Evaluation of a DCB based Transfer Molded Component with High Temperature Swings

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Abstract:

In this paper we present the results of power cycling tests of transfer molded, DCB based power components at temperature swings up to 155 K. The results are statistically analysed. The tested components show a power cycling capability approximately 10 times higher as expected from extrapolation of results of standard power modules.

I. INTRODUCTION

In the today automotive electronic systems there is the demand to electronic components for operating temperatures higher than 150 °C. The automotive standard AEC-Q101 stipulates that power components must withstand 5000 power cycles at temperature swings ($\Delta T_j = \Delta T_{jmax} - \Delta T_{jmin}$) higher than 100K. Furthermore, there is the demand of design engineers in the electronic field to predict the life-time of their components in dependence of temperature swing.

During the LESIT project standard IGBT modules with base-plate have been tested under different ΔT_j [1], the results can be summarised in the empirical rule [2]:

$$N_f = A \cdot \Delta T_j^{\alpha} \cdot \exp\left(\frac{E_a}{k_B \cdot T_m}\right) \qquad (1)$$

with:
N_f = number of power cycles;
k_B = Boltzmann-constant = $1{,}380 \cdot 10^{-23} \mathrm{JK}^{-1}$;
E_a = activation energy = $9{,}891 \cdot 10^{-20}$ J;
A = constant = 302500 $\mathrm{K}^{-\alpha}$;
α = constant = -5,039;
T_m= medium junction temperature [K]

However, since the completion of LESIT project in 1995, packaging technology was improved ;in addition it is not clear whether the equation derivated from the LESIT results can be extrapolated towards high junction temperatures.

II. PACKAGING TECHNOLOGY

Basically, the DCB based transfer molded components look similar to conventional discrete components; however significant differences become obvious regarding the cross section of an opened DCB based transfer molded package shown in figure 1.

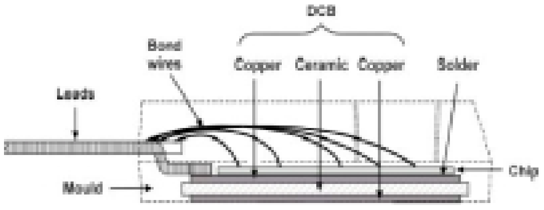

Fig.1: cross section of transfer molded DCB based component

The chips are not mounted on a solid metal lead frame, but on a DCB substrate. It consists of a ceramic substrate with copper layers bonded onto its top and bottom side. The bottom copper is used to transfer the operational heat dissipation while the top copper carries the chips, whose upper side is wire bonded towards the DCB pattern and the pins. To provide electrical and mechanical protection, this subassembly is transfer molded [3].

III. TEST SET-UP AND CONDITIONS

Three power cycling tests with ΔT_j=105, ΔT_j= 130 K and ΔT_j=155 K were performed. In each test a load current heats up the junctions of three identical half bridge components mounted on forced-air cooled AL heat sinks within the heating time t_{on}. After a maximum reference temperature on the heat sink under the centre component was reached, cooling was activated until the minimum reference temperature was reached again. We selected the heat sink temperature as a control parameter because it excludes the influence of changes in the cooling efficiency but will include the effects caused by changes in the thermal resistance of the components under test or the heat sink interface [2].

Fig. 2 shows a photograph of the test set-up with diodes under test and the cooling fans.

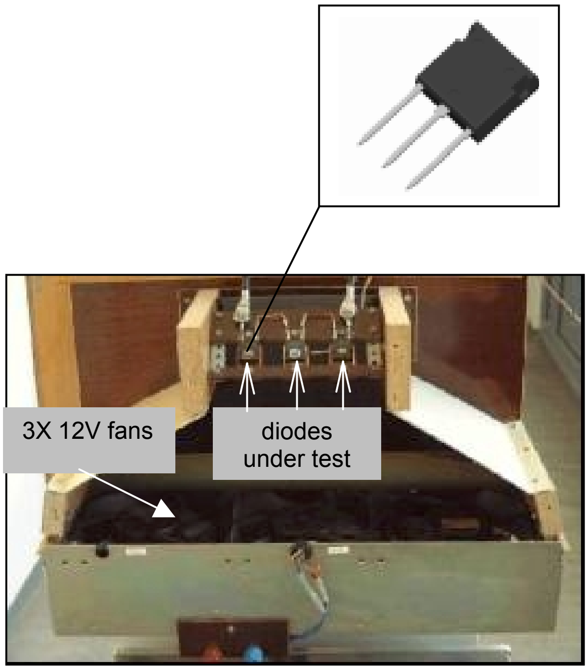

Fig.2: Section of the test station

Junction temperature(T_j), heat sink temperature (T_h) and the averaged dissipation power P_D within two typical power cycles are monitored in Fig. 3.

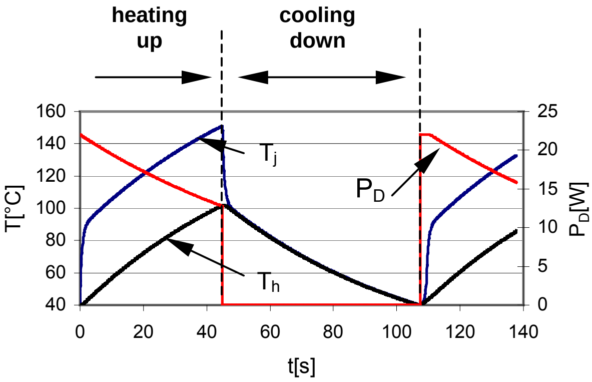

Fig.3: Typical waveform of junction and heat sink temperature and dissipation power during power cycling test

The Load current exhibits breaks of ca. 2ms, where V_F at a sense current of 50mA can be measured. According to the calibrated $V_F(T_j)$ characteristic at the sense current, the junction temperature can be determined. (see Fig.4).

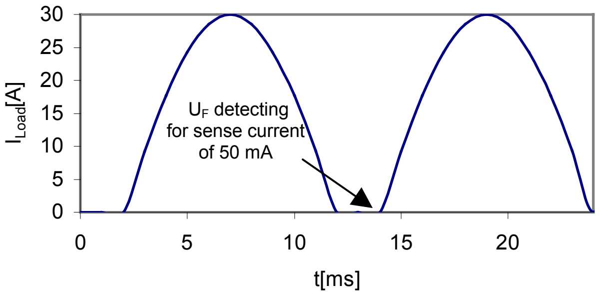

Fig.4: Determining T_j

The forward voltage V_F at 50A and room temperature, the thermal resistance between junction and heat sink ($R_{thj\text{-}h}$) and the leakage current I_R serve as failure indicators. An increase of V_F or $R_{thj\text{-}h}$ of 20% with respect to the initial values or I_R exceeding 1mA mean that the device has reached its end-of-life.

For determination of the failure indicating parameters during the test, runs were stopped on a regular basis and the assemblies were removed from the station. The V_F curve was traced up to $I_{F,max}$ =50A and the leakage current I_R was measured at rated voltage V_R=1200V; both measurement were executed at room temperature. Thermal resistance $R_{thj\text{-}h}$ was calculated according to the following equation:

$$R_{thj-h} = \frac{T_{j\max} - T_{h\max}}{P_D} \qquad (2)$$

where:

T_{jmax} =maximum junction temperature [°C]
T_{hmax} = maximum heat sink temperature [°C]
P_D = averaged dissipated power [W]

The calculation of P_D was performed according to equation (3); taking into account the temperature dependency of the barrier potential V_{F0} and the differential resistance r_B. $V_{F0}(T_j)$ and $r_B(T_j)$ characteristics were obtained by tracing V_F curve at different junction temperatures. (hence the exponential decay of P_D during the heating up traced in Fig.3):

$$P_D = V_{F0} \cdot I_{Lav} + r_B \cdot I_{Lrms}^2 \qquad (3)$$

where:

V_{F0}=barrier potential [V], r_B=diff. resistance[Ω]
$I_{L,av}$= average load current [A]
I_{rms} =root-mean-square value of load current [A]

IV. TEST RESULTS

The first group was cycled at ΔT_j=105 K. A current with the average value ($I_{L,ave}$) of 18 A heats the chips up to 145 °C within ca. 38 sec. Following, the whole system was cooled down to 40 °C within ca. 56 sec.
A representative behaviour of $T_{j,max}$ and V_F during this test is shown in figure 5. The graphic shows that a small increase of T_{jmax} can be observed after approximately 30000 cycles, while a significant increase of V_F can be detected after approximately 60000 cycles. Exceeding of the allowed 20% of the initial value of V_F was the dominant failure mode in this test.

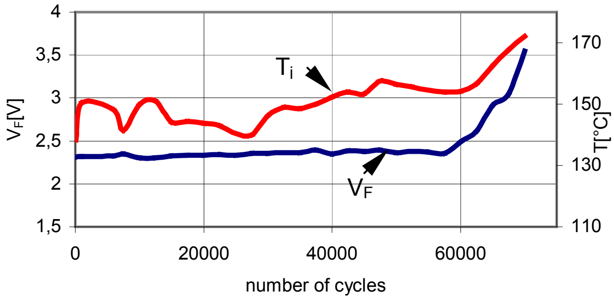

Fig.5: Power cycling test for ΔT_j=105K

In the power cycling test for ΔT_j = 130 K, the heating phase lasted ca. 20 sec. and the cooling down took ca. 70 sec. The nominal maximum and minimum junction temperatures (T_j) were 170 °C and 40 °C respectively. The average value of the load current ($I_{L,ave}$) was 28 A.

In the test for ΔT_j= 155 a total cycle time of ca. 113 sec. was achieved ca. 28 sec. for heating up and ca. 85 sec for cooling down. A load current with average value of 32 A heats the junctions up to 195 °C.

Exceeding of the maximal allowed increase of the thermal resistance from junction to heat sink (R_{thj-h}) was the primary failure mode in these two tests. An increase over the maximal allowed 20% of the initial value of V_F was not detected till test end, it might have followed shortly hereafter. Figures 6 and 7 show a representative behaviour of $T_{j,max}$ and V_F during the tests for ΔT_j =130 K and 155 K respectively.

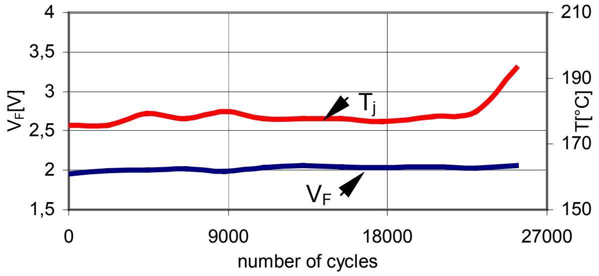

Fig.6: Power cycling test for ΔT_j =130K

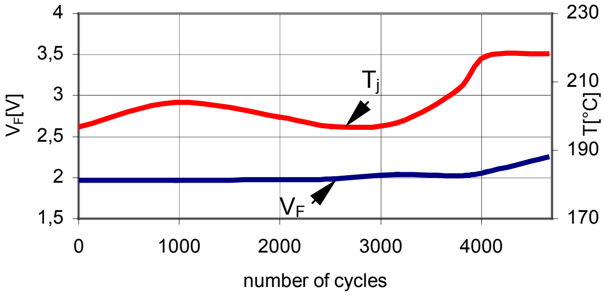

Fig.7: Power cycling test for ΔT_j = 155K

V. STATISTICAL ANALYSIS

For the statistical analysis of the results we applied Weibull distribution, which is widely used with referring to reliability considerations. Weibull analysis provides reasonable accurate failure forecasts even with small sample sizes. Furthermore, it provides a simple and useful graphic plot; the horizontal scale is a measure of life or aging parameters (i.e. number of cycles) ; the vertical scales are the probability density $f(x,\alpha,\beta)$ and cumulative percentage failed $F(x,\alpha,\beta)$ defined as follows [4],[5]:

$$f(x,\alpha,\beta)=\frac{\alpha}{\beta^{\alpha}}\cdot x^{\alpha-1}\cdot\exp\left(-\left(\frac{x}{\beta}\right)^{\alpha}\right) \tag{4}$$

$$F(x,\alpha,\beta)=1-\exp\left(-\left(\frac{x}{\beta}\right)^{\alpha}\right) \tag{5}$$

The Weibull slope (α) indicates which class of failures is present. An α lower than 1 indicates the system or the samples are more likely to fail early and become more reliable as the aging parameter increases; this period is called 'infant-mortality'. At α = 1 failures occur independent of aging parameter and an α value higher than 1 indicates wear-out failures. The characteristic life (β) is defined as the age at which 63,2% of the units will have failed [5].

The Weibull parameters α and β of the test results were obtained using the Maximum Likelihood Estimation method (MLE) [6].
The Weibull analysis of the three power cycling tests with the distribution parameters are summarised in Figures 8, 9 and 10:

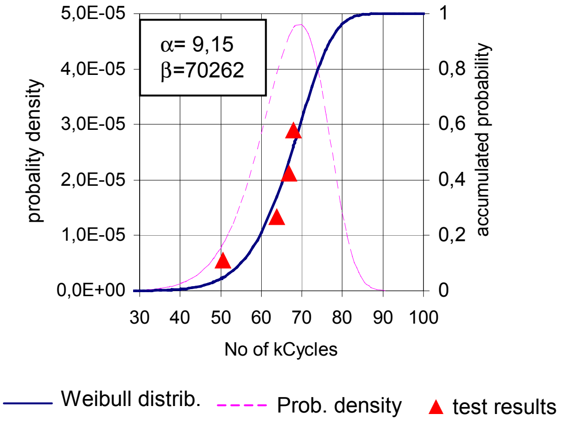

Fig.8: Weibull analysis for ΔT_j =105K

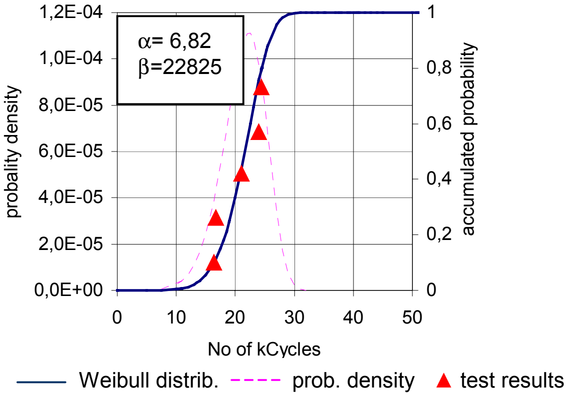

Fig.9: Weibull analysis for ΔT_j=130K

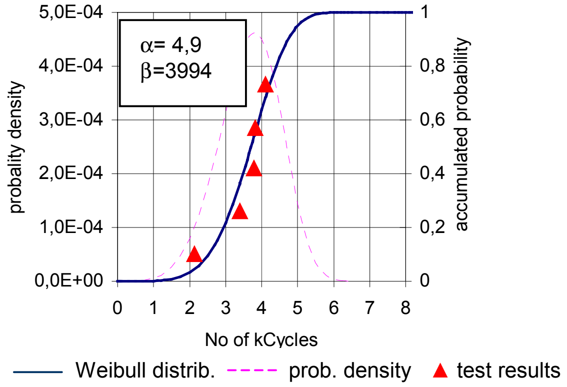

Fig.10: Weibull analysis for ΔT_j = 155K

VI. COMPONENTS AFTER TEST

Figure 11 shows the photograph of a component power cycled at ΔT_j = 105 K taken with an electron microscope. The trace of a completely lifted-off wire (see ellipse) and the heel cracking of the adjacent wires are clearly shown. This observation supports the assumption that wire-lift off; indicated by the increase of V_F was the end of life failure mode in this test. Comparable observations are in [7].

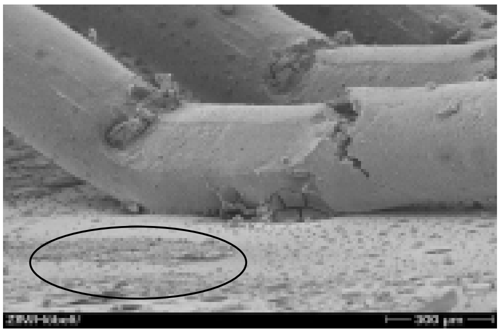

Fig.11: Bond wire lift off and heel cracking of a component power cycled at ΔT_j=105 K

It is noticeable that the above picture is from a diode which didn't fail till test stop at 75000 power cycles, however it was obvious that failure would have occur soon.

VII. EVALUATION OF RESULTS

A comparison between test results for end-of-life probability of 50% from the Weibull analysis and an extrapolation of LESIT results for the test condition $T_{j,min}$ = 40 °C is shown in Figure 12.
DCB based transfer molded components exhibit a 10 to 12 times higher power cycling capability at temperature swings between 110K and 155K compared to the extrapolation of the LESIT results.

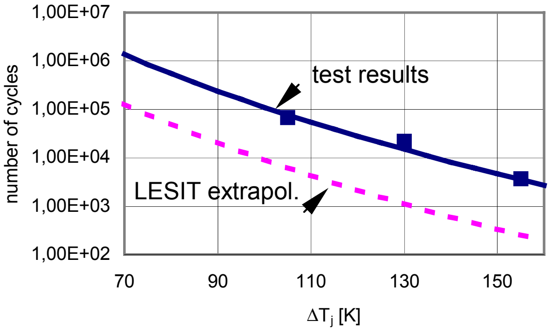

Fig.12: Test results at Weibull 50% and extrapolated LESIT results to the condition $T_{j,min}$ =40 °C

A fit of the results allows the calculation of the power cycling capability of the DCB based transfer molded components.

VIII. CONCLUSION

The DCB based transfer molded components 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 >130K.

Regarding to the analysis of the components after test, supported by the end-of-life failure mode of the tests at ΔT_j = 130 and ΔT_j = 155 K, one can assume that the compound material decelerates the bond wire lift off which clarifies the high power cycling capability of the assembly technology.

The Weibull analysis shows a satisfactory distribution of the end-of-life failure meaning that the failure mechanism is well defined.

References

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