

High Throughput Air Jetting Wafer Debonding for 3D IC and MEMS Manufacturing

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Abstract—Depending on the material, the currently available wafer debonding mechanisms include thermal slide, peeling, or laser ablation. These all require physical exposure to the thinned device wafer. On the other hand, typical batch debonding requires chemical diffusion through a thin gap or perforated holes in the carrier, which is usually considered high cost and with extremely low throughput.

In this paper we present the AirDebond™ technology, which enables instant wafer debonding at room temperature with extremely low-stress air jetting. With an isolation film layer of precisely controlled low peel adhesion on its surface, the carrier stacks the device wafer with a bonding adhesive to support fabrication processing at a later time. By breaking the isolation film sealing around the carrier, we inject a stream of airflow into the interface between the film and the carrier to separate the two, thus lifting the carrier from the stack.

A full process evaluation on a 200-mm wafer is presented, which includes the isolation film properties and coating specifications. To provide good mechanical support while enabling the ease of separation with air jetting, the material and adhesion properties of the isolation film were optimized and are thoroughly discussed in this paper.

Keywords-Bonding; Debonding; Thinnning; AirDebond; Air; Jetting; Temporary.

I. INTRODUCTION

The fabrication of thinned integrated circuit (IC) requires the temporary support of the device wafer for grinding, chemical etching, lithography, and through silicon via (TSV) processing. After fabrication, the thin wafer requires debonding from its carrier for 3D integration [1][2].

While it is a common practice to bond the carrier and device wafer under heat and pressure in a vacuum, the debonding mechanisms available to separate the carrier from the device wafer are very different depending on the adhesive systems and bonding structures [3]. The chemistry of the temporary adhesive currently used in the application includes rubber, acrylic, silicone, polyimide, and urethane, all of which are supplied by many well-known chemical companies.

One of the early debonding technologies was chemical solvent diffusion through a perforated carrier, which was considered to have low throughput, high carrier cost, and to produce unwanted fluctuation on the thinned wafer during grinding [3]. Another popular early wafer debonding

mechanism was the thermal slide [4]—a carrier sheared off from the device wafer at an elevated temperature—which is viewed as having low throughput and with high thermal stress. Recently, the laser-assisted wafer debonding has become more popular because of its ability to debond polyimide-based high-temperature adhesive [5][6]. Because the laser ablation light has to be introduced from the carrier side, the technology strictly requires the use of glass as a carrier. Also, the localized high temperature field introduced by the laser would be of concern for high-temperature-sensitive wafers. Mechanical lift-off wafer debonding has also gained a lot of recent attention thanks to room temperature debonding nature [7][8]. Room temperature mechanical peeling relieves thermal stress from the device but exerts unwanted high interfacial fracture stress along the evolving peeling line. Table I summarizes the major wafer debonding technologies currently available in the market.

In this paper we present air wafer debonding technology AirDebond™ developed by Micro Materials Inc. (MMI). The AirDebond™ enables instant wafer debonding at room temperature with controlled air jetting. A full process evaluation on a 200 mm silicon wafer is presented. With an isolation film layer spin-coated on the carrier with sufficient shear strength but minimized peeling adhesion, the carrier can be debonded from the wafer stack with controlled air inflow. During the debonding on the interface between the carrier and the isolation film, the bonding adhesive on top and the dicing tape underneath protect the thinned device wafer.

Table I. Comparison of Commercially Available Debonding Mechanisms

Debonding Mechanism	Adhesive Chemistry	Carrier Type	Throughput UPH	Thermal Stability
Chemical	Various	Perforated	Slow	Mid
Thermal Slide	Rubber/Plastic	Si/Glass	Slow	Low
Laser	Polyimide	Glass Only	Mid	High
Mechanical	Silicone	Si/Glass	Mid	Mid

II. THE PROCESS FLOW AND MATERIAL SYSTEM

Depending on the wafer's topography, we recommend two slightly different process flows and material sets for the AirDebond™ technology.

A. For Wafers with a Flat Surface

Fig.1 is the schematic of the process flow for wafers without high topography. The isolation film Z-Coat 150 is spin-coated and step-baked on the carrier to form a uniformed dry film layer. For wafer bonding, the carrier with the isolation film faces down to bond the device wafer's active surface with a bonding adhesive. Two types of bonding adhesive are currently available from MMI: (1) wet adhesive Z-Bond 601 for a wider processing temperature window and (2) tape adhesive Z-Bond 701 for processing temperature lower than 250°C. Wafer bonding occurs in two stages: (1) the soaking stage, where the carrier and wafer are under high vacuum pressure and at an elevated temperature but remain parallel and separated, and (2) the curing stage, where the carrier and wafer are glued together by the bonding adhesive with applied force. After bonding, the device wafer is then backside thinned and fabricated with full support from the carrier. Prior to debonding, the thin side of the stack is mounted to a ring-framed dicing tape to be fully supported. The wafer stack is then loaded onto the debonding plate with the carrier on top and the tape on the bottom. After both sides of the wafer stack get vacuumed flat on the plate and the interface between the carrier and isolation film is recognized by the machine vision, a stream of controlled airflow is injected into the carrier/isolation film interface through a broken seal to lift the carrier. After the carrier is separated, the isolation film and the bonding adhesive are peeled off or rinsed away by a cleaner, followed by deionized water rinse and blow-dry.

B. For Wafers with High Topography or with Bumps

High topography or bumps on the wafer greatly increase surface area and create fine feature or microstructure that drastically increase the bonding strength of the wafer stack

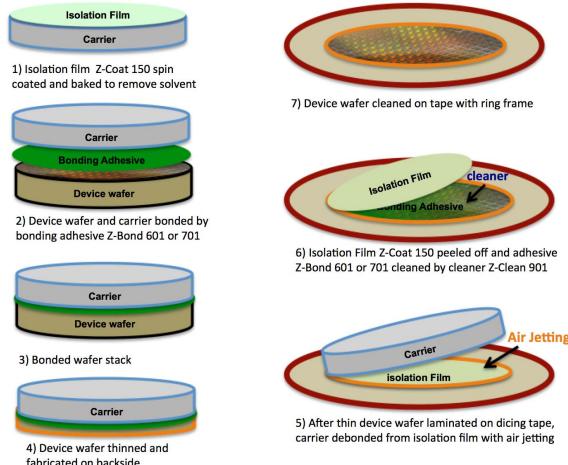


Figure 1. The AirDebond™ process flow for flat wafer.

and finer feature to clean on the device wafer.

To enable the debonding and complete cleaning of such wafers, a thin protective layer is added to the wafer and bumps before bonding. The current protective coating material, Z-Coat 100, is developed by MMI and can be applied by either spin coating or stencil printing. Drying is done at room temperature for about five minutes. Once dried, this coating is transparent and capable of withstanding high temperature processing up to 250°C. Fig. 2 is the schematic illustration of the process flow.

The wafer bonding and debonding processes are similar to those for wafers with flat surfaces. The bumped device wafer can be processed thinner and fabricated with the carrier's support throughout. The debonding is also similar in that carrier is taken off with air jetting. The isolation film and the bonding adhesive are peeled off from the protective coating surface, which are then cleaned by hot water. The device wafer is completely cleaned after a deionized water rinse and a blow-dry.

III. THE ISOLATION FILM

The key to successful air debonding is the isolation film and its controlled mechanical strength on the carrier. Even though the isolation film does not touch the device wafer, it still has to satisfy the following basic requirements: (1) thermal stability at the follow-up processing temperature, (2) high transparency after initial baking for alignment with the device wafer, (3) resistance to all process chemicals, (4) sufficient mechanical strength to withstand backgrinding and process handlings, and (5) ability to produce an uniform layer on the carrier.

A. Thermal Stability and Optical Transparency

Thermal stability often refers to the ability to resist decomposition and outgassing during the thermal process. A common method to evaluate a material's thermal stability is the thermo-gravimetric analysis (TGA), which measures weight loss in an open inert environment. Even though the material layer is sandwiched between the carrier and the device wafer with only the edge exposed, it is still commonly accepted to use TGA data to evaluate the baseline

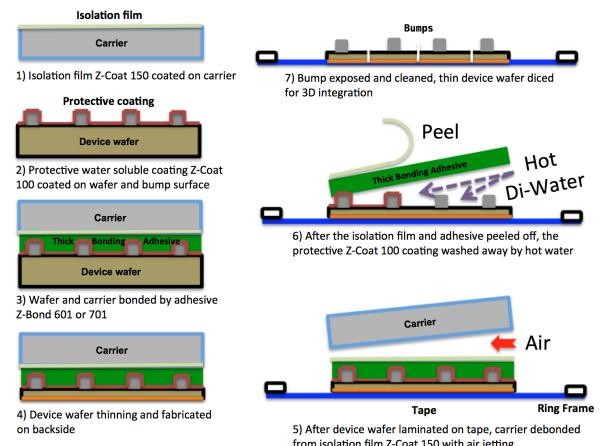


Figure 2. The AirDebond™ process flow for wafers with high topography or bumps.

performance of thermal stability. Fig. 3 shows the weight loss of the Z-Coat 150 (a) at a constant temperature 350°C for two hours; and (b) under a constant heating rate of 10°C/min. We can see that the weight loss of the Z-Coat 150 is less than 1% after a two-hour bake at 350°C. The decomposition temperature is around 500°C.

Z-Coat 150 turns to be transparent after the initial baking at 75°C. It stays at transparent during two-hour high temperature bakes up to 350°C in O₂ or 400°C in N₂ (Fig. 4). This isolation film coating is formulated to be transparent to enable accurate alignment with the device wafer prior to the wafer bonding process.

B. Chemical Resistance

The chemical resistance of Z-Coat 150 has been tested extensively. Table II summarizes the testing results under various conditions. Good chemical resistivity not only enables a variety of post-thinning chemical smoothing or surface roughing etching but also allows for photoresist stripping and via cleaning without generating residue.

C. Spin Coating Performance

Z-Coat 150 is a solvent-based liquid solution. It can be spin coated and baked at a stepped temperature profile to form a uniform transparent layer. The recommended baking schedule is at 75°C and 150°C for 10 minutes each, then 250°C for 20 minutes to completely remove the solvent. For applications that requires processing above 250°C, an additional 350°C 20-minute bake is recommended to remove any other potential volatile organic compounds (VOC).

Fig. 5 (a) shows the thickness of the film after baking, as a function of spin speed. Because the thickness decreases with increased spin speed, the average dried film thickness is about 7 μm at 3000-rpm spin speed for 20 seconds. Fig. 5(b) plots the thickness as a function of the radius distance from the center after 20 seconds at 3000-rpm. The film coating appears to be very uniform across the whole wafer, except for the edge bead, which is about 1-μm tall. It should be noted that the resolution of the thickness measurement is 1 μm.

D. Mechanical Strength and Peeling Adhesion

Sufficient shear strength is critical to ensure backside thinning without fracturing the wafer. Reference [9] studied the shear strength of some currently available temporary adhesives using a 3-inch-diameter, 300-μm thick wafer and found that the spin-on adhesive HT10.10 has the highest shear strength at around 900 kPa, and the wax adhesives' highest shear strength ranged from 40 to 250 kPa. In our shear strength study, the bonded stack was cut into 5×5 mm pieces, and then tested for die shear strength using the Nordson Dage 4000 Bond tester. Fig. 6(a) is the schematic of the die shear testing, and Fig. 6(b) shows the image after the carrier was sheared off. Fig. 7 shows the shear testing results of ten test samples. The failure mode was consistently the delamination between the carrier and the Z-Coat 150 film, and the average shear force for the 5-mm

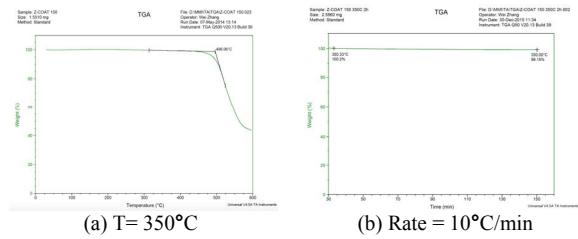


Figure 3. TGA curve of the Z-Coat 150 at (a) constant 350°C for two hours; (b) constant heat rate 10°C/min.

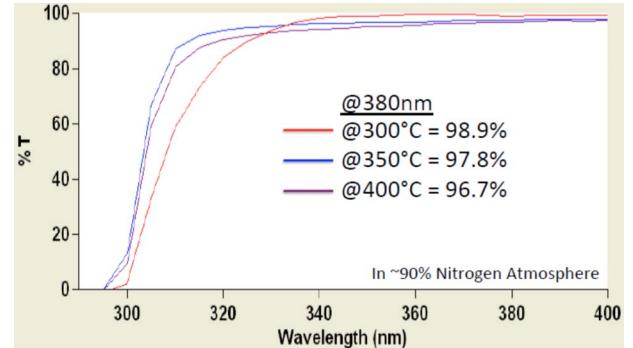


Figure 4. Transmittance of the Z-Coat 150 after two hours N₂ bake at 300°C, 350°C and 400°C.

Table II. Z-Coat 150 Chemical Resistance

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 ₂ O ₂ 30%	25 C Soak 30 minutes	
H ₂ SO ₄ 6N	25 C Soak 30 minutes	
HCl , Conc	25 C Soak 30 minutes	
H ₂ O:NH ₄ OH:H ₂ O ₂ (5:1:1)	25 C Soak 30 minutes	
H ₂ O:H ₂ SO ₄ :H ₂ O ₂ (8:1:1)	25 C Soak 30 minutes	
Isopropanol	25 C Soak 30 minutes	

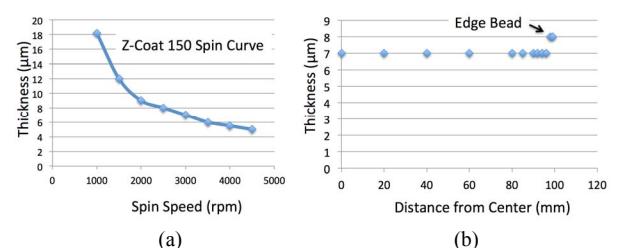


Figure 5. (a) Z-Coat 150 thickness vs. spin speed; (b) Z-Coat 150 thickness distribution in radial direction.

stack is 1.96 kgF, equivalent to about 768 kPa of shear strength.

Z-Coat 150 is very easy to peel from the carrier surface. Its peel adhesion on a silicon surface was tested using a Mark-10 peel tester with a force gauge capable of 0.05 g of force resolution. The average of ten test trials is shown in the far right column of Fig. 8, which also lists other tapes/films for comparison. The peel adhesion of Z-Coat 150 is about 1-2 gF/cm, roughly 10% of the non-UV blue dicing tape used in the test.

IV. PROCESS EVALUATION

The key aspects of the process evaluation include wafer bonding, backside grinding, protective coating on wafers with bumps, carrier debonding, and device wafer cleaning.

A. Wafer Bonding Quality

All wafer bonding was carried out in a Z-BT200 manual wafer bonder (shown in Fig. 9), designed and manufactured by MMI. Recently available to the market, the Z-BT200 is capable of producing a 10^{-3} Pa vacuum and a 10 kN bonding force with a maximum bonding plate temperature of 400°C.

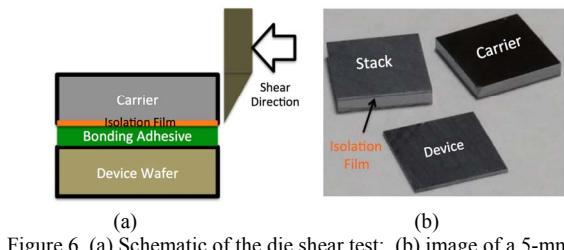


Figure 6. (a) Schematic of the die shear test; (b) image of a 5-mm die stack, a die carrier, and a thinned die.

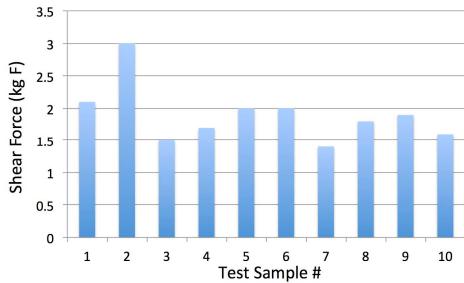


Figure 7. Shear strength of 5-mm bond stack with isolation film.

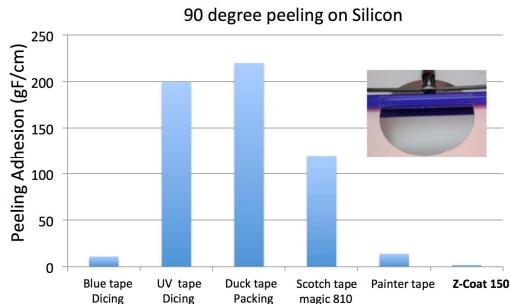


Figure 8. Z-Coat 150 peel adhesion in comparison with other tape/films.

The bonding processes are very similar for both types of bonding adhesives: (1) the bonding adhesive is coated onto the top of the isolation film; (2) the carrier is placed on the bottom bonding plate with the adhesive facing up; (3) separated by spacers, the device wafer is loaded above the carrier with the active side facing down, towards the bonding adhesive; (4) the chamber is locked and vacuum is pumped to at least 0.1 Pa, and both bonding plates are heated to about 80°C for three minutes; (5) the spacers are withdrawn to allow the device wafer to drop and realign with the carrier; (6) bonding force is applied while the temperatures of the bonding plates are ramped to 120°C for curing; (7) with high vacuum and bonding force applied, the bonding adhesive is cured to complete the bonding cycle; (8) the bonding chamber is opened after backfill. Depending on the bonding adhesive used, the specific bonding parameters may vary.

Bonding quality is often evaluated by voiding and total thickness variation (TTV) within the bonding layer. Large voids in the bonding layer cause direct wafer breakage during backside grinding while smaller (less than 1 mm) voids induce dimple marks on the thinned wafer surface and later burst defects during the backside metallization process. The TTV of the bonded stack is also important because it determines the thickness variation of the thinned device wafer. Post-bonding TTV smaller than 5 μm is a must-meet requirement for any application requiring the device wafer to be thinned to less than 100 μm .

The key factors affecting wafer bond quality are vacuum pressure, bonding force, temperature, and uniformity of the process parameters, wafer warpage, surface topography and bonding adhesive curing behaviors. Because high bonding temperatures often introduce high residual stress, we specifically designed the bonding adhesive to be curable at low temperatures.

After many process optimization and formulation redesign, we achieved voids-free and less-than-5- μm -TTV bonding on a 200-mm wafer. Fig. 10(a) shows an acoustic image of a bonded wafer stack and Fig. 10(b) plots the bond layer thickness of 40 selected points across the whole wafer stack. The thickness shown in Figure 10(b) includes both Z-Coat 150 and the bonding adhesive, and is calculated as follows: measured bond stack thickness minus the original thickness of the wafer and carrier combined.



Figure 9. Z-BT200 wafer bonder.

B. Backgrinding to 60 μm

With the support of a thick carrier, the device wafer can be backgrinded to 100 μm or less. Fig. 11 is the image of an 8-inch bonded stack with the device wafer thinned to 60 μm . The carrier is a 726 μm thick dummy silicon wafer. The isolation film has never failed during the wafer backgrinding process.

C. Protective Coating for Wafer with Bumps

As more micro bumps and Cu pillars are designed to provide a smaller size footprint and faster signal speed, the AirDebond™ technology is further optimized to be compatible with the bumped wafer. High topography or bumps drastically increase the wafer surface area, thus generating much higher bond strength between the carrier and the device wafer. Also, the bump and topography patterns produce more complex surfaces and a finer features on the wafer, leading to more trapped voids and making the device wafer cleaning mission impossible.

Fig.3 depicts our process flow for wafers with high topography or bumps. With a layer of coating on the surface, the wafer and bumps are protected from contamination and exempted from the peeling stress from the bonding adhesive removal during cleaning. Z-Coat 100 is the current protective coating material developed by MMI. It is a spin-on liquid coating capable of drying at room temperature (without additional baking). Z-Coat 100 is transparent (Fig. 12) and thermally stable at 250°C for two hours.

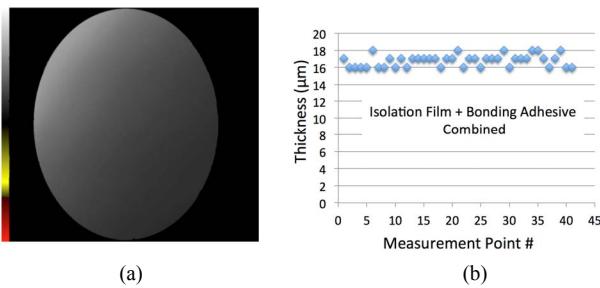


Figure 10. (a) CSAM image of bonded stack (b) bonding layer TTV.



Figure 11. A bonded stack with device wafer thinned to 60 μm .

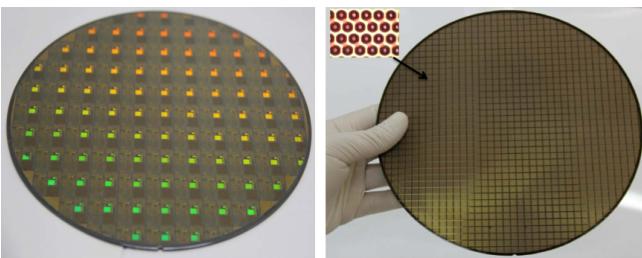


Figure 12. Z-Coat 100 is transparent after drying on (a) a flat wafer; (b) a bumped wafer.



Figure 13. Semi-auto air jetting wafer debonder Z-D200A.

D. Debonding with Air Jetting

The air wafer debonding process was conducted using Z-D200A, the semi-auto wafer debonder designed and manufactured by MMI. As shown in Fig. 13, the Z-D200A is equipped with an air jetting apparatus and capable of debonding a wafer stack within one minute. The patent-pending machine vision system design and auto interface recognition algorithm enable instant room temperature wafer debonding with air jetting, thus minimizing the stress exerted on the thinned fragile wafer.

The air jetting wafer debonding is processed as follows: (1) laminating the dicing tape on the thinned device wafer; (2) transferring the bond stack onto the debonding platform with the carrier on the top and the device wafer with tape on the bottom; (3) applying vacuum to hold both the top carrier and the bottom device wafer; (4) detecting the interface between the isolation film and the carrier; (5) piercing the isolation film from the edge of the carrier to create an air vent; (6) injecting air into the vent to separate the carrier from the isolation film, as shown in Fig.14; (7) loading the carrier onto the cassette and peeling off the adhesive off with the isolation film; (8) moving the thinned device wafer onto the tape to the next step in the process.

For wafers with a protective surface coating, an additional cleaning step is needed to remove the coating before moving to the next step.

E. Cleaning

Without any protective coating, the bonding adhesive directly contacts the active side of the device wafer, which has to be completely cleaned after carrier debonding. Z-Clean 901 is designed to remove the bonding adhesive Z-Bond 601: it is an acidic based cleaner that works best at 70-80°C degree and is biodegradable. Fig. 15 (a) shows a 200-mm wafer thinned to 60- μm thick, then cleaned after air debonding.

For the bumped wafer with a protective coating, the isolation film residue and the bonding adhesive are peeled off before Z-Coat 100 is removed with a hot water rinse and a blow-dry (Fig. 16). Fig. 17 shows a bumped wafer with Z-Coat 100 on its surface, whose left portion is completely cleaned with a hot water rinse.

V. SUMMARY

Debonding a wafer stack with air jetting at room temperature was carefully demonstrated for a wafer thinned to 60 μm . By adding an isolation film layer with a low peeling adhesion, the carrier can be detached from the bonded stack by low-stress air jetting. The total cycle time is less than one minute. The current isolation film also demonstrates sufficient shear strength and thermal stability to support the device wafer through backside thinning and other fabrications. Because the debonding is between the isolation film and carrier, the device wafer is protected throughout the process. Table III compares the AirDebondTM with laser debonding and mechanical debonding.

For wafers with bumps, a protective coating is added onto the surface for planarization and to prevent contamination. The coating can be easily removed, along with other processing residues, by a hot water rinse after the carrier is taken off by air jetting.

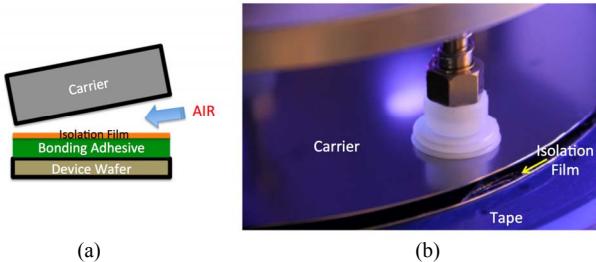


Figure 14. (a) Air debonding schematic; (b) an image of carrier lifted from isolation film.

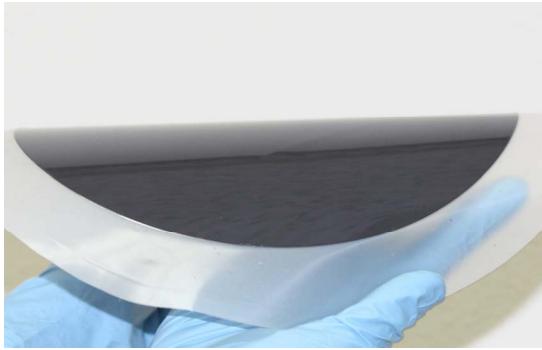


Figure 15. 60 μm thick wafer debonded with air jetting.

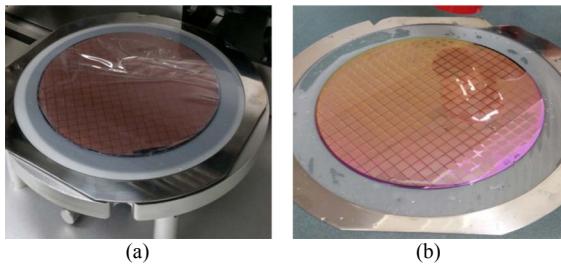


Figure 16. AirDebond on a bumped wafer: (a) isolation film left on surface after carrier was lifted off; (b) blow-drying the bump and wafer after Z-Coat 100 was removed with a hot water rinse and a blow-dry.

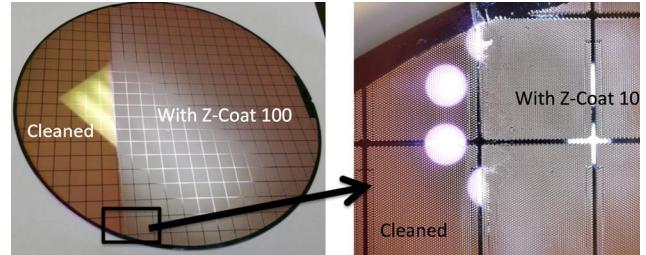


Figure 17. Left portion of a bumped wafer cleaned with hot water.

Table III. Comparison Table of Air, Laser, and Mechanical Debonding

Debonding Mechanism	Adhesive Chemistry	Carrier	UPH	Thermal Stability
Air	Silicone; Polyimide; and others compatible with isolation film	Si/Glass	High	High
Laser	Polyimide	Glass Only	Mid	High
Mechanical	Silicone	Si/Glass	Mid	Mid

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