[Technical Paper]

UV Laser Releasable Temporary Bonding Materials for FO-WLP

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Abstract

Temporary bonding/de-bonding (TBDB) technology in a FOWLP process is required to adapt to a low temperature process because of the potential for damage in handling the thin molded compound embedding dies. We have developed laser releasable TBDB materials for low temperature bonding processes that enable UV laser release with high throughput and low thermal/mechanical stress. The developed TBDB materials consist of two layers, an adhesive layer and a release layer. The appropriate wafer bonding temperature can be controlled by the molecular weight of the polymer which is the main component of the adhesive material. Good bonding property has been seen, even at 160°C by adopting the lowest molecular weight polymer. On the other hand, the release layer material exhibits excellent stability that allows for fabrication of RDLs directly onto the layer to give a stacked structure in the Chip-last (RDL-first) method. The laser energies preferred for wafer release processes are 130 mJ/cm² for a 308 nm excimer laser and 190 mJ/cm² for a 355 nm YAG. These materials will be promising for advancements of FO-WLP applications.

Keywords: Temporary Bonding, Laser de-bonding, FO-WLP, 3D Packaging, Laser Ablation

1. Introduction

In recent years, novel electronic products have become dramatically smaller and more highly functionalized. At the same time, the amount of information to be processed through semiconductor devices has increased at an accelerated pace. In order to handle huge amounts of data at high speed, small size and with low energy consumption, advanced electronic packages such as Fan-Out Wafer Level Package (FO-WLP), 2.5D interposer and 3D-TSV have been developed.

FO-WLP allows for enhanced I/O interconnections by extending the package size, through the re-distribution layer (RDL), beyond the area of the chip relative to conventional Fan-In Wafer Level Package (FI-WLP) which has a limited I/O count. Moreover, FO-WLP has the advantage of extensibility for mounting of multiple chips on a package for high performance as in functional integration process of Fan-Out System-in Package (FO-SiP). To fabricate these highly integrated devices, temporary bonding/de-bonding (TBDB) technology is necessary.

The representative FO-WLP process includes build-up RDL, epoxy molding compound (EMC), and dies on the carrier wafer (Fig. 1). Thus, it is sometimes necessary to

Fig. 1 TBDB material in FO-WLP process.

limit the process temperature to less than 200°C to prevent warpage, outgassing of the EMC wafer or solder damage. Therefore, TBDB materials must adapt to low temperature processes. Also, the TBDB materials must remain stable in the process conditions through lithography, electroplating in the RDL and mold fabrication.[1–7]

In this paper, laser releasable TBDB materials adaptable to a low temperature bonding process, and the release material with high durability through the FO-WLP process, is described.

Table 1 Comparison of laser wavelength.

Item	Laser wavelength			
	308 nm	355 nm	532 nm	1,064 nm
Mechanism	Photonic cleavage	Photonic cleavage	Thermal or Photonic	Thermal degradation
Thermal effect	Low damage	Low damage	Intermediate	High thermal damage
Equipment cost	Intermediate (excimer)	Low (solid state)	Low (solid state)	Low (solid state)

2. Technical Approach

2.1 Laser release technology

As of today, four kinds of TBDB systems received the most attention: thermal slide, mechanical release, solvent release and laser release. The laser release system has an advantage because of its low de-bonding temperature, low mechanical stress, and high throughput characteristics. [8–11] In addition, the broad process window of the laser release system is better for the FO-WLP application compared with the other conventional de-bonding systems.

The representative laser release wavelength and its features are shown in Table 1. The differences are addressed in terms of the laser-induced ablation reaction mechanism, thermal effect and de-bonding equipment cost. In this study, we focused on UV laser release systems with 308 nm and 355 nm in wavelengths because they satisfy the trend to decrease operation temperature to minimize the potential for thermal damage to a package. [12–14]

2.2 Concept of TBDB material for laser release system

Two kinds of representative FO-WLP fabrication processes are shown in Fig. 1. One is the chip-first approach which includes die placement, molding and solder ball attachment. The other is the chip-last approach. In this scheme, RDLs are built-up onto the TBDB material directly. A lower process temperature is preferred to prevent wafer warpage, outgassing from EMC, and solder damage. Moreover, durability against various chemicals such as solvents and etchants are required. After the die embedded wafer is fabricated by these procedures, further processing to the opposite side of the device can be with by a second TBDB process.

The TBDB materials we have developed consist of an adhesive layer and a release layer as shown Fig. 2. The adhesive layer, which provides high adhesion, is located on the device wafer side, and the release layer is located between the adhesive layer and glass carrier wafer. The

Fig. 2 Layout example of TBDB materials.

adhesive material is designed based on aromatic polymers which have hydroxyl groups that provide enough adhesion strength between the bonded wafer pair and allow easy removal during a wet cleaning process after laser releasing. We investigated polymer structures to satisfy low temperature bonding. On the other hand, the release material is also designed based on a thermosetting aromatic main polymer which incorporates functional groups that show high ultraviolet absorption for the cleavage of molecules in a photo-chemical manner.

3. Experimental Section

3.1 Properties of adhesive materials

Glass transition temperature (T_g) of the adhesive materials were measured by a Thermo-Mechanical Analyzer (TMA). Mechanical properties (tensile strength, elongation, and elastic modulus) were evaluated with a 20 μm thick specimen by a Shimadzu tensile testing machine AGS-500NX. Thermal stability of the materials was evaluated with the temperature of 1% weight loss determined by thermogravimetric analysis (TGA). Shear viscosity of adhesive materials were measured by Rheometer AR-G2 (TA Instruments) with specimens which were molded to 1.0 mm thick after solvent removal.

3.2 Wafer bonding

Wafer bonding was conducted by a thermo-compressive procedure under vacuum. First, a 500 nm thick release

Table 2 Film properties of adhesive material.

Item	Adhesive material		
	Adhesive-A1	Adhesive-A2	Adhesive-A3
Molecular weight of main polymer (relative ratio) ^a	1.00	0.82	0.43
Glass transition temperature	90°C	90°C	89°C
Tensile strength	56 MPa	50 MPa	52 MPa
Elongation	150%	100%	50%
Elastic modulus	1.1 GPa	1.1 GPa	1.2 GPa
Thermal decomposition temperature	>350°C	>350°C	>350°C

a. By Gel permeation chromatography (GPC)

material was spin coated onto a 200 mm glass carrier wafer. An adhesive material was then coated on top of the release material layer with a thickness of 50 μm ~80 μm and baked at 110°C for 5 minutes, followed by 200°C for 10 minutes on a hot plate. Next, a 200 mm EMC wafer and the glass carrier wafer coated with TBDB materials were bonded at various target temperatures under vacuum by wafer bonder EVG 520 (EV Group). The bonding force was 0.2 MPa. After bonding, the bonded pair was inspected for any voids or delamination. Also, a 200 or 300 mm bonded pair of glass carrier wafer and silicon wafer was prepared by the same procedure to provide for thermal stress test of adhesive.

3.3 Laser release test

Laser release was performed on the above mentioned 200 mm bonded pairs consisting of a glass support wafer coated with TBDB materials and an EMC wafer. Two UV laser sources were applied to the release. One was a third harmonic wave of Nd-doped YAG, which emits a 355 nm light with 50 kHz oscillation frequency, 200 μm irradiation spot diameter. The other was a XeCl excimer laser operated at 308 nm irradiation with 50 Hz oscillation frequency, 12.5 $\times$ 4 mm rectangular beam by ELD300 debond module (SUSS Microtec). The wafer release was carried out by laser irradiation by scanning across the entire 300 mm wafers. The irradiation pitch can be appropriately adjusted to not produce any un-irradiated areas.

4. Results and Discussion

4.1 Film properties of adhesive layer

Shear viscosity of the adhesive material is an important factor for bonding. We checked the shear viscosity and mechanical properties of the adhesive materials with different molecular weights of the polymers (Table 2). Figure 3 shows the shear viscosity of the adhesive materials at

Fig. 3 Shear viscosity curve of adhesive materials.

different temperatures. The viscosity was easily controlled by changing the molecular weight of the main polymer contained in the adhesive material. In this study, we investigated three materials with different shear viscosities; 2,600 Pa·s, 910 Pa·s, and 110 Pa·s at 200°C for Adhesive-A1, Adhesive-A2, and Adhesive-A3 respectively.

Table 2 shows the film properties of the adhesive materials. The mechanical properties of Adhesive-A1 and Adhesive-A2 were almost the same except for a slight difference in elongation. Both materials showed good thermal stability. Adhesive-A3 also showed substantially the same glass transition temperature to Adhesive-A1 and A2 despite its lower molecular weight. The mechanical strength of Adhesive-A3 is lower than the others, but it will be enough for holding a bonded pair during processes. Thereby, it is expected to be acceptable as a low temperature bonding material for the TBDB process.

4.2 Wafer bonding results

Thermo-compressive bonding of the EMC wafer onto a TBDB coated glass carrier was conducted and the results are summarized in Fig. 4 and Table 3. Adhesive-A1 yielded good bonded pairs without remarkable voids or defects at 220°C or higher. On the other hand, some voids could be seen after bonding at 200°C. In the case of Adhesive-A2,

Fig. 4 Bonding procedure.

Table 3 Bonding test results.

Bonding result ^{b, c}	Bonding temperature [°C]					
	140	160	180	200	220	240
Adhesive-A1	<div><div></div></div>	Error				<div><div></div></div>
Adhesive-A2	<div><div></div></div>		Pass			
Adhesive-A3	<div><div></div></div>	Pass				

b. Red arrow: Error (void or delamination exist)

c. Blue arrow: Pass (no void and no delamination)

Table 4 Bonded pairs of EMC and glass carrier wafer with Adhesive-A3.

Bonding temperature	140°C	160°C
Observations
	minor void No delamination	No void No delamination
Bonding temperature	180°C	200°C
Observations
	No void No delamination	No void No delamination

the threshold for the bonding temperature shifted to 180°C. Furthermore, Adhesive-A3 yielded good bonded pairs at 160°C (Table 4). From these results, reducing molecular weight of the polymer is one of the effective way to get good bonding pair of wafers. The threshold for shear viscosity to obtain good bonding pairs between EMC and the glass carrier wafer should be roughly equal or less than 1,000 Pa·s.

We also conducted thermal stress test of a bonded pair consist of a silicon wafer and a glass carrier wafer bonded with Adhesive-A3. Adhesive-A3 yielded good bonded pairs

without voids, delamination or wafer shift after the thermal stress test at 200°C and 220°C assumed to curing of insulator (Table 5). Our materials are promising candidates for low temperature bonding for FO-WLP applications.

4.3 Material performance for release layer

To achieve excellent UV laser release performance, the laser ablation reaction needs to be induced within a thin film thickness to prevent too much thermal diffusion. The release layer material must also absorb enough UV light. Moreover, the material must exhibit good stability that allows for fabrication of the RDL directly onto the TBDB

Table 5 Thermal stress test results of bond pairs of 200 mm silicon wafer and glass carrier bonded with Adhesive-A3.

	After bonding	After thermal test	
		200°C/1 hr	220°C/1 hr
Observations
	No void No delamination	No void No delamination No wafer shift	No void No delamination No wafer shift

Fig. 5 Transmittance data of release material at 308 nm and 355 nm wavelengths.

layer to create a stacked structure in the Chip-last (RDL-first) method.

To get high laser absorption with a thin film thickness, we designed a thermoset polymer with chromophore units in the molecule. Figure 5 shows transmittance data of the release layer material we developed with different film thicknesses. The transmittances of both materials at 308 nm and 355 nm wavelengths are quite low. Specifically, 308 nm light was absorbed more effectively showing <1% transmittance at 500 nm film thickness.

Chemical resistance of the release material was investigated. The release material films coated and cured on glass wafers were dipped into various process solvents such as organic solvents, photo-resist stripper, acid and alkaline. Thus, the process solvents came into direct contact with the release material. The films were then rinsed with DI water and dried. Changes in the film thickness caused by swelling or dissolution were determined by calculation of the film thickness ratio before and after the procedure. Cracking, swelling, wrinkling and discoloration were also checked visually. The results are summarized in Table 6. The release material exhibited excellent chemical

Table 6 Chemical stability of release material.

Chemicals	Condition	Result ^d
Acetone	25°C/10 min	Pass
PGME	25°C/10 min	Pass
PGMEA	25°C/10 min	Pass
IPA	25°C/10 min	Pass
PR stripper	60°C/30 min	Pass
Hydrogen peroxide aq. (30%)	50°C/10 min	Pass
Sulfuric acid aq. (10%)	25°C/30 min	Pass
TMAH aq. (2.38%)	25°C/10 min	Pass

d. Pass: film thickness change is within $\pm 10\%$ and no appearance change

resistance against the various process chemicals.

Laser releasing performance was examined by using a bonded pair consisting of a glass carrier wafer coated with release material and a bare silicon wafer coated with adhesive material (Adhesive-A1). As a UV laser source, 355 nm light by YAG solid state laser and 308 nm by XeCl excimer laser were used. Optical micrographs of the glass and silicon surface after laser irradiation are summarized in Table 7. Laser marks observed in these micrographs are the areas where the release layer color was changed due to degradation caused by laser irradiation. The material decomposed at less than 200 mJ/cm^2 using both laser light sources and the bonded pair was successfully released. The processing time to release the bonded pair was 60 seconds for 308 nm laser system and within 90 seconds for 355 nm system. Therefore, high throughput releasing can be expected due to its high sensitivity to inducing the ablation reaction.

The release performance is thought to depend to a large extent on the properties of release layer. EMC bonded to glass with Adhesive-A1 and release layer material was also

Table 7 Laser release result of 300 mm bonded pairs of silicon and glass carrier.

Laser wavelength	Irradiated condition	Laser release	Optical micrograph through the glass carrier
308 nm	130 mJ/cm ²	OK
355 nm	190 mJ/cm ²	OK

released successfully by irradiation of 355 nm UV laser in the same manner.

The residues of TBDB materials after laser releasing should be easily cleaned from both de-bonded surfaces. In our material design, the residue on the device wafer side composed of silicon and EMC is removed by wet chemicals, while on the glass support wafer side, it is removed by plasma cleaning. The both bonded surface of silicon and EMC after laser releasing were cleaned by wet chemical and the residues were confirmed to be removed completely.

5. Summary and Conclusion

Regarding adhesive layer materials, bonding properties can be controlled by changing the molecular weight of the polymer. In this study, Adhesive-A3 yielded good bonded pairs of EMC and a glass carrier at 160°C. On the other hand, the release layer material was designed to have very high absorption of UV laser light, specifically 308 nm or 355 nm in wavelength. As a result, the release layer material contributes to reducing the laser irradiation energy, reducing device damage, and shortening release process time. The bonded pair with the release material was released at less than 200 mJ/cm². Also cleaning of the temporary bonding materials both on silicon and EMC were cleaned completely by wet chemicals. Furthermore, it exhibited good stability for fabrication of RDLs directly onto the layer to give a stacked structure in the Chip-last (RDL-first) method. These results show sufficient compatibility to the TBDB process in FO-WLP technology.

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