Air jetting debonding for thin-wafer/panel and fan-out wafer-level package processing

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Unlike mechanical debonding, which generates significant peel stress on a device's surface, air-jetting debonding (AirDebond®) injects air streams between the carrier and the device, pushing the carrier up from underneath while compressing the device down. As a result, this jetting technology allows a higher strength bonding adhesive at an elevated temperature, which is typically associated with excessive warpage control. Furthermore, the airflow produces the most uniform stress distribution, and the debonding is instant at room temperature—characteristics that are best suited for large-area debonding.

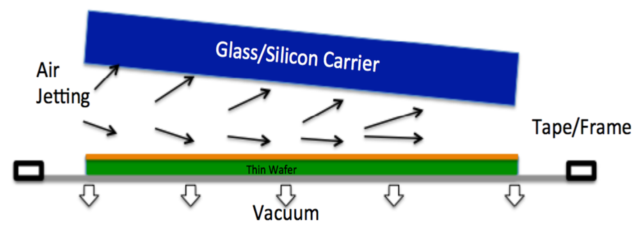

Figure 1: Illustration of the air jetting process.

Air jetting debonding

This article describes the advancements in air jetting debonding and the material developments for high-temperature temporary support of thin-wafer fabrication, fan-out wafer-level packaging (FOWLP), and integrated circuit (IC) package assembly with a large thin substrate.

The fabrication of a thin IC wafer requires a temporary support for grinding, polishing, dry reactive ion etching, dielectric development, metal deposition, chemical etching, photoresist development and/or solvent soaking, plasma ashing, and wafer cleaning. Panel-level packaging also requires temporary support for redistribution layer (RDL) build-up, flip-chip bonding, fluxing cleaning, molding, and even the solder reflow process. After fabrication, the thin-wafer/panel requires debonding from its carrier. The bonding adhesive needs to be completely removed without any trace of residue contamination.

While a carrier and a device typically bond together under pressure in vacuum, debonding mechanisms to separate the carrier from the device vary with the adhesive. It is desirable to have the debonding done with the shortest cycle time, the minimum tensile stress exerted on the device surface, the elimination of heat damage on the device's structure, and easy cleaning with an environmentally friendly cleaner.

The concept of injecting air for carrier debonding was first introduced in 2016 for thin-wafer processing [1]. Unlike mechanical peeling, air jetting debonding introduces air streams to push the carrier up from underneath while compressing the device down (**Figure 1**). The structure and pattern of the device are being protected from the airflow. Furthermore, AirDebond® allows the carrier made by materials, such as silicon, ceramic and metal (as well as glass) to best match the coefficient of thermal expansion (CTE) of the device wafer for better warpage control at a high temperature.

Table 1 summarizes the application and materials with the air jetting technology.

	High thermal 400°C stability	RDL-first fan-out WLP	High chemical resistance debond with water wash	Water wash adhesive with 280°C stability
Protective coating, or sacrificial layer coating	N/A	Z-Coat 211	Z-Coat 100/122B	N/A
Bonding adhesive	Z-Coat 451	N/A	Brewer Bond 305/Z-Coat 008	Z-Coat 110
Bonding temperature	300°C	N/A	200°C	150°C
Thermal stability	400°C	350°C	280°C	280 °C
Debonding method	AirDebond®	AirDebond®	AirDebond®	AirDebond®
Cleaning	Solvent	Peel or Cleaner	Water	Water
Pro and con	High temperature	Low cost	Easy debond/clean	Easy debond/clean

Table 1: Summary of the application and materials with AirDebond® technology.

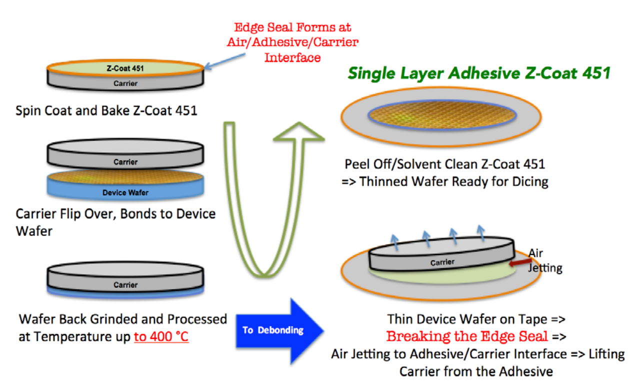

Figure 2: Typical process flow with Z451.

Temporary bonding for a wafer process >400°C

The thermal stability of an adhesive often refers to its ability to resist decomposition and outgassing during high thermal processing. Z-coat 451 (Z451) is a single-layer bonding adhesive for up to a 400°C processing application. **Figure 2** illustrates a typical process flow with Z451. **Figure 3** shows the thermogravimetric (TGA) curve of Z451 under a constant heating rate of 10°C/min to 700°C. We can see that the weight loss of the Z451 is highly stable up to 450°C. The decomposition temperature is around 500°C.

The bonded wafer stack is often backgrinded and then processed at the evaluated temperature with many types of chemicals. **Table 2** summarizes the chemical resistance testing on Z451. Good chemical resistance is needed for post-thinning chemical smoothing, surface roughing etching, photoresist stripping and via cleaning.

Chemicals	Test Condition	Result
PGMEA	25 C Soak 30 minutes	Weight Loss less than 1% surface keeps normal
0.045% KOH	25 C Soak 30 minutes	
Al Hydroxide	40 C Soak 60 minutes	
10% Oxalic Solution	47 C soak 60 minutes	
TMAH	25 C Soak 30 minutes	
Stripper	60 C soak 60 mintes	
Hydrofluoric 6N	25 C Soak 30 minutes	
Acetic acid 6N	25 C Soak 30 minutes	
H_2O_2 30%	25 C Soak 30 minutes	
H_2SO_4 6N	25 C Soak 30 minutes	
HCl , Conc	25 C Soak 30 minutes	
H_2O:NH_4OH:H_2O_2 (5:1:1)	25 C Soak 30 minutes	
H_2O:H_2SO_4:H_2O_2 (8:1:1)	25 C Soak 30 minutes	
Isopropanol	25 C Soak 30 minutes	

Table 2: Summary of chemical resistance testing on Z451.

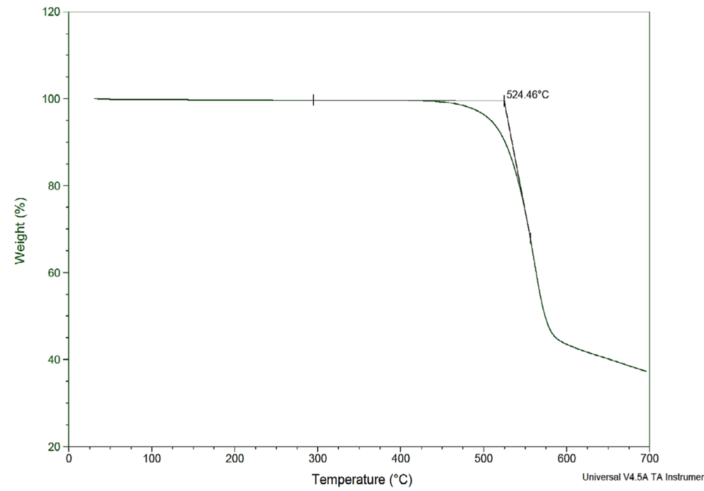

Figure 3: Thermogravimetric (TGA) curve of Z451 under a constant heating rate of 10°C/min to 700°C

Figure 4a shows an acoustic image of a bonded wafer stack after backgrinding to 60µm, and **Figure 4b** plots the total thickness variation (TTV) measurement after grinding.

Before debonding, the wafer stack was laminated onto the UV tape with the dicing frame. The Z451 stayed with the device wafer after debonding. It was then removed from the device wafer without leaving any residue.

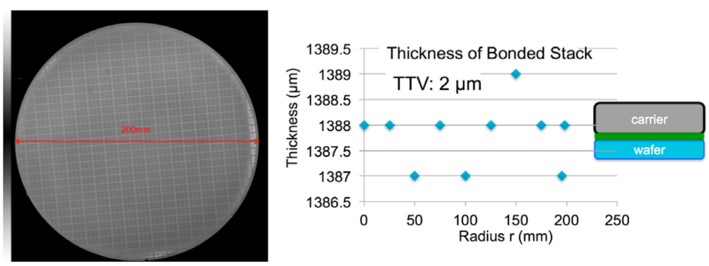

Figure 4: a) An acoustic image of a bonded wafer stack after backgrinding to 60µm; and b) A plot of the total thickness variation (TTV) measurement after grinding.

RDL-first FOWLP

In the RDL-first FOWLP process, a rigid carrier is used to support RDL build-up, die placement, and wafer molding for a finer length/spacing RDL structure with a better yield. It is commonly agreed upon that the RDL-first FOWLP approach is better suited for high-I/O-count, high-density, and high-value packages. **Figure 5** illustrates the RDL-first FOWLP process flow with the air jetting technology.

As described in **Figure 5**, a sacrificial layer coating on a rigid carrier is typically needed as the first process step prior to all other processing that follows. In general, the sacrificial layer must satisfy the following requirements: 1) Should be thermally stable at 300°C; 2) Should be resistant to all processing chemicals; 3) Should have good mechanical strength at a high temperature; 4) Should be tack free at 300°C; and 5) Can be easily removed from the molded wafer after carrier release.

Z-coat 211 (Z211) is a polyimide-based spin-on polymer designed as a sacrificial layer on a carrier. After spin coating, Z211 is step cured at temperatures up to 300°C to form a smooth, uniform, void-free yellowish dry film on the carrier. The TGA curve of Z211 at a constant heating rate of 10°C/min up to 600°C shows it is highly stable up to 425°C, with a decomposition temperature around 550°C. Z211 resists most processing chemicals in FOWLP fabrication. **Table 3** summarizes the Z211 chemical resistance testing results with various testing conditions.

In the demonstration testing, 200mm dummy silicon was used as the carrier. After a two-layer RDL build-up, flip-chip die placement, and wafer molding (granular epoxy), the carrier was released from the molded wafer with AirDebond®. It is worth noting that tape and frame are not required in debonding. Z211 stayed with the molded wafer and was cleaned by soaking in Z-clean 820C (Z820C) for 30min. It is noted that the molded wafer had an initial warpage of over 3mm with the silicon carrier. After the carrier was removed, the molded wafer exhibited no warpage.

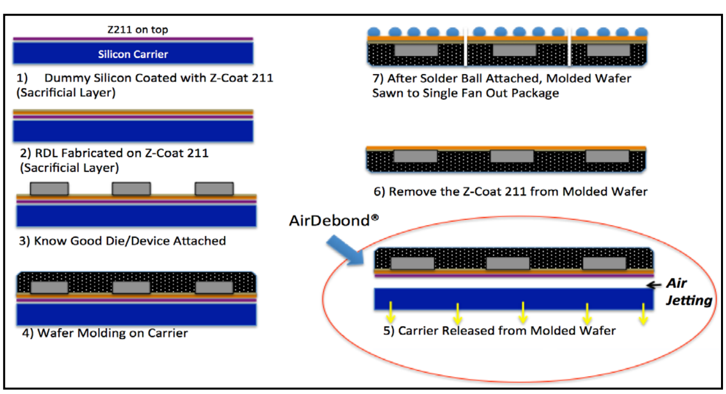

Figure 5: RDL-first FOWLP process flow with air jetting technology.

Water cleaning after the 280°C wafer process

Z-coat 100 (Z100) is a water-soluble coating designed to protect the wafer surface and bump structure in wafer temporary support. It is applied through either spin coating (for thickness <30µm) or stencil printing (for thickness >30µm). For a high topography or bump pattern, a thick Z100 coating fills in the space for surface topography planarization. The coating stays as a dry film after an initial bake and

Z211 Dry Film Chemical Resistance TEST

Chemicals	TEST Conditions	Result
NMP	40 °C 60 minutes	Good/No Failure
2.38% TMAH	25 °C 30 minutes	Good/No Failure
DMAC	25 °C 60 minutes	Good/No Failure
DMSO	25 °C 60 minutes	Good/No Failure
Hydrofluoric Acid 6N	25 °C 30 minutes	Good/No Failure
Acetic Acid 6N	25 °C 60 minutes	Good/No Failure
AK 400 developer	25 °C 60 minutes	Good/No Failure
KOH 0.045%	25 °C 60 minutes	Good/No Failure
PGMEA	25 °C 60 minutes	Good/No Failure
Cyclopentanone	25 °C 60 minutes	Good/No Failure
Acetone	25 °C 60 minutes	Good/No Failure
Al Hydroxide	40 °C 60 minutes	Good/No Failure
10% Oxalic Solution	47 °C 60 minutes	Good/No Failure
Isopropanol	25 °C 60 minutes	Good/No Failure
H2O2: NH4OH	60 °C 60 minutes	Good/No Failure
H2O2 30%	25 °C 60 minutes	Good/No Failure
H2O (8) :H2SO4 (1): H2O2 (1)	25 °C 60 minutes	Good/No Failure
Failure Modes: 1) Thickness reduction; 2) Patterns; 3) Discoloration; 4) Film Crack; 5) Surface Sticky/Tacky		

Table 3: Summary of the Z211 chemical resistance testing results with various testing conditions.

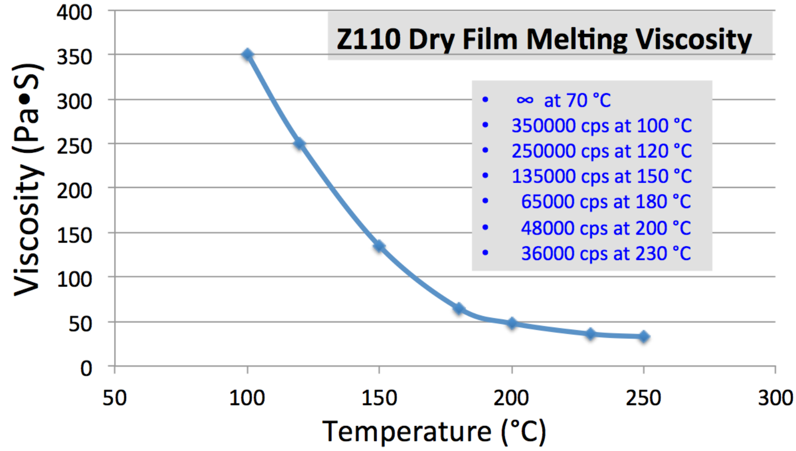

Figure 9: Plot of the viscosity vs. temperature showing that viscosity decreases with a temperature increase.

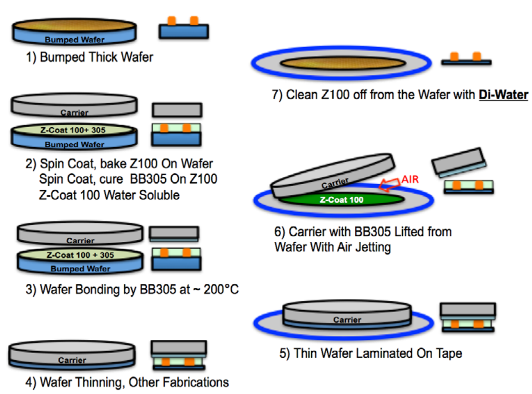

Figure 6: The processing flow with Z100 and BB305.

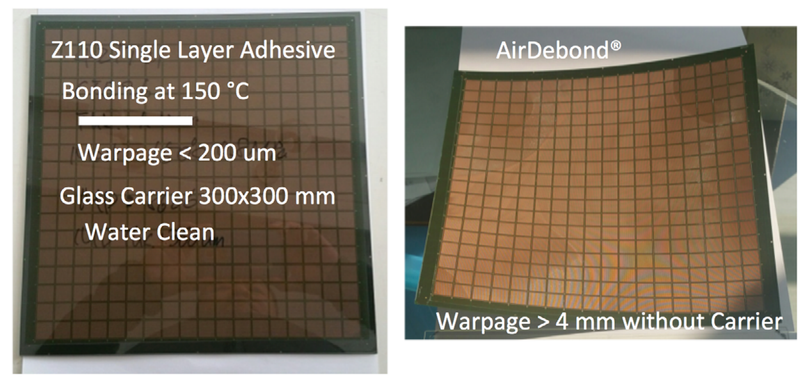

Figure 10: Comparison of the molded substrate a) with the carrier before debonding, and b) after debonding from the carrier.

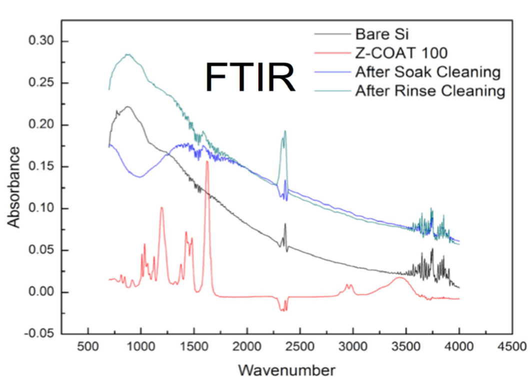

Figure 7: FTIR measurement on the wafer surface before and after the water rinse.

is thermally stable at 300°C.

BrewerBOND 305® (BB305) is an organic bonding adhesive manufactured by Brewer Science for processing up to 300°C. It has excellent chemical resistance. BB305 needs to be spin-coated directly onto the Z100 surface in order to bond the device wafer and the carrier. The BB305 coating completely covers the Z100 up from the wafer edge, including the bevel. The Z100 and BB305 combination is designed to have the wafer bonding stack able to withstand 280°C processing and resist chemical erosion. Figure 6 shows the processing flow with Z100 and BB305.

Debonding occurs at the interface between Z100 and BB305 with AirDebond® at room temperature. Z100 stays as a dry coating on the device wafer and is completely removed with a deionized (DI) water rinse. Figure 7 shows the Fourier-transform infrared (FTIR) spectroscopy measurement on the wafer surface before and after the water rinse: no trace of Z100 residue was found.

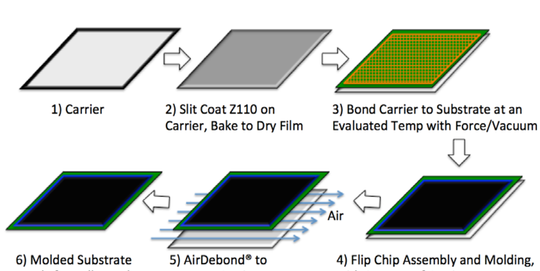

Figure 8: Schematic diagram of the process flow for temporarily bonding and debonding IC packaging with a large, thin panel organic substrate.

Water cleaning after IC package assembly with thin substrate

As the organic substrate becomes thinner and larger, it needs to temporarily bond to a rigid carrier for chip assembly and molding. Figure 8 is the schematic diagram of the process flow for temporarily bonding and debonding for IC packaging with a large, thin panel organic substrate.

Z-coat 110 is a thermal plastic aqueous adhesive. Its rheology property is optimized for stencil printing or spin coating. After coating and soft bake, the adhesive is tack free at room temperature with the Tg around 100°C. **Figure 9** shows that the viscosity decreases with a temperature increase, which is around 48,000cps at 200°C and 36,000cps at 230°C.

In the demo testing, the carrier is a 300mm x 300mm x 1mm thick glass, and the organic substrate is 296mm x 296mm in size and 0.1mm thin within a flip-chip assembly. The mold cap is a 0.4mm thick one block format. The bonding was done in 3min with thermal compression under an ~10Pa vacuum environment. With the substrate supported by the glass carrier, the flip chip was able to be assembled without any issue. After the flux residue was cleaned, the flip chip was over-molded.

The carrier was then released from the molded package with AirDebond®. The majority of the Z110 stayed with the glass carrier, but residue was observed on the side of the solder pad with the substrate. Both the glass carrier and the substrate were cleaned with a deionized water rinse. **Figure 10** compares the molded substrate: a) with the carrier before debonding, and b) after debonding from the carrier. The molded substrate exhibited severe warpage without a carrier.

Summary

A thin wafer/panel temporary support for high-temperature wafer processing emerges as a critical step in the fabrication of a thin, powerful package with maximum heat dissipation. Less expensive room-temperature mechanical debonding is sought after for its better throughput and higher yield. Also in demand are a nontoxic bonding adhesive and an environmentally-friendly cleaner to simplify the cleaning process.

In this paper, we presented AirDebond® as an advanced air-assisted mechanical debonding. It provides a more powerful separation force on the carrier with no tensile stress and no heat on the device surface. With this debonding, new wafer processing capabilities are being established with a series of temporary adhesives: 1) Z451 allows the wafer stack to be processed at 400°C for 60min; 2) Z211 enables low-cost RDL-first FOWLP with easy cleaning; 3) the combination of Z100 and BB305 allows wafer cleaning with water after temporary bonding for a 280°C processing temperature with harsh chemical soaking; and 4) Z110 enables the molded package to be cleaned with water after the flip-chip process with molded underfill assembly on a 0.1mm thin substrate.

The AirDebond® process is currently being optimized for different applications. With higher performance adhesives and a green cleaner, this technology is starting to prove its value for thin device packaging and assembly.

Reference

1. H.Tang, C.Luo, M.Yin, Y.S.Zeng, W.Zhang, "High throughput air jetting wafer debonding for 3D IC and MEMS manufacturing," IEEE 66th Electronics Components and Technology Conf. (ECTC), 2016, Las Vegas, NV, pp. 1678-1684, May 31-June 3 2016.

Biographies

Hao Tang is the founder and CEO of Micro Materials Inc., Camarillo, CA. He previously worked at various engineering and management positions with Henkel Electronics (Irvine, CA) and Nantong Fujitsu (Nantong, China), focusing on material and process development for flip-chip packaging, fan-out WLP, WLCSP, MEMS packaging, 3D IC integration, and thin substrate assembly warpage control. He received his PhD in Mechanical Engineering from the State U. of New York at Binghamton, and Bachelor of Sciences degree in Engineering Mechanics from Tsinghua U., Beijing, China. Email hao.tang@micromaterials-inc.com

My Nguyen is the Director of Material Development at Micro Materials. He has an over 15-year record of success in developing and designing new materials for semiconductor fabrication and electronic packaging assembly, and has over 50 U.S. patents on formulations of adhesives, coatings, inks and pastes. He received his PhD in Chemical Engineering from Princeton U.