Results of Active Power Cycling with High Temperature Swing

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1 Introduction

The environmental conditions of power devices, especially with respect to the maximum specified temperature, are getting harsher. In automotive applications e.g. some parts of the electronic will move under the hood where the modules are subjected to an environmental temperature higher than 100 °C. The automotive standard AEC-Q101 stipulates that power components must withstand 5000 power cycles at temperature swings higher than 100K. To fulfil the requirements in reliability the demand for module lifetime prediction of given packaging concepts at high temperature increases.

2 Investigated Packaging Technologies

In the transfer molded, DCB based technology the power semiconductor chips are soldered onto a DCB ceramic substrate together with a lead frame with up to five pins. Subsequently chips and DCB are covered by molding compound. Figure 1a shows the cross section of a DCB based transfer molded package.

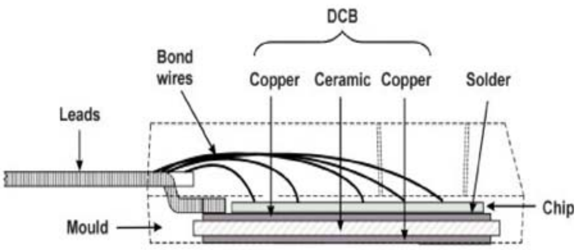

Fig.1a: cross section of transfer molded DCB based component

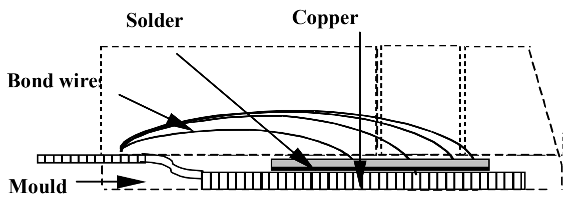

Fig.1b: cross section of transfer molded copper based component

In the transfer molded copper based technology the top side of the power semiconductor chip is wire bonded while the bottom side is soldered on copper lead frame. The package is typically moulded plastic to fix the leads for external electric connections (Fig.1b). However, the reliability of this technology is restricted by mismatch of thermal expansions coefficients of silicon chip and copper lead frame.

3 Test Results

3.1 DCB based, transfer molded diodes

Three power cycling tests with ΔT_j=105K (PC1), ΔT_j=130K(PC2), ΔT_j=155K(PC3) were performed. The minimal junction temperature ($T_{j,min}$) was 40 °C. Failure criteria, which decide that a device has reached its end-of-life, were:

- An increase of the forward voltage V_F at 50A and room temperature of 20% with respect to the initial value.
- An increase the thermal resistance between junction and heat sink (R_{thj-h}) of 20% with respect to the initial value, or
- Leakage current I_R exceeds 1mA.

The executed tests and achieved results are published in details in [1]. Figure 2a shows a photograph of a component of PC1 taken with the electron microscope after test stop. One can observe the trace of a completely lifted of wire and the heel cracking of the adjacent wires.

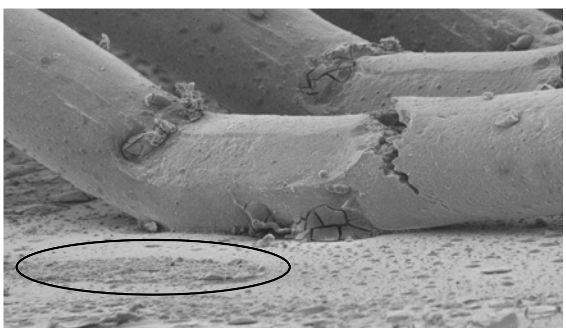

Fig.2a: Bond wire lift-off and heel cracking of a diode power cycled at ΔT_j=105 K

In PC2 (ΔT_j=130K) the majority of the tested diodes shows no significant increase of V_F, however a clear increase of T_j was obvious. Exceeding the maximum allowed increase of the thermal resistance from junction to heat sink ($R_{th,j-h}$) was the dominant failure mode. However, analysis of the diodes after test has shown that bond wires of some diodes have aged too. The failure mechanisms of bond wires and the solder fatigue seem to occur at virtually the same time.
Diodes power cycled in PC3 (ΔT_j=155K) showed a similar thermal and electrical behaviour to the diodes in PC2. However, increase of thermal resistance by solder fatigue could be clearly identified as the main failure mechanism in this test.

3.2 Copper based, transfer molded diodes.

A group of six diodes have been power cycled at ΔT_j =110K. After ca. 3800 cycles, investigations of the failure parameters have shown that two diodes exhibit no blocking capability. The crack of the chip observed in the analysis of a failed diode after test (Figure 3) clarifies this effect.
Till ca. 22000 power cycles, no further failures were registered and test was stopped because no reasonable accurate failure forecast is possible with the achieved failure data.

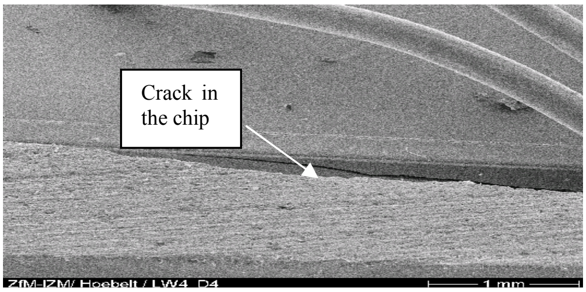

Fig.3: Chip crack of copper based, transfer molded diode power cycled at ΔT_j=110K

4 Evaluation of Results

The following diagram presents a comparison between the results achieved in the test of the DCB based components at end-of-life failure probability for 50% from the Weibull analysis (solid line) and an extrapolation of the results achieved during the evaluation of standard modules with base plate in the LESIT programme [2] with the fit given in [3] (broken line). All test results are compared for test condition $T_{j,min}$=const=40°C.

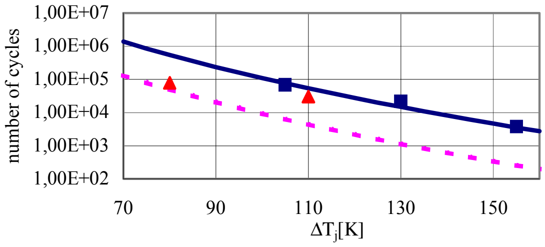

Fig.4: Comparison between transfer molded DCB based components, and extrapolated LESIT results

The DCB based transfer molded components show a clearly increased power cycling capability compared to the extrapolation of the results for standard modules.
Mechanical stress originating from mismatch of thermal expansion coefficients of silicon and copper lead frame can be identified as failure cause in the test of copper based, transfer molded devices.

5 Conclusion

The DCB based transfer molded devices show at high temperature swings a higher power cycling capability than standard modules with base plate. They promise to fulfil the automobile standard AEC-Q101 at ΔT_j>130 K Regarding the analysis of the components after test, supported by the end-of-life failure mode of PC2 and PC3, one can assume that the compound material decelerates the bond wire lift off. This clarifies the high power cycling capability of this assembly technology.
The result of testing copper based, transfer molded diodes led to the assumption that this packaging technology is unsuited for applications with temperature swings in the range of 110K, if chips large chips, e.g. with area of 63 mm^2 or more, are used.

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References

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