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# Permanent Wafer Bonding and Temporary Wafer Bonding / De-Bonding Technology Using Temperature Resistant Polymers

**Hiroyuki Ishida and Stefan Lutter***

*Bonder Division, SUSS MicroTec KK,*
*1-18-2 Hakusan, Midori-ku, Yokohama, Kanagawa 226-0006, Japan*
** Bonder Division, SUSS MicroTec Lithography GmbH, A SUSS MicroTec AG Company,*
*Ferdinand-von-Steinbeis Ring 10, 75447 Sternenfels, Germany*

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## 1. Introduction

As miniaturization and vertical integration of the devices has been increasingly required, wafer bonding technology has become more attractive and actually become one of the key processes in various applications such as MEMS, 3D-IC's and CMOS image sensors. Especially for fabrication of 3D stacking devices, thin wafer handling, or temporary bonding / de-bonding and also permanent wafer bonding are two of the enabling technologies as well as other processes such as TSV fabrication, wafer thinning, CMP (chemical mechanical polishing), micro-bumping, and backside RDL (re-distribution layer) formation [1-4].

For reliable thin wafer processing, selection of a proper temporary bonding adhesive is essentially important as the adhesive must have sufficient thermal stability, chemical resistance and mechanical strength required for actual production processes [5]. In order to realize reliable 3D interconnections, thermal stability up to 350 °C or higher temperature sometimes required for bonding adhesives [6].

In this paper we provide examples of commercially available polymer materials for permanent wafer bonding and also for temporary bonding / de-bonding processes, especially focusing on those having superior temperature resistance. In terms of temporary bonding materials, those for room temperature de-bonding methods such as mechanical lift-off and laser assisted releasing will be described.

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## 2. Materials for permanent wafer bonding

Among variety of wafer bonding options including anodic, glass frit, metal diffusion, eutectic and direct (or fusion) bonding, permanent wafer bonding with polymers (or adhesives) is a cost effective and flexibly applicable method for wafer level packaging of MEMS, LED, CMOS image sensors as well as 3D integrations. The polymer materials for permanent wafer bonding are generally categorized in either photo patternable or non-photopatternable formulations. In many cases, patterning of the polymer materials can be performed by a simple process of photolithography employing a spin coater / developer and a mask aligner. In addition to this easily-patternable characteristic, the polymer materials have advantages in surface compliant or reflow properties, which can provide superior bonding performance such as bonding strength and hermeticity.

For such applications as MEMS and 3D stacked devices, the polymers with a higher temperature resistance are often required to withstand downstream (or post-bonding) wafer processing including further wafer bonding, film deposition (which is often performed in vacuum environment) or annealing. Two materials are popular for this purpose; i.e. BCB (bisbenzocyclobutene) from Dow® (as the product name of CYCLOTENE™) and polyimide, for instance HD-7010 from HD

MicroSystems. Those materials show excellent thermal stability up to 350 °C or higher temperature, depending on the duration and/or the atmosphere at the process temperature.

In general for wafer bonding applications, the following characteristics are required to polymer materials:

- No (or less) outgas at bonding temperature and atmosphere (most cases in vacuum)
- Sufficient deformation to absorb topography of bonding surface
- Low moisture absorption, and preferably low gas permeability for good hermeticity (or air tightness).

Material properties of some polymers used for permanent wafer bonding applications are summarized in Table 1 [6-9].

Table 1. Typical properties of polymers used for permanent wafer bonding applications. (The data for blank cells was not available in published information.)

| Company | Dow® | HD Microsystems | Dow Corning |
|---|---|---|---|
| Product Name | CYCLOTENE™ 4022-35 | HD-7010 | WL-5150 |
| Material type | BCB | polyimide | silicone |
| Photosensitive Type | negative | negative | negative |
| Viscosity (Pa·s) | 192 | 27-33 | |
| Cured Thickness (µm) | 2.5-5.0 | 8-15 | |
| Glass Transition Temperature (°C) | > 350 | 260 | |
| CTE ($10^{-6}$/K) | 42 | 74 | 236 |
| Dielectric Constant | 2.65 | 3.3 | 3.2 |
| Modulus (Gpa) | 2.9 | 2.6 | 0.16 |
| Tensile Strength (MPa) | 87 | 173 | 6.0 |
| Elongation (%) | 8 | 70 | 37.6 |
| Moisture Absorption (%) | < 0.2 | | 0.24 |
| Cure Temperature Range (°C) | 250-300 | 250-400 | 150-250 |
| Bonding Temperature Range (°C) | 250-350 | 250-350 | |

## 3. Materials for temporary bonding and de-bonding

As the device layer is getting thinner down to 50 µm or less, thin wafer handling, or temporary bonding and de-bonding, has become one of the key technologies of 3D-IC manufacturing. There are several factors to be considered to select a proper process, or more specifically adhesive and release layer materials, carrier wafers, and bonding / de-bonding methods, depending on the requirements for each application.

Fig. 1 shows a general process flow for temporary bonding and room temperature de-bonding (mechanical lift-off or laser assisted de-bonding).

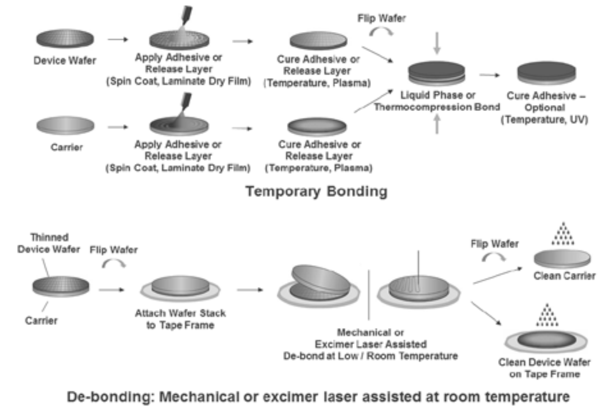


Fig. 1. General process flow for temporary bonding and room temperature de-bonding.

The following characteristics are required for temporary bonding systems in order to be employed for actual productions:

- Material survivability
- TTV (total thickness variation) after silicon wafer thinning
- Bonding and de-bonding yield
- Low CoO (cost of ownership)

In terms of material survivability, the following three properties are required: (1) vacuum process compatibility, e.g. no outgassing in PECVD (plasma enhanced chemical vapor deposition) processes, (2) temperature stability at e250 °C and (3) chemical compatibility, e.g. in photo lithography, CMP (chemical mechanical polishing), recess etching.

In order to improve bonding and de-bonding yield, the following requirements are demanded for processes: (1) void-free and low stress bonding, (2) easy to de-bond at low or more preferably at room temperature, and (3) easy to clean after de-bonding.

There are various types of adhesives available for temporary bonding today and more to appear in the near future [10-12]. In terms of bonding process, adhesive materials can be classified into three categories, i.e. thermoplastic, thermoset and UV hardening. Thermoplastic adhesives use heat and pressure to be bonded. What differentiates those materials from other adhesives is their ability to flow or deform by applying more heat or pressure. Thermoset adhesives, on the other

hand, can be bonded on the same bonding equipment as thermoplastic ones, but once the material is hardened it cannot be reworked since the crosslinking or reactive groups have been activated. UV hardening adhesives are similar to thermoset materials in the sense that it cannot be reversed once light-induced polymerization has occurred.

It is required to sort out which adhesive meets requirements for the relevant applications, such as thermal stability, chemical resistance, vacuum stability, bonding process cycle-time, de-bonding throughput, and cleaning method.

Together with the selection of adhesive material, the bonding process needs to be optimized as well. In order to minimize or eliminate void formation at the bond interface during bonding, it is best to perform bonding in a vacuum atmosphere. Another benefit to bond in a vacuum is that it also helps remove any volatile solvents remaining in the adhesive films that could outgas and cause delamination in downstream processing.

Bonding force should also be optimized depending on the state of the adhesive, i.e. liquid, gel or solid. Solid or B-staged adhesives usually require a relatively high force to achieve good bond properties; while liquid ones often need very low force. Another critical factor which should be carefully controlled is CTE (coefficient of thermal expansion) mismatch of the constituents. Though bonding is usually performed at a predetermined steady state temperature and the bonded stack should be cooled down near to room temperature, the bonded pair might sometimes be unloaded from the bond chamber at a higher temperature for throughput reasons. Due to the differences in CTE of the constituents such as adhesive, device wafer and carrier wafer, that could induce stress to the bonded stack while it is cooled down. As a consequence, these stresses can cause undesirable bow, warp and increased TTV.

Table 2 summarizes some of the temporary bonding adhesives currently available in the market.

The de-bonding method, as well as bonding, is also largely influenced by the adhesives. De-bonding methods can be categorized into four types, i.e. thermal slide-off, chemical dissolution, laser assisted, and mechanical lift-off. As the requirement for preventing any damages on the surface structure of device wafers, room temperature and low stress de-bonding is preferable, and mechanical or laser assisted de-bonding has increasingly become attractive for this reason. Fig. 2 shows schematics of these two room temperature de-bonding methods, i.e. mechanical lift-off and excimer laser assisted de-bonding. In excimer laser assisted de-bonding (actually utilizing laser ablation process), 308 nm of XeCl or 248 nm of KrF is usually employed for de-bonding polyimide based materials such as HD-3007.

Table 2. Commercially available temporary bonding adhesives. (The data for blank cells was not available in published information.)

| Company | Thin Materials | Brewer Science | HD Microsystems |
|---|---|---|---|
| Product Name | | ZoneBOND® 5150-30 | HD-3007 |
| Material type | silicone | | polyimide |
| Carrier type | Si or glass | Si or glass | glass |
| Bonding temperature (°C) | ~180 (for curing) | ~200 | ~350 |
| De-bonding method | mechanical lift-off | mechanical lift-off | excimer laser assited |
| Thermal stability (°C) | ~250 | ~250 | >350 |

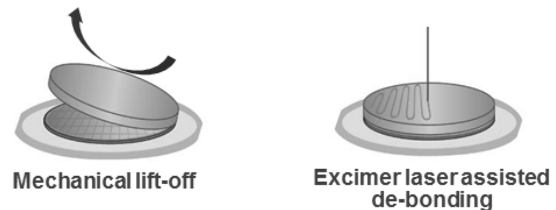


Fig. 2. Room temperature de-bonding options: Mechanical de-bonding and excimer laser assisted de-bonding.

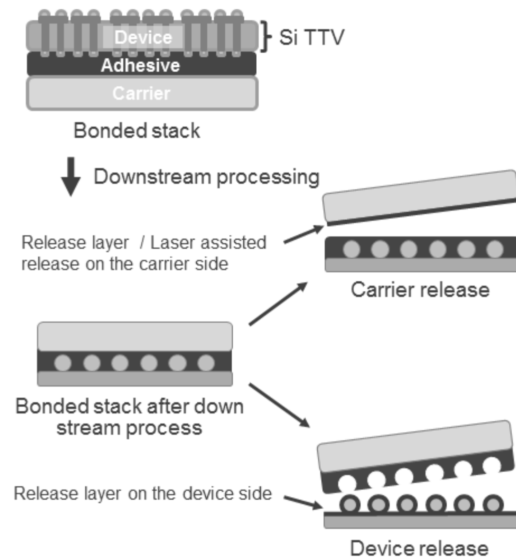


Fig. 3. Two de-bonding options: carrier release and device release.

There can be two kinds of de-bonding options in the aspect of the releasing interface as shown in Fig. 3, one is carrier release and the other is device wafer release. Thermoplastic adhesives are used in most cases for carrier release because the materials can easily be cleaned by solvent. On the other hand, device wafer release is usually selected for thermoset adhesives, which is difficult to remove by solvent.

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