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# Temperature Evolution as an effect of Wire-bond Failures in a Multi-Chip IGBT Power Module

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# Temperature Evolution as an effect of Wire-bond Failures in a Multi-Chip IGBT Power Module

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**Abstract**

Wire-bond lift-off are reproduced experimentally by sequentially sectioning the wires of the hottest die of a multi-chip IGBT module. The results shows that degradation balances the temperature of the dies, until a certain point when unbalancing occurs, and the module fails catastrophically.

## Introduction

In power cycling experiments, the temperature of switches needs to be estimated. When a switch is composed of several dies in parallel, the dies may not have the same temperature. In the absence of individual monitoring of each die, it is often assumed that the average temperature is estimated by most common TSEPs (Thermo-Sensitive Electrical Parameters) such as Von. However, the temperature of each individual die is unknown. Some studies explain and evaluate the initial temperature unbalance [1]. When the module ages due to thermo-mechanical cycles, wire-bonds degrade and lift-off, modifying the current path towards the dies, and thus modifying the loss and temperature distribution. The evolution of the estimated temperature (i.e. with Von) with degradation is assessed in [2, 3] in the case of single and multi-chip respectively. However, the evolution of the temperature distributions with degradation is not experimentally accessed in the literature.

In this paper, the lift-off of wire-bonds is experimentally reproduced, and consequences on temperature distribution are observed and analyzed. The sectioning is performed until power module functional failure. The failure was captured optically and electrically, and is analyzed.

## Experimental protocol

An industrial six-pack 1200V/150A IGBT power module was used as a DUT (Device Under Test). Its gel was removed, and the surface was black painted. The 3 phases were connected in parallel, to produce a single half-bridge leg with 3 dies in parallel.
The DUT was used in a back-to-back power converter as previously described in [Degrenne, IWIPP] in unipolar modulation mode operating at 600 V, 80A, 15 kHz, and a duty-cycle of 0.5. A thermal camera was used to capture the average temperature of the area of each die. After identification of the hottest die, the hottest wire-bond was identified and sectioned. This sectioning order was selected because hottest wire-bonds are typically the most stressed. In between each sectioning, high current pulses of 150A were generated at constant heat-sink temperature, so as to capture the electrical resistance increase associated with the cuts. The experimental protocol is shown in Fig. 1.

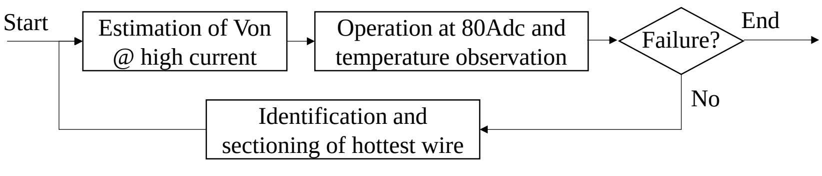


Fig. 1: Experimental protocol

## Observation and analysis of temperature distribution

The normalized results of temperature distributions are shown in Fig. 2. The graph can be divided in 3 parts. The first part is the balancing part. Initially, when 0% of the wire-bonds are cut, the die B is the hottest, and the die A the coldest. From 0% to 14% degradation, the wire-bonds of die B are cut, until the temperature of the die B and

C equalize. From 14% to 30%, the dies C and B are cut, until their temperature equalize the one of the die A. The second part is the balanced part. From 30% to 56%, the die temperatures are well balanced. The third part is the unbalancing part. At 56% of degradation, the die A is the less damaged, and probably the one crossed by the highest current, so as to compensate for its better thermal performances. It is subject to the sectioning of its 4th wire-bond. Its resistivity increases significantly, and the current is redistributed. As a result, its temperature decreases below the one of dies B and C. The same phenomenon occurs again from 56% degradation to 100% degradation. When a high temperature decrease is observed, for example at 72% and 82% of wire-bond degradation, the electrical resistance increase is also significant as shown in Fig. 3.

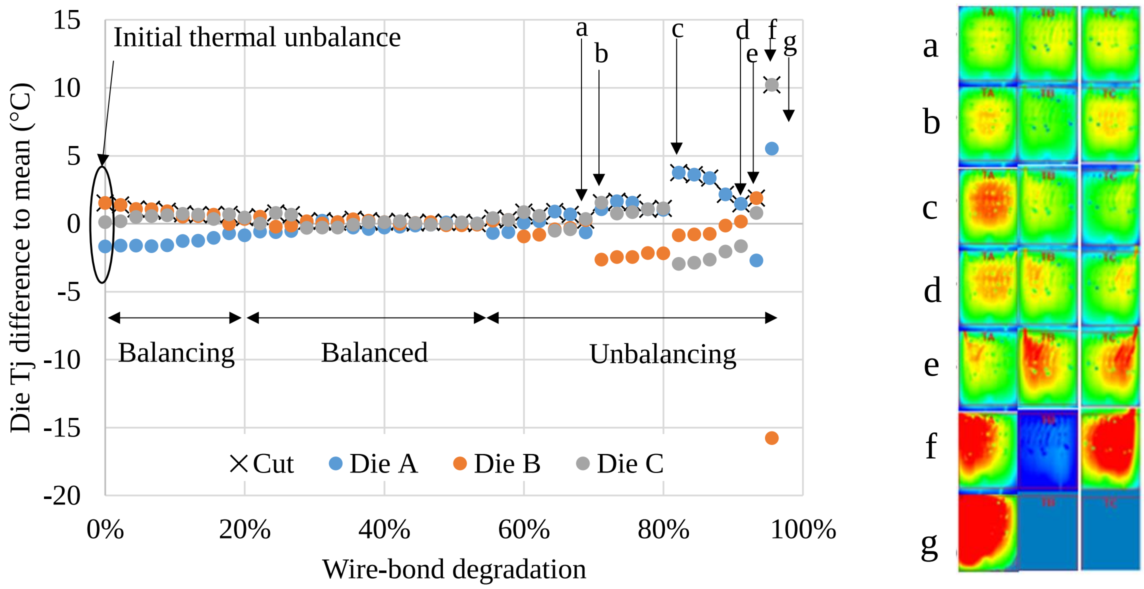

Fig. 2: Temperature distribution with wire-bond degradation

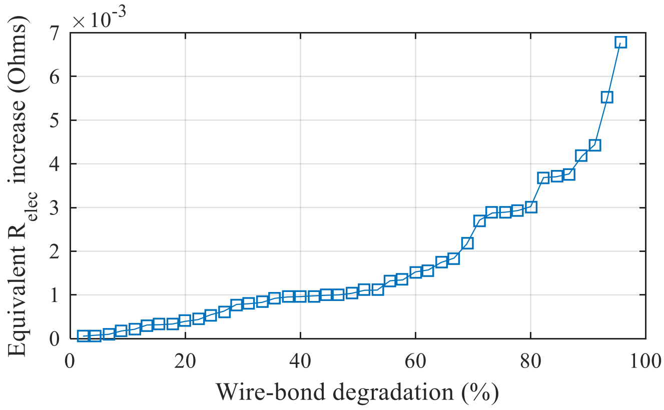

Fig. 3: Electrical resistance increase with wire-bond degradation

**Observation and analysis of catastrophic failure**

At the instant of failure, only one wire-bond was remaining on the die A. The current was increased progressively, and failure occurred for a current of 70A. The Fig.4 shows the evolution of the hot-spot (remaining wire-bond), an image of the explosion, and the electrical waveforms at the instant of the failure. The failure mode is the thermal runaway of the remaining wire-bond. The melting of aluminum leads to the complete failure of the power module in the form of a catastrophic explosion. The electrical waveforms reveal the following sequence of events:

1. Failure of top switch in short-circuit during its on-state
2. Turn-on of bottom switch leading to a type 1 arm short-circuit
3. Turn-off of bottom switch by the desat protection leading to a wrong state of the arm and to the increase of the load current
4. Turn-on of bottom switch by gate driver leading to a normal state of the arm normal and a stabilization of the current

5. Second arm short-circuit

In this experiment, the traditional desat protection was thus ineffective since the top die is uncontrollable after its failure in short-circuit. It is also likely that a protection based on over-temperature detection would be ineffective since the temperature over the 3 dies is low before explosion. On the opposite, estimation of the temperature of each individual die may be effective.

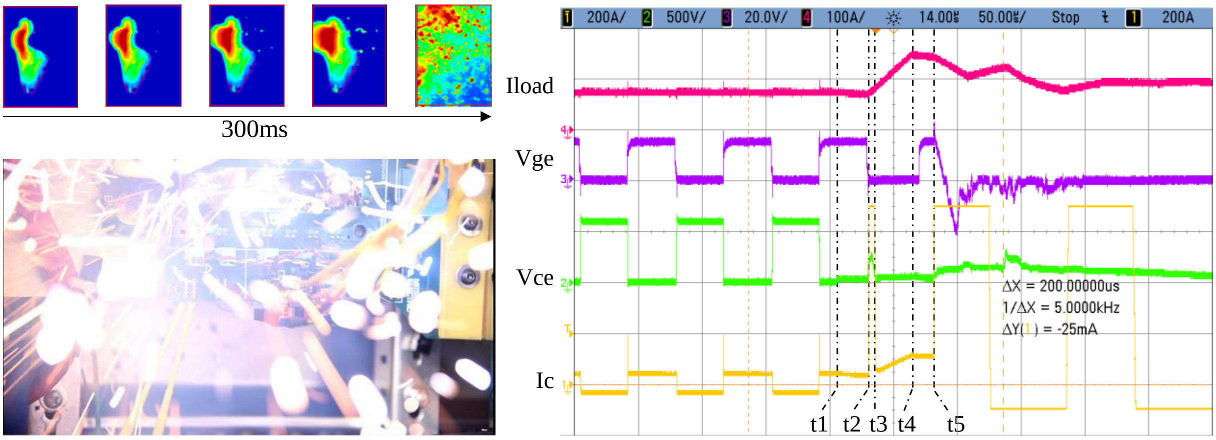


Fig. 4: Catastrophic failure

## Conclusions

If the following hypothesis is formulated: "In a real power module subject to thermo-mechanical wear-out of its wire-bonds only, the hottest wire-bond is the next to fail", the results of this experiment shows that thermal balancing occurs naturally, ultimately leading to a balancing of the degradation. After a certain level of degradation, an unbalancing occurs progressively, ultimately leading to the failure of one die. The catastrophic failure resulting from wire-bond sectioning leads to a short-circuit failure and is not prevented by the traditional desat protection. As a result, a highly energetic explosion could be observed.

## References

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