A Review of Wafer Bonding Materials and Characterizations to enable Wafer Thinning, Backside Processing, and Laser Dicing

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Abstract - **A wide range of adhesives and coatings has been reported to enable wafer bonding practices that support applications leading to 3-D packaging. These polymeric substances include among others, rosin-urethane [1], silicone [2], rubber [3], and acrylic [4]. In the case of a carrier bonded wafer, the material allows grinding and polishing to <20um, protection of the devices from backside processing such as through silicon vias (TSVs) and the associated cleans and metallization steps. In conjunction with laser dicing, the material must be removed from the wafer without residue detection. Proper characterization methods must be used to model the processing steps during fab integration. For example, thermal analysis is commonly used to identify pre-processing conditions to improve on-wafer curing. Cleaning tests may utilize the speed, extreme sensitivity, and delicate contact of the mercury probe analyzer, which has been shown to characterize film residues at below 10 angstroms [5]. Metrology tests to establish planarization, include surface roughness and total thickness variation (TTV). Although all of these measurements may tell a story about a pure material or a smooth wafer, they are especially interesting when they are used to model the process. This paper will describe a range of characterization methods with example wafer adhesives used to predict processing conditions during integration.**

I. Introduction

Wafer thinning is an integral part of the chip stacking process, otherwise referred to as 3D packaging. Wafers are bonded with a temporary adhesive to a carrier substrate in a manner that ensures a high degree of uniformity and support while thinning to below 20 um. During wafer to carrier bonding, maintaining substrate planarity and uniformity is believed to be a key parameter to achieve successful thinning [6]. Good surface planarity, usually measured as a low TTV, is believed to reduce both internal stress and wafer bow during grinding [6-9]. Liquid spin-on forms of adhesives offer easy control of TTV. When the coating is applied to smooth (native) and patterned wafers, acceptable thinning uniformity may be achieved if the TTV is $\leq$ 0.5% [1-2]. Once thinned, the adhesive continues to hold the substrate in place through backside processing, a series of steps that include TSVs, metallization, and may extend to dicing. Typical process flows are shown for single (Fig. 1) and multi-substrates (Fig. 2). The choice in a bonding material and how it is processed are important for its success in sustaining these mechanical and chemical demands.

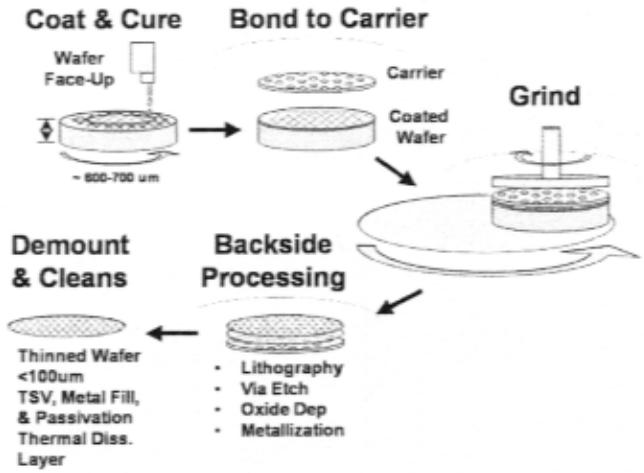

Fig. 1. Typical process flow for temporary adhesives used in wafer thinning.

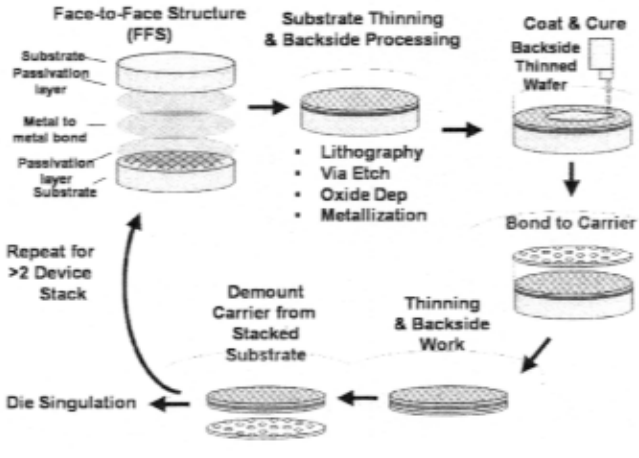

Fig. 2. Typical process flow for thinning used in chip stacking.

A. *Metrology*

Measuring a coating's texture, thickness, and its uniformity over a wide area allows one to define its metrology and begin comparative analysis for application to a process [10]. The choice in profilometer equipment includes contact-cantilever designs with laser-photodiode sensors and nanometer-size stylus tips in atomic force profilometry (AFP), as well as non-contact interferometers [11].

B. *Thermal Analysis*

Common thermal analysis methods include thermogravimetric analysis (TGA), thermomechanical analysis (TMA), and differential Scanning Calorimetry (DSC). TGA measures weight loss during an isothermal or ramping condition. TMA measures expansion and contraction under conditions of temperature, load, and environment. DSC measures heat evolved or absorbed during heating, cooling or isothermal conditions. These tools are used to acquire valuable data to predict a material's behavior during a process.

C. *Hg-Probe Testing*

The mercury probe was designed by Materials Development Corporation (MDC) to make rapid, non-destructive, contact for electrical characterization [12]. Its primary application is semiconductor measurements where alternative methods took hours and required detailed metallization. One of the first successful mercury probe applications is the characterization of thin epitaxial layers grown on silicon [13]. Another application includes the characterization of a gate contact for measurement of permittivity, doping, oxide charge, and dielectric strength [14].

The instrument platform includes two glass vials containing mercury, whereby it makes contact with the sample facing down. The surface of the platform is machined flat and then lapped to give a texture to allow a vacuum leak between its surface and the sample. In the center of the measurement platform is a small hole for the primary main mercury contact surrounded by an open annulus as a secondary mercury contact. Both of the contacts communicate with the mercury vials and are surrounded by a vacuum ring. These form the active region of the mercury probe described in Fig. 3.

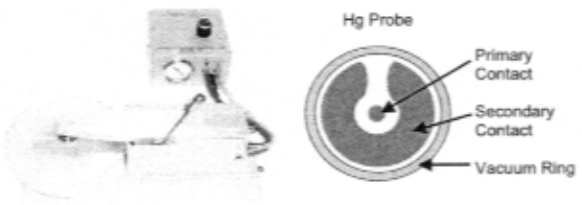

Fig. 3. Hg Probe equipment and head description showing each contact area.

For simple measurements, mercury-sample contacts should be ohmic (non-rectifying) allowing for the current-voltage instrumentation to be used to measure resistance, leakage currents, or current-voltage characteristics. Resistance is measured on thin films composed of any material that does not react with mercury. Metals, semiconductors, oxides, and chemical coatings may be measured successfully.

II. Experimental

For subsequent analytical testing, quartz substrates as are chosen and prepared at Daetec along with 100-200 mm (4-8") silicon wafers (1-0-0, ~525 µm) re-manufactured from Wollemi Technical, Inc. (Taiwan, www.wollemi.com.tw). For ease of mercury probe measurements, all wafers are copper sputtered at ~2,000 angstroms. Materials used include commercially available spin-coated adhesives as rosin [1], rubber [3], as well as acrylics, aqueous-soluble, encapsulate, and other developmental products produced at Daetec [15]. Coatings are produced on a Brewer Science, Inc. CB-100 spin-coater, while spray and encapsulation uses custom tooling designed at Daetec. Patterned wafers for encapsulation were prepared with 140 µm diameter hole size patterns and plated Pb/Sn (95/5) bumps of a height at 70 µm.

Metrology data is generated by a *XP-1* stylus profiler, *AFP-200* atomic force profiler, and a *Xi-100* optical profiler [11]. Where applicable, equipment settings include a 5 mg stylus load, minimum 4 mm distance, and speed of 0.5 mm/sec.

The Hg probe uses a dot and ring contact, model 802B-150, an HP 4140B picoammeter source supported by an MDC measurement system with an I-V plotting program @ 10 mv steps from 0-1V [12]. Typical I-V plots are produced to compare trends and to study breakdown voltage of the protective film.

III. Results

Comparative studies for roughness metrology by AFM and stylus profilometry on silicon, rubber, rosin, and acrylic (Tables 1-2, Figs. 4-5), suggest micro and macro character between materials. Spin-speed curves generated for aqueous soluble coatings vary in thickness from 0.5-5 µm (Fig. 6), while laser dicing through these coatings indicates thin is preferred for small kerf widths (Fig. 7).

TGA data in Figs. 8-9 suggest a preferred 110 C cure for ~15min is sufficient to prevent significant outgas during subsequent processing. The TMA in Fig. 10 suggests a 5% relaxation during moderate heat, consistent with enhanced adhesion after ultraviolet (UV) exposure in a two-stage cure prior to a final thermal cure (Fig. 10). A DSC of this multi-cure program shows an increase in glass transition (Tg) between the 1st (Tg ~ 54 C) & 2nd (150 C) steps (Fig. 11). DSC also shows reaction kinetics by cure temperature (Fig. 12) and cure completion (Fig. 13).

During substrate cleaning of a rubber adhesive coating, both solvent and aqueous cleans are shown to produce desirable

results. Highlighting the sensitivity of the Hg-probe, aqueous cleans have been shown to produce superior results over a blank (baseline) substrate, suggesting the removal of a native oxide on the metal (Figs. 14-15).

TABLE 1
AFM 3D surface roughness as measured relative to distance in µm.

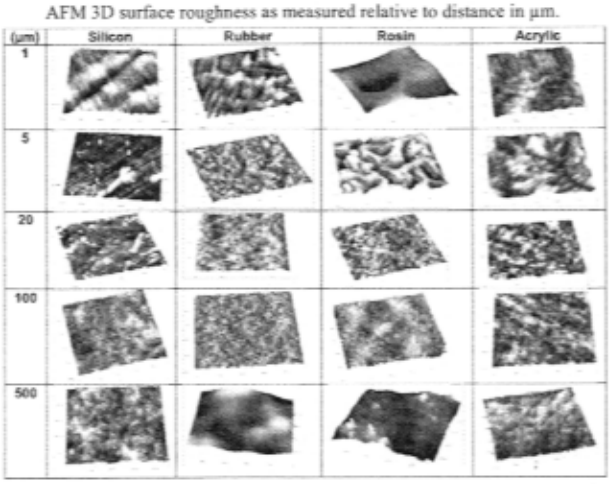

TABLE 2
Surface roughness by AFM measured as nm according to distance in µm.

(µm)	Silicon	Rubber	Rosin	Acrylic
1	0.8	0.7	5.1	0.8
5	2.5	1.0	10.2	0.5
20	5.7	0.8	6.2	0.6
100	0.9	0.7	5.1	1.5
500	0.9	19.5	15.3	12.0

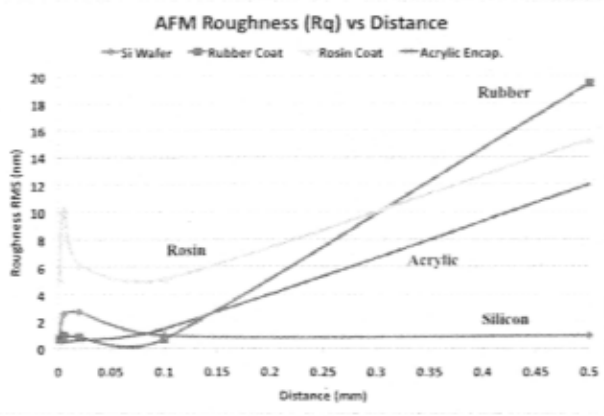

Fig. 4. AFM surface roughness vs distance, values from Table 2.

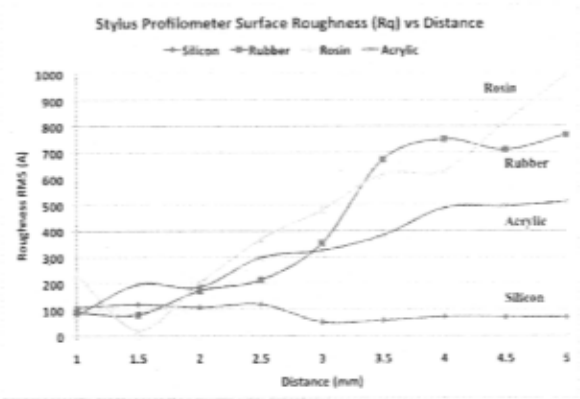

Fig. 5. Stylus profilometer roughness vs distance.

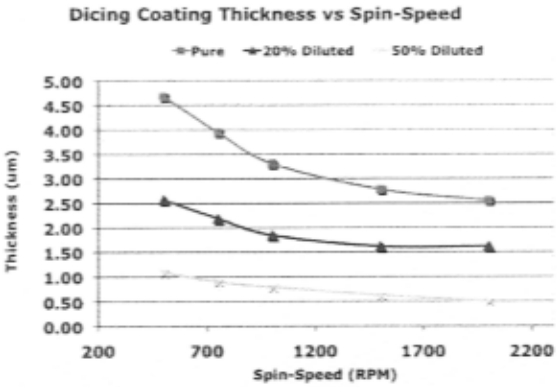

Fig. 6. Thickness vs spin-speed curves for dicing coatings.

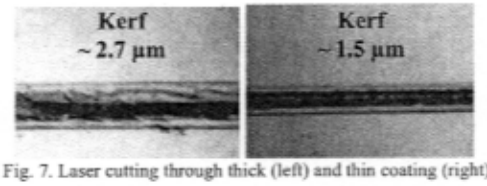

Fig. 7. Laser cutting through thick (left) and thin coating (right).

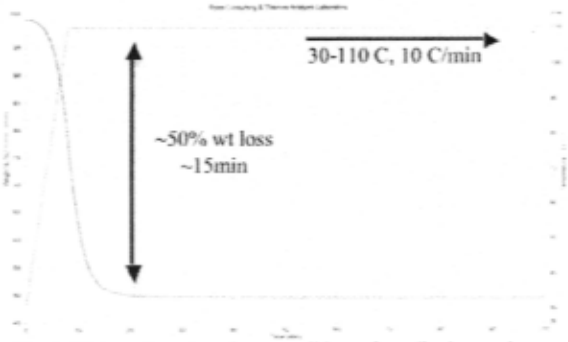

Fig. 8. TGA confirmation of cure conditions of an adhesive coating.

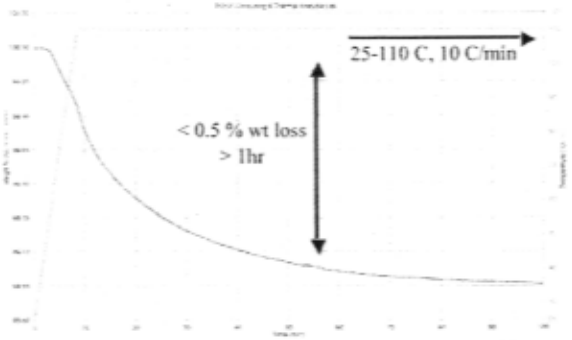

Fig. 9. Outgas TGA following post bake.

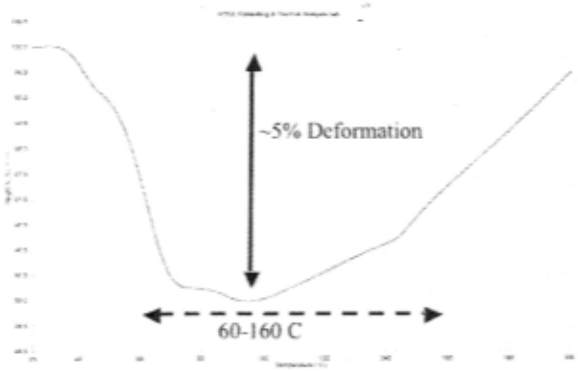

Fig. 10. Softening behavior by TMA of cured specimen.

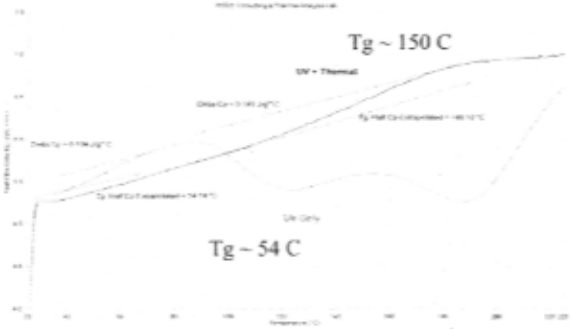

Fig. 11. Curing by DSC showing UV (wavy, bottom) and UV + Thermal.

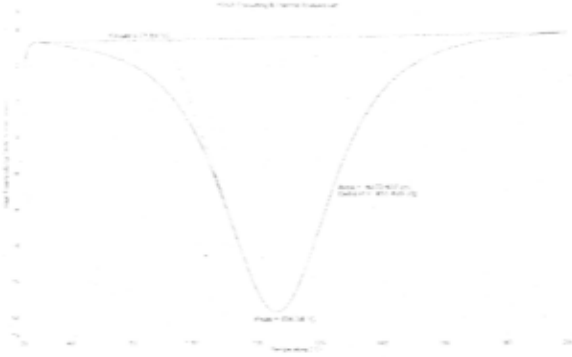

Fig. 12. Heat of reaction by DSC, onset ~70 °C, peak ~105 °C.

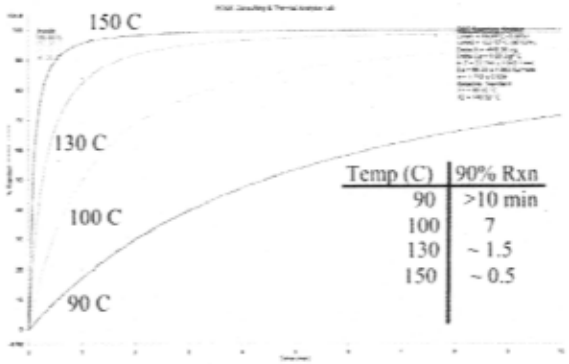

Fig. 13. Kinetics by DSC, reaction completion vs temperature.

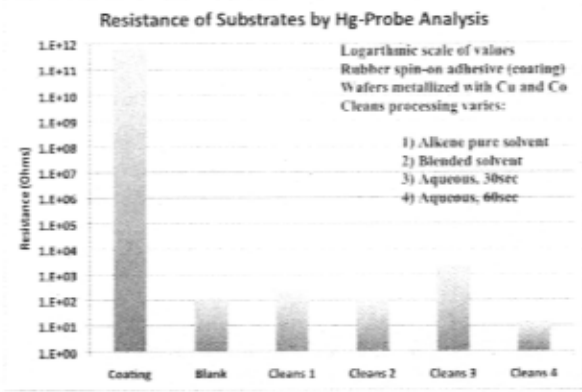

Fig. 14. Resistance by Hg-probe testing for cleans of rubber coated wafers.

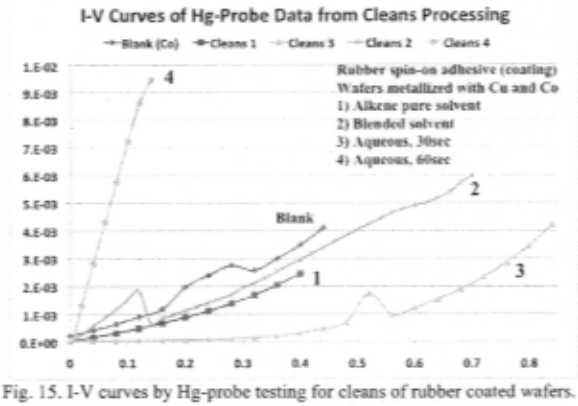

Fig. 15. I-V curves by Hg-probe testing for cleans of rubber coated wafers.

IV. Discussion

Wafer thinning and processing requires the utilization of temporary bonding systems. These bonding adhesives can range in hardness from very soft and compliant, such as rubber, to a very hard like rosin systems. Irrespective of which adhesive one chooses the question of actual performance remains large. How a system cures, the extent of thermal resistance, amount outgassing, how much it expands and

contracts whereby inducing stress, and where it degrades, are all critical to optimizing a thinning and processing program.

We have observed that several commercially available products marketed as wafer thinning adhesives exhibit a surface roughness, Rq $\geq$ 0.1 µm (Fig. 5). This brings into question the requirements of a material's texture necessary to achieve a desired configuration with low TTV. Choosing the proper curing and pre-processing conditions for the adhesive will help mechanically secure the wafer and resist thermal exposure with minimum outgassing (Figs. 8-13). In some cases, the use of dual-cure systems (UV-thermal) can lead to a new set of wafer bonding issues. Multiple curing options have more variables to control, yet allow greater processing flexibility by offering a staging approach to bonding. Cure staging may reduce internal stress, allow thicker coatings for topography (bumps or MEMS), and allow alternate configurations for edge protection.

One of the most important properties of the wafer adhesive is its ability to be easily removed (cleaned) from the surface, leaving a pristine condition. Usual cleans practices involve the application of solvents or aqueous mixtures followed by an alcohol or water rinse. Typical cleaning practices for processing silicon 300 mm wafers uses a single-wafer cleaning tool with the flow described in Fig. 16.

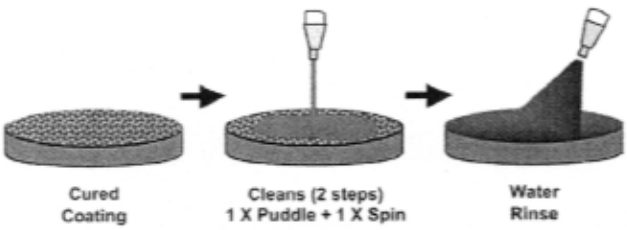

Fig. 16. General process flow for cleans following wafer demount.

Cleaning inspection uses the Hg-probe to confirm residue removal. Our study focused on chemically-resistant rubber coating removed with both organic solvents and aqueous mixtures as designed by Daetec (Figs. 14-15). Measurements are made in seconds, without surface compromise, allowing multiple processing.

Dicing may be done before or after wafer thinning. Either way, surface protection includes the use of an aqueous soluble coating, rinsed after laser processing, to remove heat activation zone (HAZ) debris [16]. Coating thickness was observed to be important for laser dicing. Thin protective coatings are believed to minimize interaction with the laser and its contact to the substrate in the HAZ. Thin coatings may help to reduce beam spreading in the HAZ, resulting in a desirable minimum kerf width (Figs. 6-7).

V. Conclusions

For purposes of achieving a satisfactory surface texture in preparation for wafer bonding, the metrology practices reported here appear to be valid in characterizing the coating. Further work is proposed to identify interactions between a coating's roughness and the material's hardness as Tg, softening point, or modulus, measured by DSC or TMA. Consistent with other reports and noted here, TGA is a valid method for identifying pre-process conditions and outgas characterization. Thin residues undetectable by many conventional and more complex methods, are easily identified by Hg-probe electrical studies.

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