High-Temperature Spin-On Adhesives for Temporary Wafer Bonding

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Abstract

Wafer thinning has been effectively used to improve heat dissipation in power devices and to fabricate flexible substrates, small chip packages, and multiple chips in a package. Wafer handling has become an important issue due to the tendency of thinned wafers to warp and fold. Thinned wafers need to be supported during the backgrinding process, lithography, deposition, etc. Temporary wafer bonding using removable adhesives provides a feasible route to wafer thinning. Existing adhesives meet only a partial list of performance requirements. They do not meet the requirements of high-temperature stability combined with ease of removal. This paper reports on the development of a wide range of temporary adhesives to be used in wafer thinning applications that use both novel and conventional bonding and debonding methods. We have developed a series of novel removable high-temperature spin-on adhesives with excellent bonding properties and a wide range of operating temperatures for bonding and/or debonding to achieve a better processing window.

Keywords

Temporary wafer bonding, temporary adhesives, spin-on adhesives, wafer thinning

Introduction

Three-dimensional wafer stacking technologies have been extensively pursued recently due to the growing interest in device miniaturization. One of the crucial steps in developing ultrathin packages is wafer thinning. The key driving forces for thinned wafers are improved heat dissipation, three-dimensional stacking, reduced electrical resistance, and flexibility of the substrate. Reduction in wafer thickness combined with an increasing wafer diameter requires new methods for wafer handling. Of the different wafer-level bonding techniques, temporary wafer bonding using adhesives is becoming increasingly important in both integrated circuit and MEMS technology, mainly due to low cost, ease of processing, and adaptability [1-5].

Adhesives for temporary wafer bonding must adhere to a variety of semiconductor substrates (for example, silicon, gallium arsenide, indium phosphide) and to different metals, insulators, and dielectrics. The adhesive layer between device and supporting wafer provides the mechanical strength required for thin-wafer handling. Adhesives should possess adequate flow properties to flow into structures on the front side of the device wafer to provide good bonding quality. The adhesives must also be easy to apply; have adequate mechanical strength, thermal stability, and chemical resistance; and exhibit minimal total

Table I. Adhesives for temporary wafer bonding.

Sample	Debonding method	Debonding temperature (ºC)	Max. thickness (microns)
Thermoplastic I	Sliding	200-250	12.5
Thermoplastic II	Sliding	200-250	30
Thermoplastic III	Sliding	200-250	35
Thermoplastic IV	Sliding	200-250	40
Thermoset I	Thermal decomposition	350-400	10
Thermoset II	Thermal decomposition	350-400	10

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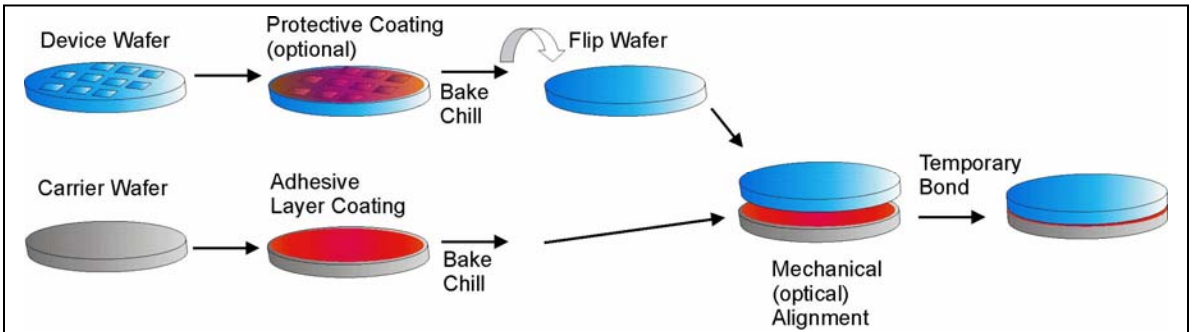


Figure 1. Temporary bonding process flow.

thickness variation (TTV) across large wafers. Also, temporary wafer bonding requires the adhesive to be easily removed without damaging the features on the active side of the wafer over short demounting times to increase throughput. At present, only a limited number of adhesives are available for this type of application. However, most of them must be removed with a solvent and require long debonding times, which significantly reduces throughput [2]. The tapes and waxes currently used for temporary wafer bonding have limited thermal stability at higher temperatures and can be used only up to 170-200º C [3,4].

The objective of this work is to develop temporary adhesives for use in different wafer-thinning applications utilizing new methods for both bonding and debonding. We have developed a series of novel removable high-temperature spin-on adhesives with excellent bonding properties and a wide range of operating temperatures (from room temperature to 400ºC) for bonding and/or debonding to achieve a better processing window. The adhesives meet all the requirements for bonding strength, chemical resistance, thermal stability, and debonding times and temperatures. The materials are soluble in safe solvents, can be spin-coated to obtain void-free thick films required for bump wafer applications, and achieve the required uniformity across the wafer. The resultant materials require a short time (less than 30 minutes) for adhesive removal and do not leave any residue after demounting. In short, the developed adhesives offer both time- and cost-efficiency.

Materials

Two different adhesive platforms have been developed based on different debonding mechanisms. Thermoplastic adhesives (I - IV in Table I) are thermally stable up to 200º C and can be debonded at temperatures ranging from 200 to 250º C due to their relatively low viscosity (< 100 poise) at these temperatures. New removable themoset adhesives have been designed for thermal stability above 300º C. These spin-on materials undergo a thermal curing step to set the adhesives, and they can be debonded either by thermal decomposition above 350º C in nitrogen atmosphere or by exposure to light and heat.

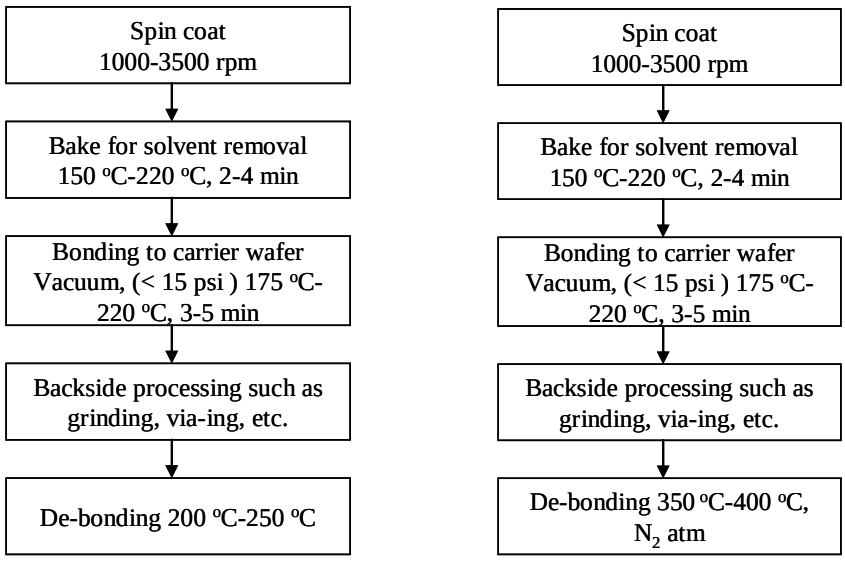


Figure 2. Process flow for temporary wafer bonding using (left) thermoplastic and (right) thermoset adhesives.

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A. Process Flow

The typical process for temporary wafer bonding is shown in Figure 1. The carrier wafer will be coated with adhesive on the front side, and the wafer will undergo an initial bake to remove the solvent. The device wafer (possibly after the application of a protective layer) will be brought into contact with the adhesive-coated device wafer under vacuum and pressure. The processing schemes for different types of adhesives for temporary wafer bonding are reported in Figure 2. The thermoset adhesives need at least two baking steps. The first is to remove the solvent, and the second is to cure the polymer. Either glass or silicon carrier wafers could be used for thermoplastic and thermally decomposable adhesives.

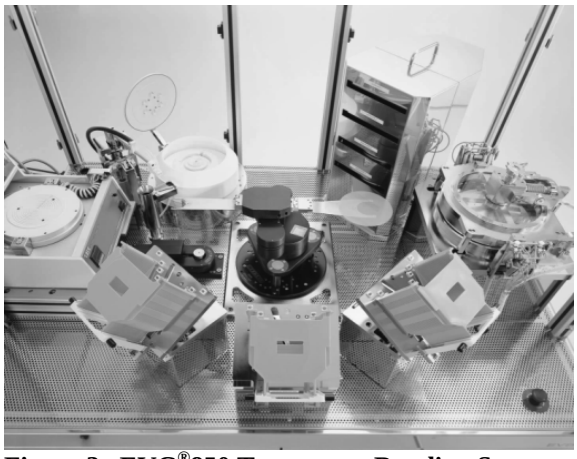


Figure 3. EVG®850 Temporary Bonding System.

In high volume manufacturing, combining all of these processes together would be beneficial to save on thermal cycling time for increased throughput. Because the very next step after solvent removal/soft bake of the adhesive film is to place it into the bonding system to undergo a thermocompression bonding process, placing the still-warm wafer into the bonding system directly saves time during the heat-up cycle of the bond process. As this will typically be the longest single step in the process, any process time reduction is favorable. In EVG®850 Temporary Bonding System (Figure 3) all these steps have been integrated. The modular design of the system allows inclusion of a coat module, a stack of bake modules (up to 4), and 2 bonding modules, which provides a capability in excess of 30 bonded wafer pairs per hour.

Experimental Procedures

The adhesive compositions were prepared dissolving the appropriate resins, additives and catalysts in solvents such as Methyl iso amyl ketone (MIAK), Propylene glycol monomethyl ether (PGME) and Propylene glycol monomethyl ether acetate (PGMEA) or mixtures there of. All adhesive samples can be dissolved up to a concentration of 40 wt%, depending on the required adhesive thickness. The higher viscosity adhesive samples were prepared by dissolving the reactants at a high temperature of 80 ^{o}C for 10 hours.

All the adhesive compositions were spun at speeds between 1000 and 2000 rpm, at an acceleration rate of 1500 rpm/s on to a silicon wafer to achieve target levels of thickness as shown in Figure 4.

The chemical resistance for the adhesive samples was determined by immersing the adhesive bonded wafers in to acid/alkaline/solvent baths for a period of 1 hour. The bond quality after the chemical exposure was used to determine chemical resistance of each adhesive.

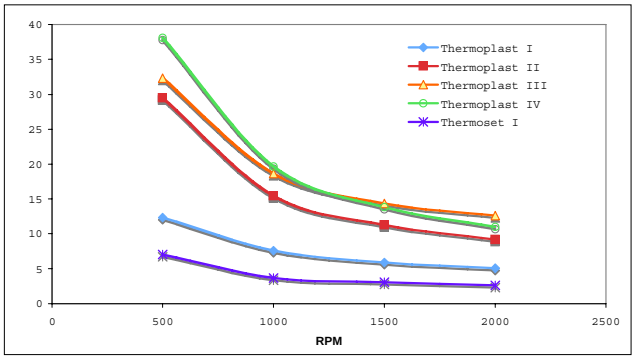


Figure 4. Spin-speed and thickness data for the new adhesives.

For experimental purposes, both 6- and 8-inch wafer pairs were processed using the EVG®150 resist processing system optimized for thick resist coating, and an EVG®520IS wafer bonding system. Because of the modular nature of the system, the modules installed in the EVG®850 system are fully equivalent to the EVG®150 and EVG®520IS systems.

The vacuum pressure during the bonding process is monitored to ensure that no outgassing of the adhesive occurs during bonding. The smooth increase of the vacuum level during the entire process shows that no products were outgassing during bonding.

Results and Discussion

A. Thickness Measurements

The spin-on solutions offer better thickness control compared to waxes and tapes used in wafer bonding [4]. As the trend toward ultrathin wafers continues, it becomes very important for the adhesive to have a high degree of uniformity across the bond interface, because thickness

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variations cause breakage and warping during backgrinding. The thickness measurements on the adhesive films were carried out using Alpha Step 200 (Tencor Instruments) and Nanospec® 6100 (Nanometrics, Inc) equipment. Adhesives that can provide large thickness values will be required for bump wafer applications. The results of thickness measurements are reported in Figure 4.

The materials all lend themselves to very good uniformity control as well (another element that is crucial to effective bonding for back-grinding). Measurements were performed on a thick spin-coated layer of the thermoset material, as coated using an EVG®150.

The film measured had a mean thickness of 13.5 µm, with a uniformity of ±1.5%. In addition, the edge bead (another critical factor, because this bond is being performed across the full layer) was <2µm high, and <0.5 mm wide.

B. Chemical Resistance

The adhesives intended for wafer bonding applications must withstand strong acids, alkalis, and solvents at high temperatures during various processes of etch and metallization. The summary of the resistance of the different adhesives to several chemicals is reported in Table II.

Table II. Chemical resistance of new adhesives.

Sample	NMP	30% KOH (85°C, 60 min)	5% H_2SO_4
Thermoplastic I	Dissolves	No attack	Dissolves
Thermoplastic II	No attack	No attack	No attack
Thermoplastic III	No attack	No attack	No attack
Thermoplastic IV	No attack	No attack	No attack
Thermoset I	No attack	No attack	No attack
Thermoset II	No attack	No attack	No attack

C. Optical Transparency

All of the adhesives are transparent in both UV and visible regions, and provide the optical transparency required for wafer-to-wafer alignment.

D. Post-bond Uniformity

The coating thickness uniformity is extremely important, but only as it contributes to the final post-bond uniformity of the bonded stack. Total stack thickness comprising of bonded silicon wafers and intermediate adhesive layers are shown in Table III. All the samples achieve less than 1% total thickness variation (TTV). The smaller the TTV, the more accurate and uniform the wafer-thinning process becomes after the bond. As substrates become thinner, TTV becomes more critical. If the TTV becomes a significant portion of the final wafer thickness (for instance, 15-µm TTV versus 80-µm thickness), the performance consistency of the devices on the wafer is in jeopardy.

To ensure good post-bond uniformity, the pressure and temperature uniformity of the bonding system are critical. The resulting achieved TTV measurements in all cases were less than 10 µm (Table III).

Table III. Post-bonding TTV values (µm).

	Adhesive	Left	Top	Center	Right	Bottom	TTV
6" Wafers	Thermoplastic	1380	1378	1382	1378	1377	5
	Thermoplastic	1380	1379	1382	1380	1380	3
	Thermoplastic	1360	1357	1361	1358	1358	4
	Thermoset I	1377	1376	1376	1376	1376	1
	Thermoset I	1376	1375	1377	1377	1377	2
	Thermoset I	1378	1377	1376	1377	1375	3
8" Wafers	Thermoplastic	1425	1426	1430	1425	1426	5
	Thermoplastic	1421	1422	1428	1423	1426	7
	Thermoplastic	1433	1436	1439	1436	1434	6
	Thermoplastic	1428	1428	1431	1424	1426	7
	Thermoplastic	1394	1396	1399	1395	1395	5

E. Adhesion Strength

The adhesives should possess high bonding strength, above 2.5 J/m^2, to support wafers during harsh processes such as backgrinding and polishing. The adhesion strength was evaluated using the peel test, the Maszara razor blade method [5], and rheological analysis.

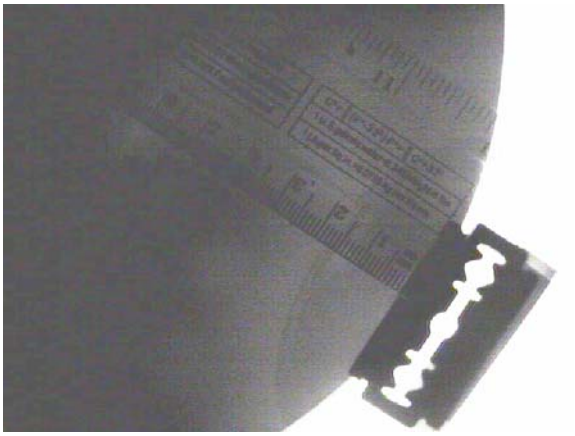


Figure 5. Maszara crack test, 15 mm.

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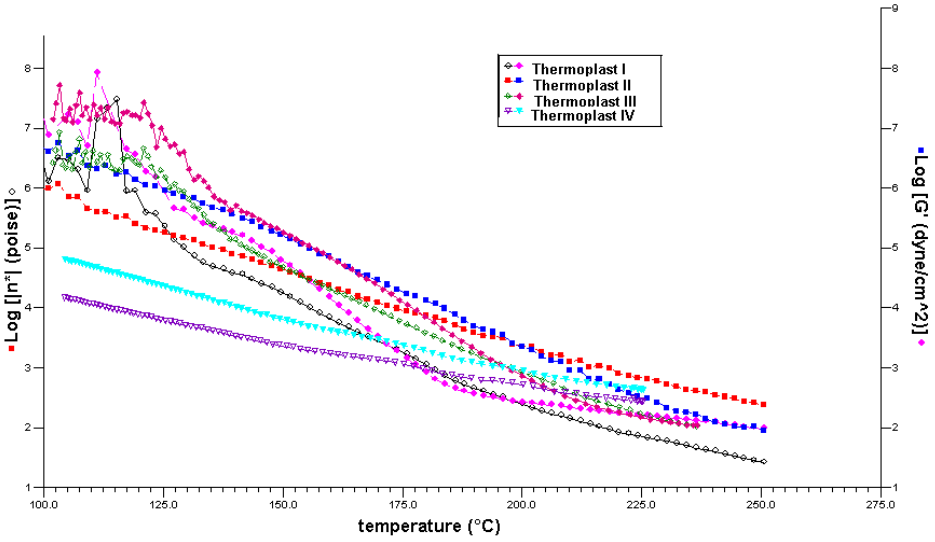


Figure 6(a). RDA analysis of thermoplastic materials.

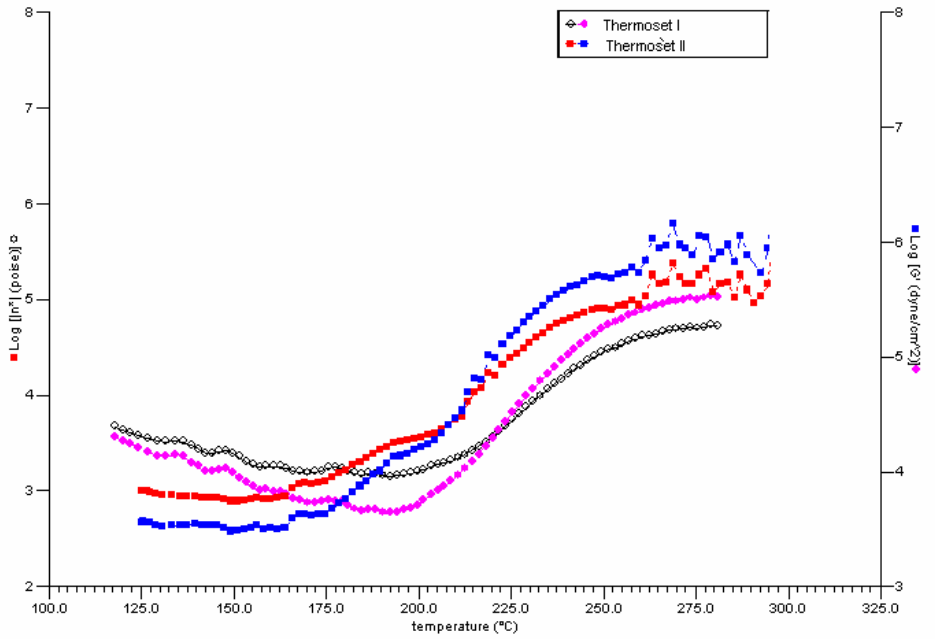


Figure 6(b). RDA analysis of thermoset materials.

The Maszara razor blade test is a method to determine the pull strength of the resulting bond. The test performed by inserting a razor blade between the two bonded wafers, and then evaluating (via infrared for silicon wafers or visually for silicon-glass bonds) the length of the resulting crack. Figure 5 shows an image of a wafer pair bonded with the thermoset adhesive undergoing the crack test. Based on the thickness of the wafers and razor and on the length of the crack, the resulting bond force in this image is ~ 1 J/m^2, which proved to be sufficient to withstand the backgrinding subsequently, performed. For the thermoplastic adhesives, the razor blade could not be inserted (breaking the wafers, instead), indicating that the bond strength is on the order of 2.5 J/m^2, the bulk fracture strength of silicon. Results of rheological analyses are reported in Figure 6. All the thermoplastic adhesives, shown in Figure 6(a), maintain good adhesion up to 200 ^{o}C due to high viscosity values (above 1000 poise), But at temperatures above 225 ^{o}C, all

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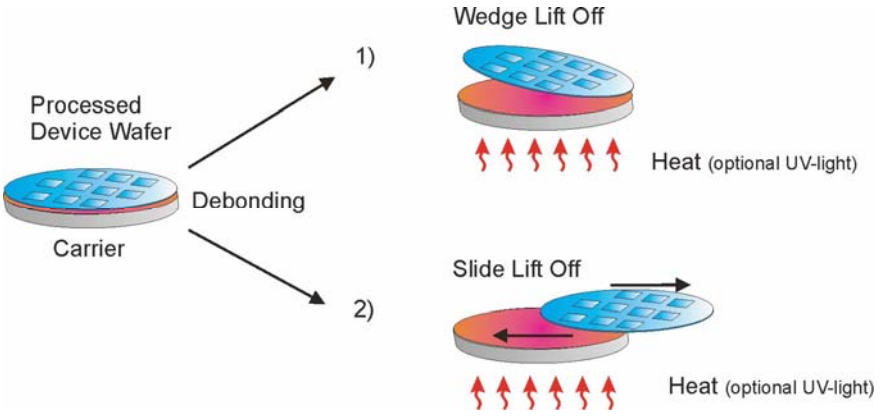


Figure 7. Debonding methods.

the thermoplastic compositions achieve viscosities less than 100 poise. Due to the low viscosities at these temperatures the bonded wafers could be separated by simple sliding at these elevated temperatures. The rheology data from Figure 6(b) indicates that the thermoset samples starts to cross-link at temperatures above 150 ^{o}C. Due to the low viscosity values at these temperatures, the wafers were bonded together at temperatures between 150 ^{o}C -175 ^{o}C to achieve good planarity. The rheology data shows that the thermoset adhesives maintain strong bond strength up to 275 ^{o}C.

F. Void-free Bonding

The final performance of the bonded pair relies not only on a good bonding uniformity in order to achieve good grinding performance but also on achieving a strong and void-free bond. Even if the bond is very strong and very planar, voids, even very small ones (~1 mm), can still cause issues in steps following backgrinding, such as metallization. Small voids such as this can burst under the conditions of the metallization process and leave defect points in the thinned substrate. However, by achieving a uniform resist coat, good pressure, and temperature uniformity during the bond (plus bonding with sufficient force); voids can be eliminated.

G. Debonding Results

As mentioned before, various methods can be used for debonding, depending on the adhesive (Figure 7).

For the thermoplastic adhesives, the debonding method involves heating the substrates to the debonding temperature (in most cases, typically above 200º C) while they are locked into a rigid frame with top and bottom heaters. The wafers are then slid apart in a controlled manner such that the wafers stay parallel to each other until completely apart. Using two heaters is critical. If only one heater were used, then as the wafers separate, the influence of air would cause one substrate to cool, increasing the viscosity of the adhesive at the boundary between the newly exposed surface and the still-covered surface. This situation would create a shear force variation, which can lead to wafer breakage.

The removable thermosets (Thermosets I and II) can be completely decomposed at temperatures above 350º C in nitrogen atmosphere. At 400º C, the adhesives could be completely decomposed within 15 minutes without leaving any residue. The thinned wafer can then be carefully removed from the carrier using a wedge-off motion.

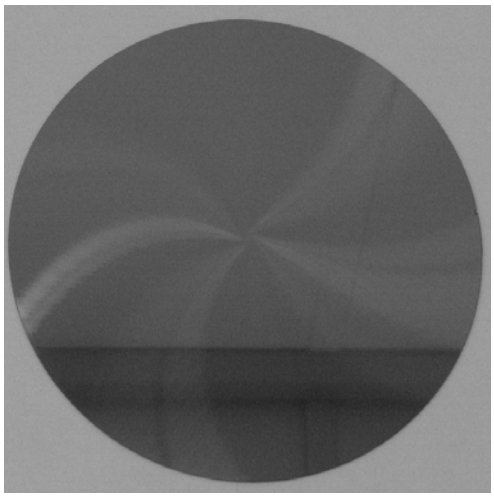


Figure 8. Thinned wafer.

All of these methods can be integrated into the EVG®850DB debonding system for high-volume automated processing of these thin substrates. Silicon

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wafers were successfully thinned down to 50 μm by using either thermoplastic or thermoset adhesives.

H. Thinned Wafer – the End Result

When all processes have been completed properly, the final result will be a completed and released thinned substrate suitable for final singulation and packaging. Figure 8 shows an image of a background 8-inch silicon wafer that has successfully completed the bonding, thinning, and debonding process.

Conclusions

Three types of adhesives were evaluated for their potential use in temporary wafer bonding. The adhesives meet all the requirements for bonding strength, chemical resistance, thermal stability, and debonding times and temperatures. Of these, thermoplastic materials meet the requirements for 200ºC applications. The materials are soluble in safe solvents, can be spin-coated to obtain void-free thick films required for bump wafer applications, and achieve the required uniformity across the wafer. In addition, all the adhesives exhibit good chemical resistance and tunable debonding temperatures. The resultant materials require a short time for adhesive removal and do not leave any residue after demounting. In short, the developed adhesives offer both time- and cost-efficiency.

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