

Reliability of WLP Structures Fabricated with ALX Dielectric Polymer

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Abstract

For wafer level packaging (WLP) applications, BCB, polyimides, epoxies, and PBO are the predominant spin-on dielectric materials used for repassivation, redistribution, and stress buffering. Each of these materials has their respective strengths and weaknesses in process and in reliability. Asahi Glass Co., LTD has developed a new spin-on dielectric polymer (ALX) designed for WLP applications that provides a unique set of material properties coupled with a low curing temperature. We have previously presented process evaluation and optimization data on ALX polymer material, which showed an application process similar to BCB with wide process latitude. In this paper we present the results of a study done to evaluate the performance of ALX polymers in WLP test structures fabricated at RTI International. Typical solder bumped repassivation and bump-on-polymer test structures have been fabricated using ALX and BCB and evaluated through bump shear tests. We have also evaluated the adhesion of ALX to typical materials encountered in WLP structures through shear testing free-standing polymer structures.

Keywords: wafer level packaging, polymer dielectrics, repassivation, bump shear

Introduction

A number of different materials are used as permanent polymer dielectrics in microelectronic packaging and interconnect today, including polyimides (PI), benzocyclobutene (BCB), epoxies and polybenzoxazole (PBO). There are several texts on these materials as they apply to microelectronics [1-2] and several reviews on the use of such materials in microelectronic applications [3-4].

Spin-on polymers are widely used in microelectronic packaging applications. For bumping and wafer level packaging (WLP), BCB and PI are the predominant spin-on dielectric materials used for repassivation and redistribution [5, 6]. Each material has its respective strengths and weaknesses. BCB, manufactured by Dow Chemical, has low moisture absorption, low shrinkage on cure, low curing temperature (210 – 250 °C), a low dielectric constant and develops an easily metallized sloped via side wall when exposed in proximity. However, it has low elongation to break and tensile strength and undergoes brittle fracture which has limited its application in bump-on-polymer applications as chips become larger than 6 mm. In fact, Amkor has recently commented that “First-generation WLCSP technologies were not capable of supporting larger die sizes due to use of materials such as BCB which have low tensile strength and low elongation to break and thus proved incapable of surviving BLR tests such as drop and temp cycle testing...” [7].

Polyimides are supplied commercially by Asahi Chemical, Toray, HD Micro and Fuji Film among others. They are superior mechanically to BCB but suffer from much higher moisture absorption (which can lead to blistering if not carefully processed), higher shrinkage on cure, higher

dielectric constants, and have cure temperatures of 320-400 °C or greater [1-4].

ALX polymer, manufactured by Asahi Glass Co., LTD, are negative tone, photoimagable, fluorinated aromatic polymers that have low dielectric constant, shrinkage, and moisture absorption superior to PI and comparable to that of BCB [8]. They can be cured at a significantly lower cure temperature (190°C) than BCB or PI and have higher elongation than BCB. Previously, we have reported on experiments to establish process windows and optimal processing conditions for the coating, exposure, and develop for ALX polymers [9]. The mechanical, thermal, and electrical properties of ALX211 are shown in Table 1, and compared to published information on BCB [10-12] and PI [13].

In this paper, we present the results of initial bump shear reliability tests carried out on WLP test structures fabricated with ALX polymers and BCB. For most properties, BCB and ALX are quite comparable. For this reason, the test structures in these experiments were fabricated with BCB and ALX polymers for comparison. Eutectic solder bumped repassivation (single polymer layer) and bump-on-polymer (two polymer layers with a Cu redistribution line in between) were fabricated on Si wafers and bump shear tests were conducted to determine the shear strength and failure mode for the structures. In addition, the adhesion of ALX was evaluated on typical WLP materials through bump shear testing of polymer bumps, providing a quantitative method of assessing adhesion.

Material Property	BCB	PI	ALX211
Modulus (GPa)	2.9	2.9-3.5	1.3
Elongation (%)	8	20-75	20
Tensile Strength (MPa)	87	120-200	90
CTE (ppm/°C @ 25°C)	42	35-55	60
Stress (MPa)	28	28-30	32
Dielectric Const. (1KHz-1GHz)	2.6	2.9-3.4	2.6
Resistivity ($\Omega\cdot\text{cm}$)	10^{19}	$> 10^{16}$	$> 10^{16}$
Water Absorption (% @ 85°C/85%RH)	0.2	~ 1-3%	0.4

Table 1: Physical Properties of BCB, PI, and ALX211

Adhesion from Polymer Bump Shear Measurements

It is normally accepted that shear testing better mimics failure modes (like the drop test) than tensile testing (i.e. stud pulls). The adhesion of ALX polymers to uniform blanket layers of Si_3N_4 , Cu, and Al on Si wafer substrates was measured using bump shear performed on arrays of polymer bumps. The polymer bump arrays were fabricated by first performing a short oxygen plasma clean on the blanket films followed by an adhesion promoter spin coat and dry (AP-903 adhesion promoter from Asahi Glass). ALX215 polymer was spin coated, exposed, and developed to form arrays of 100 μm square polymer bumps. ALX215 is a higher viscosity formulation of ALX211 and was used to achieve a layer thickness of approximately 23 μm , which was high enough to perform bump shear. The same cure process was used for both ALX211 and ALX215; 190°C for 2 hours in an inert nitrogen environment.

Table 2 shows the results of the polymer bump shear tests. The bump shears were done using a 4 μm tool lift and a 100 $\mu\text{m}/\text{sec}$ shear speed. Failure occurred at the polymer-base layer interface for all tests, indicating that the shear values represent only adhesion strength to the base materials and not a combination of surface adhesion and polymer self-cohesion.

Material	Ave. Shear Strength (g)	Std. Dev. (g)
SiN	45.1	.93
Cu	48.4	1.7
Al	47.1	0.9

Table 2: Polymer Bump Shear Strength

In order to determine if the adhesion of ALX to itself was adequate for bump-on-polymer applications, the adhesion between two layers of ALX polymer was tested in a similar manner by fabricating polymer bumps of ALX215 on a blanket layer of ALX211. A 7.8 μm blanket layer of ALX211 was applied (using a similar process as described above) to Si wafers with $\sim 3000\text{\AA}$ of thermal SiO_2 and cured at 190°C for 2 hours. AP-903 adhesion promoter was applied to the first layer of ALX211 before applying the second polymer layer of ALX215. Figure 1 shows a polymer bump-on-polymer

structure before and after shear. The failure mode of these structures was at polymer- SiO_2 interface, with a large portion of the blanket polymer layer pulling off of the SiO_2 surface around the sheared bump. No failures were seen at the interface between the polymer layers. This indicates excellent polymer-to-polymer adhesion, which is critical for multilayer polymer applications. Table 3 gives the shear strength data for the polymer bump-on-polymer shear experiment. The polymer - polymer bump shear adhesion is thus at least, and likely greater than, 68 grams since the failure was at the weakest interface, i.e. the $\text{SiO}_2/\text{ALX-211}$ interface.

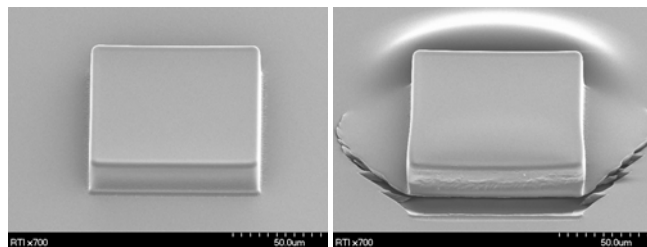


Figure 1: Polymer Bump-on-Polymer Structure Before (left) and After Shear (right)

	Ave. Shear Strength (g)	Std. Dev. (g)
ALX-215 to ALX-211	> 68.3	1.8

Table 3: Polymer Bump-on-Polymer Shear Strength

WLP Test Structure Evaluations

WLP test structures were fabricated with ALX211 and BCB and solder bump shear was used to compare the performance of the two materials.

Figure 2 below shows a repassivation/solder bump structure with a single layer of polymer applied and patterned over a surface that replicated a typical device wafer. The substrates were Si wafers coated with an evaporated stack of $\sim 500\text{\AA}$ of Ti followed by 1000-3000 $\text{\AA}$ of aluminum. Approximately 1.5 μm of PECVD Si_3N_4 was then deposited and openings were made down to the underlying Al. ALX211 polymer was applied and patterned using the previously outlined processes. The BCB polymer was applied and patterned using a process developed at RTI and based on Dow Chemical's standard processing guidelines [15]. The target final thickness of the polymer layers was 5 microns. The exposure gap for the ALX211 polymer wafers was set at 75 μm in order to achieve a via sidewall slope similar to that achieved with BCB at a 50 μm exposure gap. The vias formed in the ALX and BCB layers were opened over the Al pad in the Si_3N_4 opening.

After polymer processing, all wafers were metallized with a sputtered UBM consisting of 1000 $\text{\AA}$ of Ti and 1500 $\text{\AA}$ of Cu. A thick photoresist was applied and patterned on the UBM to define the bump pattern. A diffusion barrier of Ni (approximately 1.5 μm thick) was electroplated over the UBM, followed by eutectic Sn/Pb solder. After plating, the

photoresist was stripped, the field UBM was chemically etched away, and the bumps were reflowed.

Two different bump structures were evaluated, both having a 100 μm bump base diameter and a nominal bump height of 75 μm . The first solder bump structure had no via, (called 0/100) and sat on a blanket polymer layer. This structure was evaluated to determine the adhesion of the polymer to the underlying layers of the structure. The second structure had a via under the solder bump imaged from a 75 μm mask feature (called 75/100) which represents a 3:4 via:bump base diameter ratio.

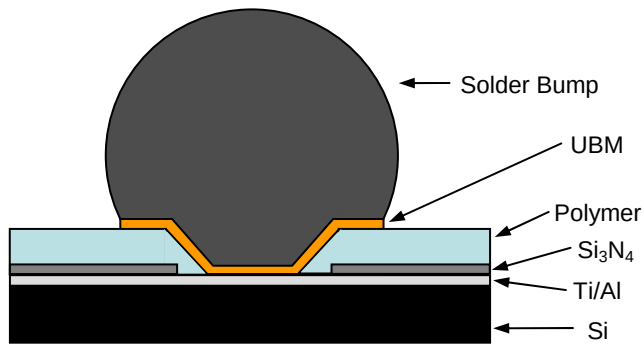


Figure 2: Repassivation Bumped Test Structure Figure

Solder bump shear testing was done in accordance with JEDEC specification JESD22-B117A Condition A, with a shear tool lift of 10 μm , a shear speed of 100 $\mu\text{m}/\text{second}$, and a test end point at 70% of the maximum shear force [16]. Table 4 shows the results of the bump shear tests performed.

The shear strengths of the repassivated bumped test structures were very similar for both BCB and ALX. A pad lift failure mode was observed for the 0/100 bump structures for both BCB and ALX samples, consisting of a separation between the UBM pad of the bump and the polymer surface. For the 75/100 bump structures there was a significant difference in the failure modes, with the ALX211 polymer samples exhibiting solder shear failure and the BCB polymer samples exhibiting a pad lift failure mode similar to that observed in the 0/100 bump structures. It is commonly accepted that the solder shear failure mode is the preferred failure mode in bump shear testing.

	Via/Bump Diameter	
	0/100	75/100
Ave. BCB Shear Strength (g)	38.4	35.7
Std Dev (g)	2.6	1.0
Failure Mode	Pad Lift	Pad Lift
Ave. ALX Shear Strength (g)	35.2	34.0
Std Dev (g)	1.1	0.9
Failure Mode	Pad Lift	Ductile Shear

Table 4: Repassivation Test Structure Bump Shear Results

To further test the performance of the ALX-211 polymer, the repassivation test structures were subjected to additional reflow cycles beyond those required for the bump fabrication process (2 reflow cycles). Bump shear tests were done after an additional 5 and 10 reflows and the results are shown in Tables 5 and 6 below.

Once again, the failure strengths of both bump structures with both polymers are similar. The failure mechanism on the 75/100 remains ductile solder shear on ALX211 samples compared with a pad lift failure mode on the BCB samples.

	Via/Bump Diameter	
	0/100	75/100
Ave. BCB Shear Strength (g)	39.0	46.8
Std Dev (g)	2.1	1.5
Failure Mode	Pad Lift	Pad Lift
Ave. ALX Shear Strength (g)	46.4	44.7
Std Dev (g)	2.1	1.4
Failure Mode	Pad Lift	Ductile Shear

Table 5: Repassivation Test Structure Bump Shear After 5 Additional Reflow Cycles

	Via/Bump Diameter	
	0/100	75/100
Ave. BCB Shear Strength (g)	40.3	45.0
Std Dev (g)	2.4	0.9
Failure Mode	Pad Lift	Pad Lift
Ave. ALX Shear Strength (g)	42.3	41.7
Std Dev (g)	1.7	0.6
Failure Mode	Pad Lift	Ductile Shear

Table 6: Repassivation Test Structure Bump Shear after 10 Additional Reflow Cycles

The second WLP structure fabricated to compare ALX211 and BCB was a bump-on-polymer structure shown in Figure 3. The bump-on-polymer structure is commonly used to improve the reliability performance of solder bumped devices by increasing the thickness of the stress buffer polymer dielectric material and moving the bump location away from the device I/O pad. For this test structure, a blanket polymer layer of unpatterned 5 μm thick ALX or BCB was applied to Si wafers with $\sim 3000\text{\AA}$ thermal SiO_2 . A sputtered Ti/Cu seed metal was deposited on the polymer layers and Cu redistribution structures were then plated using a photoresist template to define the plated areas. The thickness of the electroplated Cu RDL structures was approximately 2.5 μm . After stripping the photoresist and etching the Ti/Cu seed metal layer, a second ALX or BCB polymer layer was applied

(5 μm thick) and was photo-defined to create vias over the plated Cu RDL lines.

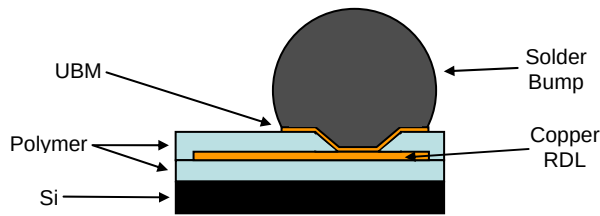


Figure 3: Bump on Polymer Bumped Test Structure

For multilayer polymer structures, it is typical to increase the exposure dose of the second layer compared to that of the first to compensate for the lack of reflected light and achieve full exposure. For the ALX211, the exposure dose was doubled for the second layer to ensure full exposure. The cure for both ALX211 layers was 190°C/2 hours in a nitrogen environment. The BCB polymer was processed using a process developed at RTI which is based on Dow Chemical's standard processing guidelines for multilayer structures [15]. The exposure dose of the second BCB layer was increased by approximately 50% in order to achieve a full exposure dose over the first polymer layer. The cure of the first BCB layer was done at 210°C/40 minutes to achieve good adhesion between the first and second polymer layers; the second layer cure was done at 250°C/1 hour. Both BCB cures were done in a nitrogen environment.

Following the second polymer layer processing, sputtered Ti/Cu UBM as described above was deposited and a thick photoresist was applied and patterned to define the areas where eutectic solder would be electroplated. Following electroplating, the resist template was stripped, the UBM layers were chemically etched away and the solder bumps were reflowed. As in the previous experiment with repassivated solder bump structures, 0/100 and 75/100 bump structures were evaluated.

Solder bump shear testing was done in accordance with JEDEC specification JESD22-B117A Condition A, with a shear tool lift of 10 μm , a shear speed of 100 $\mu\text{m}/\text{second}$, and a test end point at 70% of the maximum shear force [16]. Table 7 summarizes the results of the bump shear tests conducted on the ALX211 and BCB bump-on-polymer samples.

	Via/Bump Diameter	
	0/100	75/100
Ave. BCB Shear Strength (g)	45.5	58.5
Std Dev (g)	2.2	1.9
Failure Mode	Pad Lift	Ductile Shear
Ave. ALX Shear Strength (g)	63.5	69.8
Std Dev (g)	2.9	3.2
Failure Mode	Pad Lift	Ductile Shear

Table 7: Bump-on-Polymer Solder Bump Shear Results

The failure modes for both ALX and BCB were the same for a given via/bump diameter combination. A pad lift failure mode was seen for the 0/100 test structures for both polymers. However, the shear strength of the ALX test structures was found to be ~40% higher than that of the BCB test structures. For the 75/100 test structures, both polymers exhibited a ductile solder shear failure mode, but the ALX polymer samples had a shear strength ~20% higher than that of the BCB samples.

For both the repassivation and bump-on-polymer test structures, we hypothesize that the difference in the elongation and modulus between BCB and ALX are the primary reasons for the differences in the bump shear test results. For the repassivation test structures, the higher elongation and lower modulus of the ALX provides additional stress buffering that improves the shear strength of the bump structure compared to samples with BCB and results in a solder shear failure mode. For the bump-on-polymer structures, the increased polymer thickness improves the strength and failure mode for both BCB and ALX structures, but the elongation and modulus of the ALX appears to allow a greater load to be absorbed by the structure before the solder bump yields to ductile failure.

Conclusions

We have evaluated the adhesion and mechanical properties of Asahi Glass Corp.'s ALX-211 spin-on permanent dielectric polymer.

Bump shear testing was conducted on polymer bumps formed from ALX polymer on typical WLP materials and was found to be > 45g over a 100 μm^2 area for all tested materials. This method was chosen because the ALX polymers can be processed to achieve very thick layers in a single spin coat (> 20 μm), thus allowing a truly quantitative test to be done to measure interface adhesion.

Bump shear tests were carried out on test structures simulating typical repassivation and bump-on-polymer structures. The ALX polymer appears to improve the bump shear failure mode for repassivation bump structures over that of BCB, allowing ductile bump shears to be achieved. For bump-on-polymer structures, ALX polymer significantly improved the shear strength of the test structures.

These results indicate that ALX polymers could improve the reliability of WLP structures over comparable structures fabricated with BCB. In addition, ALX exhibits particular material property advantages over polyimide materials that make it an attractive alternative to both BCB and PI for advanced packaging applications.

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