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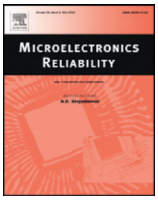

In-situ investigation of EMC relaxation behavior using piezoresistive stress sensor

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ABSTRACT

The relaxation behavior of an epoxy molding compound (EMC) subjected to a constant strain can cause new reliability challenges in automotive electronics. This problem will be exacerbated due to the ever-increasing demand in modern electronics systems for miniaturization with more functionality, yet it has not been studied extensively to mitigate its effect on reliability. In this study, a piezoresistive silicon-based stress sensor is used to understand the stress state in an electronic control unit (ECU), more specifically the relaxation behavior of EMC caused by the storage time of an ECU (i.e., duration between production and actual usage). Mechanical stresses are measured by the piezoresistive stress sensor that is encapsulated in a standard microelectronic 3 × 3 mm land grid array (LGA) package. The relaxation behavior is observed at three different temperatures for 1 week: 75 °C, 100 °C and 125 °C. The relaxation behavior is measured continuously for one more week after cooling the package to room temperature (at 25 °C). An additional test is conducted at 85 °C with 85% relative humidity to investigate the effect of moisture diffusion on the package. The experimental results clearly indicate that the proposed approach can be used for better understanding of the evolution of stresses in molded packages during their lifetime, especially during storage, which in turn can lead to more optimal designs in the future.

1. Introduction

Epoxy Molding Compounds (EMCs) are widely used in electronic packages to protect the Integrated Circuits (IC) from the environment. It has been known that EMCs show significant viscoelastic behavior; the stresses and strains of the material change with time at a constant temperature.

Fischer et al. [1] stated that package induced stress can lead to a change of the sensitivity by ±4% and of the offset voltage up to 60% of full-scale in the Hall sensor. It was also stated that the time-dependent characteristics of EMCs is one of major parameters that affect the stress inside the Hall sensor package. As a result, numerous studies of the topic were conducted in the past, most notably by Dynamic Mechanical Analysis (DMA) [2–5].

In a standard DMA relaxation test, a force evolution is measured while applying a constant strain. Under an ideal setting, the force evolution can be measured immediately after applying the strain (Fig. 1a). However, the initial strain rise in a real test is not instantaneous (Fig. 1b). The effect of this undesired strain rise has to be taken into account while evaluating the test results, which is prone to produce measurement errors. In addition, the DMA studies are usually performed on EMC specimens, which can produce the properties required for stress modeling of a package, but cannot provide information about the relaxation effect on real packages.

In this study, the stress relaxation behavior of a real package is measured by an embedded stress sensor to cope with the problem with DMA tests. The measurement results are presented and their implications are discussed after describing the experimental setup.

2. Experimental setup

A piezoresistive silicon-based stress sensor, called IForce, is used in the study. The sensing elements are created by the channels of MOSFET transistors in a current mirror circuit as shown in Fig. 2. Its specific construction enables the stress measurements with high spatial resolution.

The current mirror is very sensitive to differences in parameters of the transistors constituting it. The channels of MOSFETs are oriented in such a way that the change in stress is changing their resistivity. Both of these properties are used to measure the stresses with very high sensitivity.

By measuring the currents flowing through both branches of the current mirror, one can calculate an in-plane shear stress, σ_{XY}, and the difference in in-plane normal stress components, $\sigma_{XX} - \sigma_{YY}$, from the following relationships [6]:

$$\sigma_{XY} = \frac{1}{\pi_{11}^{(n)} - \pi_{12}^{(n)}} \frac{I_{OUT} - I_{IN}}{I_{OUT} + I_{IN}} \tag{1}$$

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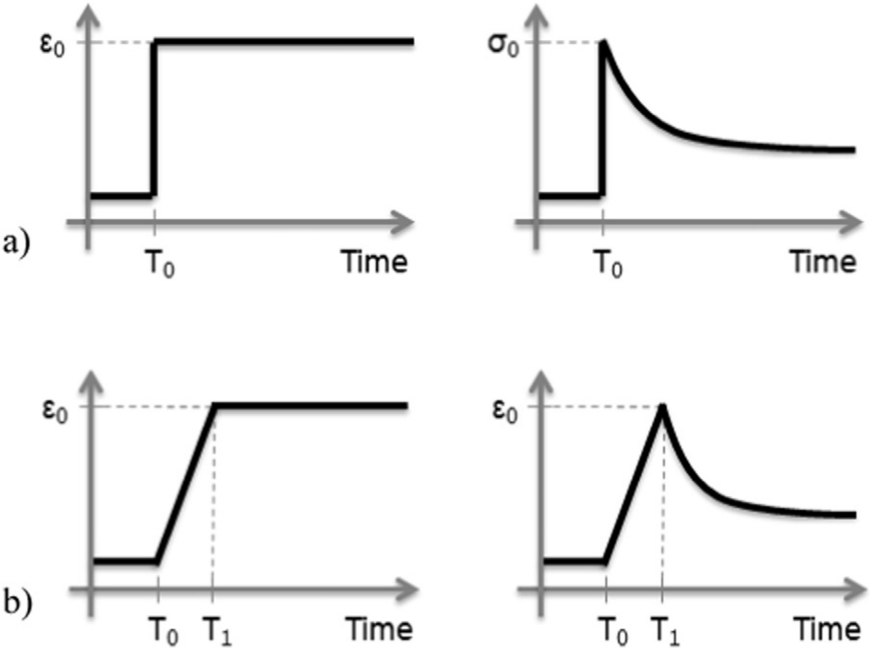

Fig. 1. Stress relaxation a) ideal case b) real case [2].

$$\sigma_{XX}-\sigma_{YY}=\frac{1}{\pi_{44}^{(p)}}\frac{I_{OUT}-I_{IN}}{I_{OUT}+I_{IN}} \qquad (2)$$

where:

π_{11}, π_{12}, π_{44} are piezoresistive coefficients of silicon, and I_{IN} and I_{OUT} currents are measured respectively at the input and at the output of current mirror.

It is important to note that, from the above relationships, it is also possible to calculate the in-plane normal stresses in the x and y directions. It is necessary, however, to have a reference measurement, which can be treated as a starting point for the in-plane stresses evolution.

In each sensor there is a whole matrix of sensing cells. The sensor with 12 sensing cells is used in the test, being placed in a 4 × 4 array. Four cells in the corners are inactive.

The silicon die is packaged in a standard microelectronic LGA package, which is widely used to encapsulate a Hall sensor. All the elements of the package are exactly the same as in the Hall sensor case; just the silicon die is replaced. Construction of the package is presented in Fig. 3. The silicon die is attached to a PCB using a die attach adhesive. Electrical connections are formed by wire bonds. There is also a dummy ceramic component soldered on the PCB. The whole construction is overmolded with commercially available epoxy molding compound. The final dimension of the package is 3 mm × 3 mm × 1 mm.

Two types of specimens were fabricated for actual tests (Fig. 4): (a) a stand-alone unattached sensor (will be referred to as "sensor"; and (b) a sensor mounted on a PCB using solder (will be referred to as "mounted sensor". The signals from the stand-alone (or unsoldered) sensor were utilized to eliminate the effect of the relaxation of PCB substrate and solder on the stress relaxation measurements.

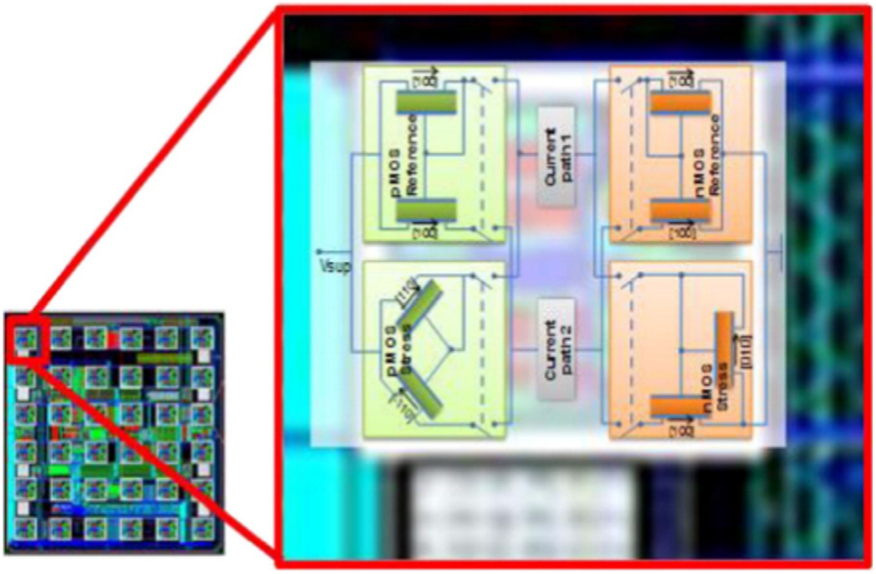

Fig. 2. Construction of IForce stress sensor [6].