

## Reducing the hygroscopic swelling in MEMS sensor using different mold materials

Pinky, Kuldeep Singh, Anuj Singal

Department Electronics and Communication Engineering,  
Guru Jambheshwar University of Science and Technology, India

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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<sup>3</sup> 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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### Corresponding Author:

Anuj Singal,

Departement of Electronics and Communication Engineering,

Guru Jambheshwar University of Science and Technology,

Hisar, Harayana-125001.

Email: [anuj.singal08@gmail.com](mailto:anuj.singal08@gmail.com)

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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 characteristics 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 sensor 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:

- MEMS devices are molded with different Mold Compound (MC) i.e. titanium and ceramic etc. to overcome the hygroscopic swelling problem of EMC.
- 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<sup>3</sup> saturation concentration and 25 °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 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.
- A silica glass capping is used to protect the silica glass membrane.
- 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.

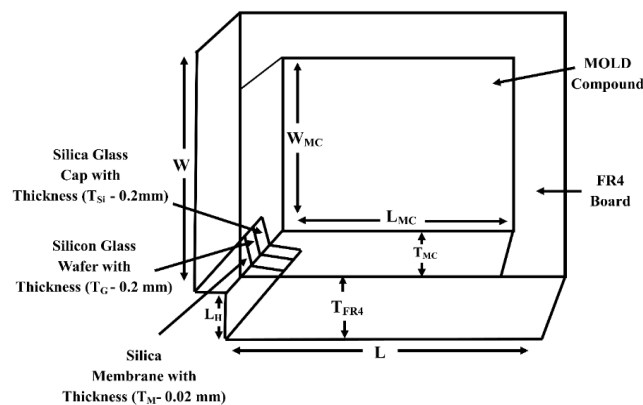


Figure 1. MEMS sensor model [23]

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/m<sup>3</sup>. 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 hygroscopic swelling, relative mass concentration and displacement for various time duration in EMC containing MEMS sensor model from Figure 2 to Figure 7. Further, the various MC i.e. titanium and ceramic etc. is used to reduce the hygroscopic swelling presents in EMC. So, the hygroscopic 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,  $140 \text{ mol/m}^3$  saturation concentration and  $25^\circ\text{C}$  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 simulation 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 result 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 2 days. The results in Figure 5 shows approximately  $0.35 \text{ }\mu\text{m}$  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.

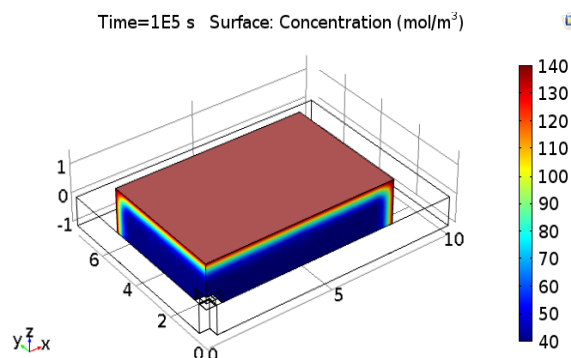


Figure 2. Moisture concentration in the EMC after 2 days

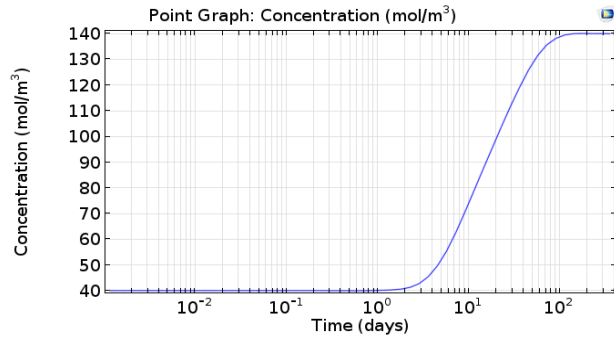


Figure 3. Moisture concentration at die location over time for EMC

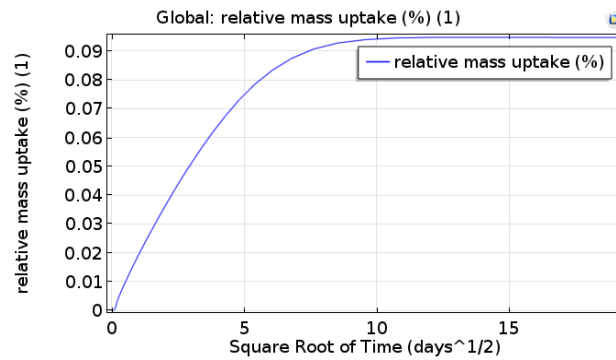


Figure 4. Total mass uptake in the EMC

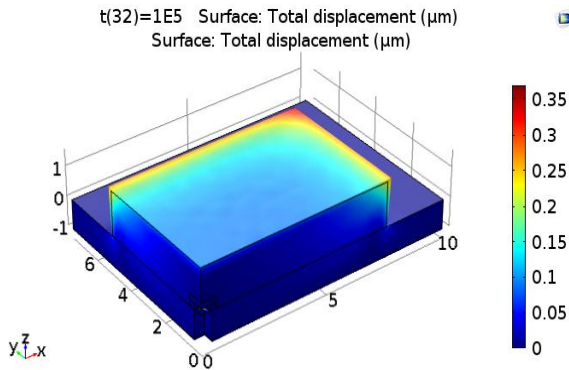


Figure 5. Displacement after 2 days

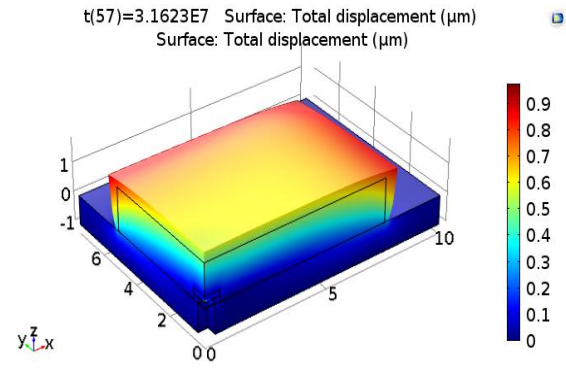


Figure 6. Total mass uptake in the EMC

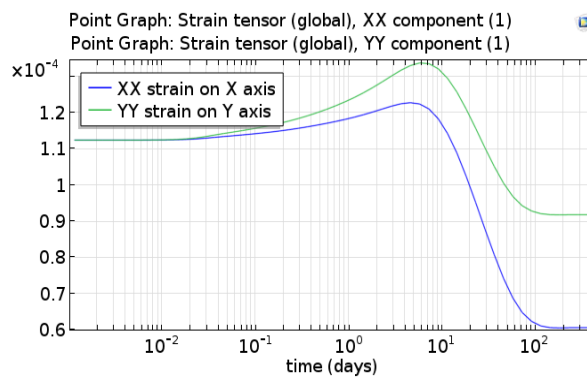


Figure 7. Total mass uptake in the EMC

### 3.2. Titanium mold compound (TMC)

Here, Figure 8 and Figure 9 depicts the hygroscopic 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.

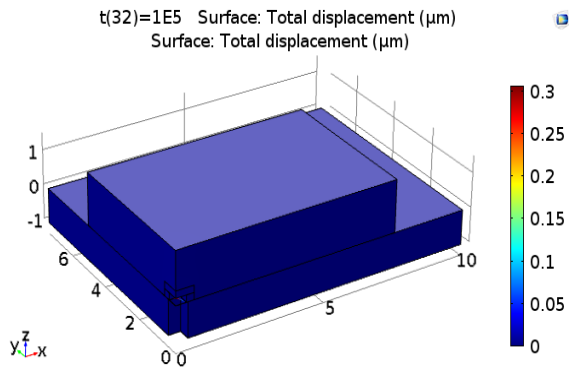


Figure 8. Displacement after 2 days

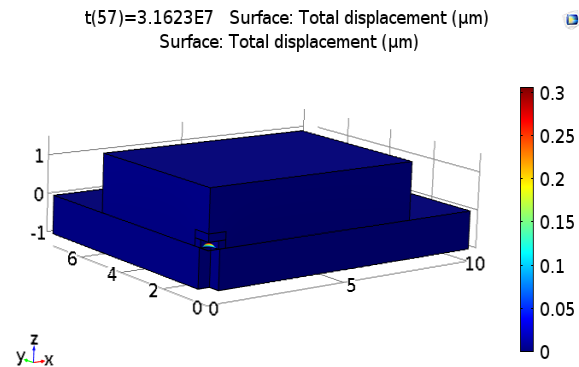


Figure 9. Displacement after 1 year

### 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 uptake and surface total displacement for CMC as shown in Figure 10 and Figure 11 respectively. The results show that relative mass uptake in ceramic mold compound is reached to maximum value after the same time as in case of EMC. But, it has relatively less mass uptake and surface displacement than EMC.

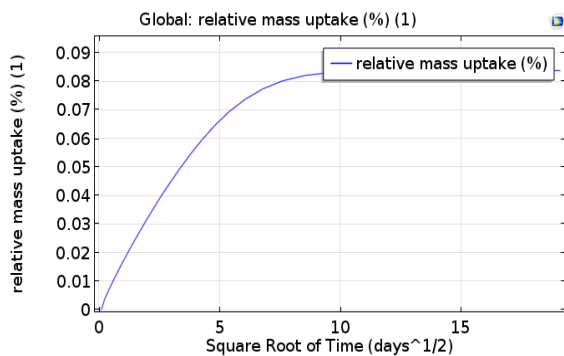


Figure 10: Total mass uptake in the CMC

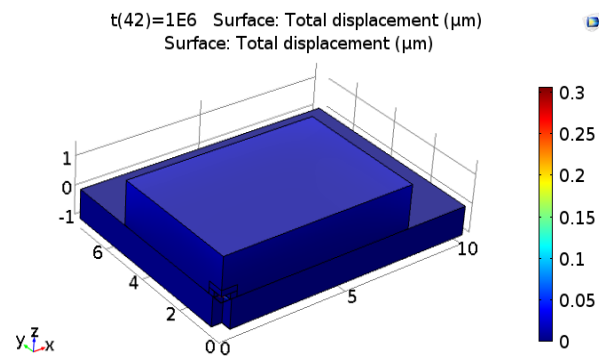


Figure 11: Displacement after 1 year

## 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 has a significant effect on the sensor sensitivity, which has to be taken into account during the measurements, or when designing the sensor. Also, a comparative performance analysis of the various mold compounds i.e. epoxy, titanium, and ceramic with MEMS pressure sensor has been studied at 60% humidity, 140 mol/m<sup>3</sup> saturation concentration, and 25 °C. The simulation results prove 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 titanium. Therefore, we have used Ceramic Mold Compound to reduce this high cost with very little hygroscopic swelling. Further, the Ceramic Mold Compound has comparatively very little hygroscopic swelling i.e. approximately 0.05 mm displacement than epoxy.

## REFERENCES

- [1] M. K. Naji, A. D. Farhood, A. H. Ali, "Novel design and analysis of RF MEMS shunt capacitive switch for radar and satellite communications," *Indonesian Journal of Electrical Engineering and Computer Science (IJECS)*, vol. 15, no. 2, pp. 971-978, Aug. 2019.
- [2] M. J. Adamson, "Thermal expansion and swelling of cured epoxy resin used in graphite/epoxy composite materials," *International Journal of Materials Science*, vol. 15, no. 7, pp. 1736-1745, 1980.
- [3] I. Khalilullah, T. Reza, L. Chen, A. K. M. Monayem, H. Mazumder, J. Fan, C. Qian, G. Zhang and X. Fan, "In-Situ Characterization of Moisture Absorption and Hygroscopic Swelling of Silicone/Phosphor Composite Film and Epoxy Mold Compound in LED Packaging," *IEEE International Conference on Thermal, Mechanical and Multi-Physics Simulation and Experiments in Microelectronics and Microsystems*, pp. 1-9, Apr. 2017.
- [4] E. H. Wong, R. Rajoo, S. W. Koh and T. B. Lim, "The Mechanics and Impact of Hygroscopic Swelling of Polymeric Materials in Electronic Packaging," *Transactions of the ASME Journal of Electronic Packaging*, vol. 124, pp. 122-126, 2002.
- [5] H. Ardebili, E. H. Wong, and M. Pecht, "Hygroscopic swelling and absorption characteristics of epoxy molding compounds used in electronic packaging," *IEEE Transaction on Components, Packaging and Manufacturing Technology*, vol. 26, no. 1, pp. 206-214, Mar. 2003.
- [6] Sunil K. Karad, "Mechanisms of moisture absorption by cyanate ester modified epoxy resin matrices: the clustering of water molecules," *International Journal of Polymer*, vol. 46, pp. 2732-2738, 2005.
- [7] P. Nogueira, "Effect of Water Sorption on the Structure and Mechanical Properties of an Epoxy Resin System," *Journal of Applied Polymer Science*, vol. 80, pp. 71-80, 2001.
- [8] R. Liu, H. Wang, J. Wang, H. H. Lee, and S. B. Park, "Moisture Diffusion and Hygroscopic Swelling of Adhesives in Electronics Packaging," *IEEE International Conference on Electronic Components and Technology*, pp. 2203-2209, May 2016.
- [9] N. A. M. Jamail, M. A. M. Piah, N. A. Muhammad, and Q. E. Kamarudin, "PDC Analysis of LLDPE-NR Nanocomposite for Effect of Moisture Absorption," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 7, no. 6, pp. 3133-3139, Dec. 2017.
- [10] X. Ma, K. M. B. Jansen, G. Q. Zhang, L. J. Ernst, "Hygroscopic Effects on Swelling and Viscoelasticity of Electronic Packaging Epoxy," *IEEE International Conference on Electronics Packaging Technology*, pp. 1-5, 2006.
- [11] H. C. Hsu, Y. T. Hsu, W. L. Hsich, M. C. Weng, S. T. ZhangJian, F. J. Hsu, Y. F. Chen, S. L. Fu, "Hygroscopic Swelling Effect on Polymeric Materials and Thermo-hygro-mechanical Design on Finger Printer Package," *International Conference on Microsystems, Packaging, Assembly & Circuits Technology*, pp. 291-294, Oct. 2008.
- [12] W. Zhu, P. Lai, S. Yang, "Effect of Hygro-thermo-Mechanical Stress on Reliability of Stacked Die Package," *IEEE International Symposium on Advanced Packaging Materials*, pp. 204-208, Oct. 2011.
- [13] S. Yoon, C. Jang, and B. Han, "Nonlinear stress modeling scheme to analyze semiconductor packages subjected to combine thermal and hygroscopic loading," *International Journal on Electronic Packaging*, vol. 13, no. 2, 2008.
- [14] M. D. Placette, X. J. Fan, J.-H. Zhao and D. Edwards, "Dual stage modeling of moisture absorption and desorption in epoxy mold compounds," *Microelectronics Reliability*, vol. 52, pp. 1401- 1408, 2012.
- [15] R. H. Kronorfer and Y. K. Kim, "Packaging effect on MEMS pressure sensor performance," *IEEE Transaction on Component Packaging Technol.*, vol. 30, no. 2, pp. 285-293, Jun. 2007.
- [16] J. Keller, "Effect of moisture swelling on MEMS packaging and integrated sensors," *International Journal on Microelectron. Rel.*, vol. 53, pp. 1648-1654, 2013.
- [17] E. Stellrecht, H. Bongtae and M. G. Pecht, "Characterization of hygroscopic swelling behavior of mold compounds and plastic packages," *IEEE Transactions on Components and Packaging Technologies*, vol. 27, pp. 499-506, 2004.
- [18] D. Liu and S. Park, "A note on the normalized approach to simulating moisture diffusion in a multimaterial system under transient thermal conditions using ANSYS 14 and 14.5," *Journal on Electronic Packaging.*, vol. 136, no. 3, 2014.
- [19] D. G Yang, Jansen, L. G. Wang, L. J. Ernst, G. Q. Zhang, H. J. L. Bressers, X. J. Fan, "Micromechanical modeling of stress evolution induced during cure in a particle-filled electronic packaging polymer," *IEEE Transactions on Components and Packaging Technologies*, vol. 27, no. 4, pp. 676-683, 2004.
- [20] S. Yoon, B. Han, S. Cho, and C.-S. Jang, "Non-linear finite element analysis for electronic packages subjected to combined hygroscopic and thermo-mechanical stresses," *Proceeding on Electron. Packag. Technol. Conf. (EPTC)*, vol. 2, pp. 569-574, Dec. 2005.
- [21] Seokbeom Kim, Bora Lee, Yeowon Yoo, Thomas Thundat, and Jungchul Lee, "Static and dynamic operation of metal-coated hydrogel cantilever humidity sensors based on hygroscopic mismatch," *IEEE International Conference on Solid State Sensors, Actuator and Microsystem (Transducers)*, pp. 18-22, Jun. 2017.
- [22] Y. Kim, D. Liu, H. Lee, R. Liu, D. Sengupta and S. Park, "Investigation of Stress in MEMS Sensor Device Due to Hygroscopic and Viscoelastic Behavior of Molding Compound," *IEEE Transactions on Components Packaging and Manufacturing Technology*, vol. 5, no. 7, pp. 945-955, 2015.
- [23] E. H. Wong, S. W. Koh, K. H. Lee and R. Rajoo, "Comprehensive Treatment of Moisture Induced Failure Recent Advances," *IEEE Trans. On Electronics Packaging Manufacturing*, vol. 25, no. 3, pp. 223-230, 2002.
- [24] C. Jang, B. Han, and S. Yoon, "Comprehensive moisture diffusion characteristics of epoxy molding compounds over solder reflow process temperature," *IEEE Trans. Compon. Packag. Technol.*, 33(4), pp. 809-818, Dec. 2010.
- [25] C. Jang, S. Yoon, and B. Han, "Measurement of the hygroscopic swelling coefficient of thin film polymers used in semiconductor packaging," *IEEE Trans. on Compon. Packag. Technol.*, vol. 33, no. 2, pp. 340-346, Jun. 2010.