as an interferometer. The HSPMI consists of a Polarization Beam Splitter (PBS), a retroreflector, quarter waveplates and a plane mirror.

In the HSPMI the reference beam reflects and exits through an optical fiber. The measuring beam goes through the HSPI. Reaching the investigated mirroring surface it is reflected back to the HSPMI and exits on the same optical fiber as the reference beam. In the same time a part of the two laser beams coming out of the back of the laser and are conducted by an optical fiber to the measuring card serve as reference.

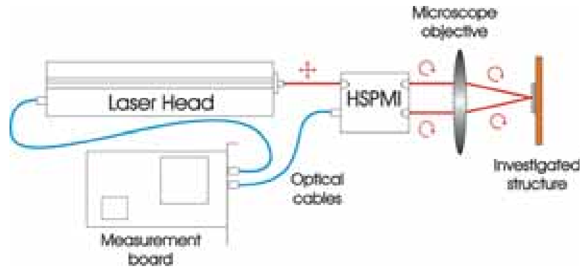

Fig.2. The laser interferometer set-up

As mentioned before in HSPI the recombined beams are redirected into an optical fiber and sent to the measurement board. The measurement board produces the phase measurement (using the heterodyne principle) between the measured and reference beams coming from HSPI. A Multifunction Counter/Timer Digital I/O PC card is used for measuring the signals coming from the card of the interferometer. The sampling rate of the system was about 1000 sample per a second. The resolution (LSB value) of the measured displacement was about 9nm.The set-up of the laser interferometer is shown in Fig. 3.

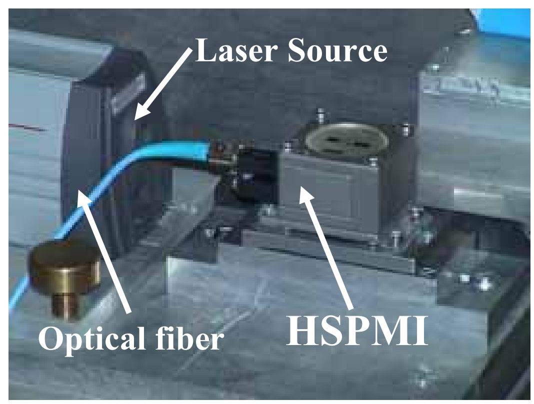

Fig.3. The laser interferometer measuring set-up

The diameter of the laser beam is about 4mm. This diameter is appropriate to measure packages having larger surfaces. But in case of microstructures an optical microscope is needed for reducing the diameter. In our measurements the laser beam diameter can be focused down to approx. 100µm, so a pad of a chip could be easily pointed at. For recording the thermal transient, and drive the measured electrical devices (e.g.: transistor, thermal test-chip) the T3Ster Thermal Transient Tester was used [5].

4 INVESTIGATION OF PACKAGES

In order to investigate the feasibility of the chip/package temperature measurement by interferometer some experiments have been proceeded. First of all the thermal expansion of the package of a BD245C power transistor was measured. Besides the dilatation of the package the internal temperature of the chip has been recorded simultaneously. The temperature dependent forward voltage of the base-emitter diode was used for this goal. The collector current heated the transistor, this resulted in the heat expansion of the package. A mirror was attached to the top surface of the package to reflect the incident laser beam. The temperature of the transistor and the displacement of the package top surface were recorded during the measurement. The transistor was attached to a 100×100×10mm aluminum slug – acting as a heat sink – by a hold-down bolt.

We heated the transistor for 120sec by a 0.5A collector current. The collector voltage was l0V so the dissipated power was 5W. The transistor warmed up to 19°C degree and the centre of the package dilated by 4995nm. The ambient temperature was 23°C. The result of the measured heat expansion of the centre of the package is shown in fig 4. The dilatation measured near the edge of the top surface as well. This was 4541nm which is slightly less than what was measured in the centre. (The operation condition was the same as mentioned above).

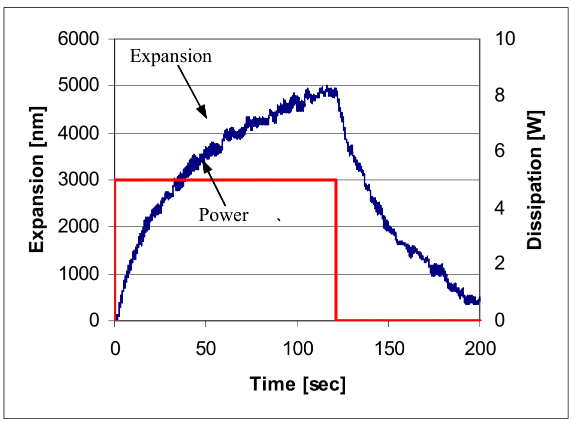

Fig.4 The measured dilatation of the centre of the package

Further the dilatation was measured also on several points of the package. This way the complete dilatation map of the transistor package can be recorded. The dilatation of the package on the sides was smaller than near the centre of the package. As expected, above the active region of the IC the higher temperature change causes higher displacement. On the sides the lower temperature changes - caused by only the heat conduction – result in smaller displacement.

To verify the accuracy of the results a control measurement was done by Talystep. The measured dilation response was 4.2um for the same 5W power step excitation. The temperature change was 17°C. Unfortunately measurement setup was slightly different, as the big aluminum heat-sink did not fit under the needle of the Talystep. A thinner but bigger heat-sink was applied in this measurement, that has changed the thermal property of the entire structure. Despite of this the two results measured by different techniques were coincident in the range of dilatation. The measured dilation by Talystep on the edge of the top surface of the transistor package was less by about 500nm than the measured dilatation by using the contactless measuring method. During these measurements the smallest detectable dilatation was about 100nm because of the relatively large displacement.

Method	Interferometer		Talystep	
Pad	middle	edge	middle	edge
Temperature change [°C]	19	19	17	17
Dilatation [nm]	4995	4541	4200	3750

Table 1: Measured temperature and dilatation results

5 MEASUREMENTS

After the experiments on packages we measured the dilatation of a silicon chip itself. The subject of these investigations was a thermal test chip [7], mounted on an open ceramic package. This choice held more advantages: (i) it was easy to apply a power step since the chip was bonded, and (ii) the temperature of the chip can be easily monitored by using the built-in temperature sensor circuitry.

The microscopic image of the measured thermal test die is shown in figure 6. The die originally is intended for the thermal characterization of IC packages. The die consists of 6 identical units, arranged into a 2×3 array. Each unit contains a large dissipating resistor and a diode for measuring the temperature. The area of the units is 1×1 mm^2. During the measurements the 5th and 6th units were used. The temperature was measured by the diode on the 5th units. In the first measurements the dissipating resistor was driven for 20sec by 200mA current. The power step was 0.88W. The dilatation was measured on the inner pads of the 5th unit as shown in figure 7, labeled by a. b. and c.

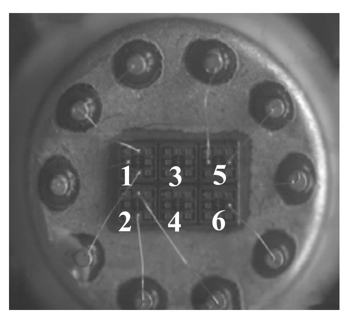

Fig.6. Micro-photograph of the thermal test die

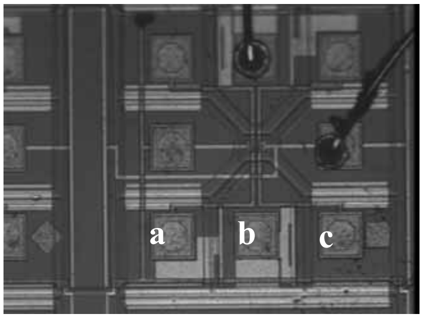

Fig.7. The microscopic image of the 5th unit

The middle pad was heated more intensively than the outer or the inner pads, as the dissipating resistors heated it from two sides. It can be observed in Fig. 8 that the inner pad cools down faster (137sec) than the outer (205sec) or middle (170sec) one (nearer to the side of the chip) because of the generated heat can be conducted away through a bigger surface.

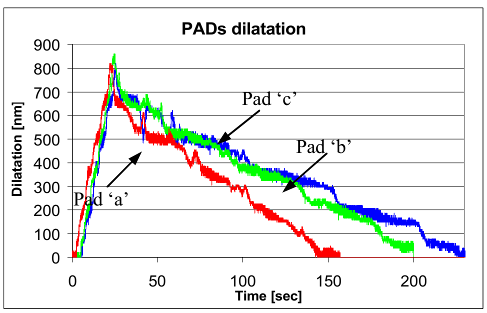

Fig.8. Measured dilatation transients

In the next experiments the cooling dilatation transient of the middle pad was measured by applying different heating times. The power step was 0.88W. The measured transient curves are shown in figure 9. The measured maximum dilatations and temperature changes were as follows:

Heated for 40sec 860nm (42.05°C)
Heated for 20sec 474nm (30.05°C)
Heated for 10sec 247nm (22.65°C)

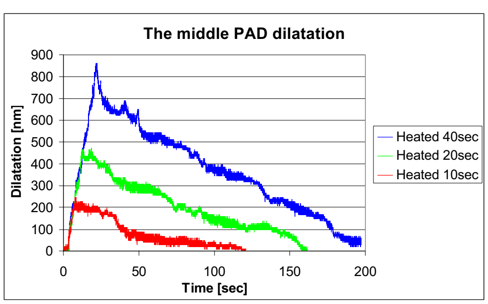

Fig.9. The measured dilatation transient of the middle pad

In our expectations this part of the function is very sensitive for the die attach thermal resistance. In order to investigate this effect measurement of a good and a bad samples are needed. This will be the subject of our further experiments.

6 CONCLUSIONS

We have presented a contact-less and a contact measuring method for detecting thermal expansion resulted dilatation of different structures. We presented the importance and the different parameters which can be determined by using these measuring techniques.

These measurements allow us to determine the displacement of the top surface of a packaged power transistor or a structure of different chips or MEMS elements to find out the inner structure distortions from the ideal.

The resolution of the dilatation was in the nanometric scale. The results promise a new possibility for qualifying different movable MEMS structures or the quality of the die-attach by using these measuring methods.

ACKNOWLEDGEMENT

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