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Temporary Wafer Bonding Materials with Mechanical and Laser Debonding Technologies for Semiconductor Device Processing

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***Abstract*—Advanced wafer-level packaging (WLP) techniques, mainly driven by high-performance applications in memory and mobile market, have been adopted for large-scale manufacturing in recent years. Temporary wafer bonding and debonding technology have been widely studied and developed over the last decade for use in various WLP technologies, such as package on package, fan-out integration, and 2.5-D and 3-D integration using through-silicon-via. Temporary bonding technology enables handling of thinned substrates (<100 μm), which can no longer self-support during backside processing and packaging. Moreover, some applications require the temporary bonding materials to withstand temperatures up to 250°C in high-vacuum conditions, and even up to 350°C or higher during the dopant activation step required for manufacturing power devices. Therefore, a simple yet effective temporary bonding process and material that can survive all the backside processes is highly desired.**

In this study, a series of formulations based on polar thermoplastics was developed for temporary wafer bonding applications. These materials target high-temperature survivability and improved adhesion to prevent the premature delamination during downstream wafer processing. All these materials provide high thermal stability up to 250°C or higher, and are able to be bonded to carrier wafers treated with release layers, which can be selectively debonded by either mechanical or laser release after backside processing. The material left on device wafer after debonding can be easily cleaned using common industrial solvents. Wafers bonded with these materials demonstrate lower overall stack total thickness variation (<5 μm) after grinding and have successfully passed a 200°C plasma-enhanced chemical vapor deposition (PECVD) process without any delamination during grinding and PECVD processes.

***Keywords*—Temporary wafer bonding, mechanical debond, laser debond, high-temperature survivability**

Introduction

One of the major forces driving the demand for thinner, smaller, and highly integrated semiconductor packages is from mobile market, such as smartphones, tablets, and other handheld devices [1]. In addition, the packaging technology for these applications needs to enable higher speed, better functionality, and longer battery life for increased bandwidth, smaller die size, and lower power consumption [2,3].

Wafer-level packaging (WLP) has been widely developed and used to achieve higher-performance packaging, lower cost, smaller form factor, and a higher level of integration. Generally speaking, most WLP applications, such as semiconductor packaging for high input/output density is accomplished by flip-chip processing. As alternatives, many other attractive advanced packaging platforms using different interconnect technologies have been developed over the last few decades, such as quad flat no-lead, fan-in WLP, fan-out WLP (FOWLP), 2.5-D integration, and true 3-D integrated circuit (IC) integration [4]. Temporary wafer bonding/debonding processes are involved in many of these technologies to enable innovative high-density applications. For example, to prevent the loss of mechanical self-support after thinning down to 100 μm or thinner, a device wafer with full thickness must be temporarily bonded to a rigid carrier wafer before going through the backside grinding process [5]. In addition, reconstituted wafers used in FOWLP usually exhibit huge wafer warpage, especially being processed at elevated temperature higher than 150°C, which creates significant challenges to handle the wafers in tools used for high-volume manufacturing. Also, the 300-mm reconstituted wafers acquire a flexible behavior that no longer allows self-supporting handling when the wafer thickness drops below 400-450 μm. As a solution, temporary bonding/debonding technology has been adopted to successfully overcome the warpage and support the wafer during processing [6].

A schematic illustration of a temporary wafer bonding/debonding process and handling is shown in Fig. 1. Prior to bonding, the carrier wafer is coated with a thin release layer to facilitate debonding and a thick bonding layer is coated on the front side of device wafer to protect its features. Usually, both the release and bonding layers are based on organic polymeric materials. Then the wafers are bonded using a thermal compression process under vacuum. The device wafer, together with the supporting carrier wafer, is then subjected to backside grinding as well as other backside processes. After completing the backside processes, the device wafer is then separated from the carrier wafer using the appropriate debonding method, such as laser or mechanical debonding, as determined by the release layer. Then the device wafer is cleaned using common industrial

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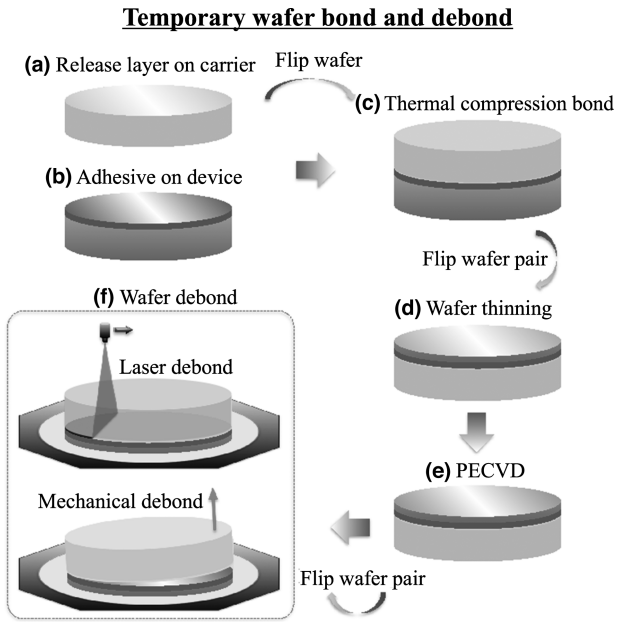


Fig. 1. Illustration of wafer processing and handling flow.

solvents. The temporary bonding/debonding technology offers an easy-to-implement and cost-competitive solution to handle thin wafers [7]. However, it is necessary to understand the substrates and processing conditions for different applications to use appropriate bonding and release materials that are able to survive wafer backside processes involving high temperature and high vacuum conditions, such as plasma-enhanced chemical vapor deposition (PECVD). Furthermore, a simple debonding process with easy removal of bonding material without complex tooling is also required to minimize total cost of ownership [8].

In this article, a series of materials based on polar thermoplastics was developed for temporary wafer bonding applications in 3-D IC fabrication. All these products provide high thermal stability up to 300°C, and are compatible with release layers for laser and mechanical debonding methods. After debonding, the bonding material is cleaned using common industrial solvents. The results show that the wafers bonded with these materials demonstrate lower overall stack total thickness variation (TTV) after grinding and survive 200°C PECVD process. The results also demonstrate good adhesion without any premature delamination during grinding and PECVD process.

Experiment

A. Material Properties

The properties of three temporary bonding materials based on polar thermoplastics are listed in Table I. The properties of the commercially available BrewerBOND® 305 bonding material, a nonpolar material, are also listed in the table for comparison. The melt viscosity data of these materials are shown in Fig. 2.

Both mechanical and laser debonding methods were used for wafer pair separation. The properties for both release layers are shown in Table II.

Table I
Properties of Temporary Bonding Materials

Material	T_d (°C)	Melt viscosity (Pa·s) at 200°C
Material A	320	4,052
Material B	390	47,620
Material C	334	88
BrewerBOND® 305	402	4,923

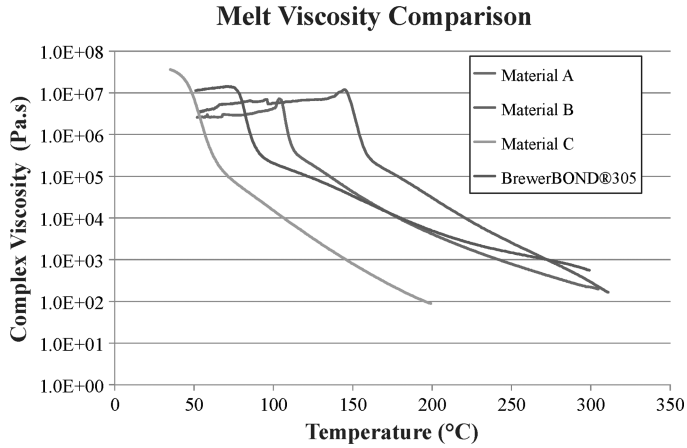


Fig. 2. Melt viscosity comparison of four materials.

Table II
Properties of Release Layers

Release layer	T_d (°C)	Debonding mechanism
BrewerBOND® 530	434	Mechanical peel
BrewerBOND® 701	520	Laser

B. Bonding Process

The temporary bonding materials, A, B, and C, were evaluated on 8-in. blank Si wafers. The bonding conditions for each material and the corresponding release layers that were tested for the experiment are listed in Table III. A typical bonding process involves coating of the bonding material on an 8-in. device wafer and coating of the release layer on an 8-in. carrier wafer using a spin coating process, followed by baking the wafers on bake plates and finally bonding the two wafers in a wafer bonder. The carrier wafer is usually a glass carrier for laser release processes. Otherwise, Si wafer will be used as carrier wafer. In this experiment, while using bonding Material A, the device wafer was coated with a 42-μm coat of bonding Material A by spin coating at 1,000 rpm, with 3,000 rpm/s acceleration for 30 s. Then the wafer was baked at 60°C for 2 min, 120°C for 2 min, and 200°C for 2 min. The carrier wafer was then coated with BrewerBOND® 530 material mechanical release layer by spin coating the material at 1,500 rpm, with 3,000 rpm/s acceleration for 30 s and then baking at 200°C for 2 min. Both wafers were then bonded at 210°C and 2,500 N for 3 min under vacuum (<5 mbar) using an EVG Model 510

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Table III
Bonding Processing Conditions

	BrewerBOND® 530 material (270 nm)	No release layer	BrewerBOND® 701 material (150 nm)
Material A (42 μm)	210°C, 2,500 N, 3 min	N/A	210°C, 2,500 N, 3 min
Material B (23 μm)	270°C, 4,000 N, 3 min	N/A	270°C, 4,000 N, 3 min
Material C (54 μm)	N/A	160°C, 1,800 N, 3 min	160°C, 1,800 N, 3 min

bonder. The bonded pair was then examined with a C-mode scanning acoustic microscope (CSAM) from Sonix.

C. Adhesion Test

The improvement in adhesion strength with polar thermoplastics was tested and verified by using an international standard pull-up adhesion tester (PosiTest ATA adhesion tester). The experimental setting and tooling are illustrated in Fig. 3. The device wafer coated with the bonding material was bonded to the carrier wafer already coated with a release layer, then an aluminum dolly was adhered to the backside of carrier wafer with epoxy glue to form a strong bond between the carrier wafer and aluminum dolly surface. During the pull-up test, the dolly was attached to the pull-up tester and the stack separated at the adhesion interface between bonding layer and mechanical release layer. Two material combinations were evaluated in this study and the test results are listed in Table IV.

D. Backside Grinding and PECVD

The bonded wafer pairs were subjected to backside grinding and PECVD test. The device wafer was thinned down to 50 μm (DGP8761, Disco), followed by deposition on the thinned wafer in a PECVD (AMAT Producer SE) chamber at 200°C for 2 min.

E. Mechanical and Laser Release Test

The bonded wafer pairs using BrewerBOND® 530 material as a mechanical release layer were mechanically debonded by using a Cee® Apogee™ mechanical debonder after initiation without any edge soaking or cleaning. The bonded pairs using BrewerBOND® 701 material as a laser release layer were debonded using a 308-nm laser wavelength (SUSS ELD12 laser debonder), or with a 355-nm laser wavelength (Kingyoup LD-Semi Automatic 200/300).

Result and Discussion

A. Material Properties

One of the critical requirements for organic polymer-based bonding materials to survive the wafer backside processes is thermomechanical stability. Table I shows that all the three materials tested possess thermal stability in the range of 300-400°C and are able to withstand high-temperature processes without thermal decomposition. Fig. 2 illustrates the melt viscosity of the materials, indicating that the Materials A and B possess excellent mechanical stability to support the thinned device wafer during backside processes. Material A shows comparable melt viscosity with BrewerBOND® 305 material and Material B has relatively higher melt viscosity than both Material A and BrewerBOND® 305 material, which indicates its capability to support wafer pairs better than Material A, especially in the applications where severe stress is generated at elevated temperatures, such as the reconstituted wafer used in FOWLP. In contrast, Material C has a melt viscosity as low as ~100 Pa·s at 200°C, so it may not be suitable for supporting a highly stressed device wafer during high-temperature processes, even though Material C possesses relatively high T_d at ~334°C. But on the other hand, the low melt viscosity of Material C is beneficial to thermal slide debonding methods as an alternative debonding route to mechanical and laser debond.

B. Adhesion Evaluation

Bonding materials based on polar thermoplastics are expected to potentially exhibit significantly improved adhesion when compared with ones based on nonpolar thermoplastics. This theory was verified by comparing the adhesion of Material A and BrewerBOND® 305 material using the same mechanical release material, BrewerBOND® 530 material. As shown in Table IV, the adhesion between Material A and BrewerBOND® 530 material is almost twice as high as the adhesion between BrewerBOND® 305 material and BrewerBOND® 530 material.

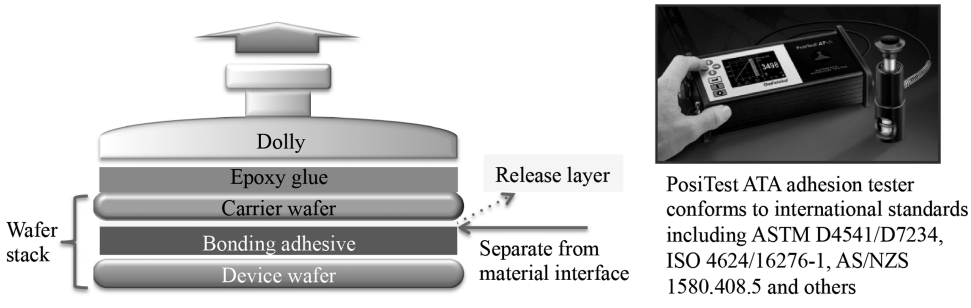


Fig. 3. Illustration of pull-up adhesion test.

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Table IV
Adhesion Test

Combination	Debonding pressure (psi)
Material A/BrewerBOND® 530 material	9 ± 1.7
BrewerBOND® 305 material/BrewerBOND® 530 material	5 ± 1.1

One possible reason for the adhesion improvement from Material A is its possession of abundant polar functional groups. The significance of this study is that we are capable of selectively fine-tuning the adhesion between bonding material and mechanical release layer by carefully choosing the suitable materials, to achieve the balance between good adhesion during processing and facile release during debonding. Therefore, the material combinations can be well optimized according to different needs from different customers and applications.

C. Bond and Thermal Simulation

The bonded wafer pairs prepared according to the processing conditions in Table III showed no defects or voids after bonding, and the wafers also survived the thermal process. The CSAM images presented in Fig. 4 show good bond line stability without any voids after bonding and thermal simulations. Materials A and C passed the thermal simulation on a bake plate at 260°C for 30 min and Material B survived 250°C for 1 h. Also, Material B can survive even at 300°C for 1 h without observation of any defects or voids in CSAM images. Material B also exhibits high melt viscosity between 200°C and 250°C as shown in Fig. 2, so it is an appropriate bonding material for FOWLP applications for handling highly stressed reconstituted wafers. In addition, low stack TTV between Material A and BrewerBOND® 530 material was detected, which was lower than 5 μm.

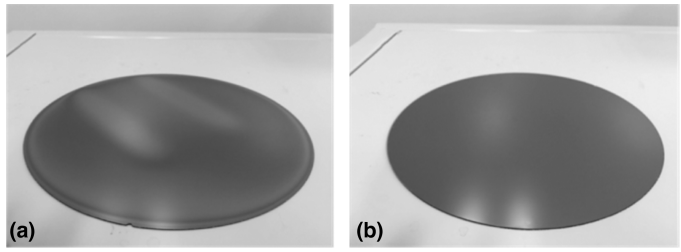


Fig. 5. Wafer pair using Material A and BrewerBOND® 701 material after grinding and PECVD, (a) frontside and (b) backside.

D. Backside Grinding and PECVD

All the bonded wafers were thinned down to 50 μm and passed PECVD process at 200°C for 2 min. The wafer pairs contained no defects, voids, or delamination after thinning and PECVD. Fig. 5 shows the image of the front and backside of a wafer bonded using Material A and BrewerBOND® 701 material after grinding and PECVD, and shows no defect after processing. Furthermore, the same wafer pair was successfully debonded using laser debonding with 355-nm laser wavelength as illustrated in Fig. 6. No damage was observed on the thinned device wafer.

E. Debond and Cleaning

The wafers were debonded using mechanical or laser debonding methods as defined by the specific release layer applied to the carrier wafer. Materials A and B bonded with BrewerBOND® 530 material were mechanically debonded by

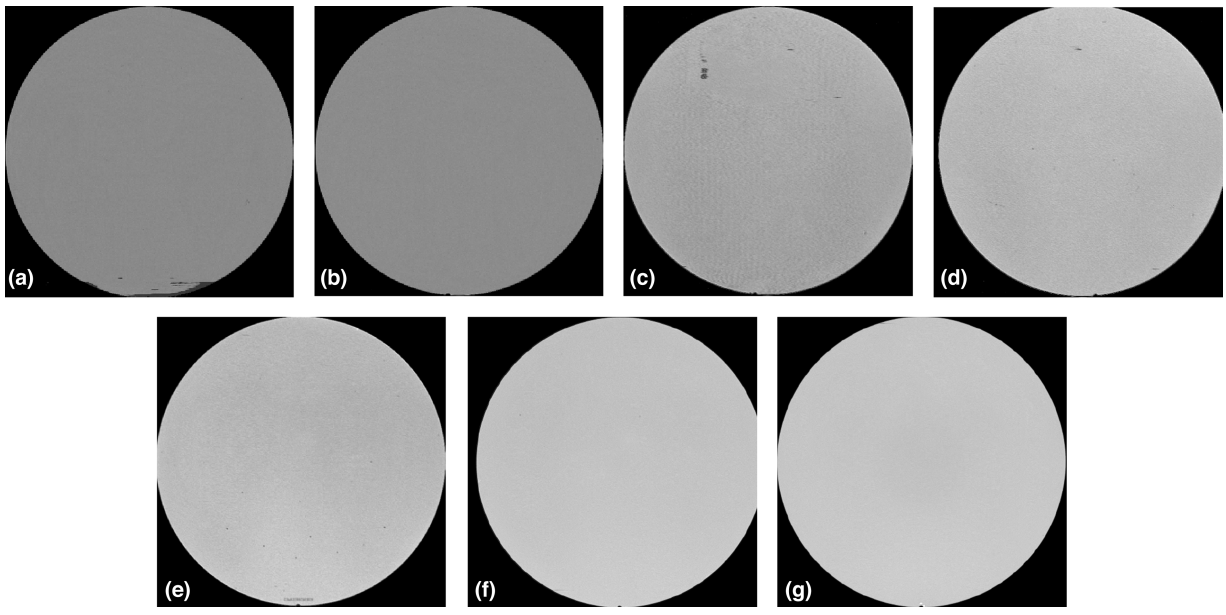


Fig. 4. CSAM of (a) Material A/BrewerBOND® 530 material after bond; (b) Material A/BrewerBOND® 530 material after 260°C for 30 min; (c) Material B/BrewerBOND® 530 material after bond; (d, e) Material B/BrewerBOND® 530 material after 250°C for 1 h and 300°C for 1 h; (f) Material C after bond; (g) Material C after 260°C for 30 min.

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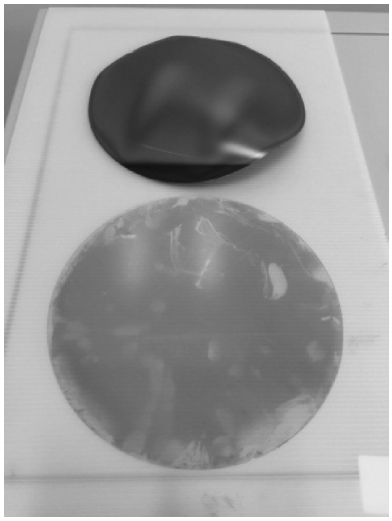


Fig. 6. Laser debonding of wafer pair with Material A and BrewerBOND® 701 material after grinding and PECVD.

using a Cee® Apogee™ mechanical debonder after initiation without any edge soaking or cleaning.

The bonded wafer pairs that used BrewerBOND® 701 material as the laser release layer used a laser separation tool for debonding the wafer pairs. The bonded pair with Material A was debonded by either a 308-nm laser wavelength with a power of 190 mJ/cm^2, or a 355-nm laser wavelength with a power of 4 W without any wafer damage. The wafer pair with Material B was debonded by a 308-nm laser wavelength with a comparable power of 200 mJ/cm^2 and the wafer pair with Material C was debonded using a 355-nm laser wavelength with a power of 3.5 W. The data are summarized in Table V.

The bonding material left on the device wafer was removed using common industrial solvents. After cleaning, the wafers did not contain any residue upon inspection for particulate residues using a surface inspection lamp.

Table V
Debonding Test

		BrewerBOND® 701 material	
	BrewerBOND® 530 material	308 nm	355 nm
Material A	Debonded with initiation	190 mJ/cm^2	4 W
Material B	Debonded with initiation	200 mJ/cm^2	N/A
Material C	N/A	N/A	3.5 W

The results showed that successful wafer debonding and cleaning can be achieved by using mechanical or laser debonding methods for these material sets.

Conclusions

A series of temporary wafer bonding materials based on polar thermoplastics was successfully developed and evaluated for temporary wafer bonding applications in WLP. The results show that all these materials provide high thermal stability up to 250°C or higher and are able to be bonded to fully treated carrier wafers, which can be selectively debonded by either mechanical separation or laser release after high-temperature treatment. After debonding, the bonding material left on the device wafer can be easily cleaned using common industrial solvents. In addition, the results also demonstrated that the wafers bonded have successfully survived 200°C PECVD process. The results clearly indicate the suitability of these materials for thinned wafer handling in various applications in WLP, and even the potential to handle the reconstituted wafers in FOWLP.

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