Transient thermal measurements for dynamic package modeling: new approaches

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Abstract

The first part of the paper presents a measurement approach that can be applied for the generation of multi-port compact dynamic thermal models of IC packages. In the second part of the paper our recent advances in the development of the appropriate measurement tools are described, as a new thermal transient test chip or a new thermal transient test equipment.

1. Introduction

The latest challenge in the field of thermal characterization is the generation of the dynamic compact thermal models of the packages. The usual way for the data acquisition for such a purpose is the thermal transient measurement: the recording of the "heating curve" or the "cooling curve". In these measurements a dissipation step is applied to (or switched off from) the test chip mounted into the package and the temperature response of the chip is recorded. The evaluation of the recorded responses is a question that many researchers have been dealing with for the last two decades – see e.g. [1], [2], [3], [4].

Using sophisticated evaluation methods the compact model of the package can be extracted from these responses.

This methodology works quite well if the generation of "one-port" models is intended only. In other words: if the thermal boundary conditions are fixed on each side of the package. Assuming multiple terminals, the package has to be considered as a *thermal multi-port*. Several authors recognized this earlier; a good summary of these papers can be found e.g. in [5]. Reports of recent results in this field can be found in [6] and [7]. For the generic "multi-port" modeling the one-port methodology can be extended for the price of a more complex measuring sequence: the responses have to be recorded for a number of thermal boundary conditions on the outer sides of the package [8]. If we use the electrical analogy of the thermal conduction, the situation is similar to the one presented in Figure 1. Applying measurements only on the 1st port while the terminations are changed on the other ports identifies the behavior of an electrical multi-port in such a case. Neither measurement nor excitation is applied on the further ports. Based on these measurements, the identification of the model is possible however the problem is rather ill conditioned.

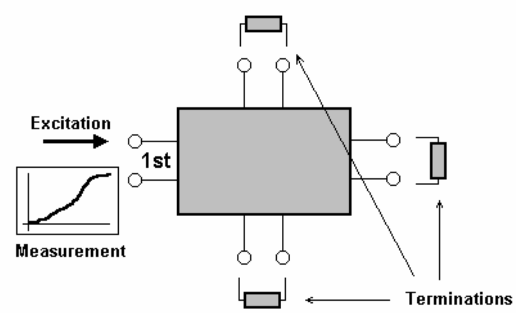

Figure 1. A method for the identification of a multi-port: both the excitation and the measurement are done on the primary port while the terminations on the further ports are varied

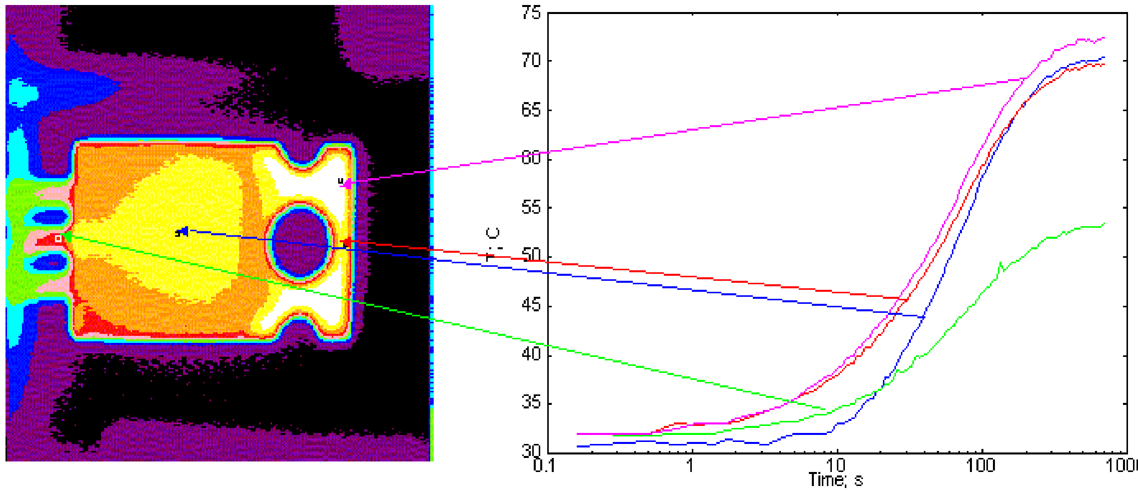

Figure 2. Thermal transients on the surface of the package of a power BT, recorded using IR thermography

In this paper first we describe an attempt to overcome the above-mentioned problem. In section 2 our idea of multi-port thermal transient measurements is discussed in more detail. The second part of our paper in section 3 describes some advances in the field of "conventional" (one-port) thermal transient measurements.

2. Multi-port thermal transient measurements

To overcome the ill conditioned nature of the problem highlighted in section 1, the proposition is straightforward: in the measurement procedure not only the first port but all further ports should be used as well. This way we acquire more information about the package and we obtain more precise knowledge about the package regions far from the first port.

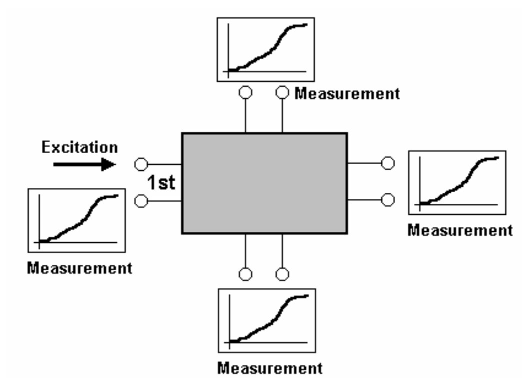

Figure 3. Excitation is on the primary port, measurement on the further ports as well

The first step is to measure on the "further" ports, see Figure 3. This means to measure the thermal transients on the outer surface of the package. In our experiments we used IR thermography to achieve this goal. We completed the AGA782 infrared imaging system in our laboratory such that it is now capable to record "thermal movies". From the recorded frame sequence the temperature vs. time function for any spot of the image can be extracted. Such functions are shown in Figure 2. The device under test (DUT) was excited electrically at the "first port" and the heating curve was recorded in several surface points of the package. The recording was quasi-logarithmic on the time scale, with a maximal sampling rate of 40 ms. The signal-to-noise ratio on the measured functions is about 40 dB.

The second step is to apply excitation on the "further" ports as well, see Figure 4. A power laser beam is suitable to provide such an excitation. The temperature response can be measured either on the first port inside the package using the thermal test chip, or on the "further" ports using the IR method. This experiment is still in progress.

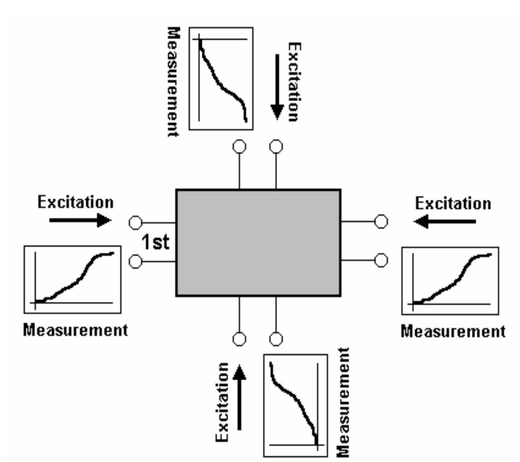

Figure 4. Both excitation and measurement are carried out on every port

Data acquired from multi-port thermal transient measurements are the basis of multi-port dynamic compact models. For the identification of such multi-port models heuristic approaches are already known in the literature (see e.g. [9]), but we are targeting a more generic approach. Our first steps in this field were already briefly described [8].

3. Advances in the field of one-port thermal transient measurement

In the following we describe our developments regarding a new method of thermal transient measurements and we also describe a new thermal transient test equipment.

3.1. Thermal transient testing without a tester

Recently we presented a new method for the thermal transient measurement [10], [11] where the measuring equipment was completely eliminated and its functions were transferred partly into an "intelligent" thermal test chip (TTMC chip), partly into the control software – constituting the TTMK, our Thermal Transient Measurement Kit, see Figure 5.

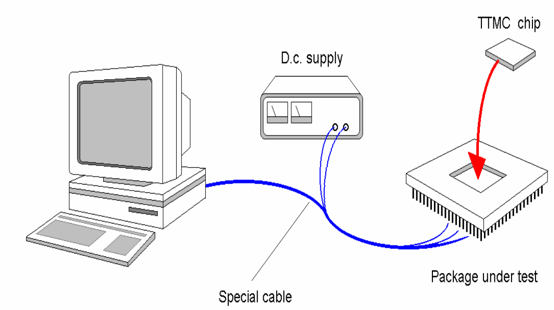

Figure 5. Arrangement for thermal transient measurement "without a tester"

One of the advances is that first version of the "intelligent test chip" (shown in Figure 6) can be replaced by a newly designed one, see Figure 7.

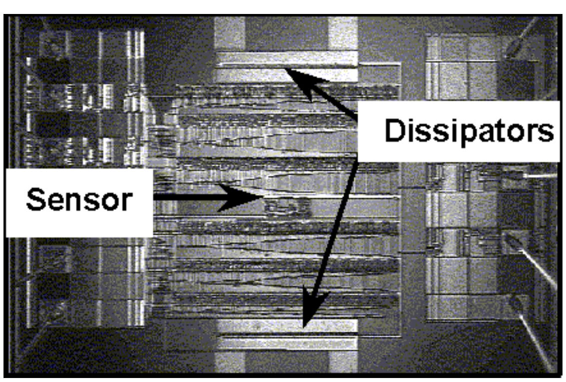

Figure 6. The present test chip of TTMK

In order to meet the JEDEC standards the dissipating device has been changed in the new design: now a resistor is switched by a MOS transistor – see Figure 8 – instead of the transistor itself. This way covering the dominant part of the chip surface with dissipating element became possible.

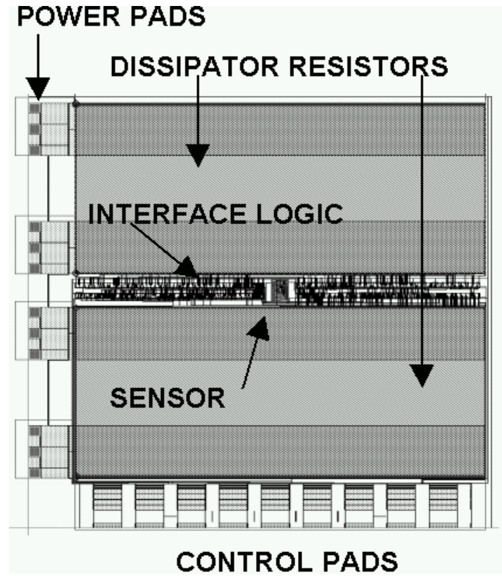

Figure 7. The new TTMC

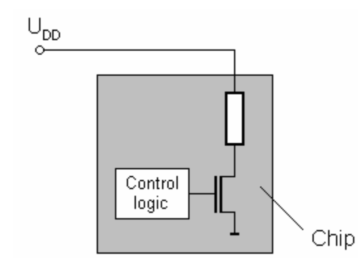

Figure 8. Control of the dissipation in the new TTMC

The size of the new chip is 4×4 mm^2. The dissipation of one dissipating resistor inside the chip in case of 5 V heating supply voltage is about 1.9 W. Note, that this dissipation level can be easily adjusted to the actual needs by changing the voltage applied at the U_{DD} pads of the test chip. The dissipation level is limited by the maximal allowed current density on the aluminum lines connecting the resistors to the power pads. The maximal allowed dissipation can be reached at a power supply of 15 V, resulting in a dissipation level of a resistor of about 17 W. Further flexibility is allowed by the special pad arrangement of the new chip. Note that pads are placed on two sides of the chip only. In this way large package cavities can be tiled as shown in Figure 9.

The applied frequency-output temperature sensor has also been modified: its output frequency is increased by a factor of 2.5. The interface logic was also modified a little such that in the ultimate digital temperature value a further bit was gained. This means that either the temperature resolution or the maximal sampling rate can be increased by a factor of 5 with respect to the earlier TTMC chip. This new design is in the foundry phase now.

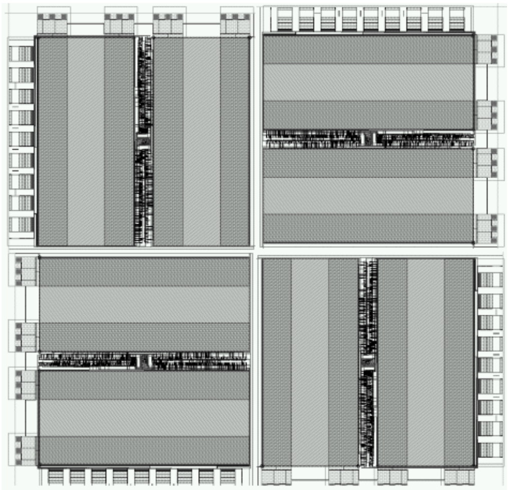

Figure 9. Tiling a large area with the new TTMC chip

Another new feature of the Thermal Transient Measurement Kit is that the measurement software is running now on advanced computing platforms. The original DOS-based software runs now under 32-bit Windows operating systems. The major challenge was to implement the measurement loop with very strict timing requirements in a multitasking environment such. In our experiments with the Win32-based measuring software we realized, that proper measurements can be executed only with PC-s with a clock rate of 200 MHz or faster. On slower computers, although the measuring software does not become unstable, it may lose measured samples of the thermal transient responses, resulting in unusable recorded functions.

The new software integrates the control of the measurement and the evaluation of the results into a single framework, see Figure 10. Different results of the measurement evaluation (provided by the THERMODEL program [12]) are shown simultaneously in child windows, where the function plots can be copied from by the usual copy-paste mechanism e.g. into a word processor.

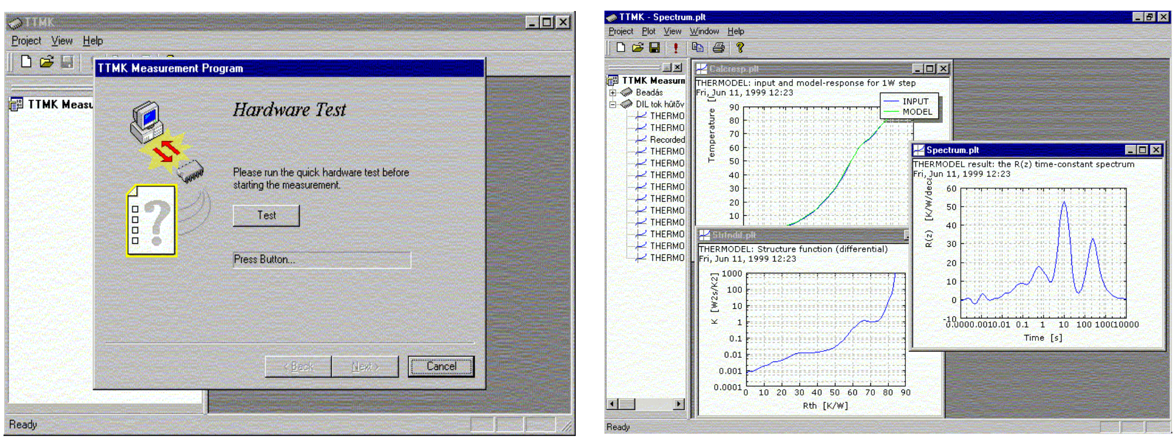

Figure 10. Screen snapshots of the new, Win32 based software of the Thermal Transient Measurement Kit.

3.2. A new Thermal Transient Tester

Based on the earlier experience gained in the THERMINIC project by an experimental equipment, MicReD has developed its own equipment: *T3ster*™, the *T*hermal *T*ransient *T*ester. This new equipment allows high precision "conventional" (one-port) thermal transient measurements as well as multi-port measurements with the help of specially designed thermal test chips, such as THBII, which was developed and presented earlier [8].

The technical parameters of the equipment are as follows: the sampling rate can be changed stepwise in subsequent powers of 2, between 1 µs and 16 s. The resolution of the temperature measurement is 12 bits with the LSB corresponding to 0.006 – 0.01 K (using a diode as temperature sensor).

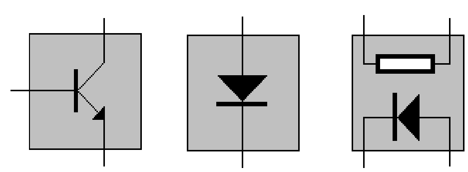

Figure 11. Thermal test structures handled by the basic T3ster model

The basic model of the equipment provides four channels for four simultaneous measurements. There is an option for a thermocouple channel, too. The equipment is completed with a thermostat for calibration. The control of the equipment is performed by a computer, which is connected by a conventional parallel interface card. This allows continuos displaying of the acquired data during the measurement process. The basic equipment is designed for measurements with three different kinds of test structures (see Figure 11) inside the package under test: either a bipolar transistor, a diode or a conventional thermal test chip with a resistor and sensor diode can be used. With optional hard-ware/software modules sophisticated thermal test chips, such as THBII shown in Figure 12 or TTMC chips (see Figure 6, Figure 7 and Figure 9) can also be used in the future. In case of application of THBII-like arrangements (with an array of dissipators and sensing elements) multi-port measurements inside the package cavity will be possible.

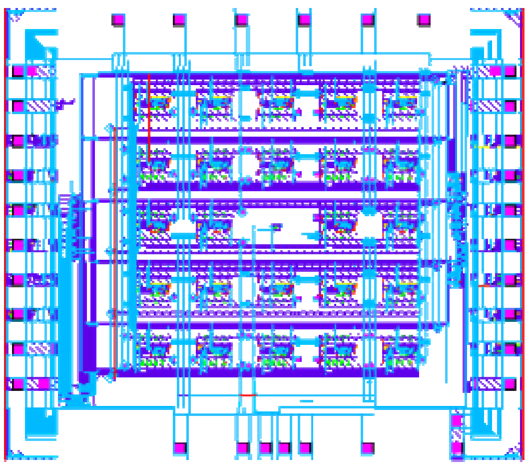

Figure 12. Layout diagram of the THBII thermal benchmark chip with an array of dissipator and temperature sensor cells and a temperature sensor diode in the middle

4. Conclusions

In this paper we highlighted the importance of multi-port thermal transient measurements. A new measurement arrangement – using laser beam excitation and IR measurements at various locations – has been suggested. Advances in conventional, one-port thermal measurement tools have also been described, such as the new, JEDEC-conformant thermal transient measurement chip and the new software of the TTMK kit, or the new thermal transient tester, which with special thermal test chips is also capable to perform multi-port measurements.

5. Acknowledgements

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