Journal of Microelectronics and Electronic Packaging (2010) **7**, 214-219

ISSN: 1551-4897

Using Permanent and Temporary Polyimide Adhesives in 3D-TSV Processing to Avoid Thin Wafer Handling

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***Abstract*—3D chip integration processes use thinned silicon wafers in conjunction with through silicon vias. Polyimide adhesives are evaluated for use as temporary and permanent adhesives to enable handling of thinned wafers and subsequent bonding into 3D stacks. These adhesives are found to have a combination of thermal and mechanical properties and processing capabilities required for 3D chip integration applications.**

***Keywords*—Polyimide adhesives, wafer-bonding, HD-3007 polyimide, HD-7010 photosensitive polyimide,**

Introduction

Three-dimensional (3D) chip integration has the potential to improve performance and reduce package size. Many different process flows have been proposed for the manufacture of 3D devices; several of these processes incorporate polymeric materials as temporary and/or permanent adhesives [1, 2]. The process scheme illustrated in Fig. 1 envisions the use of polyimides as both temporary and permanent adhesives to enable stacking of thinned wafers without the need to handle a thinned wafer in isolation [3].

Materials and Methods

HD-3007 Temporary Adhesive

In a number of proposed 3D-assembly process schemes, the wafer stack is bonded to a carrier wafer using a temporary adhesive. When the 3D-assembly is complete, the carrier is released from the assembly and can be recycled. One material under evaluation as a temporary adhesive is HD-3007 from Hitachi Chemical DuPont MicroSystems (HDMS, Parlin, NJ). HD-3007 is a spin-applied formulation that cures to a thermoplastic polyimide film. Table I lists solution and cured film properties of HD-3007, along with process highlights.

HD-3007 must be fully imidized prior to bonding; films are cured by holding in an oven for one hour at a temperature of 250°C or above. Alternately, films can be cured on a hot plate at 300°C with a six-minute hold time. After cure, the HD-3007 polyimide film is stable and can be held indefinitely before bonding.

Bonding and Flow of HD-3007

The cured adhesive film is not completely planar because of underlying metal or oxide topography and because there is a bead of increased thickness at the edge of the wafer. Consequently, proper bonding to a carrier wafer requires flow of the adhesive. Bonding conditions were evaluated at the Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration (IZM) in Berlin using Borofloat glass carrier wafers so that bonding defects are readily seen. After bonding at 200°C much of the wafer surface is well bonded (Fig. 2), but the circumference is not bonded because of the nonplanar edge-bead. At bonding temperatures greater than 300°C (Fig. 3), there is enough resin flow that the bond layer is void-free over the entire wafer surface.

The resin flow is determined by the bonding conditions and the melt rheology of the HD-3007 polyimide (Fig. 4). The melt viscosity drops exponentially with temperatures above 220°C; consequently, the bond temperature has a greater effect on the bonding result than pressure or bond time.

The effect of bond temperature on flow is also seen for an HD-3007 coating over a 2-μm thick patterned aluminum coating (Fig. 5): wafers that were bonded at 260°C show nonbonded regions adjacent to the topography, whereas wafers bonded at 350°C show complete bonding. Studies show that HD-3007 is highly planarizing over small features; this explains why bonding defects are not seen immediately adjacent to fine features but appear in broad areas around the patterns.

At the edge of the wafer, adhesive flow into the space between the curved wafer edge and the carrier wafer is important. Edge flow can be characterized by cross-sectioning the bonded wafer pair (Fig. 6). During the backside grinding and polishing of the bonded wafer, the resin enveloping the wafer edge provides mechanical support and prevents edge chipping.

Bonding conditions that yield void-free bonds are summarized in Table II. We found that lower bond temperature could be used with thicker adhesive coatings. Researchers at Fraunhofer IZM used the conditions indicated for 5-μm coatings to bond 200-mm wafers to perforated and plain glass wafers. They found excellent retention in through-thickness variation (TTV) in the bonding process [4].

Adhesion of HD-3007

Backside and through-silicon processing of the bonded wafer impart a variety of thermal and mechanical stresses on

Manuscript received July 2010 and accepted January 2011
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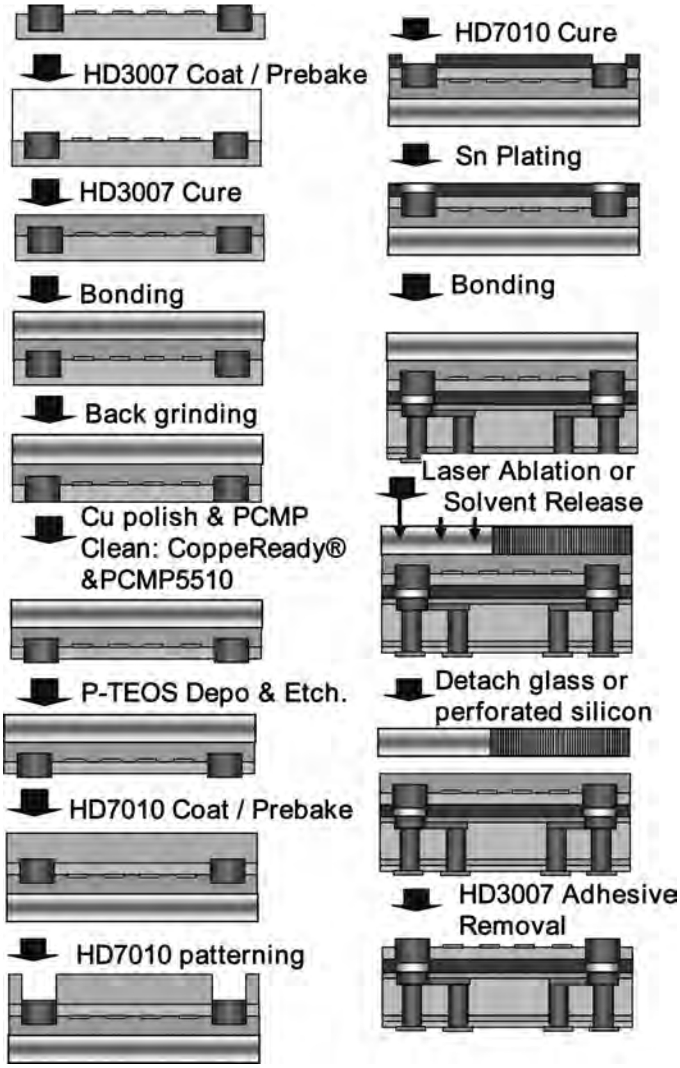

Fig. 1. Via-First process sequence with temporary and permanent adhesives.

the bond layer. We evaluated three methods for evaluating the bond strength of the adhesive (see Fig. 7). The edge loading method [5] measures the equilibrium surface energy: for HD-3007, the equilibrium value of 80 mJ/cm^2 was reached slowly (many hours). Die shear testing was a much more rapid test method; however, at room temperature, the parts generally failed by silicon fracture rather than shear failure of the adhesive. When the shear test was run at approximately 150°C, the adhesive failed at a shear strength of 400 kg/cm^2. Stud-pull testing is also a rapid, fairly simple test: this method found adhesive failure of HD-3007 polyimide at 140 kg/cm^2.

Thermal Stability of HD-3007

A number of process steps in 3D integration require temperatures of 250-400°C, including copper-to-copper bonding, metal bond annealing, and backside redistribution layer (RDL) formation. Polymeric adhesives must be stable at these process temperatures. HD-3007 polyimide exhibits good thermal stability [6]; we found a 1% weight-loss temperature of 520°C and a 0.2% per hour linear weight-loss at 400°C.

Table I
HD-3007: Typical Properties and Process

Property/Condition	Units	HD-3007
Liquid viscosity	Ps	9-11
Nonvolatile contents	%	24-26
Cure temp range	°C	250-350
Bonding temp range	°C	300-350
Bonding press	N/cm2	>14-22
Contact time	minutes	5-10*
Cured dielectric thickness	m	2-10
Glass transition temp (Tg)	°C	180
Weight loss @ 350C	%	0.2
CTE	ppm/ °C	50
Dielectric constant	z	3.4
Tensile strength	MPa	130

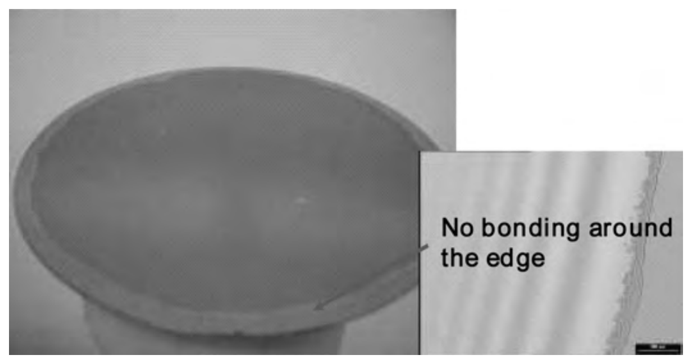

Fig. 2. Incomplete bonding of HD-3007 at 200°C.

Fig. 3. Complete bonding of HD-3007 at 300°C.

Debonding of Carrier Wafer and Residue Cleaning

Once the 3D assembly is complete, the wafer stack needs to be removed from the carrier. The carrier wafer can be recycled if it is removed before the dicing step. When a glass carrier is used, debonding of HD-3007 can be accomplished

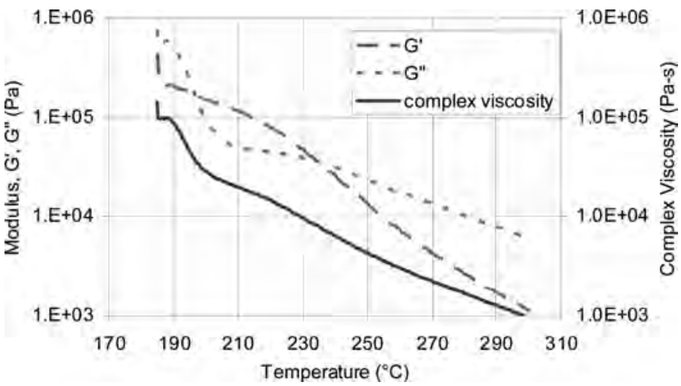

Fig. 4. Melt rheology of HD-3007 polyimide.

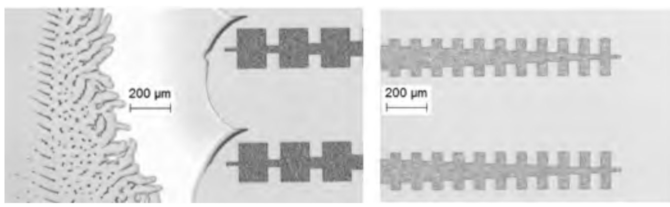

Fig. 5. Bonding over aluminum metallization: (a) bonded at 260°C (*left*), (b) bonded at 350°C (*right*).

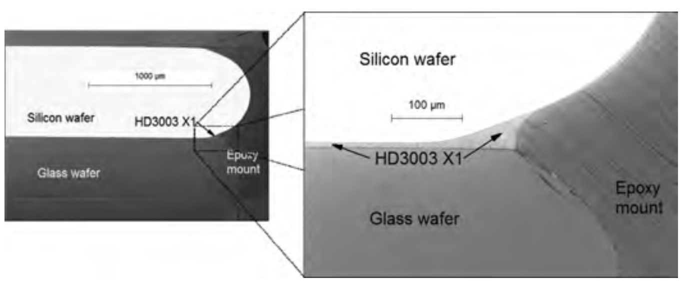

Fig. 6. Adhesive flow at the wafer edge after bonding at 350°C (polished cross-section).

Table II
Bonding Conditions for HD-3007

Adhesive thickness (m)	4-5	8-10
Preheat top chuck (°C)	350	300
Preheat bottom chuck (°C)	180	180
Bottom chuck bond temp. (°C)	350	300
Bond time (min)	10	1
Bond pressure (N/cm2)	14.5	22

by irradiation with an ultraviolet (UV) laser. Laser ablation of polyimides is a fairly well known process. Most polyimides absorb strongly in the UV; above the threshold energy fluence, the absorbed light causes very rapid bond scission and expulsion of low molecular weight fragments at supersonic velocities.

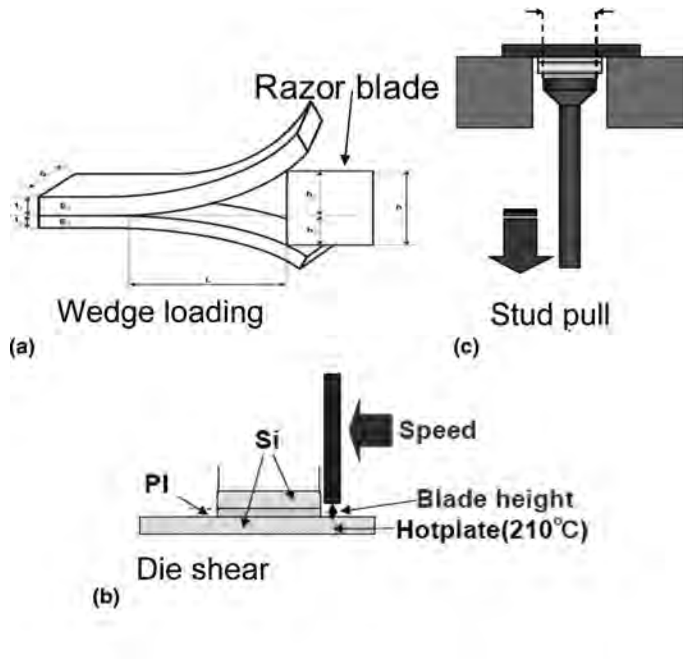

Fig. 7. Schematic of adhesive tests.

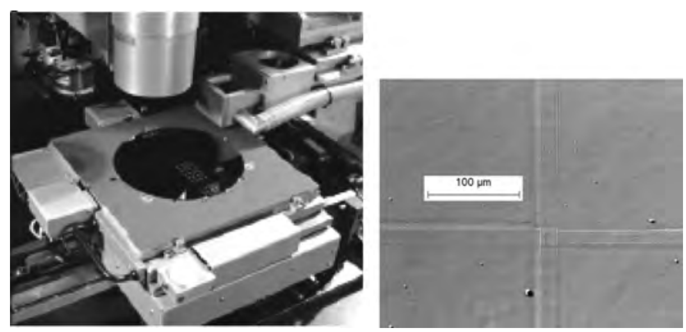

Fig. 8. UV Laser de-bonding: (*left*) wafer on precision stage below the laser, and (*right*) residue from overlapping pulses on the carrier, after debonding.

The UV absorbance spectrum of HD-3007 shows that at 248 nm, 99.9% of the light is absorbed in a 200-nm film. Experiments were conducted at Tamarack Scientific (Corona, CA) using a 248 nm UV excimer laser to debond 500-μm thick Borofloat glass wafers from HD-3007. Fig. 8 shows the set-up for debonding the wafer. The bonded pair is held on a stage, which is driven below the laser beam. The driving speed is controlled so that consecutive laser pulses overlap by 50 μm.

After bonding a glass carrier to a 200-mm silicon wafer with HD-3007, the wafer was back-ground and polished to a 50-μm thickness. Fig. 9 shows this thinned wafer and the glass carrier after they were debonded using the laser. In this experiment, the laser beam spot size was 6.5 mm^2 and the debond time was approximately 30 seconds.

After debonding the carrier wafer, HD-3007 residues must be removed. We found that EKC865 (DuPont EKC, Hayward, CA) was effective at removing these residues: an 8-μm debonded film of HD-3007 was cleaned in 90 seconds when

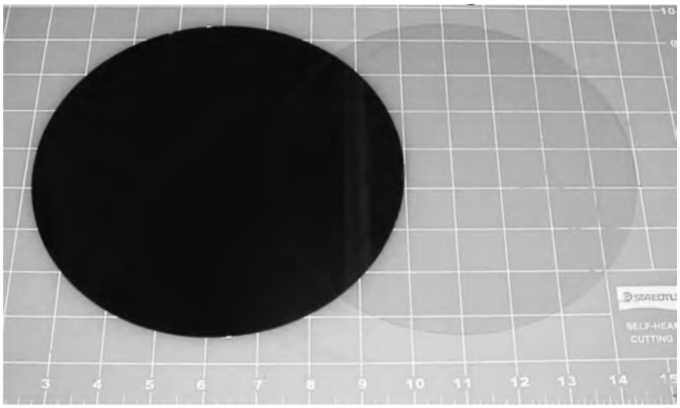

Fig. 9. Glass carrier and 50-μm thick silicon wafer after laser debonding.

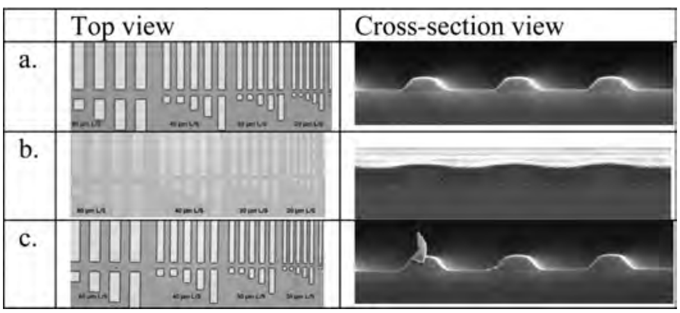

Fig. 10. Selective removal of HD-3007: (a) patterned film of HD-4004, (b) cured HD-3007 coated over the patterned film, and (c) HD-4004 pattern after removal of HD-3007 with EKC800. Top views of 20-60 μm L/S, cross-section view of 6 μm L/S.

immersed in EKC865 at 60°C. EKC865 has excellent compatibility to sensitive metal films (e.g., aluminum, copper, titanium, nickel, chrome, tungsten, and other metal alloys) and to cured polyimides used for RDL (e.g., HD-4104).

Selective removal of HD-3007 polyimide adhesive from HD-4004 is illustrated in Fig. 10. HD-4004 was coated on a silicon wafer, photo-imaged and cured. HD-3007 was coated on top of the HD-4004 and then cured. After curing, the HD-3007 was effective at planarizing the patterned surface (compare Fig. 10a and 10b). The HD-3007 was then removed by dipping in EKC800; no swelling or attack of the HD-4004 was observed (Fig. 10c).

We evaluated the use of EKC865 in conjunction with a perforated carrier wafer (obtained from Schott Lithotec, Grünenplan, Germany) as an alternative method for debonding HD-3007 adhesive [7]. We found that debonding times depend on the solvent temperature, as shown in Fig. 11. Debonding times below 10 minutes were obtained at solvent temperatures of 70°C or greater.

HD-7010 Permanent Adhesive

We have begun to evaluate polyimides for use as redistribution layer coatings and/or adhesives on the backside of thinned wafers bonded to a carrier with HD-3007. The temporary adhesive must be compatible with all the process steps used

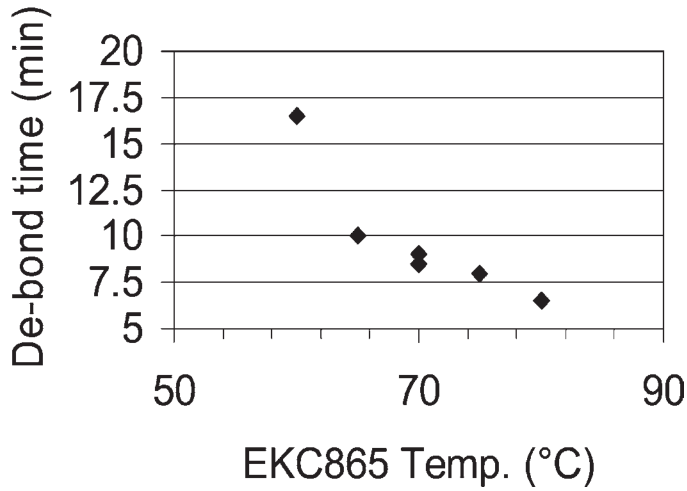

Fig. 11. Debonding of HD-3007 using EKC865 and effect of solvent temperature on debond time.

Table III
Typical Properties and Process for HD-7010

Property/Condition	Units	HD-7010
Liquid viscosity	Ps	27-33
Nonvolatile contents	%	35-40
Cure temp range	°C	250-400
Bonding temp range	°C	250-350
Bonding pressure	N/cm2	14-22
Contact time	minutes	5-10
Cured dielectric thickness	microns	8-20
Glass transition temp	°C	250
5% weight loss temp.	°C	395
CTE	ppm	74
Dielectric constant		3.3
Tensile strength	Mpa	173
Modulus	Gpa	2.6
Elongation	%	70

for the backside polyimide, including coating, imaging, curing, and bonding. In this article we describe experiments with HD-7010, which has been evaluated for both RDL and adhesive applications.

HD-7010 is a photo-definable polyimide precursor formulation from HDMS; its properties are summarized in Table III. Soft-baked films can be photo-imaged (see Fig. 12); the material is negative tone (reduced solubility where exposed) and is developed with solvent based developers and rinses (e.g., PA-401D and PA-400R from HDMS).

Bonding of HD-7010

HD-7010 films were coated on silicon wafers and then cured. Samples were diced and bonded to glass with a die bonder. The effects of the cure temperature and the bond temperature on adhesion were evaluated by stud pull testing. As shown in Table IV, films cured at 250°C appeared to outgas

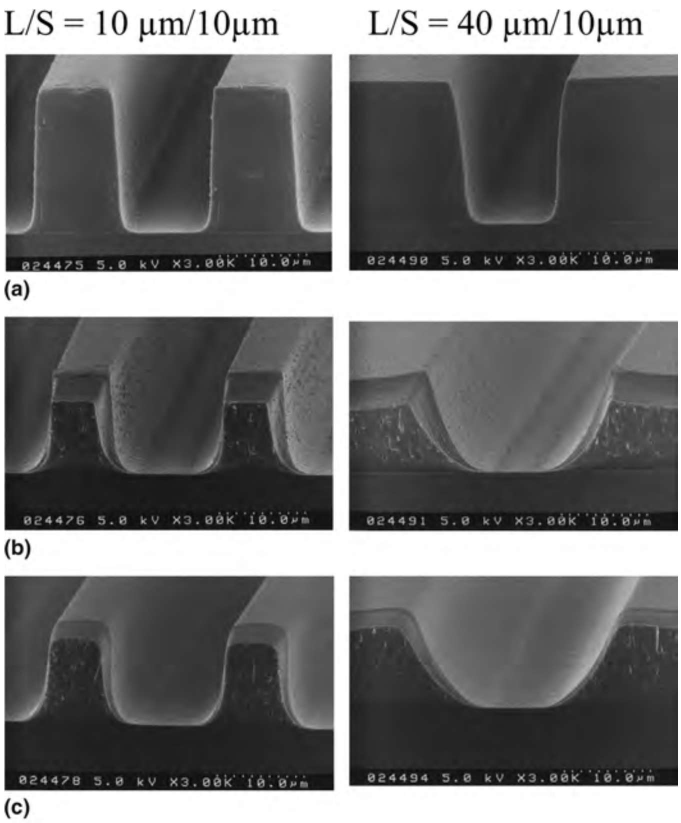

Fig. 12. Photopatterning of HD-7010—exposure with I-line stepper: (a) after development, (b) cured at 350°C, and (c) cured at 400°C.

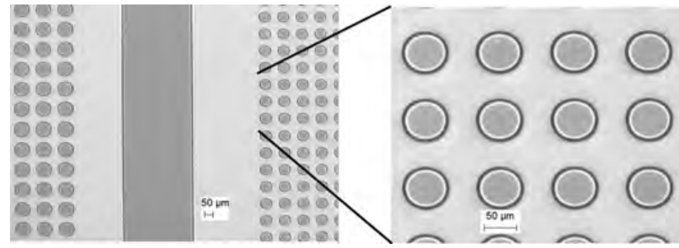

Fig. 13. Patterned HD-7010 film after bonding: (a) arrays of 80 and 60 μm vias with street (*left*), (b) 60 μm vias (*right*).

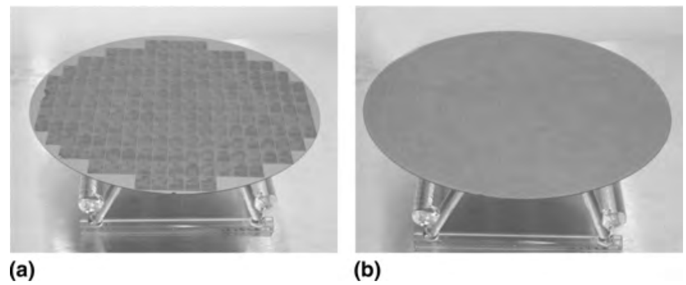

Fig. 14. Structured and cured HD-7010 on a thin bonded wafer: (a) HD-7010 on silicon, (b) glass carrier bonded to wafer front-side with HD-3007.

Table IV
Die-Bond Adhesion of HD-7010: Effect of Cure and Bond Temperatures

Cure Temp. (°C)	Die Bond Temp. (°C)	Bond Quality	Failure Mode
250	300	Good	Glass cohesion
250	350	Marginal	Glass cohesion
250	375	Poor (with voids)	Glass cohesion
350	300	Good	Glass cohesion
350	350	Good	Glass cohesion
350	375	Good	Glass cohesion

Table V
3D Integration Using Polyimide Adhesives

Process	Unit Process Confirmed	Integrated Process Confirmed
HD-3007 coat/bake/cure	Yes	Yes
Bond to carrier	Yes	Yes
Back-grind & polish silicon	Yes [4]	
Metallize backside	Yes [4]	
P-TEOS deposition & etch	Yes	
HD-7010 coat/pattern	Yes	Yes
HD-7010 cure	Yes	Yes
Sn plating		
HD-7010 Bond	Yes	
Debond carrier – laser or solvent	Yes	
Clean HD-3007	Yes	

when bonded at 350°C or higher, whereas films cured at 350°C did not outgas during bonding at temperatures as high as 375°C. Even when the bonding was not ideal, the adhesion of HD-7010 to glass was strong enough to cause cohesive failure in the glass.

Fig. 13 shows an example of a patterned HD-7010 film bonded to a glass wafer: in this case the HD-7010 was cured and bonded at 250°C. HD-7010 exhibits low flow during bonding, so imaged features are not distorted during the bonding process.

A structured film of HD-7010 was prepared on a thinned silicon wafer that had been bonded to a glass carrier with HD-3007. HD-7010 was cured at 350°C with no visible change in the HD-3007 adhesive layer between the glass carrier and the thinned silicon (Fig. 14).

Conclusion

HD-3007 has been evaluated as a temporary adhesive for wafer to wafer bonding. After curing, HD-3007 has a desirable combination of properties (high thermal stability and excellent adhesion) and process capability (flow during bonding and solvent and laser debonding). HD-7010 has been evaluated for application as both a passivation layer for wiring redistribution and as an adhesive.

The process scheme shown in Fig. 1 illustrates the use of these polyimides in the fabrication of a 3D-through silicon via (TSV) package. As shown in Table V, HD-3007 and HD-7010 have been demonstrated in each of the process steps which directly involve the polyimide. We have begun to confirm the compatibility of these materials in tandem for relevant process steps. Future work will focus on evaluating the stability of these adhesives to other 3D TSV process conditions.

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