狭窄的晶圆处理——研究临时晶圆粘合材料和工艺

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Abstract—这篇论文审查了用于三维TSV薄晶圆处理的主要粘合剂和工艺，提供了材料和工艺的热和其他性能数据，并试图建立一个关于工艺相关的热性能的近似值，使用一个常见的分析方法。

I. INTRODUCTION

对于摩尔定律的终结的预测相当常见。有成本和复杂性问题的限制导致了晶圆尺寸的缩小。半导体行业很快建立了一条新路径，专注于三维堆叠集成电路。通过在相同的较小尺寸中增加第三个维度，堆叠电路可以不缩小电路特征来放置更多的晶体管。这些层像摩天大楼一样堆叠起来，有效让摩尔定律继续，尽管是沿着一条稍微不同的路径。

三维集成或垂直堆叠的芯片或晶圆需要新的技术和新的设备，特别是新的粘合剂和300mm晶圆的绑定。就像化学机械抛光（CMP）在几年后成为行业的一个使能技术一样，粘合剂被识别为下一个重要的使能技术。

临时粘合和脱粘已经出现，对大多数三维集成方案都是具有挑战性的过程。选择合适的临时粘合剂是关键。通过硅片（TSV）处理过程，特别是在硅片上。粘合剂的热稳定性是其在高温下保持完整性和防止晶圆与载体分离的能力。对粘合剂的热稳定性的关注必须考虑，因为已经报告过在高温处理后的主要问题[1]。粘合剂的热稳定性与材料在高温下的时间期间抵抗降解和释放的能力有关。通常报告的粘合剂失败模式是在高温条件下晶圆从载体分离的区域，晶圆上的空洞。

III. THERMAL STABILITY

除了必须注意临时粘合剂的热稳定性外，因为主要问题已经报告过，它们发生在高温处理后[1]。粘合剂的热稳定性与材料的热处理能力有关，其在高过程温度的暴露期间抵抗分解和放气。高温处理对高温处理的处理已经影响到有需要更换载体的晶圆的完整性和防止晶圆弯曲。

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the thinned wafer delamine in the form of centimeter sized bubbles; and “flowers” where the thinned wafer exhibits millimeter sized flower shaped defects [2]. Many of these defects occur during high temperature, high vacuum processing indicating that the pressure of the volatile decomposition products is reinforced by the high vacuum. The goal of any measurement of thermal performance should be to indicate the tendency of the adhesive to form these defects.

There are many different ways to measure the thermal stability of a temporary adhesive, but a simple measure uses thermo-gravimetric analysis (TGA). TGA measures the weight loss of a polymer as a function of temperature and time. Decomposition byproducts are gases and vapors that can also be analyzed if desired. TGA data is normally collected while the material is held in an open, inert ambient (nitrogen purged) vessel during analysis. However, this measurement does not directly represent the actual use of the polymer where it is sandwiched between two wafers and not exposed to an ambient.

One benefit of conventional TGA measurement is that the byproducts of decomposition are allowed to escape and reduce the sample mass that can be directly measured. If the byproducts of decomposition were to be captured between two wafers, then the mass would not be reduced while the pressure from these gases remained trapped under the thinned wafer causing delamination and other defects, rendering the test less useful as an indicator. Consequently, there is a strong argument to accept normal TGA data as a useful predictor of adhesive performance when measured under expected process temperatures. TABLE 2 shows the thermal stability of the adhesives. Polyimide, which is used extensively in semiconductor processing and known for its excellent thermal properties, provides a benchmark in performance among the listed adhesives.

<table>
<thead>
<tr>
<th>Reference</th>
<th>220°C for 60 min</th>
<th>250°C for 60 min</th>
<th>300°C Several min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brewer HT10.10</td>
<td>~2%</td>
<td>~6%</td>
<td>3.8%</td>
</tr>
<tr>
<td>3M WSS</td>
<td>1.6%</td>
<td>3.3%</td>
<td>Not tested</td>
</tr>
<tr>
<td>T-MAT</td>
<td>Not tested</td>
<td>0.27%</td>
<td>0.13%</td>
</tr>
<tr>
<td>HD3007 Polyimide</td>
<td>0%</td>
<td>&lt;0.1%</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

A. Brewer Science, Inc. WaferBOND HT10.10

Brewer’s material uses an adhesive cast in solvent which is spin coated and baked much like photoresist. Bonding is done in a vacuum chamber at moderate force (<8kN) and at ~200°C. Debonding is conducted using a thermal-slide process where the wafer stack (carrier, adhesive and thinned wafer) is heated and the thinned wafer is slid off the carrier wafer. The thinned wafer must then be cleaned using a solvent to remove the residue of the adhesive, figure 2.

The defining characteristic of this process is the use of heat and lateral force to debond the thinned wafer, otherwise known as thermal-slide debonding or thermal-slide processing. HT10.10 is one of several materials, including waxes, high temperature polyimide (HD3007) and other thermoplastic polymers that are debonded using a thermal-slide approach. The bond process for this class of adhesives is very simple and because the adhesive is non-tacky after baking, like photoresist, it is easy to process on almost any bonder. The debond process is much more complicated when compared to others. The difficult portion lies in supporting the thinned wafer during the thermal-slide and subsequent solvent cleaning without breaking the wafer.

B. 3M Wafer Support System

3M’s material system uses a room temperature UV curable adhesive coated on the CMOS wafer and joined to a laser absorbing adhesive layer coated on a glass wafer carrier. The laser absorbing material is known as Light To Heat Conversion (LTHC) material. Debonding can occur after the wafer stack is attached to a tape frame with the thinned wafer attached to the tape. A laser then irradiates the stack through the glass side allowing easy removal of the glass carrier. The thinned wafer remains constantly supported by and attached to the tape/frame. The adhesive remaining on the thinned CMOS wafer is removed by a peeling process using detaping tape. 3M’s adhesive does not require cleaning after debonding. The overall process is shown in figure 3.

IV. ADHESIVE SYSTEMS

There are three major adhesive systems used as temporary adhesives for thin wafer handling: Brewer Science Inc.’s WaferBOND® HT10.10 [3], 3M™ Wafer Support System adhesive system [4] and Thin Materials AG adhesive system (T-MAT) [5].

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1 TGA data collected at varying ramp rates ranging from 10°C/min up to 40°C/min. Data provided by respective suppliers.
2 TGA results are estimated from the data provided by Brewer to match the data provided by other suppliers.
3 Brewer Science Inc. also offers other adhesives and is in the process of developing higher thermal stability materials.
The use of laser release allows the selection of an adhesive based on the needs of the process. Higher thermal performance can be achieved while maintaining a low temperature, low stress method to remove the carrier. Key characteristics of the 3M process include room temperature bonding and debonding; high temperature capable adhesive; reliable support of the thinned wafer throughout the entire process; and no need for wafer cleaning after debond.

A remarkable characteristic of the T-MAT process is that the added release layer allows separation of the polymer’s adhesive properties from its thermal and mechanical properties. The release layer also creates a situation where the holding force of the adhesive is very strong in the plane of the wafer but much weaker and adjustable in the direction perpendicular to its surface. These properties allow room temperature debonding, very high temperature capable adhesive and reliable support of the thinned wafer throughout the entire process.

V. MECHANICAL PROPERTIES

Mechanical hardness and strength of the adhesive becomes important during the wafer thinning process and during permanent bonding. It also plays a role in providing strength to hold the thinned wafer flat to the carrier during high temperature processing.

Each adhesive supplier has tuned their adhesive to allow the proper removal rates during the wafer thinning process. The parameters of the grinding equipment used must be adjusted for each adhesive to obtain the desired results. Occasionally, simple grinding experiments may be required to match a customer’s grinding process to the recommendations of the material’s supplier.

Tests were conducted to determine the suitability of the adhesive to withstand a Dow CYCLOTENE™ (BCB) permanent bond process before debonding. The test simulated a 3D integration scheme using wafer to wafer bonding. The test wafer consisted of 3000A Cu posts which were bonded to Cu pads on a 50 µm thick wafer supported by the adhesive on an appropriate carrier. The bond process was 320°C for 30 minutes using SUSS MicroTec’s process of record. Scanning acoustic microscopy was used to check bond quality, and the bond strength was tested by destructive means.

Not all adhesives were capable of withstanding this processing. The 50µm thick wafer behaves like a flexible membrane supported by the adhesive while the Cu posts act like pistons pushing against the thinned wafer. The rigidity of the HT10.10 material drops, as expected, with increasing temperature during the bond process, allowing the membrane-
like thin wafer to bend under the force of the Cu posts. During the cooling process the adhesive regains its strength and hardens in the shape it took on during the bond process. Figures 5a and 5b show the effects observed during the testing. The resulting bond strength was lower, as not all the Cu posts properly bonded, while localized wafer deformation could be measured using a KLA P16 profilometer. This effect was not observed with the other adhesives.

**TABLE 3**

Comparison the overall processes, carrier requirements and mechanical properties of temporary bond adhesives.

<table>
<thead>
<tr>
<th>Brewer HT10.10</th>
<th>3M WSS</th>
<th>T-MAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Material Class</td>
<td>Rosin/rubber</td>
<td>Acrylic/rubber</td>
</tr>
<tr>
<td>Reported Spin Coat Thickness</td>
<td>10 - 40µm +/-</td>
<td>20-200 µm</td>
</tr>
<tr>
<td>Adhesive Solvent</td>
<td>1-dodecene</td>
<td>100% solids</td>
</tr>
<tr>
<td>Carrier Type</td>
<td>Si or glass</td>
<td>Glass only</td>
</tr>
<tr>
<td>Bond Temperature</td>
<td>~180°C+/−</td>
<td>Room temp</td>
</tr>
<tr>
<td>Debond Temperature</td>
<td>150 - 220°C</td>
<td>Room temp</td>
</tr>
<tr>
<td>Thin Wafer Support During Debond</td>
<td>Not directly, use vac. chuck</td>
<td>Tape/frame</td>
</tr>
<tr>
<td>Chemical Resistance</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Mechanical Strength (at upper temperature)</td>
<td>Poor</td>
<td>Good</td>
</tr>
</tbody>
</table>

VI. SUMMARY AND CONCLUSIONS

Each of the studied temporary adhesives has unique properties which should be considered when selecting a material for 3D TSV applications. Adhesives used for 3D TSV will be stressed more and exposed to generally higher process temperatures over longer periods of time compared to adhesives used for MEMS or GaAs applications on smaller wafers. The process flows allow all of the adhesives to be bonded using similar equipment whereas debonding requires a process and equipment tuned to each system.

After thermal performance, the ability to reliably and firmly support the thinned wafer during debonding is one of the most critical issues. The process flow of each adhesive sets the boundaries for how the thinned wafer can be supported. When the desired wafer thickness approaches ≤50µm, process flows that allow the thinned wafer to be continuously supported can produce higher yields through lower wafer breakage (for example, by transferring the thin wafer to a tape/frame or by transferring the wafer via permanent bonding to another wafer.)

The desired properties for temporary adhesives are extremely challenging. An approach to quantify thermal performance of temporary adhesives at high temperatures using TGA data has been presented. The approach appears reasonable as a first order estimate of the complex processes that occur at high temperatures.

With respect to process flows, a thermal-slide process is self limiting in thermal performance. Almost by definition, a thermal-slide process requires the debond temperature to exceed the maximum process temperature. This creates a challenge for 3D integration where high temperatures are needed for dielectric formation and lower temperature solders balls or joints are formed for interconnections. Debonding at the higher temperature would cause the solder to reflow when it is not desired. The use of a laser or mechanical release layer to separate thermal performance from debond temperature can allow for interesting and unique 3D integration schemes.

ACKNOWLEDGMENT

The author would like to acknowledge and thank Mark Previtt of Brewer Science, Inc.; Blake Dronen of 3M Corporation; and Dr. Franz Richter of Thin Materials AG for providing data on their respective materials and processes.
REFERENCES

[3] Brewer Science Inc. product documentation
[4] 3M™ WSS product documentation
[5] Thin Materials AG product documentation