Reducing the hygroscopic swelling in MEMS sensor using different mold materials

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ABSTRACT

Today, Hygroscopic swelling is one of the biggest challenging problem of Epoxy mold compound (EMC) in packaging with Microelectromechanical system (MEMS) devices. To overcome this hygroscopic swelling problem of EMC and guard the devices, MEMS devices are molded in this paper with different Mold Compound (MC) i.e. titanium and ceramic etc. during their interconnection with the board. Also, a comparatively performance analysis of this various mold compound with MEMS pressure sensor has been studied in this paper at 60% humidity, 140 mol/m^3 saturation concentration and 25 °C. It was observed that hygroscopic swelling does not take place in the titanium mold compound. But, titanium is very costly so we have to consider something cheaper material i.e. ceramic in this paper. The Hygroscopic swelling in Ceramic Mold Compound after 1 year is nearly 0.05 mm, which is very less than epoxy.

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1. INTRODUCTION

Now days, microelectromechanical systems (MEMS) sensor devices are being very popular and worthwhile for industry, instrumentation, medical, navigation, defense and vehicle security systems etc. [1, 2]. High-precision sensor is required in many of these applications during semiconductor packaging. In addition, the distortion stability and a high level of measurement is needed in MEMS sensors devices irrespective of external ecological circumstances [3, 4]. In MEMS sensor devices, Epoxy Mold Compound (EMC) are being used as a major packaging material due to its high productivity, lower material as well as manufacturing cost and great effectiveness [5, 6]. But, it absorbs moisture when it is operated in the humid environment. This moisture absorption which is known as hygroscopic swelling affects the material characterstics which can not be neglected. Due to this moisture absorption, a viscoelasticity transformation and swelling is observed in material packaging. Therefore, hygroscopic swelling in Mold Compound (MC) is one of the critical issues in designing of electronics parts of MEMS sensor devices [7-10].

The packaging in MEMS sensor devices are highly sensitive to the environmental conditions. Moreover, a composite materials have different thermo-mechanical and hygro properties. Due to this materials property mismatching, it induces hygroscopic stresses that can be measure in same way as thermal stress into the electronic material packaging. In addition, this induced hygroscopic stresses can further causes the cracks, delamination and deformation in the material package [11-14]. The hygroscopic and thermal stress are mostly ignored during the performance analysis of MEMS senor device is just because of lack of characterization technique like unfamiliarity with hygroscopic modeling and moisture diffusion, lack of material hygroscopic swelling characteristics and under or over evaluation of the hygroscopic stress

magnitude. Therefore, it is important to identify and evaluate the hygroscopic swelling during material packaging in order to optimize the performance of MEMS sensor device and its reliability [15, 16]. In the past, a lot of research was also carried out to understand the impact of hygro-thermo-mechanical stresses induced in MEMS sensor device packages [17-22]. Also, in this paper, we analyze the impact of hygroscopic swelling and stress on MEMS sensor device and used different materials to mitigate this problem.

Problem Statement:

The main contribution of this paper is summarized below:

a. MEMS devices are molded with different Mold Compound (MC) i.e. titanium and ceramic etc. to overcome the hygroscopic swelling problem of EMC.

b. A comparatively performance analysis of the various mold compound i.e. epoxy, titanium and ceramic with MEMS pressure sensor has been studied at 60% humidity, 140 mol/m^3 saturation concentration and 25 ^{o}C.

   The remainder of this research paper has been organized as follows. Section 2 provides an overview of MEMS Sensor Model. The simulation results are discussed in the Section 3 and finally conclusions are drawn in Section 4.

2. MEMS SENSOR MODEL

   In this section, we consider a basic MEMS sensor model with MC, which is presented as shown in Figure 1. Integration in microelectronic circuits, MEMS and other electronic devices are often molded with different Mold Compound (MC) to guard the devices and their interconnection with the board. The epoxy, polymers etc. are subject to moisture adsorption and hygroscopic swelling, which can cause delamination between the MC and the board or to incorrect behavior of MEMS components. It is sufficient to model a quarter of the whole structure due to the symmetry. The geometry of MEMS sensor model is combination of FR4 board and a pressure sensor dies [23] as explained below:

   The lower part of the MEMS model is taken as a FR4 board and on which the pressure sensor die is glued. Here, the pressure sensor die is basically made of three parts as presented below:

a. A silicon component with a processed membrane. This membrane is modeled with a shell interface and strain on the membrane surface is used to measure the pressure.

b. A silica glass capping is used to protect the silica glass membrane.

c. A Mold Compound that covers the die and a large part of the board. When external pressure is applied on the bottom face of the membrane, the membrane deforms and the strain is measured by means of a Wheatstone bridge made of piezo-resistors.
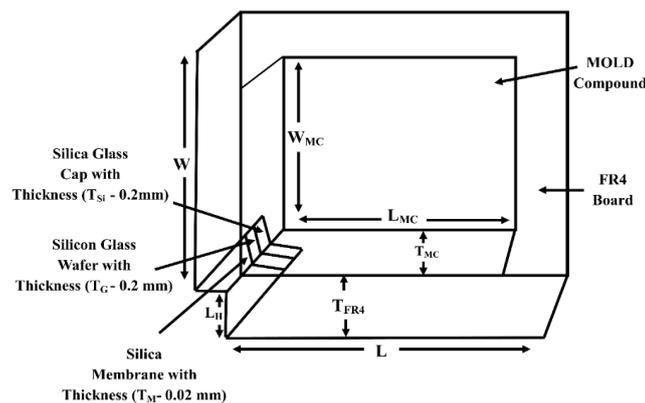
Figure 1. MEMS sensor model [23]

   In the above Figure 1, we have considered various parameter which are summarized in Table 1. The initial moisture concentration after molding is set to 40 mol/m3. This value can be also taken as reference for hygroscopic swelling because all the stresses are assumed relaxed just after molding. In order to avoid problems that can be caused by the discontinuity of concentration at initial state, the concentration boundary condition is applied smoothly and a boundary layer type mesh is used near those boundaries. The response of a MEMS pressure sensor is computed for a period of one year [24, 25].

As hygroscopic swelling induces a one-way coupling between concentration and mechanics. The concentration is calculated in a first time-dependent study and then the structural domains are computed in a stationary study. This sequential approach reduces the computation time compared to a single solution including all physical interfaces.

Table 1. Parameters used in designing of MEMS sensor device [23]

Sr. No.	Parameter	Value
1.	Length of the device (L)	20[mm]
2	Width of device (W)	15 [mm]
3	Length of Mold compound (L_{MC})	15[mm]
4	Width of Mold compound (W_{MC})	10[mm]
5	Thickness of Mold compound (T_{MC})	1.5[mm]
6	Side length of sensor (L_{Die})	1.2[mm]
7	Side length of membrane (L_M)	0.7[mm]
8	Side length of hole in FR4 (L_H)	0.8 [mm]
9	Thickness of FR4 (T_{FR4})	1[mm]
10	Thickness of silicon (T_{Si})	0.2 [mm]
11	Thickness of membrane (T_M)	0.02[mm]
12	Thickness of glass wafer (T_G)	0.2[mm]

3.   RESULTS AND DISCUSSIONS

In this section, firstly we examined the hygoscoping swelling, relaitive mass concentration and dispalcemt for various time duration in EMC containg MEMS sensor model from Figure 2 to Figure 7. Further, the the various MC i.e. titanium and ceramic etc. is used to reduce the hygoscoping swelling presents in EMC. So, the hygoscoping swelling reduction performance analysis is presented in Figures 8-9 for titanium MC and Figure 10 and 11 for ceramic MC. Here, we analyzed the result with consideration of 60% humidity, 140 mol/m^3 saturation concentration and 25 ^{o}C temperature condition during the simulation.

3.1. Epoxy mold compound (EMC)

In Figure 2 we analyze the moisture concentration in the EMC after 2 days. Here, Figure 2 depicts that the moisture diffuses progressively in the EMC and it has reached partially the top face of the die after 2 days. In the simulations results, it is noticed that the moisture concentration at the die location starts to increase after 2 days and it reached to maximum value in approximately 100 days as shown in Figure 3. This results is also confirmed by the mass uptake as shown in Figure 4, where the maximum value is reached after the same time.

In Figure 5, we analyze the surface total displacement in EMC after 2days. The results in Figure 5 shows approximately 0.35 um displacement on the EMC surface and EMC swells only on its boundaries during the first 2 days. But, it swells everywhere after one year as shown in Figure 6. During the first 2 days, the expansion on the exterior boundaries implies a stretching on the membrane and thus an increase of the measured strain. However, the expansion of the center implies compression on the die and a decrease of the strain along the axes as shown in Figure 7. The moisture adsorption and hygroscopic swelling have significant effect on the sensor sensibility, which have to be taken in account during the measurements or designing the sensor.
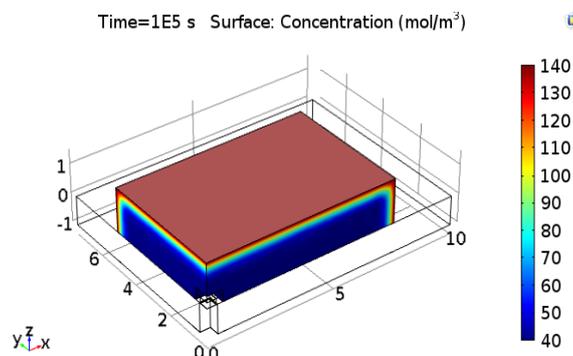
Figure 2. Moisture concentration in the EMC after 2 days
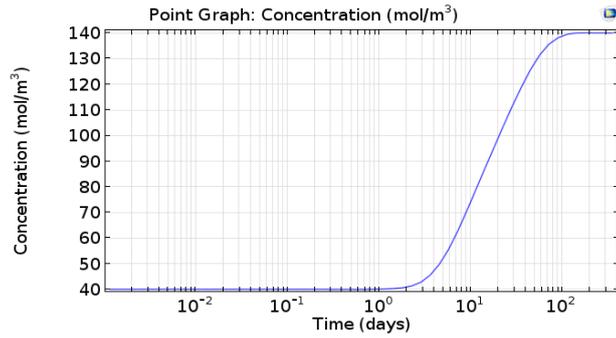
Figure 3. Moisture concentration at die location over time for EMC
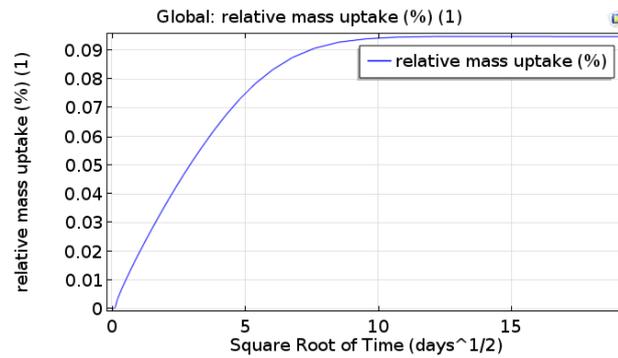
Figure 4. Total mass uptake in the EMC
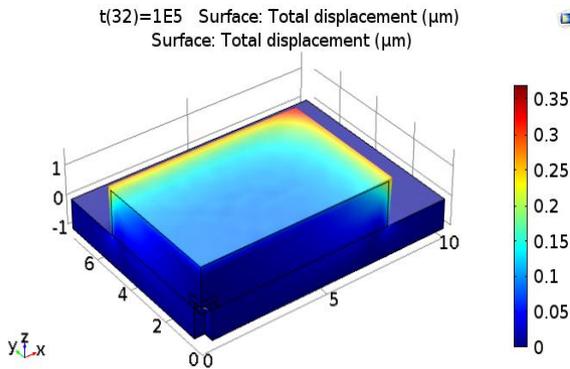
Figure 5. Dispacement after 2 days
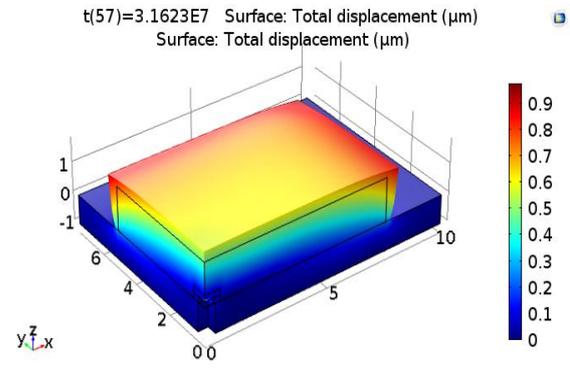
Figure 6. Total mass uptake in the EMC
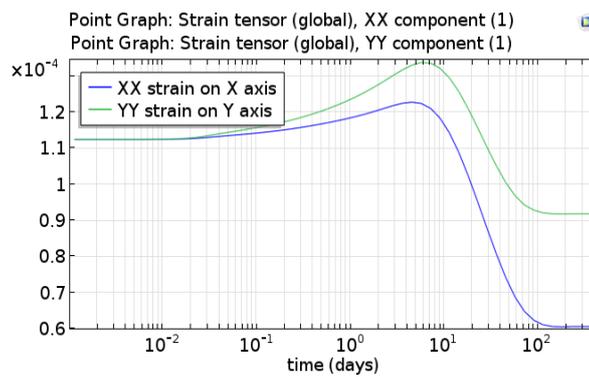
Figure 7. Total mass uptake in the EMC

3.2. Titanium mold compound (TMC)

Here, Figure 8 and Figure 9 depicts the hygoscoping swelling for TMC containing MEMS system after 2 and 100 days respectively. In the simulation results, no displacement is observed in TMC after 2 days as shown in Figure 8. Also, similar results is obtained in TMC after 1 year. Therefore, TMC reduces the impact of hygroscopic swelling which is comparatively very large in EMC.

Figure 8. Dispacement aftyer 2 days

Figure 9. Dispacement aftyer 1 year

3.3. Ceramic mold compound (CMC)

In the previous section 3.2, we have noticed that TMC reduces the impact of hygroscopic swelling in a very effective manner. But, the cost of titanium is comparatively very large than epoxy. So, here we analyze the relative mass update and surface total displacement for CMC as hown in Figure 10 and Figure 11 respectively. The results shows that relative mass uptake in ceramic mold compound is reached to maximum value after the same time as in case of EMC. But, it have relatively less mass uptake and suface dispacement than EMC.
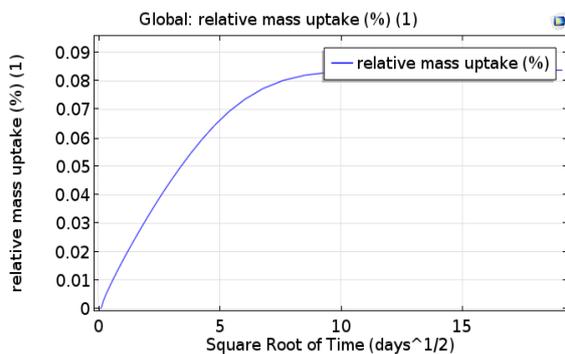
Figure 10: Total mass uptake in the CMC
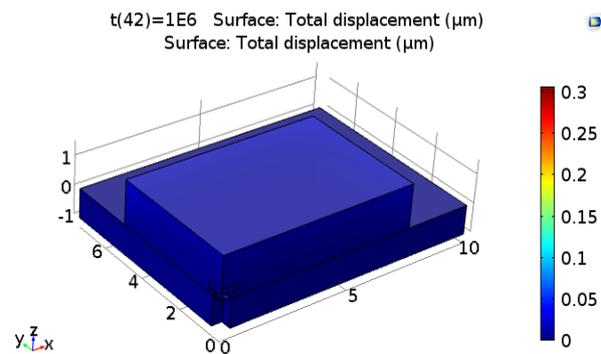
Figure 11: Displacement after 1 year

4.   CONCLUSION

In this paper, MEMS devices are molded with different Mold Compound (MC) i.e. titanium and ceramic etc. to overcome the hygroscopic swelling problem of EMC. This Hygroscopic swelling have significant effect on the sensor sensibility, which have to be taken in account during the measurements, or when designing the sensor. Also, a comparatively performance analysis of the various mold compound i.e. epoxy, titanium and ceramic with MEMS pressure sensor has been studied at 60% humidity, 140 mol/m^3 saturation concentration and 25 $^{\circ}$C. The simulation results proves that hygroscopic swelling does not take place in titanium mold compound. However, it increases the cost of the devices due to the high cost of the Titanium. Therefore, we have used Ceramic Mold Compound to reduce this high cost with very less hygroscopic swelling. Further, the Ceramic Mold Compound have comparatively very less hygroscopic swelling i.e. approximately 0.05 mm displacement than epoxy.

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