SR-EMC Interface Analysis for Highly Reliable Automotive Packaging Applications.

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Abstract

This paper introduces a new methodology for the quantitative measurement of adhesion at the interface between solder resist (SR) and epoxy molding compound (EMC) to provide more accurate and reproducible results. Additionally, this paper discusses the impact of SR filler particles on SR–EMC adhesion.

Innovations in automotive semiconductors have accelerated the development of electric vehicles (EVs) and autonomous driving systems. Ensuring the reliability of automotive semiconductors under harsh conditions is essential. A critical issue identified in reliability testing is the delamination between SR and EMC, which can severely impact product durability. However, the current method of SR-EMC adhesion provides only qualitative data, and it has been highly challenging to measure it quantitatively.

This paper first introduces a novel methodology for quantitatively evaluating SR-EMC adhesion, enabling comparison of different material combinations. The new test method was applied to examine the impact of fillers in SR materials and revealed that fillers significantly affect adhesion with EMC. Specifically, the choice and treatment of filler materials were found to be critical factors in resolving delamination issues. These results mark a significant step towards improving the reliability of automotive semiconductors. The results in this study are expected to contribute to improving the reliability of automotive semiconductors, driving continued innovation and growth in the automotive industry.

Keywords

solder resist, epoxy molding compounds, interface, adhesion

I. Introduction

Automotive semiconductor technology has evolved rapidly, greatly driving innovation throughout the automotive industry. These semiconductors play an extremely important role as the foundation of new automotive technologies such as electric vehicles (EVs), autonomous driving systems, and connected cars. The advancement of these technologies is enabling safer, more efficient, and more sustainable forms of transportation.

Automotive semiconductors must remain reliable even under harsh conditions, and the Automotive Electronics Council (AEC) has driven standardization of automotive electronic components. Notably, the most stringent standard, AEC-Q100 Grade 0 [1] requires conformity with extremely tough tests, such as 1000-hour high-temperature storage (HTSL) at 175°C and a 96-hour unbiased highly accelerated stress test (uHAST).

In semiconductor packaging substrates, solder resist (SR) and epoxy molding compounds (EMC) form the outermost layers, playing a vital role in protecting the printed circuit board and IC chips.

However, there have been reports of failures attributable to the SR-EMC interface, particularly in reliability tests such as the B-HAST. Notably, insulation reliability failures due to delamination between SR and EMC occur in some cases.

As both SR and EMC comprise the outermost layers of the semiconductor package, they are exposed to prolonged high-temperature and high-humidity environments during reliability tests. If delamination occurs at the SR-EMC interface, moisture can penetrate the interfacial gap, causing the SR to absorb more moisture, which in turn can promote copper migration and ultimately lead to short circuits.

Accordingly, enhancement of the SR-EMC adhesion is an effective approach to improve the reliability of automotive semiconductors.

To improve SR-EMC adhesion, it is critical to have a well-established method for quantifying the adhesion strength. The most common evaluation method is the shear test, in which EMC pins are formed on SR and a bond tester is used to measure the force to break the bond; this is based on JEITA ED-4703.

However, measuring SR-EMC interfacial adhesion strength is difficult [2]. When the shear test is performed on a semiconductor package substrate, delamination does not occur at the SR-EMC interface, but rather at the SR–Cu circuit interface or as internal substrate failure. As a result, SR-EMC interfacial bond strength cannot be evaluated.

Furthermore, even after the B-HAST test, delamination does not always occur at the SR-EMC interface, with adhesion failures often dominated by SR–Cu interface delamination or internal substrate fracture.

This situation led us to develop a reliable evaluation technology capable of selectively inducing interfacial fracture at the SR-EMC interface and quantitatively measuring its adhesive strength.

This study first aims to establish a quantitative adhesion testing method for the SR-EMC interface and then utilizes this method to explore strategies for improving interfacial adhesion between SR and EMC.

II. Experiment and Result

A. Test Setup

The shear test was selected as the method for measuring the adhesion between EMC and SR. As shown in Fig 1, EMC pins were formed on the SR, and a bond tester was used to measure the shear force at the EMC–SR joint, measuring the failure mode and the breaking strength. As the SR material, a dry film type was used as a standard material because its flatness offers good compatibility with assembly processes. The SR surface was plasma-treated, and EMC was molded using a transfer molding machine (MPC-06M, APIC YAMADA Corp.). The bottom of the EMC pin was in contact with the SR through a circular area with a diameter of 2.5 mm, corresponding to an area of approximately 4.9 mm².

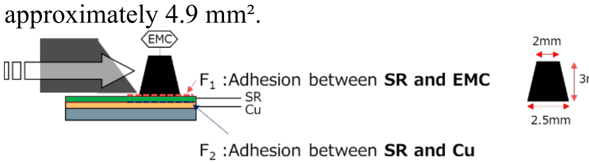


Fig 1. Diagram of Shear Test
(Thickness of each material: SR:15 um Cu:18 um Substrate:800 um)

B. Establishing SR-EMC Adhesion Measurement Method

To measure the adhesion strength at the SR-EMC interface, a new approach that consistently induces delamination at this interface is required.

In shear testing, if the interfacial adhesion F_1 between SR and EMC exceeds the adhesion F_2 between SR and Cu ($F_1 > F_2$), delamination occurs at the SR–Cu interface. Thus, to shift delamination to the SR-EMC interface, it is necessary to establish the situation of $F_1 < F_2$. In this paper, two approaches were investigated: (1) increasing SR–Cu adhesion, and (2) decreasing SR-EMC adhesion.

We first investigated (1). To improve SR–Cu bonding, we considered two approaches: a chemical method using adhesion promoters and a physical method involving Cu surface roughening. As chemical effects may decrease under high moisture conditions due to hydrolysis, we focused on the physical approach by enhancing Cu roughness. Cu roughening was performed using MEC's CZ-8101 solution.

It was found that as surface roughness (Ra) increased, SR–Cu adhesion F_2 also increased. Increasing Ra from 0.2 µm to 0.54 µm yielded about a 10 N increase in bond strength (Fig 2). The images above each plot in Fig 2 show the observations of the SR surface after the shear test.

Despite the increased roughness, adhesion failure occurred at the SR–Cu interface, as the exposed Cu surface was clearly observed, indicating that failure occurred at the SR-Cu interface.

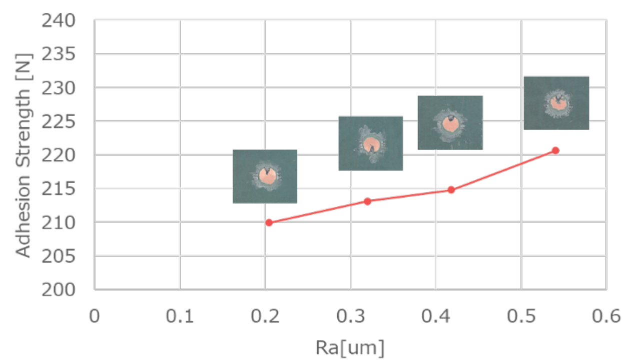


Fig 2. Adhesion strength vs. SR surface roughness (Ra)[um]

We also attempted to increase SR–Cu adhesion by raising the lamination temperature of the dry-film SR (DFSR), so that the resin could better permeate the roughened Cu surface. Although the combination of enhanced Cu roughness and higher lamination temperature increased F_2, delamination at the SR–EMC interface was still not induced (Fig 3).

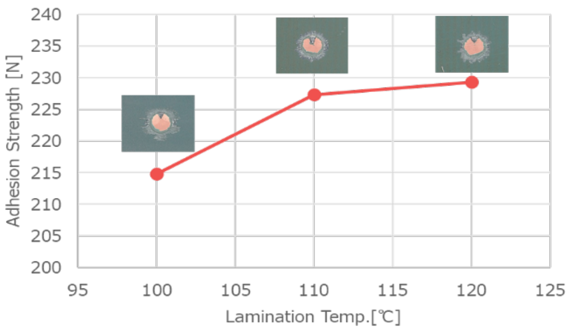


Fig 3. Adhesion strength vs.SR Lamination Temperature [°C]

The above approaches indeed increased F_2 (SR–Cu adhesion) by about 20 N, but this alone was insufficient to shift the failure mode from SR–Cu to SR–EMC. Therefore, in addition to increasing F_2, we explored reducing F_1 (SR–EMC adhesion) by applying a uHAST treatment, expecting this would selectively reduce F_1 while leaving F_2 relatively unaffected.

The uHAST condition were 130°C and 85% R.H., in line with AEC-Q100. After 300 hours of uHAST treatment, delamination was observed specifically at the SR-EMC interface, indicating significant reduction in F_1. This enabled quantitative evaluation of post-HAST SR–EMC adhesion.

These results demonstrate that combining multiple strategies —such as increasing Cu roughness, raising lamination temperature, and HAST processing — can effectively change the interfacial failure mode.

CZ etching [um]	2	
Lamination Temp.[℃]	120	
Unbiased-HAST	w/o	w
Top View		
Delamination	SR-Cu	SR-EMC
Adhesion Strength [N]	216.1	144.9

Table 1. Adhesion strength before and after HAST treatment

C. Approaches to SR-EMC Adhesion Enhancement

Using the established quantitative method, we investigated approaches for improving SR–EMC adhesion as the next step.

As discussed earlier, there are two major approaches (i) physical method: increasing physical anchoring, and (ii) chemical method: enhancing chemical bonding, such as additional polar groups. Notably, plasma treatment before EMC molding is a standard process to improve wettability between EMC and SR. During plasma processing, the SR surface resin is selectively etched while filler particles are less affected, resulting in a topography with increased exposed-filler fraction. This increases the anchor effect, while exposed fillers, such as SiO_2, may offer surface hydroxyl groups which can form hydrogen bonds with polar groups in EMC resin, further enhancing interfacial bonding. To investigate these effects, we performed plasma processing to examine the relationship between the exposed filler surface area and SR-EMC adhesion. SR material includes SiO_2 fillers for their favorable electrical and CTE characteristics. It is also known that organic silane treatment of fillers creates strong chemical bonds at the resin–filler interface, suppressing interfacial failure.[3][4]

Three types of SiO_2 fillers with different silane treatment degrees were prepared: sample A (no treatment), sample B (half-treated), and sample C (fully-treated). After plasma treatment of SR, exposed-filler fraction and SR-EMC adhesion were quantitatively measured.

Argon plasma treatment was performed for durations from 0 to 3 min. After treatment, SR surfaces were imaged by SEM (×10,000), then contrast enhancement was applied to binarize the images into resin (black) and filler (white), so that the exposed filler fraction could be calculated (see Fig 4).

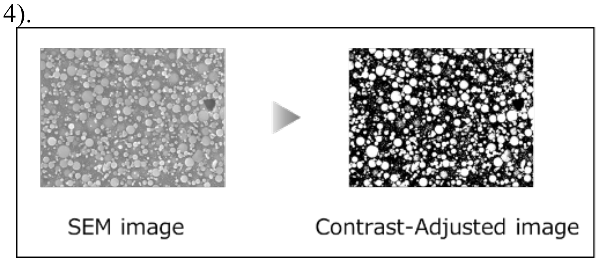


Fig 4. Contrast-Adjusted image

* The filler exhibits greater brightness than the resin in secondary electron images.

The results for the exposed-filler fraction versus plasma time are summarized in Table 2 and Fig 5. No significant differences in the exposed-filler fraction were observed regardless of the degree of surface treatment.

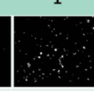
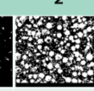
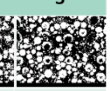
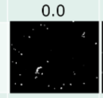
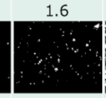
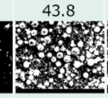
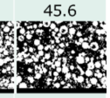
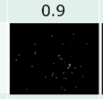
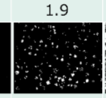
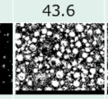
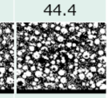
Plasma Time[min]	0	1	2	3
A(Non-Treatment Filler)				
Filler exposure ratio[%]	0.0	1.6	43.8	45.6
B (Less-Treatment Filler)				
Filler exposure ratio[%]	0.9	1.9	43.6	44.4
C (More-Treatment Filler)				
Filler exposure ratio[%]	0.3	4.3	47.2	46.6

Table 2. Surface images as a function of plasma time

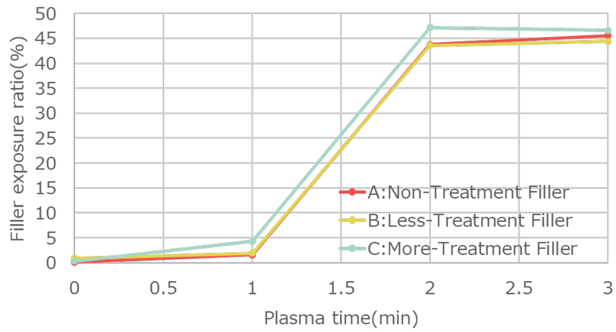


Fig 5. Exposed-filler fraction ratio vs. plasma time

Adhesion strength was measured as a function of plasma time. For sample A (untreated filler), plasma treatment increased adhesion strength by only about 20 N, and higher exposed-filler fraction had little effect on adhesion. For B (less-treated) and C (more-treated), adhesion strength increased significantly (by up to approximately 80 N) with increasing plasma treatment time and corresponding exposed-filler fraction. No difference in adhesion strength was observed between B(less-treated) and C(more-treated), indicating that once the amount of surface treatment on the filler reaches a certain threshold, its effect becomes saturated.

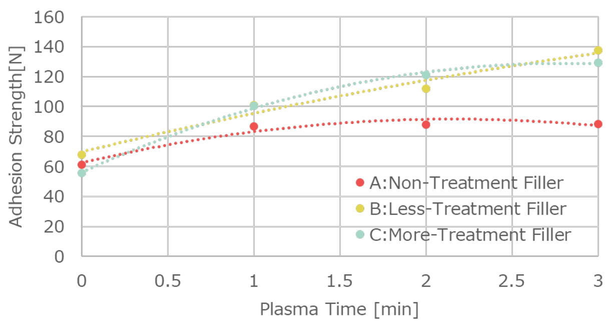


Fig 6. Adhesion strength vs. plasma time

Post-shear testing images of the interface for A and B revealed that the fracture mode changed according to filler treatment: Sample A with non-treated filler showed SR residue on Cu as shown in Table 3, indicating cohesive failure within the SR. Adhesion strength of sample A was lower than that of sample B, indicating stronger adhesion between SR-EMC at sample B.

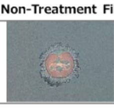
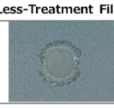
Filler	A(Non-Treatment Filler)	B(Less-Treatment Filler)
Top View		
Adhesion	Cohesive Failure	SR-EMC
Adhesion Strength[N]	86.8	146.1

Table 3. Comparison of adhesion strength with and without surface treatment

Observation of the surfaces after separation at the SR-EMC interface revealed that, for untreated filler, a large amount of filler fragments from SR adhered to the EMC, and cavities were present at the resin–filler interface in SR (Fig 7). In contrast, with treated filler, there was neither detached filler nor interfacial voids, indicating that filler drop-out from the SR matrix is a major contributor to poor adhesion.

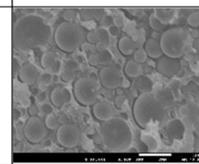
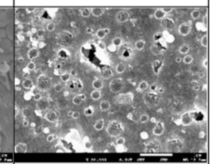
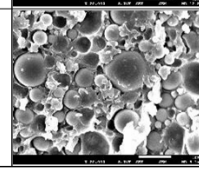
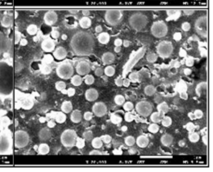
	Non-Treatment	Less-Treatment
EMC after test		
SR after test		

Fig 7. Surface images of SR and EMC after shear test

Finally, the mechanism of filler drop-out is illustrated (Fig 8): without surface treatment, the interaction between filler and SR resin is weak, allowing filler to be easily pulled out, leading to lower interfacial adhesion and cohesive failure. Surface-treated filler forms a strong chemical interface, suppressing filler drop-out and leading to significantly enhanced SR–EMC interfacial adhesion.

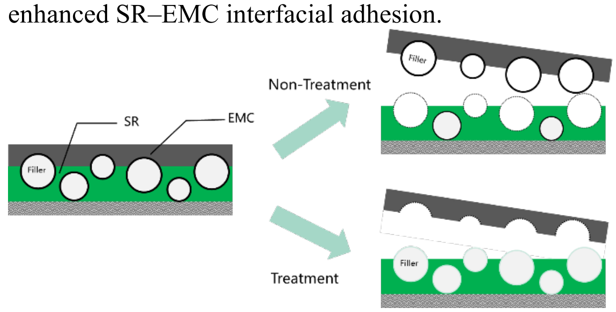


Fig 8. Diagram of SR-EMC delamination

III. Conclusion

In this report, we developed and established a new measurement technique for quantifying SR-EMC interfacial adhesion using the shear test for measurement. To enable measurement of adhesion strength at the SR–EMC interface, experimental conditions were optimized by increasing the adhesion between SR and Cu and decreasing the adhesion between SR and EMC.

By utilizing the developed adhesion measurement protocol, we have successfully investigated some effective approaches for adhesion improvement. We demonstrated surface silane treatment of SR filler particles and conducted plasma treatments to control the exposed-filler fraction. This significantly enhances SR-EMC interfacial adhesion and is highly effective in preventing cohesive fractures and filler drop-out. These findings are expected to make a substantial contribution to the design and process optimization of high-reliability automotive package materials.

Reference

[1] AEC-Q100-Rev-H, 2014, AEC Technical Committee.
[2] Kenny Mahan, Byung Kim, Bulong Wu, Bongtae Han, Ilho Kim, Hojeong Moon, Yong Nam Hwang, ” Modified single cantilever adhesion test for EMC/PSR interface in thin semiconductor packages” Microelectronics Reliability, Vol. 63, 2016, pp 134-141.
[3] Sawako Shimada, Kazuya Okada, Tomoya Kudo, Chiho Ueta, Yuya Suzuki, ” High Reliability Solder Resist with Strong Adhesion and High Resolution for High Density Packaging” IEEE Electronic Components and Technology Conference(2019) pp1015-1021.
[4] Rok Šinkovec and Branka Mušič, “Effect of Organosilane Coupling Agents on Thermal, Rheological and Mechanical Properties of Silicate-Filled Epoxy Molding Compound” Materials, Vol. 13, 2020, 177.