Automated test system for in-situ testing of reliability and aging behaviour of thermal interface materials

M. AboRas[1,4,6], R. Haug[2], R. Schacht[4,7], C. Monory-Plantier[3], D. May[4,8], B. Wunderle[5,8], T. Winkler[1], B. Michel[5,6]

[1] Berliner Nanotest and Design GmbH, Berlin, Germany, Email: aboras@nanotest.org
[2] Robert Bosch GmbH, AE/EAI2, Stuttgart, Germany
[3] Robert Bosch GmbH, AE/ETC2, Stuttgart, Germany
[4] Fraunhofer Institute for Reliability and Microintegration IZM, Berlin, Germany
[5] Fraunhofer Institute for Electronic Nano Systems ENAS, Chemnitz, Germany
[6] Micro Materials Center Berlin e.V., Germany
[7] University of Applied Sciences Lausitz, Senftenberg, Germany
[8] Technical University Chemnitz, Germany

ABSTRACT

Thermal interface materials (TIMs) are widely needed to improve thermal contacts for facilitation heat transfer in electronic packaging, such as that associated with the flow of heat from microprocessor to a heat spreader or a heat sink in a computer. Due to thermal mismatch between these components mechanical strain occur which cause pump-out, cracks or delamination of TIM. In order to qualify the reliability and aging of TIMs, traditional power cycle test is commonly used to detect potential thermal failures. This traditional power cycle test is a time consuming process due to its long heating and cooling time. Therefore a new automated test system for in-situ reliability testing of TIMs is developed and will be presented in this paper. The new test system is designed to be able to analyze the aging and reliability behavior of most common TIMs. The TIMs can be measured in-situ and under real conditions as they are used in real applications.

Keywords: Thermal Interface Materials, thermal resistance, thermal conductivity, thermal characterization, reliability test, material aging, TIM delamination, greases pump-out

1 INTRODUCTION

Interfaces between electronic packaging materials or components have a significant impact on the thermal impedance of electronic systems and in practice they can be the dominant factor in achieving the effective thermal transfer. TIMs are used to connect an electronic device to the thermal transfer medium such as substrate, heat pipe and heat sink, or connecting the thermal management components to each other. In some cases they are important to perform the tasks of attachment, stress/stain relief and thermal transfer. [1]

Characterization of thermal interface materials (TIMs) becomes even tougher a challenge at low bond line thicknesses (BLT) and higher thermal conductivities of the interface materials as more accurate measurement techniques are required. Thermal characterization methods for TIMs narrate a long story of confusion, as results from different characterization methods often disagree formidably. Even worse, thermal conductivity values will be different when applied to the real device, likely to cause over-, or more often, fatally under designed thermal heat paths. The reason for this misjudgment is often that TIM characterization is done under laboratory conditions (e.g. polished surfaces, excessive pressure conditions) or disregarding technological influences (e.g. cure regime for adhesives, dissimilar surfaces) [2, 3].

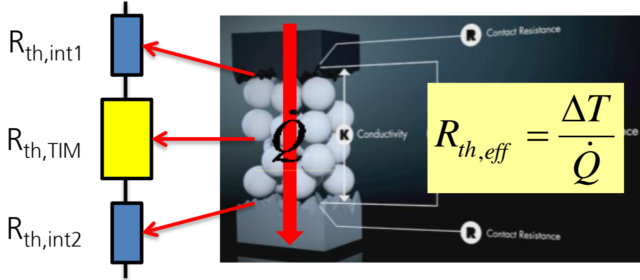
The long-term stability and reliability of the TIMs is its ability to provide a sufficient thermal conductance even after an extended time or extensive use of the electronic equipment. The main initiator of deterioration of TIMs is the thermal mismatch between used components. Thermal mismatch may cause harden or pumping-out of uncured TIMs such as greases or gap fillers or crack and delamination of inflexible TIMs such as adhesives or solders.

2 TEST SYSTEM FOR CHARACTERIZATION OF TIMS

In order to characterize thermal interface materials under real conditions as they occur in real assemblies the test stand TIMA-TESTER was developed. The first generation of TIMA-TESTER was reported in [4]. The measuring principle of TIMA-TESTER is based upon the standard method ASTM D5470. [6]

2.1 Measuring Principle

TIMA is a steady state test system. TIMs have been tested between a hot plate and cold plate. To determinate the thermal resistance of TIM, the temperature gradient on TIM and heat flux through the TIM have to be measured.



Where ΔT: temperature gradient on TIM.
Q: heat flux through TIM

The calculated thermal resistance $R_{th,eff}$ is the sum of thermal resistance of TIM $R_{th,TIM}$ and the thermal interface resistances to contact mediums $R_{th,int1}$ and $R_{th,int2}$

$$where;\quad R_{int1} + R_{int2} = R_{th,0} \qquad \text{(Equation 1)}$$

$$\Rightarrow \quad R_{th,eff} = R_{th,TIM} + R_{th,0} \qquad \text{(Equation 2)}$$

$$\Rightarrow \quad R_{th,eff} = \frac{1}{\lambda_{TIM} \cdot A} \cdot BLT + R_{th,0} \qquad \text{(Equation 3)}$$

It can be seen in (Equation 3) that effective thermal resistance is a linear function of the bond-line thickness (BLT) of TIM, where:

$\frac{1}{\lambda_{TIM} \cdot A}$ *: is the slope of linear function and*

$R_{th,0}$ *: is the intercept.*

A: is the contact area of TIM

Having several measurements of the same TIM at different thicknesses the bulk thermal conductivity and the thermal interface resistances can be determined.

2.2 Standard Characterization of TIMs

For the characterization of the most common TIMs the following test method is used.

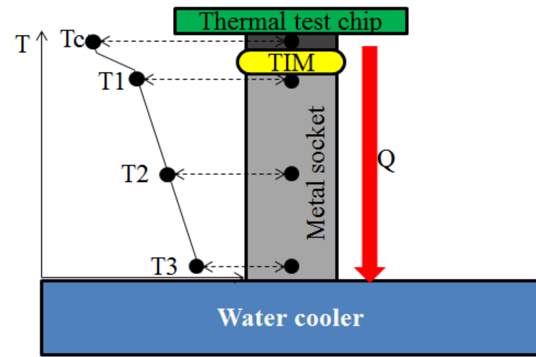


Figure 1: measuring principle of TIMA-TESTER

TIMs are tested between silicon thermal test chip and metal socket which can be aluminum, copper or any other metal. The thermal test chip is assembled by flip-chip technology and has been used as heat source as well as for temperature measurement on the top side of the TIM by integrated diodes. For the temperature measurement in points T1, T2 and T3 in the metal socket NTC's have been used. By temperatures T1, T2 and T3 the temperature on bottom side of TIM and heat flux through the TIM can be determined.

The test set-up is integrated in a platform. The platform is designed to be able to integrate different measurement variants to characterize the most common thermal interface materials under different conditions and applications. Following modules are developed:

- Quick-tester module for standard characterization of most common TIMs
- Long-term-tester module for reliability testing of most common TIMs
- Sissy-tester module for high accuracy testing of TIMs special for very thin layer of TIMs
- High-lambda-tester module for characterization of highly conductive TIMs, such as solders or mono-metal sintered TIMs

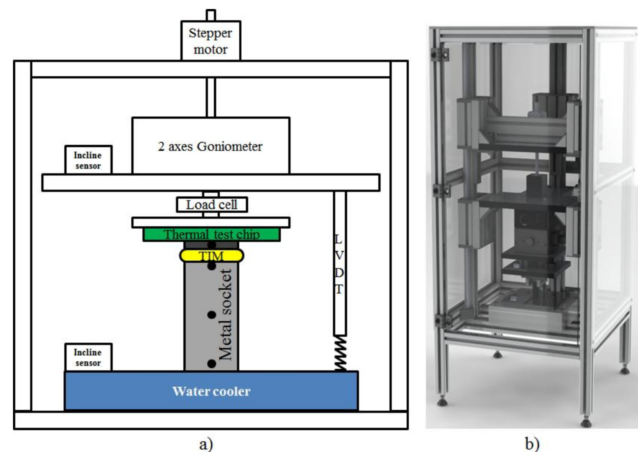


Figure 2: a) schematic of platform; b) photography of platform

NSTI-Nanotech 2011, www.nsti.org, ISBN 978-1-4398-7139-3 Vol. 2, 2011

Following are the main features of the platform:

- In-situ measurement of BLT by integrated LVDT distance meter with resolution up to 1 µm
- In-situ measurement of force by integrated load cell with ± 200 N measuring range
- Adjustable BLT of TIM by using a stepper motor with resolution up to 250 nm
- Adjustable tilt by using two axis goniometer and incline sensors with resolution up to 30 arcsec

2.3 Reliability and aging analyses of TIMs

Reliability and long-term stability of thermal interface materials (TIMs) is often depended on the type of the TIMs (viscous, inflexible, phase changed etc.) as well as on the real application conditions. So thermal greases are drying-out due to high temperature or pumping-out between the package and the heat-spreader due to thermal mismatch. Grease "dry-out" occurs due to the separation of the filler from the polymer matrix at elevated temperatures. The polymer matrix tends to flow out of the interface preferentially and results in 'drying-out' of the thermal grease. This results in increased in-situ thermal resistance of the material.

In the case of inflexible TIMs like adhesives, solders or cured gap fillers the interface delamination and bulk cracks are the main initiator of reducing thermal performance and the lifetime of package.

Following picture shows one of a typical application of TIM (between flip-chip and heat sink) and some potential applied load of TIM during duty cycles.

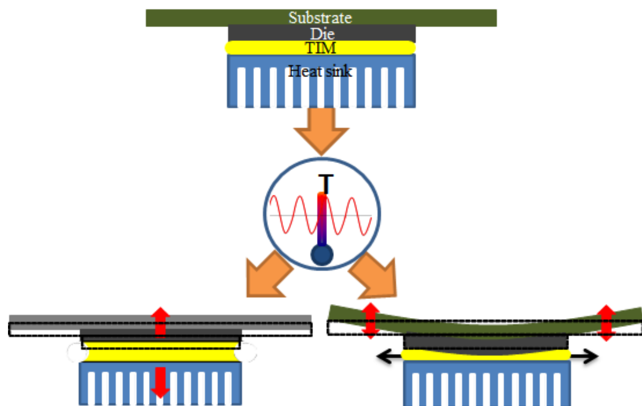


Figure 3: schematic of a typical application of TIM and some potential applied load of TIM during duty cycles; Left: low thermal mismatch between substrate and die Right: high thermal mismatch between substrate and die

In order to qualify the reliability of thermal interface materials in an electronic package cooling application, traditional power cycle test is commonly used to detect potential thermal failures due to grease pump-out, grease dry-out, adhesive delamination etc. [5]. This traditional power cycle test is a time consuming process due to its long heating and cooling time. Therefore, the test stand TIMA was advanced.

In order to accelerate the potential applied load of TIM during the operation without the time consuming power cycle test, the test stand and the platform in Figure 2 were used to simulate the squeezing action of TIM and to measure in-situ the changing of thermal resistance of TIM. TIM is mounted between a silicon flip-chip and metal socket (Al or Cu). Metal socket is fixed on water cooler. The thermo test chip is joined to the stepper motor which movie it in vertical direction (expansion and compression of TIM).

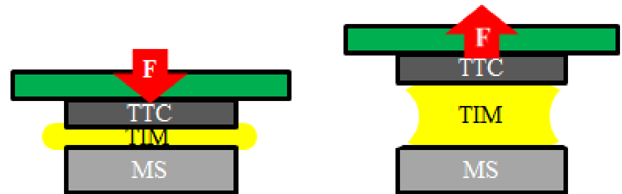


Figure 4: schematic of test setup left: compression condition. Right: expansion condition

The thermal resistance on TIM can be measured in-situ analog to standard characterization of TIM which was described in section (2.2 Standard Characterization of TIMs)

3 EXPERIMENTAL INVESTIGATION

Scores of thermal interface material in different conditions were characterized by this new test stand with respect to its aging behavior. In this paper the investigation results of one gap filler material will be presented. The reliability of the same gap filler was tested. The gap filler was cured under following conditions:

a) The gap filler was cured for 1h at 100°C
b) The gap filler was cured for 5h at room temperature
c) The gap filler was stored for 500h at 125°C

Figure 5 shows the progression of one cycle. One cycle consists of 10 steps:
1th step: initial condition
2th step: compression of TIM
3th step to 7th Step: expansion of TIM
8th step to 10th step: compression to initial condition

For the following experiments the maximum compression and expansion were predefined by a preliminary investigation.

Maximum compression is 2% of initial bond line thickness
Maximum expansion is 5% of initial bond line thickness

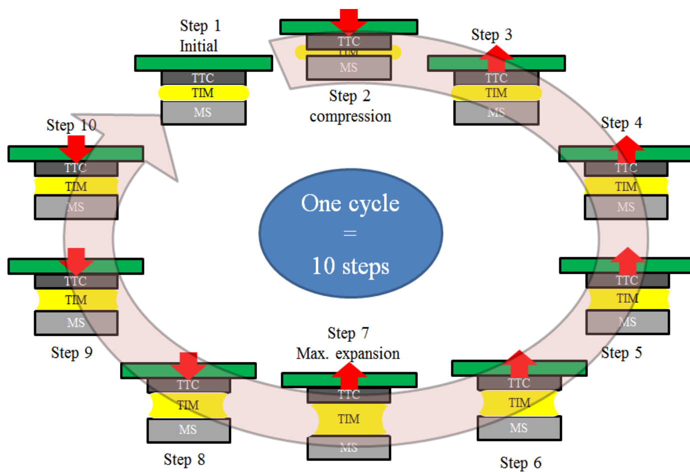


Figure 5: schematic of progression of one cycle

The results of the investigation will be shown in following sections:

a) The gap filler was cured for 1h at 100°C

Thermal conductivity of TIM was measured at all steps. Figure 6 shows trend on thermal conductivity for each step as function of cycle number for the investigated gap filler which was cured for 1h at 100°C.

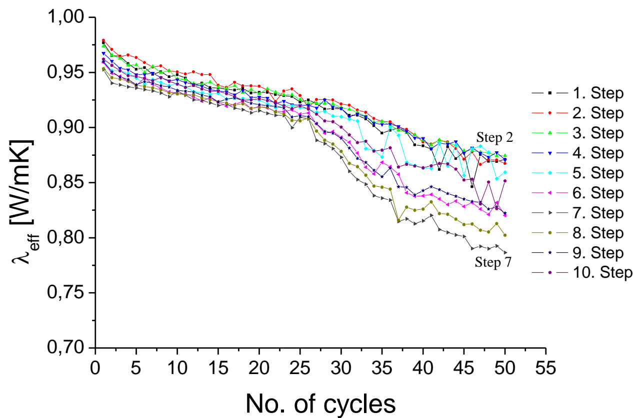


Figure 6: thermal conductivity as function of cycle number for all 10 steps for the case, gap filler was cured for 1h @ 100°C

It can be seen that thermal conductivity was changed step by step; the maximal percentage changing for each step after 50 cycles is listed in following table. Thermal conductivity was degraded 10% to 20% after 50 cycles.

Table 1: percentage changing for all steps, the main value M is -14% of initial value

Step	1	2	3	4	5	6	7	8	9	10	M
Δλ [%]	-11	-12	-11	-10	-11	-15	-20	-18	-15	-14	-14

b) The gap filler was cured for 5h at room temperature

The same gap filler was cured for 5h at room temperature; both curing conditions were given by the manufacturer of this gap filler. Gap filler was tested here under the same conditions as in the case a). Figure 7 shows that thermal conductivity was improved at some steps. It can be also seen that thermal conductivity value in initial state is lower than thermal conductivity value in initial state of gap filler cured at 100°C. It seems that gap filler was not cured after 5h at room temperature and during the measurements the curing process is happen due to the work temperature of 120°C.

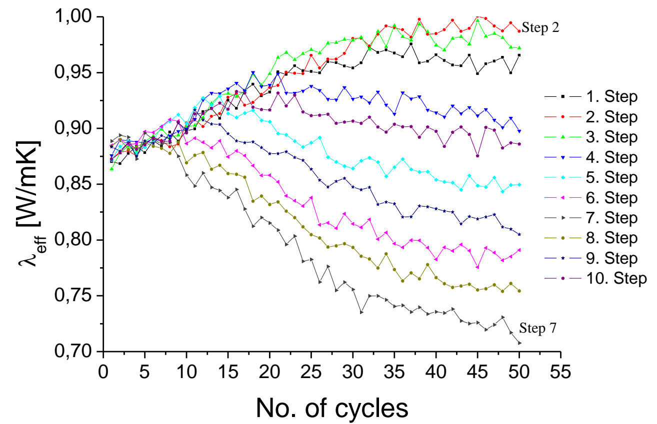


Figure 7: thermal conductivity as function of cycle number for all 10 steps for the case, gap filler was cured for 5h @ room temperature

The percentage changing for each step after 50 cycles is listed in following table.

Table 2: percentage changing for all steps, the main value M is -2% of initial value

Step	1	2	3	4	5	6	7	8	9	10	M
Δλ [%]	10	13	11	2	-4	-11	-19	-15	-9	1	-2

c) The gap filler was stored for 500h at 125°C

In order to investigate the influence of long-term usage at high temperature on the thermal properties of the gap filler, the gap filler was assembled and stored for 500h at 125°C. After the storage the gap filler was tested under the same conditions as in the cases a) and b).

Figure 8 shows the trend on thermal conductivity for each step as function of cycle number, it can be seen that it is a minimum changing of thermal conductivity after 50 cycles.

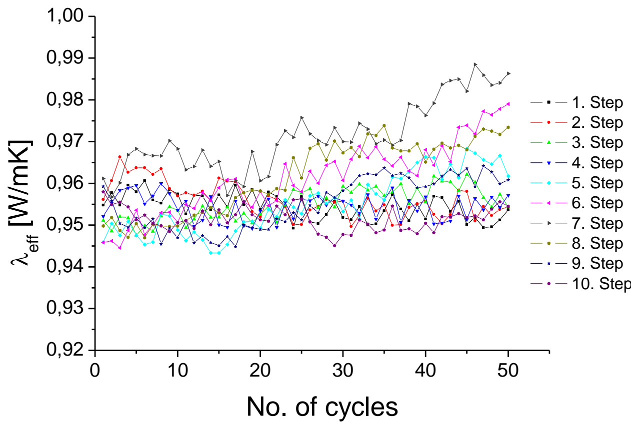


Figure 8: thermal conductivity as function of cycle number for all 10 steps for the case, gap filler was stored for 500h @ 125°C

The percentage changing for each step after 50 cycles is listed in following table.

Table 3: percentage changing for all steps, the main value M is +1% of initial value

Step	1	2	3	4	5	6	7	8	9	10	M
Δλ [%]	**-0,4**	**-0,8**	**0,5**	**0,1**	**1,7**	**3,4**	**2,6**	**2,4**	**0,6**	**0**	**1,0**

It seems that gap filler is adhered very well to the silicon and aluminum surfaces due to the storage for 500h at 125°C. Following experiment proves this statement.

After the cycle testing the gap was step by step opened (1 step = 10-15µm) and the thickness of the gap and the tensile adhesive strength were measured. It could be determined that delamination results only after 370 kPa and 30% increasing of gap size. Figure 9 shows the strength-displacement curve. It can be seen, that after start the delamination at 30% increasing of the gap size, the tension of TIM is removed. The strength is relieved completely at 50% increasing of gap size.

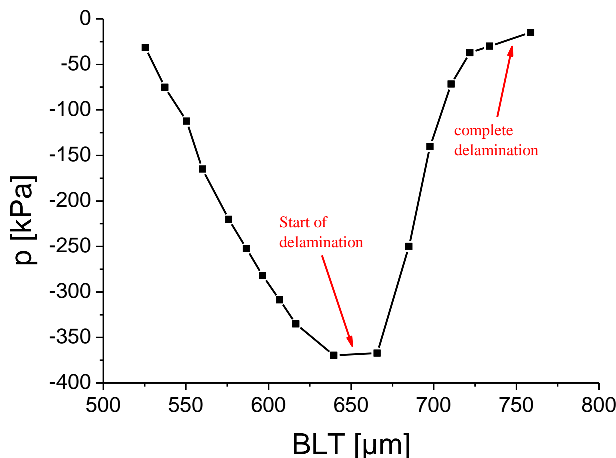


Figure 9: Strength-displacement curve (expansion of TIMs)

4 CONCLUSIONS & OUTLOOK

In this paper we have presented a new developed TIM-tester for accelerated and combined analyses of aging behavior of the most common thermal interface materials. The presented tester is based on steady state technique. TIMs have been tested under real conditions, all needed parameters have been measured in-situ i.e. temperature, pressure, heat flux, bond-line thickness. Furthermore TIMs can be tested under preset tilt or under different working temperatures. The measurements are controlled by software. Some results of investigated gap filler were also discussed. The gap filler was cured under different curing conditions. All samples were tested under the same condition (50 cycles á 10 steps). The results show large differences in respect to reliability and aging behavior of TIMs. More results of further materials under new applications will follow and be presented soon in another paper.

ACKNOWLEDGMENT

The Authors appreciate the support of the EU FP 7 Integrated Project "Nanopack". We would like to thank Marcus Schulz, Raúl Mrossko, Enrico Merten and Jürgen Keller for their encouragement, further thank goes to Anton Sattelmayer for his great job.

REFERENCES

[1] Young R, et al (2006) Developments and trends in thermal management technologies – a mission to the USA. www.lboro.ac.uk/research/iemrc/ documents/ ... /CB2007.pdf

[2] B. Wunderle, J. Kleff, D. May, M. Abo Ras, R. Schacht, H. Oppermann, J. Keller and B. Michel. "In-situ measurement of various thin Bond-Line-Thickness Thermal Interface Materials with Correlation to Structural Features". Proc 14th Therminic 2008, Rome, Sept 24-26 2008

[3] M. Abo Ras, B. Wunderle, D. May, H. Oppermann, R. Schacht, B. Michel. "Influences of technological processing and surface finishes on thermal behaviour of thermal interface materials", 16th Therminic 2010, Oct 6-8, Barcelona, Spain, 2010.

[4] R. Schacht, D. May, B. Wunderle, O. Wittler, A. Gollhardt, B. Michel and H. Reichl. „Characterization of Thermal Interface Materials to Support Thermal Simulation". Proc. 12th Therminic 2006, Sep 27-29, Nice, Côte d'Azur, France, 2006

[5] Chia-Pin Chiu; Biju Chandran; Mello, K.; Kelley, K. "An accelerated reliability test method to predict thermal grease pump-out in flip-chip applications" Electronic Components and Technology Conference, 2001.

[6] ASTM: Standard Test Method for Thermal Transmission Properties of Thin Thermally Conductive Solid Electrical Insulation Materials, Designation D 5470-01