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Electronic packaging enhancement engineered by enhancing the reliability via rapid cooling

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Semiconductor packaging continues to reduce in thickness following the overall thinning of electronic devices such as smartphones and tablets. As the package becomes thinner, warpage of the semiconductor package becomes more important due to the reduced bending stiffness and driven by thermal residual stresses and thermal expansion mismatch during the epoxy molding compound (EMC) curing to manufacture package. The warpage not only decreases the reliability of the semiconductor package but also lowers the production rate yield, causing the semiconductor price to rise. In this study, we developed a modified cure cycle that adds rapid cooling step to the conventional cure cycle (CCC) to enhance the reliability of the EMC molded to a copper substrate (EMC/Cu bi-layer package) by lowering the bonding temperature of the EMC/Cu bi-layer package. Analysis of package's bonding temperature via Timoshenko theory considering effective cure shrinkage allowed the rapid cooling step to be quantified and confirmed through experiments. The modified cure cycle results in reduction of residual internal strain and curvature, 26% and 27% respectively, and increase in peel strength, 40% compared to CCC.

NOMENCLATURE

EMC = Epoxy molding compound
EMC/Cu bi-layer package = EMC molded to copper substrate
CCC = Conventional cure cycle
FBG = Fiber bragg grating
3D-DIC = Three dimensional-digital image correlation
ECS =effective cure shrinkage

1. Introduction (Times New Roman 10pt)

Over the years, the importance of semiconductor packaging technology increases due to the demand for miniaturization and high performance of semiconductor products. One of the important roles of the semiconductor package is to protect the silicone chips and wires from mechanical and thermal shocks. However, as the package become thinner, warpage of the semiconductor package is occurred due to the reduced bending stiffness via the area moment of inertial, caused by thermal residual stresses. The warpage in semiconductor packaging has been critical issue during the semiconductor packaging process as multi-layer structured semiconductors become thinner. This warpage can not only damage a thin silicon chip, but also cause the crack of the package and delamination of the package/chip interface, which has detrimental effects on the reliability of semiconductor package. In addition, the possibility of cracking the solder joint between the package and motherboard increases, which lowers the semiconductor production yield [1,2].

In this study, we developed a modified cure cycle that adds rapid cooling step to CCC to enhance the reliability of EMC/Cu bi-layer package by lowering the bonding temperature of EMC/Cu bi-layer package. Rapid cooling setpoint of modified cure cycle was conducted as rheological-based point, such as lowest viscosity, gelation. To compare the mechanical and physical properties of EMC/Cu bi-layer package with respect to rapid cooling setpoint, the internal strain, peel strength, curvature and bonding temperature was analyzed. Finally, the modulus and degree of cure of EMC were measured to investigate the effect of EMC with respect to the rapid cooling setpoints.

2. Experiment

2.1 Experimental setup

EMC/Cu bi-layer package was prepared in the form of strip to analyze the warpage according to the EMC curing process. The Cu substrate was immersed in acetic acid for 10 minutes to remove the oxide layer of Cu substrate [3]. Figure 1 shows the experimental procedure for specimen preparation according to the cure cycle. EMC/Cu bi-layer package was prepared by compression molding using hot press (QM900A, QMESYS, Republic of korea) under vacuum condition. CCC by EMC manufacturer was compose of temperature ramp by uniform rate of 10 °C/min from room temperature to 175 °C and applied 4MPa pressure during the ramp and then cure at 175 °C for 2hours as cure process. The designed modified cure cycle with cooling and reheating was applied at the same ramp 10 °C/min until specific temperature for rapid cooling was reached. Thereafter, the specimen was cooled rapidly to room temperature by dipping it into liquefied nitrogen to suppress the

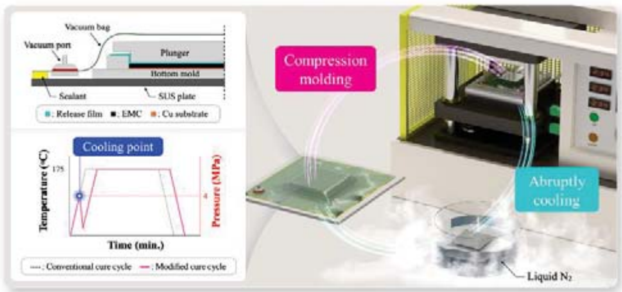

Figure 1. Experimental schematic and conventional cure cycle

curing reaction, which results in lower curvature. Subsequently, the specimen was reheated to the cure temperature and cured under the same conditions as CCC.

2.2 Mechanical and rheological properties

Rheometer and dielectric sensor were used to analyze the rheological properties of EMC, such as the cure start, the lowest viscosity, gelation and solidification for rapid cooling setpoint. Residual internal strain of EMC/Cu bi-layer package was analyzed using FBG sensor with respect to rapid cooling setpoint. FBG sensor and thermocouple were embedded with EMC mold. 90° peel test was performed to measure the peel strength of EMC/Cu bi-layer package with respect to rapid cooling setpoint. The dimension of the specimens and testing condition were based on D 6862-11. of EMC/cu bi-layer package was measured using 3D-DIC compared with respect to rapid cooling setpoint. The bonding temperature using Timoshenko theory in consideration with ECS of EMC was calculated using measured curvature. Finally, the modulus and degree of cure of EMC was measured using 3D-DIC and DSC, and compared with respect to rapid cooling setpoint to investigate the effect of cooling [4,5].

3. Results

3.1 Rheological properties of EMC

Figure 2 shows the rheological properties of EMC using dielectric sensor and rheometer. The cure start temperature, lowest viscosity, gelation and solidification temperature of EMC were 97, 123, 143, 161 °C, respectively. Through these results, the rapid cooling setpoint of modified cure cycle were 100, 120, 140, 160 °C.

Figure 3 shows the curvature and analytical bonding temperature considering ECS with respect to rapid cooling setpoint. The curvature and analytical bonding temperature w/ ECS of EMC/Cu bi-layer package manufactured with rapid cooling setpoint of 140 °C was significantly reduced by 26% and 22% compared to those manufactured with CCC (NC). Figure 4 shows the EMC modulus and degree of cure with respect to rapid cooling setpoint. Based on these results, rapid cooling of modified cure cycle did not affect the mechanical properties of EMC.

Figure 5 shows the residual internal strain and peel strength of EMC/Cu bi-layer package with respect to rapid cooling setpoint. Similar to the results in the comparison of curva6ture, the residual internal strain of modified cure cycle decreased regardless of the rapid cooling setpoint. The specimen fabricated in modified cure cycle with rapid cooling at 140 °C showed the lowest residual strain, which was reduced by 26% compared to the specimen fabricated in the CCC. The peel strength of the EMC/Cu bi-layer package shows a similar trend to that of the residual internal strain. The peel strength of specimen fabricated in modified cure cycle with rapid cooling at 140 °C increased by approximately 40% compared to that of specimen fabricated in CCC. Consequently, it was confirmed that the reduction of the bonding temperature led to reduced curvature and residual internal strain, and improved peel strength of EMC/Cu bi-layer package.

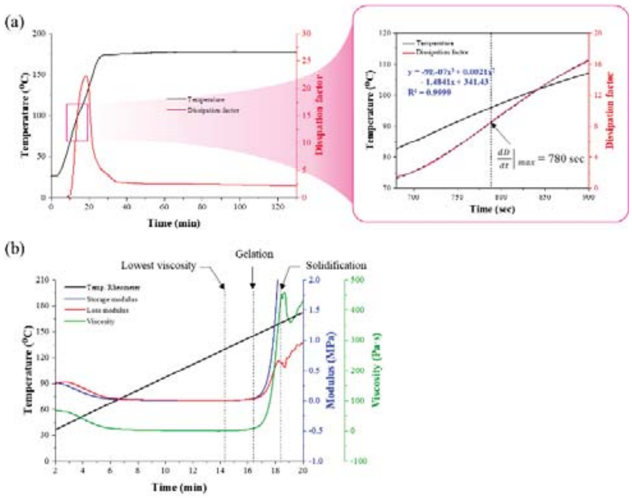

Figure 2. The rheological analysis: (a)dissipation factor of EMC for cure start and (b) rheometer data of EMC in the CCC

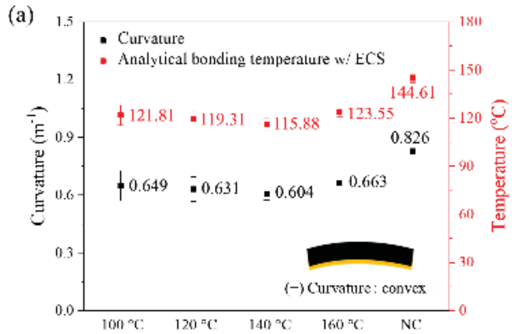

Figure 3. Curvature and bonding temperature of EMC/Cu bi-layer package with respect to rapid cooling setpoint.

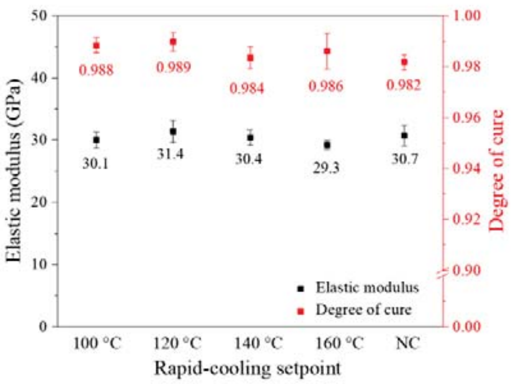

Figure 4. Elastic modulus and degree of cure with respect to rapid cooling setpoint.

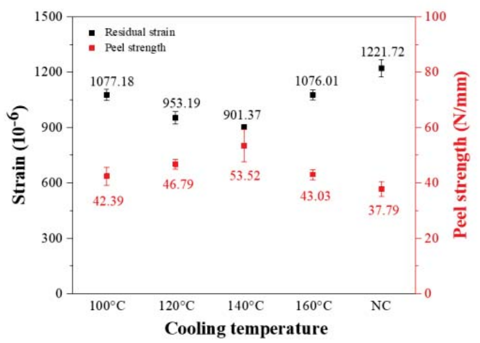

Figure 5. Comprarison of residual interal strain and peel strength of EMC/Cu bi-layer package with respect to rapid cooling setpoint.

3. Conclusions

In this study, we applied modified cure cycles with rapid cooling to enhance the reliability of the EMC/Cu bi-layer package. The effects of the rapid cooling were investigated by measuring the bonding temperature, residual strain, peel strength, and curvature. Based on these results, the following conclusions were drawn:

1) The analytical bonding temperature considering the cure shrinkage of the EMC was calculated by measuring the curvature of the EMC/Cu bi-layer package fabricated by CCC, and verified through the interfacial strain measurement of EMC and Cu using the FBG sensor.

2) When the specimen was rapid cooled shortly before the experimentally-determined bonding temperature for CCC, the residual internal strain and curvature decreased by 26% and 27%, respectively, and the peel strength increased by 40% compared to the specimen fabricated in CCC.

3) The modulus and degree of cure of the EMC were constant regardless of the cure cycles.

4) The reduction in residual strain and curvature and the improvement in peel strength are attributed to the reduced bonding temperature of the EMC/Cu bi-layer package fabricated in the modified cure cycle.

From these results, it should be noted that the exact prediction of the bonding temperature considering the effective cure shrinkage makes it possible to find the optimum cooling setpoint, and consequently enhance the reliability of the EMC/Cu bi-layer package. For the future works, a rapid heating and cooling device using carbon nanotubes will be applied to the modified cure cycle to replace the rapid cooling using liquid nitrogen.

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