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Prediction of the epoxy moulding compound aging effect on package reliability

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ABSTRACT

Most semi-conductor devices are encapsulated by epoxy moulding compound (EMC) material. Even after curing at the prescribed temperature and time in accordance with the supplier's curing specifications often the product is not yet 100% fully cured. As a consequence, the curing process of a product continues much longer, leading to curing effects of the EMC during the lifetime of the package. In this paper, the effect of EMC curing during lifetime on package reliability is investigated. The visco-elastic mechanical properties of two commercial EMC materials are measured as a function of aging time. The resulting data is used to construct material models that are used in FE calculations. Aging effects on critical semi-conductor failure modes die cracking, compound cracking, wedge break, and delamination are addressed. Die and compound crack risks are predicted by common stress analysis. The risk of wedge break occurrence is investigated by detailed 3D modeling of the actual wires in the package using a global–local approach. Conclusions on delamination risks are made based on a parameter sensitivity analysis using a 3D cohesive zones approach to predict transient delamination. The package reliability study shows that the effect of EMC aging affects relevant failure modes in different ways.

1. Introduction

The concept-phase and design-phase of a new product in the semi-conductor industry generally represent an evolution through a number of iterations based on three main activities: design-rules, testing (including accelerated reliability testing) and simulations. Most typically, simulations are used to predict product behavior during manufacturing and testing based on material characteristics known from previous tests or provided by suppliers. In this manner improvements are accomplished in product behavior and manufacturability. If performed correctly, the results obtained provide valid input with respect to typical behavior at the beginning of product-lifetime. Some application areas of semi-conductor products are characterized by harsher requirements (in terms of environment, temperature cycle testing, etc.) than others (see e.g. [1]). In that case it is useful, if possible, to also consider through simulations product behavior during the product-lifetime.

Chemical and physical aging of plastics has been studied in e.g. [2,3]. The qualitative behavior of aging of EMCs can be captured, but quantitative behavior is highly dependent on manufacturer, composition, manufacturing processes, etc.

In this paper we present a pragmatic approach to analyse a semi-conductor product behavior both at start and during the product-lifetime by assuming that the largest aging effect is exhibited by the EMC and by benchmarking EMC behavior at three product-lifetime moments: 0 h, 1000TCs (thermal cycles) and 2000TCs. Section 2 explains the material characterization. Section 3 presents the effect of aging on the thermo-mechanical properties of a typical semi-conductor EMC. The effect on die and EMC crack risks, wedge break risks and delamination risks is discussed in chapters 4–6, respectively.

2. Determining the aging effect

The thermo-mechanical material properties of two typical semi-conductor epoxy moulding compounds (EMC) were measured at 0 h, after 1000 thermal cycles and after 2000 thermal cycles. The 0 h material is identical to the EMC material after moulding and 4 h PMC at 175 °C, which is in correspondence with the supplier specifications. Thermal cycles (TC) are performed between −50 °C and +150 °C following the relevant JEDEC standard (see [4]). The EMC materials are referred to as EMC A and EMC B. At each stage the coefficient of thermal expansion (CTE) and Young's modulus (E) as a function of temperature were characterized by

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Thermo-Mechanical Analysis (TMA) and Dynamic Mechanical Thermal Analysis (DMTA) respectively. The CTE was determined by differentiation of the measured thermal strain to temperature. The DMTA measurement was used to fully characterize the visco-elastic properties as a function of time and temperature. Thus the visco-elastic master curve of the EMC could be created (see [5]). Initially, the properties at 0 h of one third of the test samples were measured. Next the remainder of the batch is subjected to thermal cycles. After 1000 cycles half of the remaining samples and after 2000 cycles the other half of the samples were characterized.

3. Aging effect on thermo-mechanical properties

In this section the measured thermo-mechanical properties of the EMCs at 0 h, after 1000 and after 2000 thermal cycles are compared.

Fig. 1 shows the CTE at $T = -50$ °C and at $T = 150$ °C at three different stages in time. The results are normalized to the −50 °C 0 h CTE result of EMC A. Firstly, note that at −50 °C, the CTE of EMC B is much higher than the CTE of EMC A, whereas the CTE at 150 °C is in the same range. At 150 °C the CTE of EMC A is two to three times higher than at −50 °C, whereas the CTE of EMC B only increases by a factor of approximately 1.5. This can be understood from the different glass transition temperatures T_g of EMC A and EMC B.

As can be seen from Fig. 2 T_g for EMC A is in the range of 150 °C, meaning in the range of the upper measurement temperature for CTE. But T_g of EMC B is in the range of 180 °C, meaning well above the upper measurement temperature for CTE. This difference means that CTE at 150 °C for EMC A is already much closer to the rubber state than for EMC B and thus explains the lower factor between CTE at −50 °C and CTE at 150 °C for EMC B compared to EMC A. At both temperatures the CTE of the aged EMCs reduces with respect to the 0 h result. At −50 °C a respective approximate linear reduction of 8% and 2.5% for EMC A and EMC B per 1000TC is observed. At 150 °C the CTE of EMC A initially decreases by 28%, but the result after 2000TC is 5% higher than the 1000TC result.

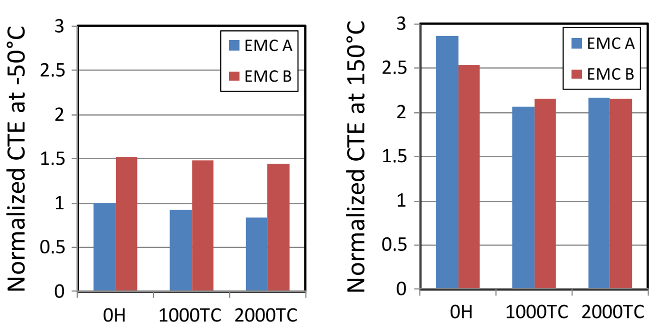

Fig. 1. Aging effect on EMC.

For EMC B the CTE result decreases by 15% at 1000TC and is unchanged from 1000TC to 2000TC. The CTE increase–decrease behavior of EMC A can be explained by the change of the glass transition temperature T_g over thermal cycling as shown in Fig. 2. Initially T_g is located at 145 °C which is slightly lower than the highest evaluated temperature. After 1000 and 2000 cycles T_g has evolved to a constant value of 155 °C, which is slightly higher than the maximum temperature in this analysis. This means that CTE at 0 h is already near the rubber CTE which is considerably higher than the glass state CTE, while the CTE of the 1000TC and 2000TC result is still in the glass transition region. Consequently, the CTE considerably reduces after cycling with respect to the 0 h CTE. The difference between 1000TC and 2000TC at 150 °C is more arbitrary. The strain change in the glass transition region is very rapid introducing a larger variation on the measured values. This means that it is more difficult to determine the CTE in the glass transition region in an accurate way. Therefore, the small increase from 1000TC to 2000TC can be attributed to the reduction of measurement accuracy in this region. Since the glass transition temperature of EMC B stays well above 150 °C changes in CTE are mainly due to curing. Therefore, it can be concluded that curing has little effect on CTE levels of EMC B after 1000TC.

The Young's modulus at −50 °C and 150 °C at the respective points in time is compared in Fig. 3. Again normalization is performed with the 0 h result of EMC A at −50 °C as the norm. For all results, the Young's modulus increases with increasing cycles. The Young's modulus at −50 °C increases with 2% (A) and 8% (B) after 1000TC. For EMC A the Young's modulus stays constant after that. For EMC B, however, the Young's modulus increases by another 5%. At 150 °C the Young's modulus increases with 21% after 1000TC and additionally 4% after 2000TC for EMC A. This significant relative difference in increase can again be explained by the shift of T_g. The Young's modulus of EMC B shows the opposite behavior. Here a small increase of 6% after 1000TC is followed by another 20% increase after 2000TC. This behavior of EMC B at 150 °C is remarkable, the more since the CTE shows more increase after 2000TC than after 1000TC. At this point no clear explanation was found.

In summary, the observed effects of EMC properties as a function of thermal cycling are:

- Increase of Young's modulus.
- Increase of glass transition temperature.
- Decrease of CTE below T_g.

These are in line with literature results (see [2,6,7]) reporting on material properties as a function of curing degree. Therefore, it seems that the observed change in material properties can be attributed to further curing of the EMC during accelerated reliability testing. Furthermore, it shows that the contribution of curing as a function of TC to material properties change is different for

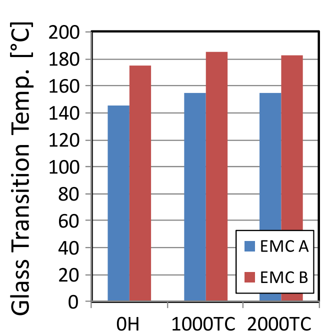

Fig. 2. Aging effect on T_g.

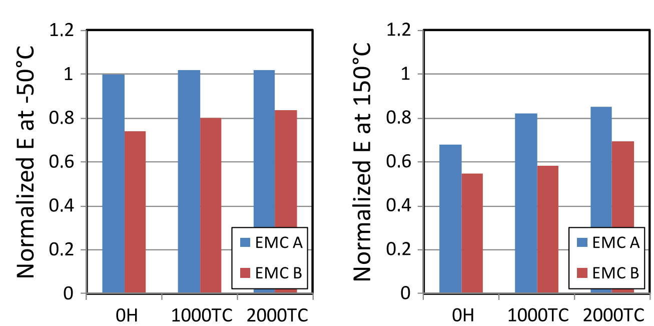

Fig. 3. Aging effect on Young's modulus.