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To cite this article: P Rafiee *et al* 2017 *J. Phys.: Conf. Ser.* **790** 012026

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Evaluation of thermal degradation of polymer based electronic materials by non-destructive testing

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Abstract. Thermal degradation of polymeric materials used in microelectronic packages was studied by means of experimental modal analysis in combination with finite element methods. The devices were subjected to vibrational loads subsequent to various stages of high temperature storage and their modal response was recorded. Statistical methods and finite element analysis were applied to quantify and evaluate the alteration of the modal response of the packages due to the degradation / delamination of the silver filled epoxy adhesive and the glass filled epoxy resin molding compound. It was shown that changes in the material properties of the molding compound due to surface oxidation is the dominant cause for alteration of the modal response of encapsulated packages exposed to high temperatures.

1. Introduction

Semiconductor packages are exposed to various environmental and loading conditions which may lead to their degradation and subsequent failure during the operational life [1]. Mechanical and interfacial adhesion properties of the epoxy resin based packaging materials like the molding compound (MC) and chip adhesive (CA) are sensitive to high temperature exposure especially in the presence of oxygen and moisture [1-3].

In this study finite element analysis (FEA) and vibrational based modal analysis were employed for detection of thermally induced damage of the epoxy based packaging material in microelectronic devices. While the experimental modal analysis provided information on the time and temperature dependent total degree of damage, FEA allowed separate calculation of the effect of thermal degradation of MC and CA on the alteration of the modal response of the packages.

2. Experimental procedure

The test devices consisted of commercial microelectronic packages in molded and unmolded conditions provided before trimming and forming of the lead frame. The MC consisted of an epoxy resin with quartz fillers and the chip adhesive was a silver-filled electrically conductive epoxy material. Aging was performed at 250°C up to 230h at air for molded devices and 250°C up to 100h in argon atmosphere for unmolded ones. The harsh storage temperature was chosen to induce higher degrees of damage to the epoxy material [2,4]. The specially designed sample holder allowed precise mounting and removal of the sample for intermittent measurements between the thermal treatments without any changes in the test conditions (Figures 1a-b). The molded chips were excited using a fixed-free set-up and a fixed-fixed set-up was used for testing the unmolded chips (Figures 1c-d). A



sweep signal within the frequency range of 0.1-10 kHz was applied for excitation of the samples. The mode shapes and the frequency response were recorded by a SLDV (Polytec PSV400).

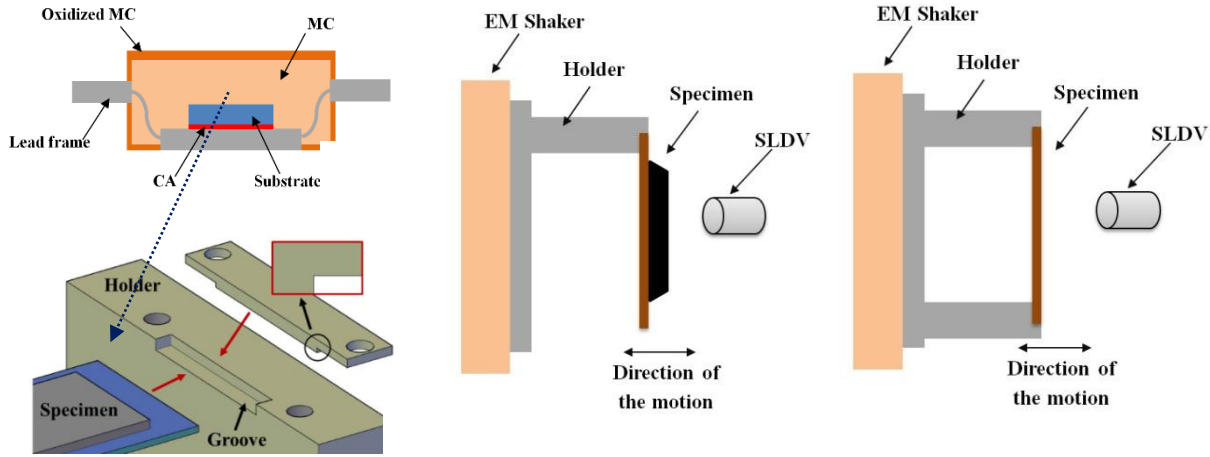


Figure 1. Schematic images of (a) molded package, (b) sampleholder for positioning of the device, (c) fixed-free set-up for molded and (d) fixed-fixed set-up for unmolded devices.

The degree of thermal damage was evaluated by intermittent failure analysis. The oxidized MC layer reached a thickness of 70 μm after 230 hours as determined from metallographic cross sections. Scanning acoustic microscopy analysis showed that minor local delamination of the CA occurred in the unmolded devices and the unmolded ones were not affected [4]. Statistical evaluation of the data was conducted by ER [5] and MAC [6] methods by using equations (1) and (2) in which $g(f)$ and $r(f)$ are the resonant frequencies and ψ_x and ψ_A the mode shapes of the sample in the aged and original conditions.

$$ER = \frac{\int [g(f) - r(f)]^2 df}{\int [r(f)]^2 df} \quad (1)$$

$$MAC(A, X) = \frac{\left| \sum_{j=1}^n (\psi_X)_j (\psi_A)_j \right|^2}{\left(\sum_{j=1}^n (\psi_X)_j (\psi_X)_j \right) \left(\sum_{j=1}^n (\psi_A)_j (\psi_A)_j \right)} \quad (2)$$

The accuracy of the set-up was verified by repeated mounting/testing/un-mounting of several original sample from which an average ER value of 3.9e-5 with a standard deviation of 5.3e-5 was obtained.

3. Results and discussions

3.1. Experimental modal analysis

The shift of the resonant frequencies of the molded sample as a function of aging time is presented in figure 2. The minor changes in 1st and 2nd and the rapid drop of the 3rd and 4th resonance frequencies after 90 hours indicate changes in the material properties or degradation processes in polymeric material. The calculated ER values reached from 3.9e-5 for non-aged (original) samples to 0.038 for those aged up to 230 hours with an increase of about thousand fold (9.5e2). The dependency of ER and 1-MAC values to increase in aging time is given in figure 3. The ER method appears to be more sensitive to the slight thermally induced changes of the material properties to the thermal exposure up to 100 hours.

The effect of chip adhesive degradation on the modification of the modal response is presented in figures 4a and 4b. Storage at 250°C results in thermal decomposition and mass loss of the epoxy adhesive material and on the other hand occurrence of interfacial delamination between the Si chip and the lead frame. The latter effect results in a reduction of the stiffness of the structure. The observed increase and the subsequent decrease of the ER is a result of opposite effects of the reduction of the mass and stiffness on the resonant frequency shifts (Figure 4b). Numerical analysis of this experiment showed the same trend as explained in the next section.

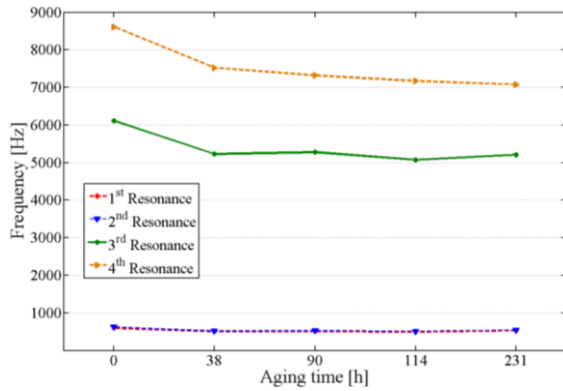


Figure 2. Variation of resonant frequencies as a function of thermal aging of molded packages.

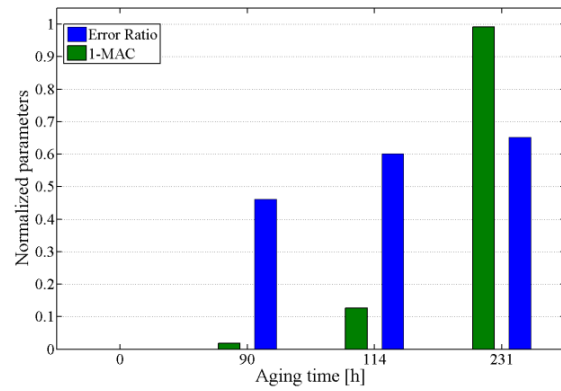


Figure 3. Variation of the modal response as quantified by MAC and ER methods.

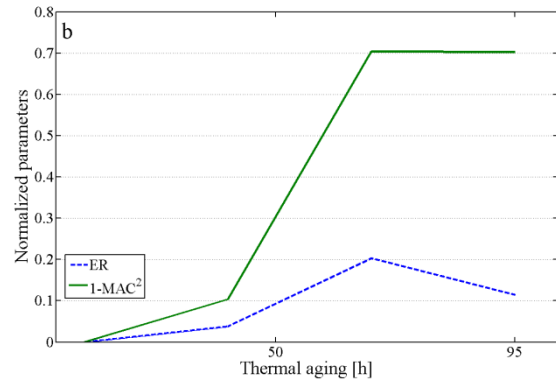
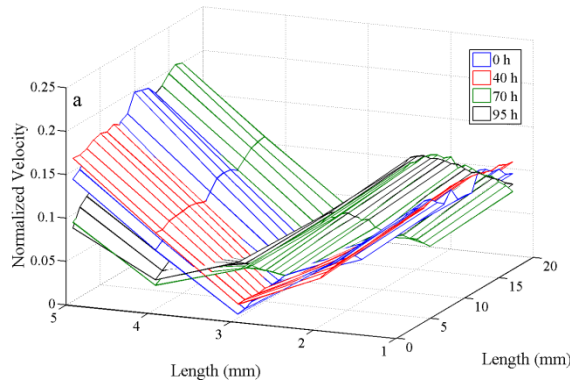


Figure 4. (a) 3D experimental plots of the 1st mode shape and (b) normalized ER and MAC values obtained for unmolded samples as a function of aging time.

3.2. Finite element analysis

The separate effect of MC and CA degradation on the alteration of the modal response was analyzed by using ANSYS software according to the simplified model presented in figure 5. The corresponding material properties are listed in table 1. Young's modulus of the oxidized layer was calculated by equation (3), where E_{OM} and E_{av} are Young's modulus of the oxidized layer and the average modulus of the MC after oxidation, L_1 and L_2 are marked as thickness of the sample and oxidized layer respectively [2].

Values of the * have been determined from [2].

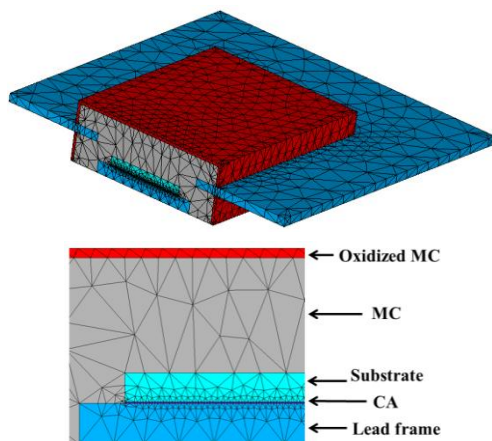
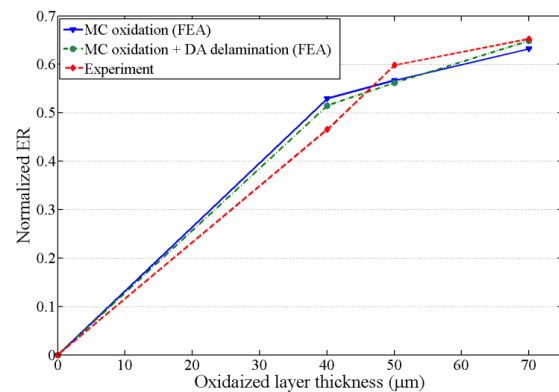
$$E_{OM} = \frac{E_{av} \cdot \frac{L_1}{2} - \left(\frac{L_1}{2} - L_2\right) \cdot E_1}{L_2} \quad (3)$$

Table 1. Material properties used in the simulations.

Layer	Density (g/cm ³)	E (GPa)	Poisson's Ratio
Lead Frame	8.92	97.6	0.33
Chip Adhesive	5.4	7.713	0.35
Si substrate	2.329	130	0.33
MC	1.74	26	0.33
Oxidized MC	1.5486	*	0.33

Decomposition and delamination of the CA was modeled by removing the corner areas of the adhesive layer. The calculated ER increases to a value of 2.3×10^{-3} with reduction of area up to 15% and then drops to 1.8×10^{-3} as the degree of delamination increases to about 30%. Though the obtained ER values are rather small, but the trend of increase and subsequent decrease of the ER with reducing the chip adhesive area complies well with the experimental results shown in figure 4b.

Figure 6 shows the calculated effect of MC oxidation for a non-delaminated chip and one with 15% delamination in comparison with the experimental plot. The ER values for both models are almost overlapping showing the dominant effect of the MC oxidation on the frequency response of the devices.

**Figure 5.** Cross section of the model with an enlarged section demonstrating different materials.**Figure 6.** Comparison of experimental and calculated ER as a function of MC oxide thickness layer.

4. Conclusion

Application of experimental and numerical modal analysis for the detection of thermally induced failures and delamination effects in polymeric materials used in microelectronic packages were demonstrated. The main failure mechanisms were oxidation of the MC and delamination of the chip adhesive. Oxidation of the molding compound was determined as the most dominant parameter affecting the alteration of the modal response of the packages. The proposed method provided promising results; however, the resolution of the quantitative modal analysis depends on type, size and combination of the failure modes requiring further studies for an extended application.

Acknowledgments

We acknowledge the financial support of FFG in the frame of Comet program and the Christian Doppler Gesellschaft Austria.

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