An Overview - Temporary Wafer Bonding / Debonding for 2.5D and 3D Technologies

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Abstract

In recent years, material suppliers in collaboration with equipment suppliers have developed many new materials/process options for temporary bonding and debonding to be used in 2.5D and 3D technologies. . These options are still being evaluated and at best they are in prototype stage. As a result, the cost is still perceived to be high, there are no reliability data available and many new users in the market are confused about which option and corresponding equipment set should they invest in. I will present the requirements for ideal temporary bonding debonding solution, describe the available technology options for temporary bonding and debonding and their status.

The primary technologies for temporary bonding are adhesive-based. These adhesives are tailored so the adhesive bonds can be broken either by laser ablation, thermal-slide, ZoneBond process, solvent release or mechanical peel-off. It appears that a single solution will not be applicable to all different 2.5D/3D technologies that are being developed and thus, multiple options will be the forerunners.

Key words: 2.5D, 3D, temporary bonding, debonding, laser ablation, thermal-slide, ZoneBond, solvent release, mechanical peel-off.

I. Introduction

The purpose of this report is to provide an overview of requirements and description of different processes and materials that are presently available for temporary bonding/debonding for use in 2.5D and 3D Technologies.

Temporary bonding/debonding enable a variety of advanced IC integration technologies by making a non-permanent bond between a semiconductor wafer and a carrier wafer. The main use of the temporary bonding of a carrier wafer is to provide a support for very thin semiconductor wafers, which are mechanically fragile and will break during handling. The process steps involved for wafer thinning to a few micrometers to couple of hundreds micrometers, and subsequent thru-silicon-via (TSV) and assembly processes will require carrier support using a temporary bonding technology. After these processes are completed, the semiconductor wafers have to be cleanly debonded from the carrier.

Some of the common examples of the use of the temporary bonding/debonding are listed below.

(a) In fabricating 3D/2.5D IC Stack Technologies.
(b) Wafer-level Chip-scale-package (WLCSP) technologies. (Since the front side of the devices in LEDs, MEMS and Power applications is not available for flip-chip bumps, TSVs are fabricated to enable bumping on the backside of the die.)
(c) Thin Packaging (e.g. thin BGAs, QFPs.)
(d) Packaging of Compound Semiconductors and Power devices. (In certain applications, these devices have to be thinned to ~100 microns for optimum RF and thermal performance).

The applications listed in (b), (c) and (d) have been using temporary bonding/debonding for several years primarily for wafer/device thinning. In this document, our main focus will be on the use of temporary bonding/debonding technologies for 2.5D/3D technologies (a), where temporary bonding is used for thinning as well as subsequent processes and assembly steps. This application imposes special requirements for carrier bonding technology. In recent years, many different versions of 2.5D and 3D technologies with different process flow have been developed. Figure 1 and Figure 2 illustrate typical examples of process flow for 2.5D and 3D technologies, respectively. The major process steps requiring temporary bonding are highlighted. As shown for 2.5D technology, typically temporary bonding has to survive the processes involving wafer thinning, redistribution layers fabrication on single or both sides, bump metallization and final die-to-interposer interconnect attachment. For 3D technology, typically the carrier bonding has to survive processes involving wafer thinning, copper pad etch-back, bump metallization, die-to-stack attachment and in some cases TSV process.

II. Temporary bonding/debonding Methods

There are three broad categories of methods for temporary bonding.

1. Adhesive bonding[1-5]
2. Electrostatic bonding[6-7]
3. Patterned support ring (Carrierless) method[8-9]

Of these three, adhesive bonding is the leading method for temporary bonding of carrier. Electrostatic bonding is not a very practical method because it involves high voltage application to create the bond, which could be a safety hazard in production. In addition, this method requires the use of more expensive special carriers. Although this method is not a practical one for direct use in 2.5D/3D process flows, it is used in debonding equipment to hold-down the carrier-wafer assembly during debonding process. Third method is a carrierless method that involves providing the support to the device wafer by leaving a periphery thicker patterned support ring on the backside of the device wafer. This method is also more costly and risky, and very likely will not be the leading method. In this document I have mainly focused on adhesive bonding.

III. Requirements

Temporary bonding has to survive different process conditions based on the particular processes they are subjected to. Since there are many variations of the technologies and process flow, the requirements for bonding/debonding will also vary accordingly. However, some general requirements are listed below that include requirements for adhesive materials and processes for high yielding manufacturing.

a. Bond/debond material-process-equipment system should be cost-effective.
b. Bond/debond processes should be fast (a few minutes long).
c. Device wafer should not be damaged during bond/debond process.
d. Top (device wafer) surface should have a good planarity with bottom (carrier) surface (see Figure 3).
e. Adhesive thickness should be uniform with low Total Thickness Variation (TTV) < 2 micrometers.
f. Metrology (Thickness, TTV, defects in adhesive bondline) should be monitored before and after bonding.
g. Preferably the method should be capable of low temperature (<200^{o}C) bonding. (Memory devices are affected at temperatures above 200^{o}C)
h. The method should be capable of low Temperature debonding (Preferably at Room Temperature).
i. Bonding materials (adhesive in particular) should not outgas during subsequent processes
j. No bubble/air-voids should form in the adhesion layer before and during wafer processing
k. The bonding should withstand
   (i) Mechanical stress and vibration caused during subsequent processes
   (ii) Aqueous and solvent based processes
   (iii) Alkali and acid based wet etch processes
   (iv) Ion or plasma based dry etch processes
l. The device wafer edges must be well supported. (The issue and the two potential solutions are illustrated in Figure 4).
m. Materials-Processes-Equipment system should provide a path to high yielding manufacturing process.
n. The materials and processes should be scalable for 300 mm diameter wafers (and in the future to 450 mm diameter wafers).
o. The carrier wafer material, silicon or glass, have to be chosen based on the processes and cost. The disadvantages and disadvantages of silicon and glass are shown in Figure 5.
p. Carrier wafers should be cost-effectively recycled.

IV. Description of Different Temporary Bonding/Debonding Methods

In last several years, the adhesive material suppliers have teamed-up with different equipment vendors and end-users to develop different adhesive debonding approaches. The leading temporary adhesive debonding methods are:

A. Laser Debonding [9-13]
B. Thermal-slide Debonding [14-15]
C. ZoneBOND (Combination of Mechanical lift-off in the center/Solvent release or thermal-slide on the edge [14, 16-17]
D. Solvent Release (Chemical) Debonding [18]
E. Mechanical Peel-off Debonding [19-20]

The different methods are described below.

A. Laser Debonding

In this technique, adhesively bonded glass carrier and device wafer are subjected to a laser beam through the glass carrier, which will debond the adjoining adhesive layer. The two material suppliers who have developed this method are 3M and DuPont.

1. 3M[9-11]: This bonding/debonding technology is illustrated in Figure 6. 3M offers a complete Wafer Support System, which includes all the materials and processes needed for bonding/debonding and has partnership with equipment suppliers, namely Suss, Tazmo and Yushin. 3M offers UV curable adhesive for bonding a glass carrier to device wafer. A special laser to Heat Conversion (LTHC) coating is deposited on the glass carrier that allows easy, stress-free debonding when laser beam is applied on the glass carrier side. Both bonding and debonding is done at room temperature and the bond is stable to 250^{o}C to 300^{o}C. This temperature range is desirable for 2.5 D technologies and some of the 3D technologies.
2. DuPont[12-13]: This technology is illustrated in Figure 7. DuPont offers their polyimide based adhesives, which is stable to 400^{o}C. If the 3D chip-stacking process requires the temporary bond to survive a high temperature, > 300^{o}C, this is the only adhesive option. The disadvantage is that the polyimide has to be bonded/cured at 300^{o}C. As in the case of 3M technology, a laser beam focused on the adhesive layer through the glass carrier will debond the adhesive from the glass carrier.

B. Thermal-slide Debonding (Brewer Science Technology)

This technology is shown in Figure 8. Brewer Science has developed thermoplastic polymer adhesives, WaferBond[14-15], that will soften above 190^{o}C so that carrier and device wafers can be separated by sliding. The bonding is done at 180^{o}C. The bond is stable to 320^{o}C for short times (1 hour). Brewer Science has partnered with both EVG and Suss Microtec to develop the production equipment.

C. ZoneBond Debonding Technology (Brewer Science Technology)

The technology steps are illustrated in Figure 9. In Brewer Science's Zonebond technology[14, 16-17], the carrier (glass or silicon) wafer is bonded to device wafer with two distinct zones. Most of the wafer area in the center has low adhesion, while he edge has normal adhesion. Low adhesion in the center is achieved by depositing a 'release layer' in the center of the carrier wafer. The adhesive, either thermal-slide or solvent release, is coated on the device wafer. The two wafers are bonded with heat and pressure. Debonding is done in two steps. The first step is to debond the edge of the bonded wafers, depending on the type of the adhesive used, either thermal slide or solvent release. The second step will be to lift-off the carrier wafer by holding the bottom device wafer firmly. The bonding, debonding and stability temperatures depend on the type of the adhesive used.

D. Solvent Release Adhesive (Tokyo Ohka Kogyo [TOK] Technology)[18]

The technology for bonding and debonding is shown in Figure 10. Bonding of perforated carrier wafer to device wafer is done at 220^{o}C with near-zero pressure (0.012MPa). Debonding is done by spraying solvent or by immersing the bonded stack in solvent.

E. Mechanical Release (Peel-off) Adhesive Technology (ThinMaterials)

The technology[19-20] is illustrated in Figure 11 . A special pre-cursor is spin-coated on the device wafer, followed by PECVD treatment that converts the pre-cursor into a 'release layer'. A coating of elastomer liquid is spin-coated over the carrier wafer. Then the device wafer is aligned and bonded to a carrier wafer at 180^{o}C. The bonded wafers have very little adhesion force in z-direction. Wafers are debonded by holding the bottom device wafer firmly and then lifting-off the carrier wafer similar to that in ZoneBond technology.

V. Conclusions

Although these technologies have been in use for many years in wafer/device thinning applications in Power devices, LED technologies, wafer-level CSPs, MEMS, and in RF devices, they have not been fully qualified for 2.5D and 3D technologies. There are no reliability or cost data published yet for large-scale production. Since the process flow for 2.5D/3D technologies varies widely, it will be harder to narrow the choice of temporary bonding/debonding technologies to one technology. There will probably multiple options that will be forerunners.

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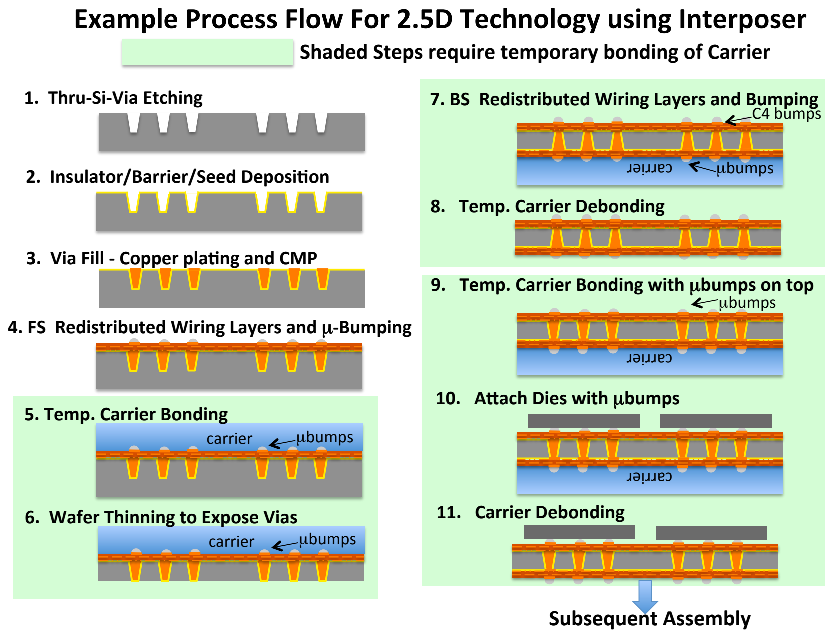

Figure 1: Process flow for 2.5D technology using interposer.

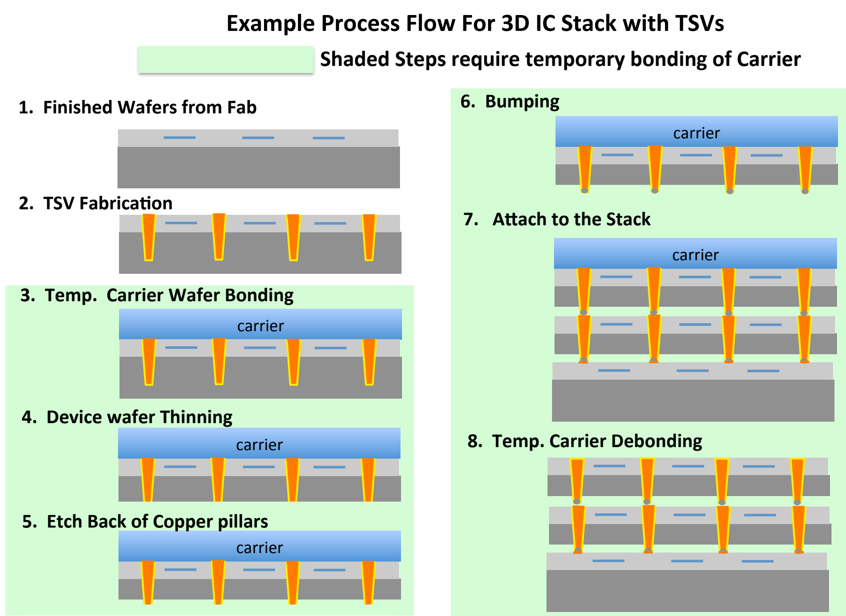

Figure 2: Process Flow for 3D IC Stack Technology.

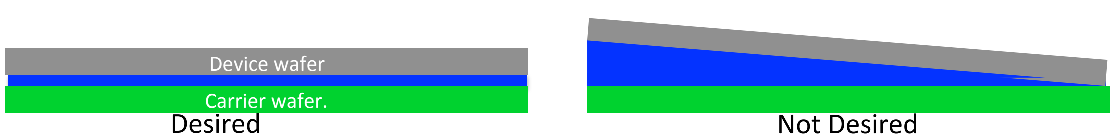

Figure 3: Desired and not desired adhesive coating application.

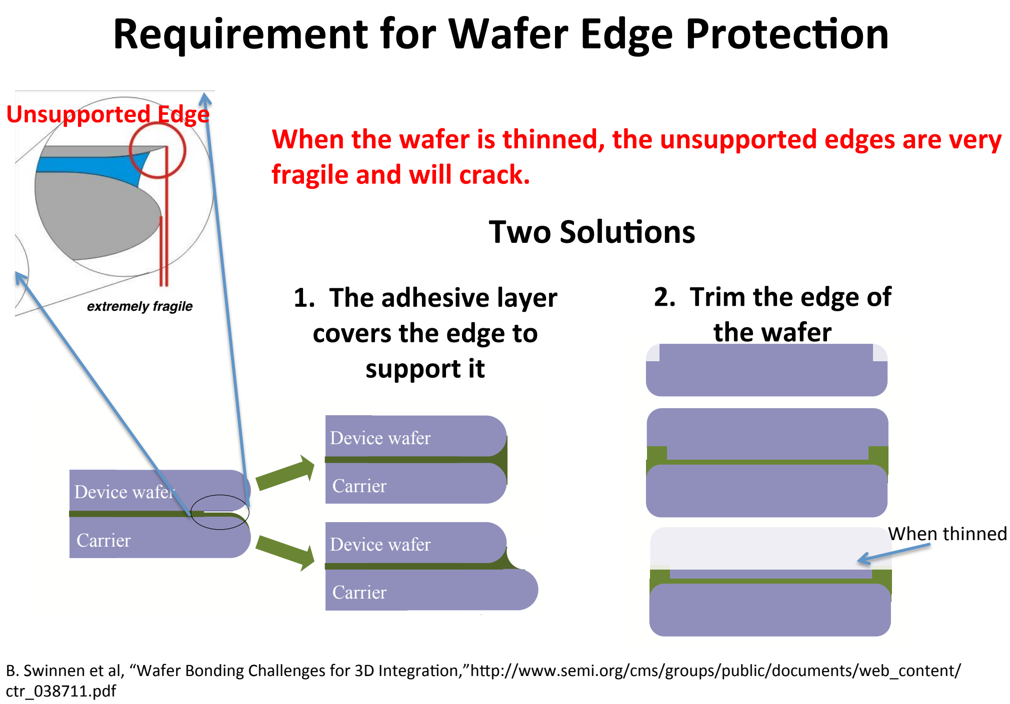

Figure 4: Wafer edge protection by adhesive coating.

Glass Carrier

+ Transparent carrier: allows for optical debonding techniques (typically laser based)
- Glass must be SI-CTE matched across a large temperature range
- Glass must be ground to tight TTV specification (high cost)
- Not compatible with electrostatic chucks

Glass carriers are more expensive, but they are only option for UV/laser release adhesives.

Silicon Carrier

+ Highly compatible to semiconductor equipment
+ Readily available with good TTV (low cost : device grade not required)
- Not transparent: laser-based release methods not applicable

If given a choice, silicon is a preferred carrier material

Figure 5: Comparison of advantages/disadvantages of using glass or silicon carrier.

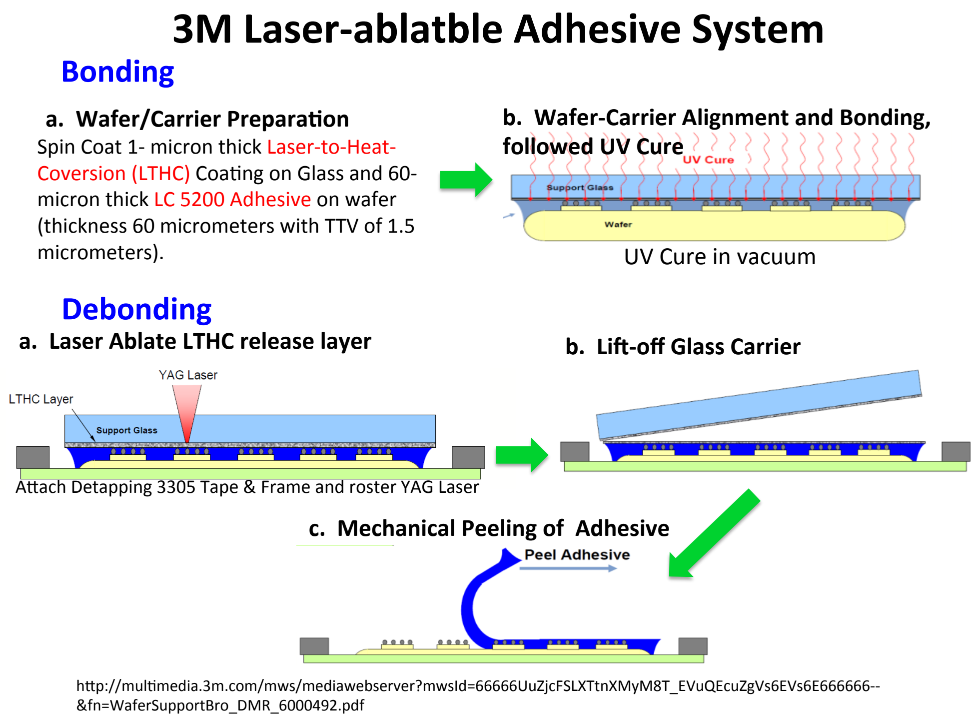

Figure 6: Bonding and debonding with 3M laser-ablatable adhesive system.

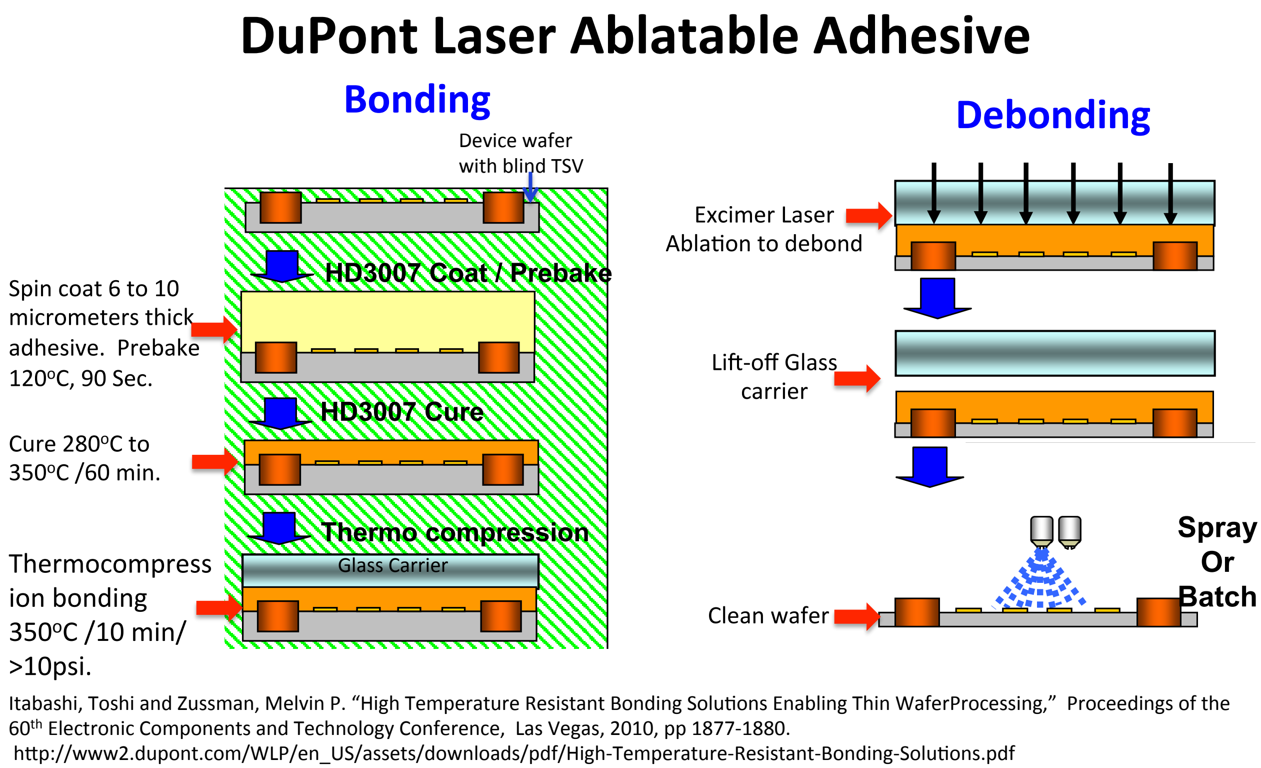

Figure 7: Bonding and Debonding with DuPont Laser-ablatable adhesive system.

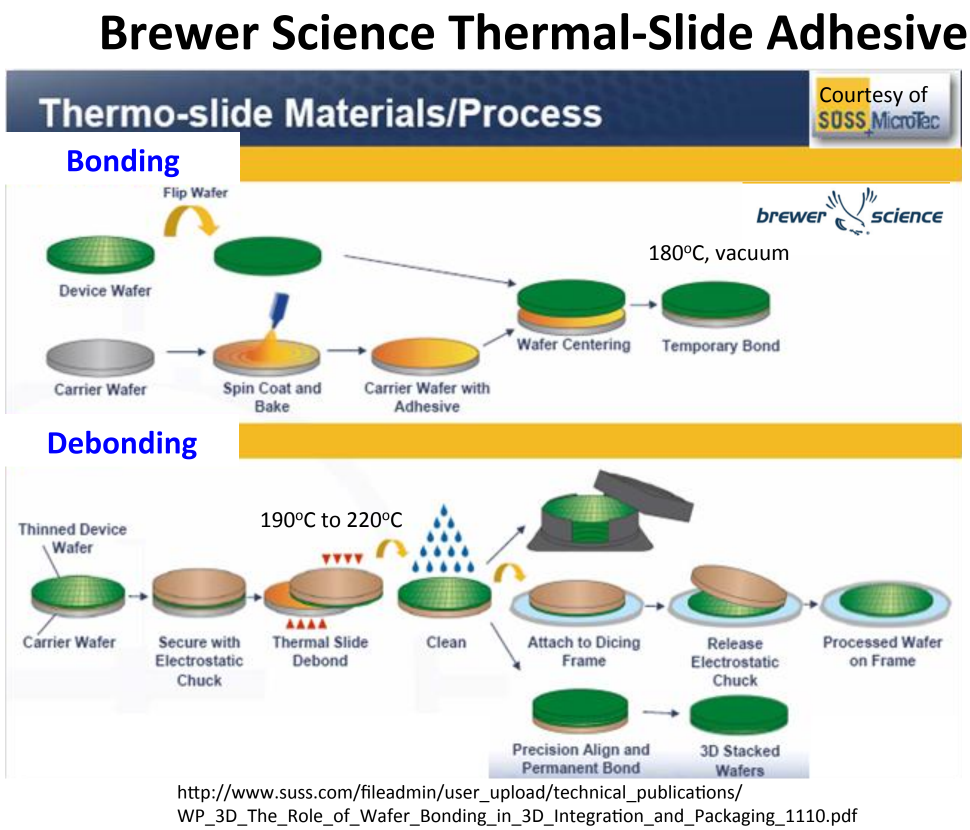

Figure 8: Bonding and debonding with Brewer Science thermal-slide adhesive system.

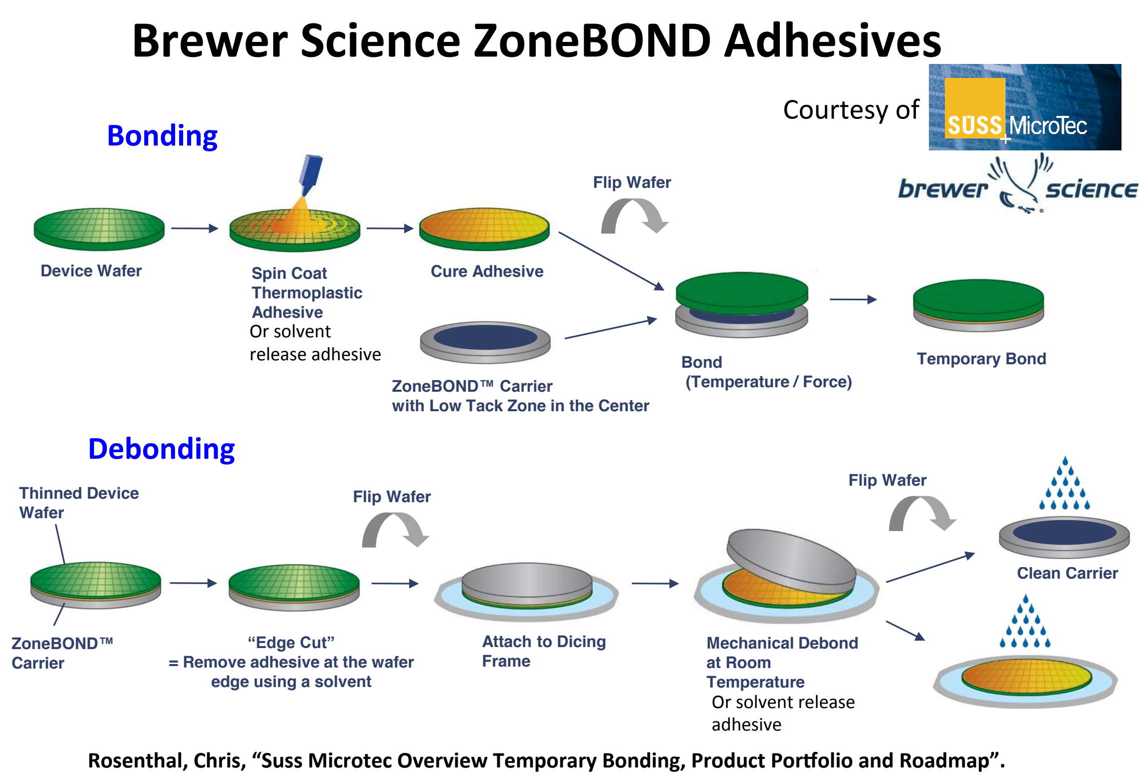

Figure 9: Bonding and debonding with Brewer Science ZoneBond adhesive system.

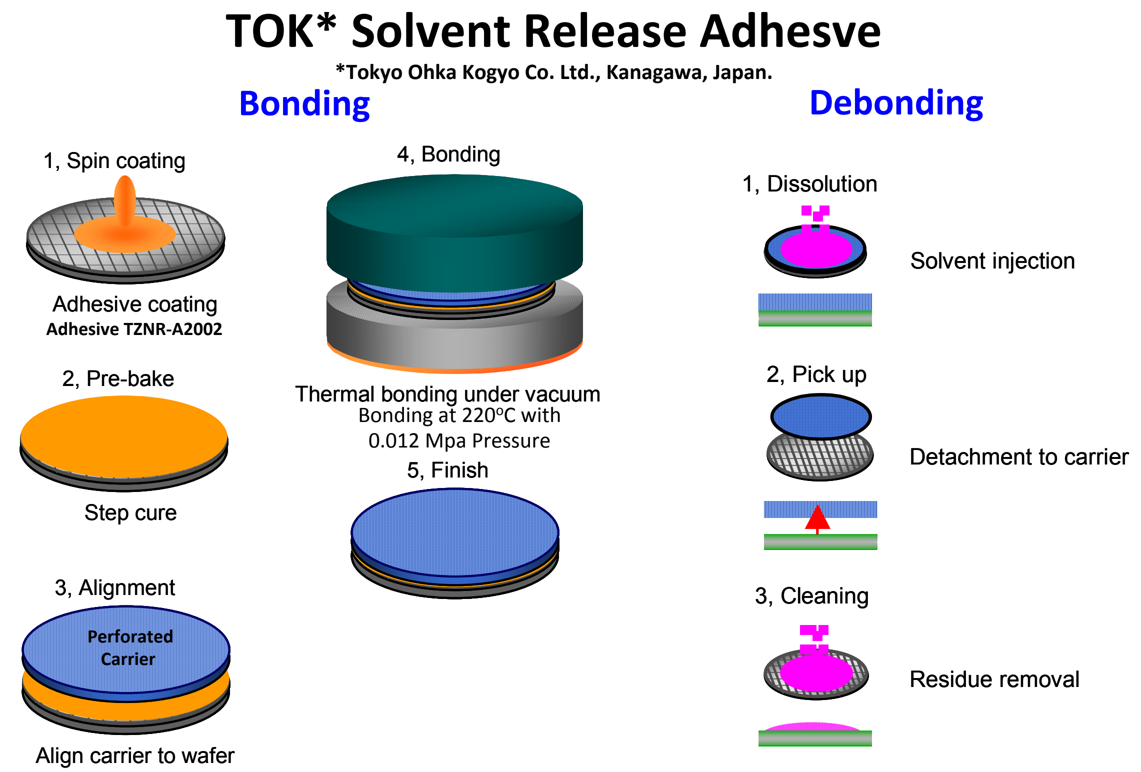

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Figure10: Bonding and debonding with TOK solvent release adhesive system.

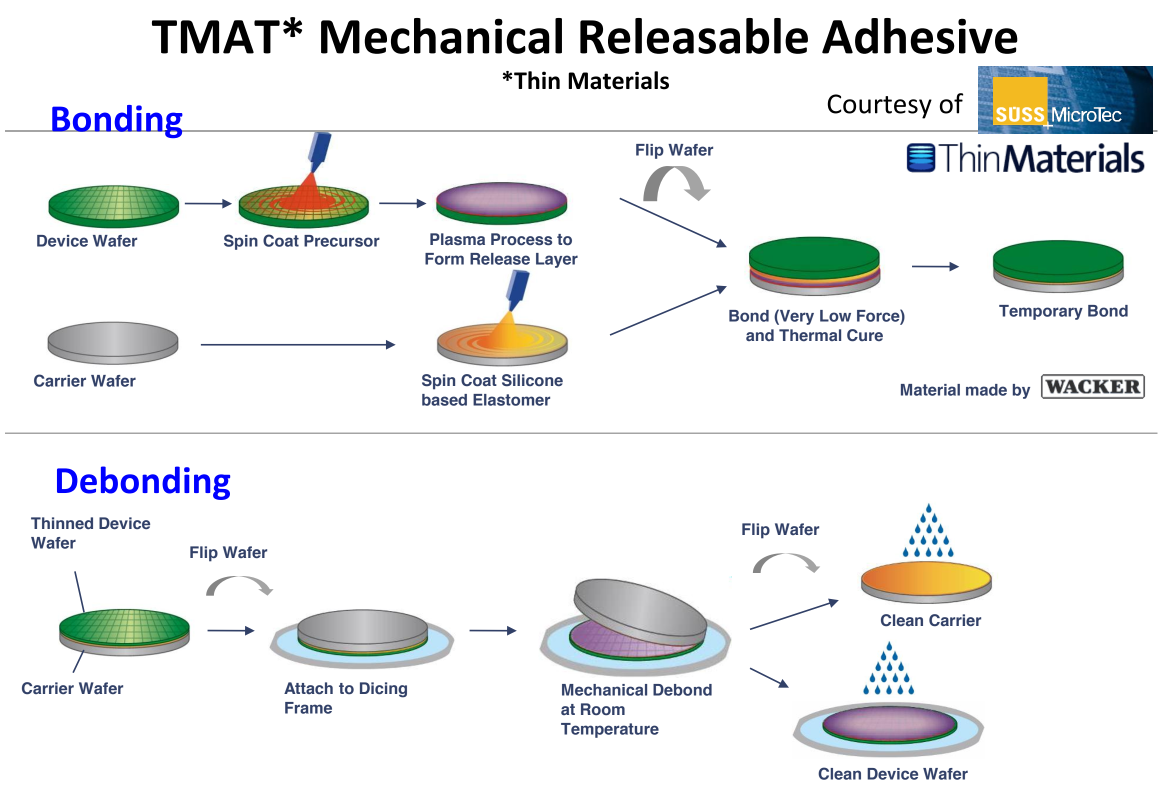

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Figure 11: Bonding and debonding with TMAT mechanical releasable adhesive system