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Thermal aging modeling of Molding Compound under High-Temperature Storage and Temperature Cycling Conditions

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Abstract

In microelectronic packages, generally the chip is encapsulated by a molding compound (MC). The MC provides a mechanical support for the chip and isolates it from the environment and as a result protects the encapsulated chip. It is well known that MC's are polymer-based materials. When packages are exposed to a harsh environment such as to high-temperature storage or to thermal cycling, the mechanical properties of the MC's can change significantly. Consequently this could result into reliability issues of these packages. For a long time, there was no simple and efficient model method available to simulate the mechanical behavior of these packages under thermal aging conditions. As a result, it was hard to forecast the package reliability after a period of thermal aging. Since in our previous work [1,2] the thermomechanical properties of MC's before and after thermal aging were systematically characterized, the above problem was merely solved. A simple and efficient modeling method was proposed to simulate the thermal aging effects on MC's [2]. In this paper, a bi-material sample consisting of a MC layer on a Copper substrate is prepared and used to verify the proposed modeling method at two different thermal conditions: High-temperature storage (HTS) and Temperature cycling (TC). Based on the proposed modeling method the mechanical behavior of the bi-material sample after aging under these (different) thermal conditions are established throug FEM simulation. The simulation results match the experiment results quite well.

1. Introduction

MC's are polymer-based material, which include various ingredients to comply with various requirements. In order to match the mechanical properties of the silicon chip as good as possible, a high percentage of silica filler is present, bonded together by an epoxy matrix and some additive ingredients. The material properties of the filler are stable during application of HTS and TC conditions. However, the material properties of the epoxy matrix can change significantly when the temperature exceeds a certain temperature and while exposed to air. These changes can be attributed to chemical processes such as oxidation and degradation. In fact, during thermal aging a thin outer layer of the MC is oxidized. This oxidized layer has different properties compared to the original MC. Meanwhile, the thickness of this layer is growing with the (exposure) time. As a result, the thermomechanical properties of whole MC change significantly. As a result a mismatch between the oxidized layer and the unaged core is present. With increasing thickness of the oxidized layer the influence of this mismatch is increasing too. In turn, this leads to a changing state of stress and strain in a package and consequently affects the reliability of the package under TC and HTS. Due to the impact on long-term reliability, the characterization and modeling of the aging process in MC's has become an important issue.

In the past, some models to simulate the aging behavior were proposed [4-8]. However, these have some disadvantages for direct application in commercial FEM software. Additional programming is needed. Therefore, a simple and efficient modeling approach is required.

In our previous work [2], a simple and useful modeling method was proposed which is called the "two-layer" model to take into account the thermal aging effects of MC's. A systematical characterization approach was introduced as well [1]. In the present paper, the modeling method and the specific characterization data are applied to model the thermal aging effects of a bi-material sample under two different thermal conditions: HTS and TC. First, in Chapter 2, the bi-material sample preparation and testing is introduced. Next, in Chapter 3, the measurement results of the mechanical behavior of the bi-material samples before and after thermal aging are presented. Also cross-sections of the bi-material samples after HTS and TC conditions are considered by applying fluorescence microscopy. Finally, in Chapter 4, the simulation results as obtained by using the proposed modeling method are shown and compared to the experimental data.

2. Bi-material sample and Tested Setups

2.1 Sample Preparation

In order to independently verify the proposed modeling method and characterization parameters of unaged and aged MC, a special bi-material sample is designed and manufactured. The bi-material sample consists of a MC layer on a Copper substrate is presented in Figure 1. Firstly, sample is produced using same condition as in real production line . After the molding process, standard post-mold curing is performed. The sample is cut into bi-material strips for mechanical testing.

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2.2 Test Setup

In order to be able to simulate the behaviour of the bi-material samples under HTS and/or TC conditions, first appropriate material models for aged and unaged MC are required. These models and characterizations were reported in previous work [1].

The bi-material samples have to be aged under two different thermal conditions, HTS and TC. For HTS a normal isothermal oven is used. The oven used for TC is shown in Figure 1. It includes two parts: a cold chamber and a hot chamber. The transportation of samples from the hot part to the cold part (and reverse) only takes a few seconds. The Temperature Profiles are characterized in Figure 2. For HTS the samples are aged at a constant temperature. For TC the samples are exposed to high temperature for many short periods of time and also for an equal amount of short periods of time a low temperature.

Fig.1: TC oven

A special setup was developed to measure the magnitude of warpage of a bi-material sample due to aging and temperature loading. Here, at a chosen position the normal displacement is monitored in real-time during testing. The principle is shown in Figure 3.

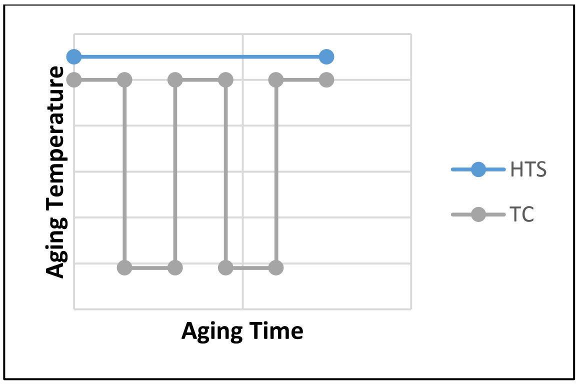

Figure 2: Temperature profiles

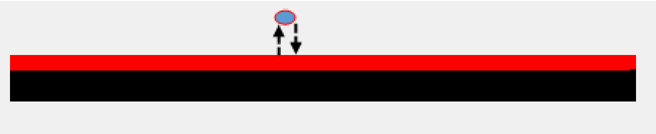

Figure 3: Principle of measurement method

3. Measurement Results and Discussion

The MC's properties will change not only under HTS, but also under TC. This was found in our material characterization of MC after the TC treatment. The purposes of these material characterizations is: on the one hand, to see the difference in the material property changes under HTS and TC exposure, and on the other hand, to check if the proposed model method can capture the mechanical behavior changes of the bi-material samples after exposure to HTS and TC conditions. Thereby, a number of pure MC's and bi-material samples are exposed in the HTS and TC ovens for several weeks, seperately. After that, the material characterization for aged MC's and verification testing for aged bi-material samples are performed subsequently.

In this section, only measurement results are shown and discussed. The detailed information of the measurement procedures can be found in our previous work [1].

3.1 Mechanical Testing

Normally, a Dynamic Mechanical Analysis-DMA was performed to obtain the viscoelastic model of MC. After the same period of exposure in HTS and TC, the MC's are taken out from the ovens to perform a DMA test to generate the viscoelastic model for FE simulation. The results are shown in Figure 4-7.

The DMA tests are performed for samples of two different thicknesses. The storage and loss modulus of aged MC's at various exposure times are plotted in the above pictures. Following conclusions can be drawn:

- The storage modulus of aged MC's in case of HTS is higher than in case of TC (with the same exposure time).
- For the thick sample, two peak values of the loss modulus are always found after HTS as well as after TC. Meanwhile, the first peak value remains the same in thick samples after HTS and TC, only the second peak value is shifting to high temperature with increasing exposure time. For the thin sample, only one peak value was found after 1-week of TC treatment. And two peak values were found after 1 week and 2 weeks HTS treatment. After that, only one peak value existed in the loss modulus after HTS. The reason is that the oxidation process is continuously going on during the exposure.
- Within the same exposure time, the temperature at the second peak value in the HTS oven is always higher than in the TC oven. It means the aging level of MC is different. This is explained in the next section.

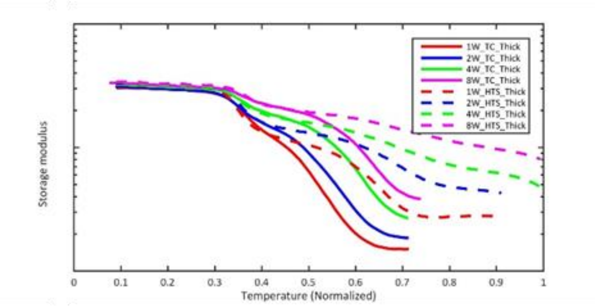

Fig.4: Storage Modulus after HTS & TC (Thick samples)

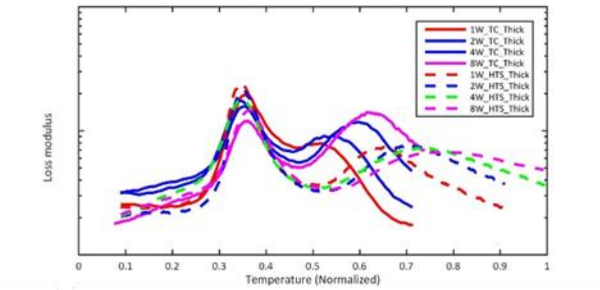

Fig.5: Loss Modulus after HTS & TC (Thick samples)

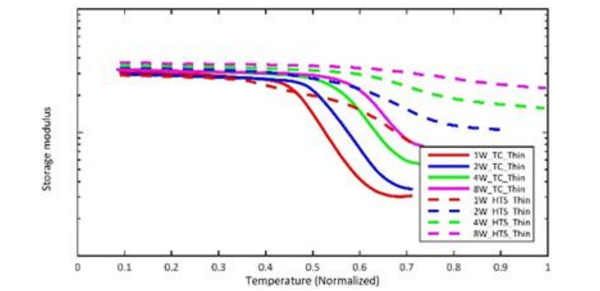

Fig.6: Storage Modulus after HTS & TC (Thin samples)

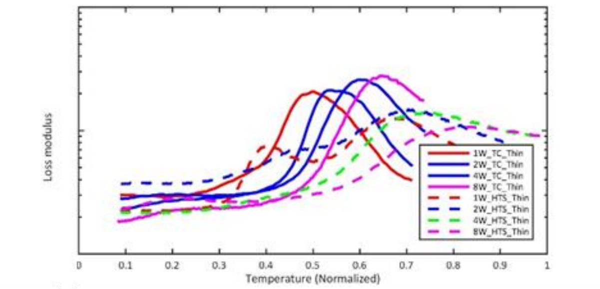

Fig.7: Loss Modulus after HTS & TC (Thin samples)

3.2 Microscopy

To visualize the difference between two different thermal conditions, the cross section of samples after various exposure times is checked by fluorescence microscopy. Meanwhile, the measurement settings are kept the same for all samples. Just looking to the color of the aged layer, it is observed that the aged layer in HTS is closer to dark (Figure 8). However, the light-yellow zone is found in Figure 9. It means that the aging level in HTS is much higher than in TC. That's the reason why the DMA test result of the storage modulus in HTS is much higher than in TC (in particular the rubbery states) and the temperature at the second peak value of the loss modulus in HTS is much higher than in TC.

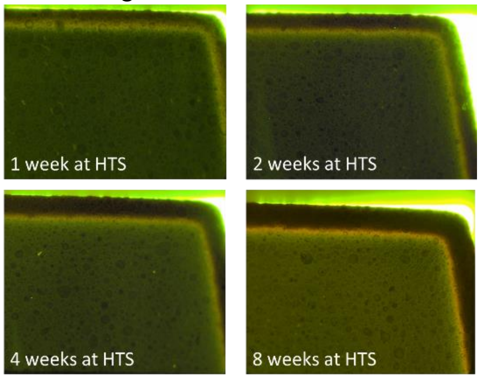

Fig.8: Cross Section of MCs after HTS

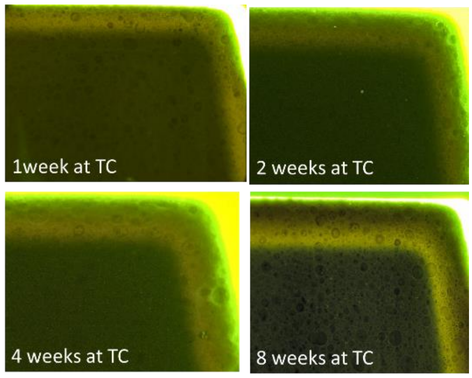

Fig.9: Cross Section of MCs after TC

3.3 Test Results of Bi-material samples

The goal of this paper is using the proposed modelling method to predict the mechanical responses of the bi-material after HTS and TC treatment. The samples are divided into two parts: one part is exposed in the HTS oven and the rest is exposed in the TC oven. The measurement procedure is introduced in section 2. Here, only the tested results are discussed.

The curvatures of bi-material samples at room temperature are different for both exposure conditions. With increasing exposure time, more curvature was found. In this paper, only the bi-material sample exposed for 500 hours in HTS and TC are considered, separately.

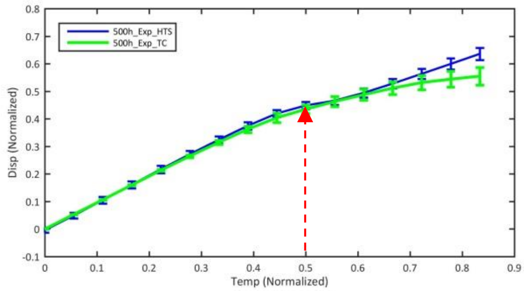

Fig.10: Curves of displacement vs. temperature after 500h exposure at HTS and TC

The results show that the bi-material samples previously exposed to different conditions have a different mechanical behavior, especially at the second part of the curves. The turning point in the curves is the glass transition temperature of unaged MC, since after 500 hours aging those bi-material samples are only partly aged (see Figure 11). In general, a second turning point should be found in this measurement. However, here it is not the case because the test- temperature is limited. The initial curvature of the bi-material samples was not considered here. Only measurement data under temperature loading are compared. Therefore, the curves are starting from 0 at the beginning.

4. Simulation and Discussion

Based on previous work [1-2], simulations were performed for the bi-material samples, after exposure to HTS and TC as required. After a certain exposure time, the cross section of this bi-material sample was considered by fluorescence microscopy (Figure 11). It is clear to see that an oxidized layer was created at the surface of the MC and no oxidation layer was found at the interface between MC and Copper except at the edge. Based on this picture, a 3D FE model was established as shown in Figure 13. The outside layer is the aged layer and the core is unaged MC. The bottom is the copper substrate.

The measurement was discussed in the section 3. The simulation process followed the measurement procedure. For comparison between simulation and measurement the curves of displacement vs. temperature are plotted together in Figure 14. (simulation: red dot line; measurement: solid line). The simulation could very well predict the mechanical behavior of aged bi-material for the different thermal exposure conditions. It means that the modelling method as proposed in [2] could capture the mechanical behavior under HTS and TC treatment quite well.

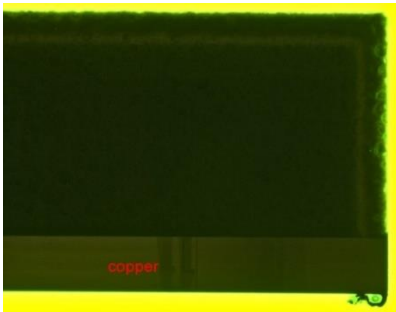

Fig.11: cross section of bi-material sample after aging

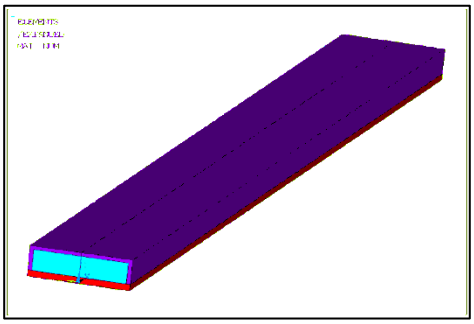

Fig.13: 3D FE model of aged bi-material sample

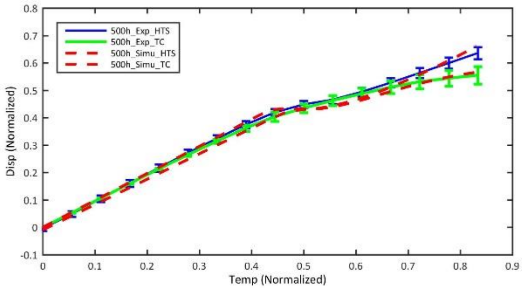

Fig. 14: Simulation vs. Experiment

4. Conclusions

In this paper, the MC's and a special bi-material samples under two different thermal exposure conditions were investigated and compared. The conclusions are as follows:

1) The mechanical properties of aged MC's under two different thermal exposure conditions show differences after the same exposure time;
2) A special test method was developed for verification purposes;
3) The proposed modelling method could not only capture the mechanical behaviour change after HTS, but also after TC.

References

1) Zhang, B., Johlitz, M., Lion, A., Ernst, L., Jansen, K. M. B., Vu, D. K., & Weiss, L., "Aging of epoxy moulding compound-Thermomechanical properties during high temperature storage". In 2016 17th International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems (EuroSimE2016).
2) Zhang, Bingbing, *et al.*, "Modelling of thermal aging of Moulding Compound by using an equivalent layer assumption." Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems (EuroSimE), 2017 18th International Conference on. IEEE, 2017.
3) J.de Vreugd. "The Effect of Aging on Molding Compound Properties", PhD. Thesis, Delft University of Technology, Delft, The Netherlands, 2011

4) D.G. Yang, F.F. Wan, Z.Y. Shou,et al. Effect of high temperature aging on reliability of automotive electronics. Microelectronics Reliability, 2011, 51(9-11): 1938–1942
5) Ge, Dandong, Chai Chee Meng, lan K. L. L, Walter M, "A Comparison Study of Thermal Aging Effect on Mold Compound and Its Impact on Lead-frame Packages Stress", International Symposium on Advanced Packaging Materials (APM), pp 403-409, 2011.
6) Reinhard Pufall, Michael Goroll, J Mahler, Werner Kanert,M Bouazza, Olaf Wittler, and Rainer Dudek. Degradation of moulding compounds during highly accelerated stress tests–a simple approach to study adhesion by performing button shear tests. Microelectronics Reliability, 52(7):1266–1271, 2012.
7) Jansen, K. M. B., *et al*., "Thermal aging of molding compounds." Electronic Packaging Technology & High Density Packaging (ICEPT-HDP), 2010 11th International Conference on. IEEE, 2010.
8) Johlitz, M. On the representation of aging phenomena. J. Adhesives, 2012, 88:620-648.