

Temporary Wafer Bonding Materials with Adjustable Debonding Properties for Use in High-Temperature Processing

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Abstract

Three-dimensional (3-D) integration is a very promising technology with the potential to improve device performance, increase device functionality, reduce power consumption, and decrease device size. One of the challenges in 3-D integration is processing the thinned wafer at high temperatures and in chemically stringent environments while the thinned wafer is still supported on a carrier wafer with a temporary bonding material. A new kind of spin-on materials for temporary wafer bonding has been developed to satisfy the high-temperature requirements of backside processes such as deposition, etching, curing, and plating. In addition to their high-temperature stability, these materials enable debonding from the carrier wafer by a “slide-off” mechanism to eliminate risk of wafer breakage. The most important feature of these materials is that their debonding properties can be tuned to satisfy broad process requirements. This paper discusses pertinent properties of these materials, such as high coating and bonding uniformity, short debonding time, and ease of removal with industry-accepted safe solvents, and the processes developed to achieve these properties.

Key words: temporary wafer bonding, spin-on coating, high temperature, 3-D integration, 3-D packaging.

Introduction

Three-dimensional integration is a very promising technology with the potential to improve device performance, increase device functionality, reduce power consumption, and decrease device size. Industry-leading experts claim that 3-D integration and packaging present the semiconductor industry's direction for the future, and the use of through-silicon via (TSV) technology has been proposed to further reduce the package footprint, improve performance, and reduce the time delay. However, 3-D integration brings forward the challenges associated with increasingly thin and fragile product wafers. To meet the current industry need, Brewer Science and EV Group have collaborated to create a new temporary wafer bonding technology to provide a novel solution for processing ultrathin wafers. This technology solution is comprised of Brewer Science's WaferBOND™ HT series of temporary wafer bonding materials, EV Group's bonding and debonding equipment platforms (EVG® 850TB/DB), and the development of a solution for safely and reliably processing sub-100 micron thinned wafers [1-7].

To prevent thin wafers from being damaged during processing, they can undergo temporary bonding to a carrier wafer by using temporary wafer bonding materials. Such materials not only provide the mechanical support during backside processing but also protect the active surface of the device wafer and the brittle wafer edge. The WaferBOND™ materials exhibit excellent coating and bonding uniformity to reduce grinding damage, breakage at the edge, and wafer-to-wafer post-thinning variation. Debonding wafers joined using these temporary wafer bonding materials can be conducted by using a “slide-off” approach, and the materials can be easily removed with an environmentally safe solvent in a short time without damaging the device wafer features. Reported in this paper is the development of a new kind of temporary wafer bonding materials. These materials have excellent thermal stability to meet the current industry requirements for high-temperature processes such as deposition, etching, curing, and plating. The most important feature of these materials is that their debonding properties can be tuned to satisfy broad process requirements. In this paper, we will show how this tunability works, and then we will focus on one material to show its excellent processability.

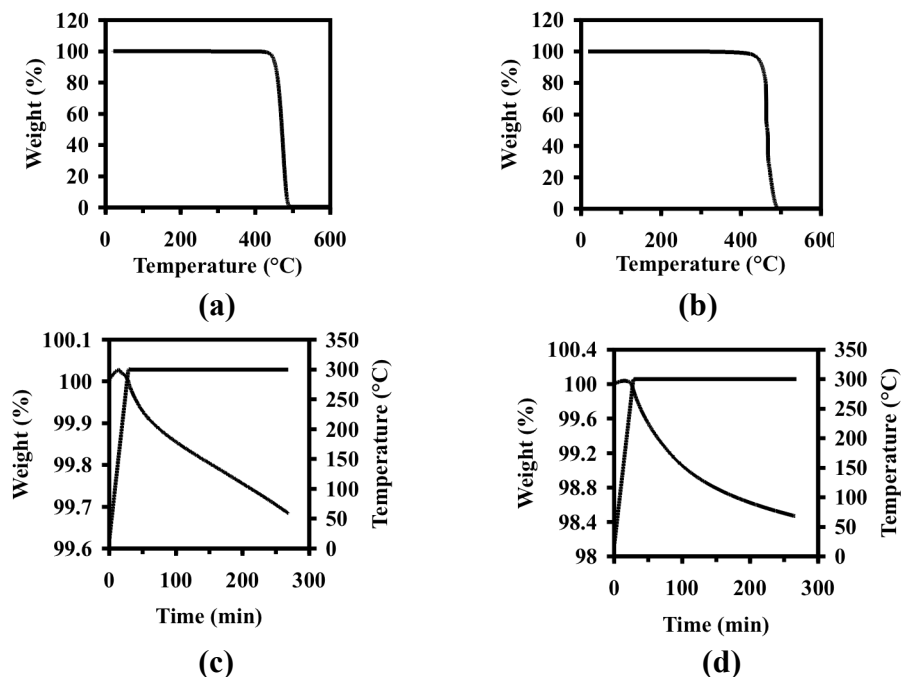


Figure 1. Thermogravimetric analysis of (a) component 1 and (b) component 2, and isothermal stability of (c) component 1 and (d) component 2 at 300°C in N₂.

Materials

A two-component system (components 1 and 2) was used to make the bonding material having tunable debonding properties. We first tested the thermal stability of these two components to ensure they could survive the stringent backside processing conditions.

Thermogravimetric analysis (TGA) was performed on both components individually. Thermal stability results are shown in Figure 1 (a) and (b). The temperature ramp is 10°C/minute. Components 1 and 2 have similar thermal stability. They both are stable up to 420°C. Isothermal study was also performed for both materials in nitrogen at 300°C for 4-hours. As shown in Figure 1 (c) and (d), components 1 and 2 have a weight loss of 0.3% and 1.5%, respectively. The excellent thermal stability ensures that the product made by blending these two components can be used at temperatures higher than those at which waxes and tapes cannot survive [8-9].

Tunability

The tunability of the material is achieved by blending components 1 and 2 at different ratios into solution. Because debonding depends on the melt viscosity of the materials, a series of products have been designed by adjusting the component ratio to achieve the desired viscosity. Table 1 lists the component ratio used in products A, B, C, and D, and Figure 2 shows the melt viscosity of these products. The melt viscosity data were obtained on a TA Instruments AR 2000 rheometer.

Table 1. The ratio of components 1 and 2 in products A, B, C, and D.

Products	Component 1 (wt%)	Component 2 (wt%)
A	30	70
B	50	50
C	57	43
D	85	15

As shown in Figure 2, the melt viscosity of the products at specified temperature increases as the amount of component 1 in the product increases. Debonding wafers bonded with a product that contains more component 1 must be performed at a higher temperature. The most important fact is that we can achieve the product debonding properties required by a specific process to make the best use of a customer's current process setup.

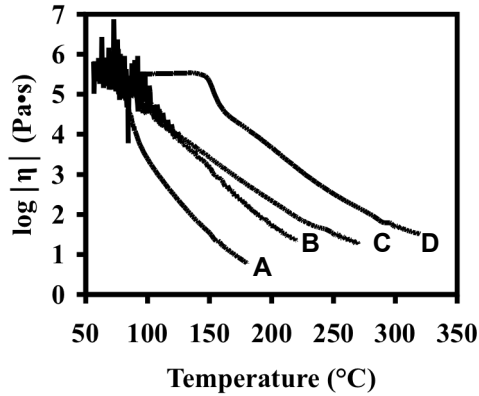


Figure 2. Melt viscosity of product A, B, C, and D.

Processability

The debonding property of the final products can be controlled by adjusting the component ratio in the product. The rest of this paper will focus on product C in Table 1. We will discuss pertinent properties of this material, such as high coating and bonding uniformity, short debonding time, and ease of removal with industry-accepted safe solvents, and the processes developed to achieve these properties.

The typical process flow for spin-on temporary wafer bonding materials and a brief introduction of the EVG® 850 TB automated bonding system was described previously [1,6,10].

Chemical Resistance

To ensure that the product would perform well during backside processing, the chemical resistance of product C was examined. Table 2 lists the chemical resistance of product C in various chemicals. These chemicals are very common in wafer fabrication processes. Product C was first spin-coated onto 4-inch wafers. After baking at 120°C and 180°C for 2 minutes,

respectively, the coated wafers were immersed into the chemicals at the conditions listed in Table 2. No film cracking or peeling was observed during this study. Because the temporary wafer bonding materials will be used in the bonded state, and the materials can be exposed to the chemicals only at the wafer or via edge, the chemical resistance study using coated single wafers is good for ensuring the material will be stable during backside processing.

Table 2. Chemical resistance of product C.

Chemicals	Temperature (°C)	Time (min)	Coating
Acetone	20	15	No change
Isopropanol	20	15	No change
PGME	20	15	No change
PGMEA	20	15	No change
Ethyl lactate	20	15	No change
HCl 37 %	20	15	No change

Film Thickness and Coating Uniformity

The coating uniformity of the bonding material is very important for the wafer thinning process because film thickness variation can result in delamination (from voids after bonding) and wafer-to-wafer post-thinning variation. The films were coated on 4-inch wafers, and film thickness and coating uniformity were measured using Foothill reflected light spectroscopy. Figure 3 shows a spin curve of product C. A film thickness of 12 to 31 μm can be achieved by adjusting the spin speed between 750 to 2000 rpm. The spin time is 60 seconds to ensure good coating uniformity.

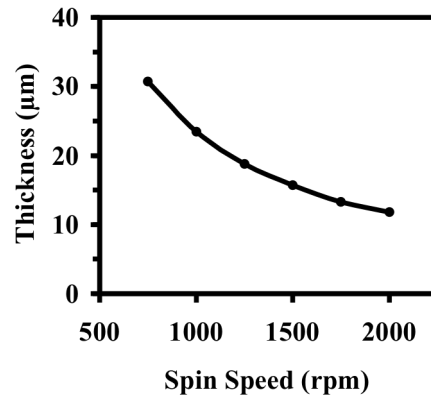


Figure 3. Spin curve of product C. Spin time is 60 seconds.

Product C exhibited very good coating uniformity. Figure 4 is a 3-D thickness plot of this material coated at 1500 rpm for 60 seconds. The mean thickness of the film is 15.7 μm , and the maximum and minimum thicknesses of the film are 15.9 and 14.9 μm , respectively. The resulting total thickness variation (TTV) is $\pm 3.2\%$. Good coating quality is crucial to effective bonding for backside grinding.

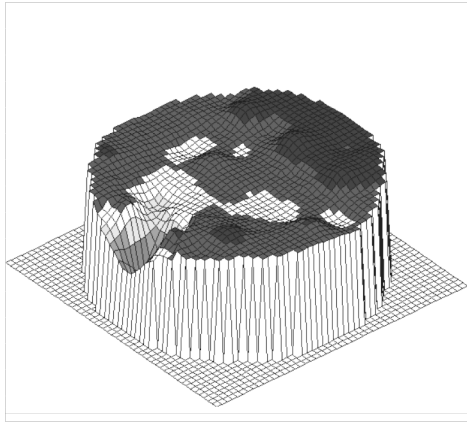


Figure 4. Coating surface in 3-D.

Bonding Quality

A good bonding process will reduce the film thickness variation and produce good bonding uniformity. Wafer bonding was performed with 8-inch coated wafers on an EVG[®] 850 TB automated system. The wafers were first spin coated with product C at 1500 rpm for 60 seconds. The resulting films were then proximity baked at 100°C for 3 minutes and then at 180°C for another 3 minutes. The two-step baking process removed most of the solvent. The wafer was then sent to the bond chamber to bond with another 8-inch wafer after pre-alignment. The bonding process can be performed at specified temperature and force under vacuum.

A Sonix[™] scanning acoustic microscope (SAM) was used to obtain the image of a bonded wafer pair. SAM can detect bonding defects such as voids, delamination, and thickness variation of the film. For each product, the bonding process must be optimized to obtain a good bond quality. Figure 5 shows a SAM image of a wafer pair bonded on EVG[®] 520IS wafer bonding system with materials developed from components 1 and 2. The bond is very uniform. No voids, flower pattern, or sharp color

difference were observed, which indicates a high-quality bond.

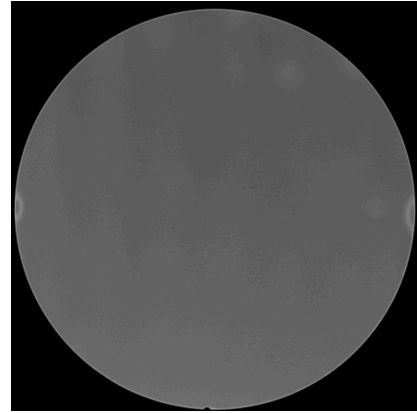


Figure 5. SAM image of bonded wafer pair.

Debonding

The debonding temperature and speed are very important features of the temporary wafer bonding materials. The melt viscosity must be controlled to be less than a certain value so that the debonder can initiate the debonding process without damaging the thinned wafers. As shown in Figure 2, because melt viscosity is a function of temperature, the debonding must be performed above a certain temperature. Also maximum debonding speed should be used to achieve a good throughput for the overall process. However, after backside processing, many materials may be deposited onto the device wafer, which would require debonding to be performed at lower temperatures. Our products have the advantage of possessing tunable debonding properties. Instead of debonding at a specified temperature, we can design different products to satisfy various customer requirements and to achieve fast debonding.

Figure 6 shows the debonding force of product C as a function of time. Two 8-inch wafers were bonded with product C with a coating thickness of 22 μm before bonding. The debonding was performed on debonding equipment that can evaluate the debonding force during the debonding process. The debonding temperature was 240°C, and the speed was 2 mm/s. The maximum debonding force was 24 lb,

which was the force required to initiate the process, and then the debonding force was gradually decreased until the two wafers were separated completely. Increasing the temperature or reducing the speed will reduce the debonding force needed to initiate debonding. One can optimize the debonding conditions according to the process requirements.

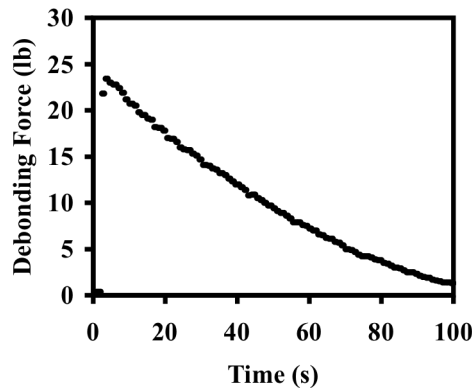


Figure 6. Debonding force of product C as a function of time.

Cleaning

It is very important that the temporary wafer bonding materials can be cleaned completely from the device wafer after backside processing. The cleaning of product C is evaluated by puddling the coated and baked (120°C and 180°C, 2 minutes each) wafer with an industry-accepted safe solvent and then rinsing it with isopropanol and deionized water. Table 3 lists the cleaning procedures. Puddling the solvent multiple times resulted in a better cleaning efficiency than puddling once with the same total solvent covering time.

Table 3. Cleaning procedure for product C.

Step	Speed (rpm)	Acc. (rpm/s)	Time (s)
Solvent dispense	50	500	6
Puddle	0	0	30
Solvent removal	1000	3000	4
Solvent dispense	50	500	6
Puddle	0	0	30
Solvent removal	1000	3000	4
Solvent dispense	50	500	6
Puddle	0	0	30
Solvent rinse	700	3000	20
Isopropanol rinse	700	3000	20
DI Water rinse	8 strokes		
Spin dry	3000	1000	30

Grinding and TSV

The wafer pair bonded with product C underwent successful grinding down to 135 μm . The grinding was performed on an OKAMOTO tool with one coarse and one fine wheel. Figure 7 shows a picture of the grinded wafer. No breakage and delamination was observed after grinding.

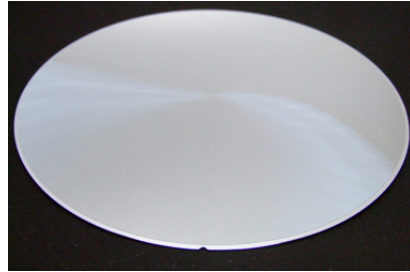


Figure 7. A picture of a wafer that underwent grinding and that was bonded with product C.

The thinned wafer will go through a TSV process of about 20 steps. The diameter of the TSV will be 70 microns so that the final aspect ratio of the vias will be ~ 2 . The TSV formation results will be reported when they are available.

Conclusions

A special kind of temporary wafer bonding materials has been successfully developed. The melt viscosity of the products can be adjusted to satisfy debonding requirements over a wide temperature range. These materials demonstrate excellent coating and bonding qualities, and the debonding temperature and speed can be adjusted for best performance. Wafers bonded with these materials underwent successful grinding to 135 μm , and work on TSV formation is underway. These materials can be cleaned easily from the wafer surface with industry-accepted safe solvents.

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