ADVANCED MULTIFUNCTIONAL TEMPORARY BONDING MATERIALS WITH HETEROGENEOUS INTEGRATED PROPERTIES FOR VARIOUS ADVANCED PACKAGING APPLICATIONS

Xiao Liu, Dongshun Bai, Lisa Kirchner, Rama Puligadda, and Tony Flaim*
Brewer Science, Inc., 2401 Brewer Drive, Rolla, MO 65401, USA
*Corresponding Author's Email: xliu@brewerscience.com

ABSTRACT

There is always an increasing demand for new materials with unique properties as technical enablers to facilitate different semiconducting advanced packaging platforms. This long-lasting demand is more urgent than ever due to the era of a slowing Moore's Law, which indicates advanced packaging will play a key role in achieving smaller factor, higher I/O density, better electrical performance, and lower cost of ownership in final devices in the future semiconductor development. A tremendous amount of effort has been carried out on development of various platforms in advanced packaging, such as flip chip, fan-in wafer-level packaging, fan-out wafer-level packaging, embedded die, and through-silicon vias. Therefore, with the addition of newly emerging advanced packaging platforms comes increased needs for new materials that can implement these technologies.

In this work, a class of advanced multifunctional temporary bonding materials with heterogeneous integrated properties is presented. The concept is based on the combination of various unique properties such as low softening temperature, curability by either heat or UV light, and laser sensitivity in a single-component material. As a result, the newly developed materials can be bonded or laminated at relatively low temperature followed by hardening under heat or UV light for desired mechanical/thermal stability to ensure the success in downstream processes. In the end, a laser debond can be conducted to facilitate wafer/substrate detachment. The materials have been extensively characterized with various characterization methods. In addition, the preliminary data will be presented to demonstrate their potential as technical enablers in diversified advanced packaging platforms, such as in integrated fan-out (InFO) and redistribution layer (RDL)-first fan-out (FO).

INTRODUCTION

The advanced packaging technologies are currently undergoing an era of revolution because of a slowing Moore's Law and demand for heterogeneous packaging. [1,2] All efforts and technologies focus on achieving smaller factor, higher I/O density, better electrical performance, and lower cost of ownership in final devices in the future semiconductor development. [3,4] For better response to these demands, several innovative integration approaches have emerged, such as 3D-IC chip stacking, package-on-package (PoP), 2.5-D interposer integration, system-in-package (SiP), and fan-out packaging technologies. [5] In order to better enable and facilitate these emerging advanced packaging platforms, a new class of multifunctional materials is proposed and presented in this work.

MATERIAL CHARACTERIZATION

The concept of a multifunctional material is based on the combination of various functionalities in a single material that will enable and simplify the processing in different applications.

High thermal stability is one of the critical requirements for various advanced packaging applications. Table 1 shows the summary of properties of Material A as an example of a multifunctional material. Material A exhibits very good thermal stability with 357 ℃ for 2% weight loss in nitrogen from TGA. Also, the TGA isothermal test indicates minimal weight loss (0.43%) at 250 ℃ for 1 hour in nitrogen condition. In addition, the low T_g (below 100 ℃) makes it possible to process this material at much lower temperatures for processes such as temporary bonding/debonding (TB/DB), substrate lamination, pattern imprinting, and die placement. For example, Material A has the melt viscosity of 3296 Pa·s at 100 ℃ as shown in Figure 1, which indicates that a good bond line can be obtained at this temperature during the wafer bonding process. This temperature is much lower than other commonly used thermoplastic bonding materials. Furthermore, Material A can be cured unsing 365-nm UV irradiation. Figure 2 illustrates the UV curing process of Material A, with data showing complete curing within 15 minutes of continuous irradiation. This property will be very beneficial for permanent bonding applications as well as in TB/DB, especially for high-temperature applications where cured Material A will not reflow and can survive high-temperature processing conditions.

Table 1. Property summary of Material A

	$T_{d\ 2\%,N2}$ (°C)	**Weight loss at 250°C, 1hr in N_2**	**T_g (°C)**	**Viscosity at 100°C (Pa·s)**
Material A	357	0.43%	80.3	3296

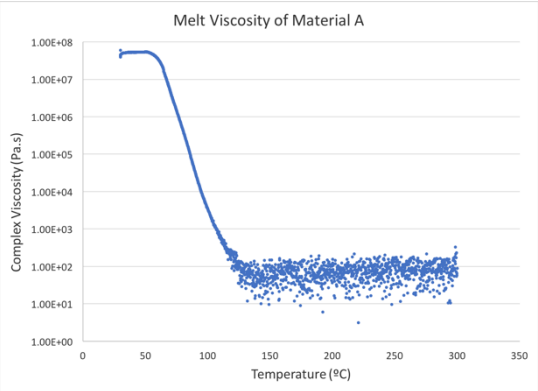

Figure 1: Melt viscosity of Material A.

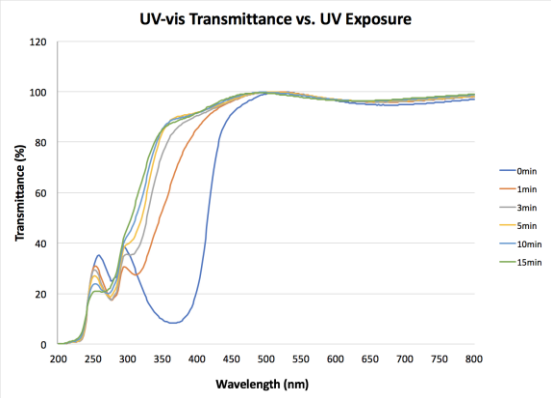

Figure 2: UV-vis transmittance of Material A vs. UV curing time.

LASER DEBONDING PERFORMANCE

A good response to laser is another critical property for wide applications in advanced packaging such as laser drilling, laser patterning, and laser debonding. The laser performance of Material A was tested on a bonded wafer pair.

The wafer bonding process flow was demonstrated in Figure 3. Due to its low T_g and good material reflow, a good bond line was obtained with a bonding temperature between 100 ℃ and 150 ℃ without obvious defects or voids. The wafer pair was subjected to UV curing at 365 nm for 10 minutes to solidify the Material A, followed by grinding of device wafer down to the target thickness of 50 µm. The photo image and thinned device FRT scan were shown in Figure 4. The data demonstrated good survivability during device wafer thinning using Material A for the target thickness without any detectable defects.

The thinned wafer was debonded using 308-nm excimer UV laser. One of the criteria to indicate good laser debonding performance of material is the k value. In general, the higher k value is, the lower energy required by the material to debond, because the high-k material needs less thickness to absorb sufficient laser energy for either photo-decomposition or thermal decomposition to ensure successful debonding. Table 2 provides the summary of k values of Material A before and after curing at different UV wavelengths. It clearly indicates that the UV curing process can significantly quench the UV absorbance of Material A at the wavelengths in the mid-UV range. This is because of the chemical structure change of a functional group in Material A. The two duplicate thinned wafer pairs can be successfully debonded using a 308-nm excimer laser debonder. The thinning and laser debonding results were summarized in Table 3.

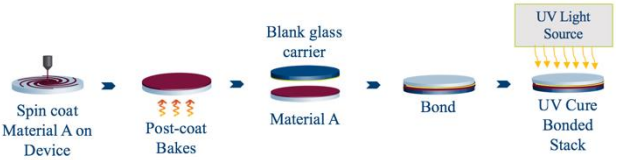

Figure 3: Process flow of wafer bonding.

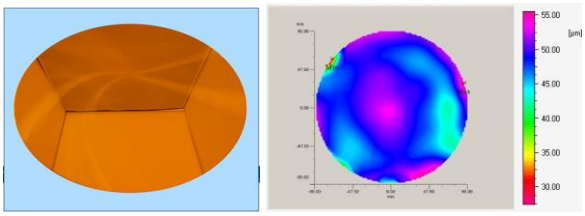

Figure 4: Photo image and thinned wafer scan by FRT

Table 2. k value of Material A

Laser wavelength	308 nm	343 nm	355 nm
Before curing	0.087	0.18	0.21
After curing	0.059	0.022	0.018

Table 3. Wafer thinning and laser debonding results.

Material A, Wafer Pair No.	Material thickness (µm)	Device thickness (µm)	Debond dose (mJ/cm^2)
Wafer Pair 1	34.2	49.2	360
Wafer Pair 2	34.6	50.2	390

EMBOSSING STUDY

Another unique property of Material A is its ability to integrate into an embossing process. This involves more than the perceived simple transfer of patterns from a stamp substrate in an imprinting step. For successful embossing, the material must maintain integrity during the imprinting process, be capable of transferring small features, even submicron size, be solidified by UV or heat, and cooperate with other processes.

The process flow of an embossing process is illustrated in Figure 5. First, the desired patterns were formed on the template material, followed by pattern transfer to form a stamp substrate. Later, the stamp was used for final pattern imprinting on target Material A.

Figures 6, 7, and 8 show the characterization of the patterns during different stages during process flow. In Figure 6, the data verified good pattern formation on the template material by a laser ablation technique. Well-defined line/space and via structures were generated with 10-µm depth. In the next step, the patterns were able to transfer to stamp with a mirror image as shown in Figure 7. Finally, the patterns were successfully transferred to Material A as in Figure 8. During transfer process, no obvious defect was observed for large features (≥ 10 µm). However, the features smaller than 10 µm showed some difficulty with successful transfer. One of the major reasons for the difficulty is that the material sticks to the stamp in the small features during transfer. Therefore, process optimization is needed in order to achieve a good pattern transfer with small features in future work.

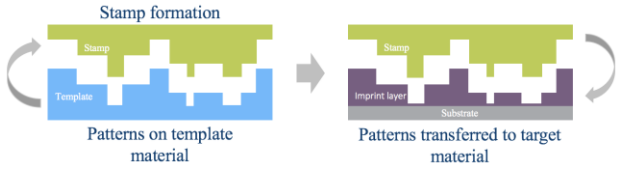

Figure 5: Process flow of embossing

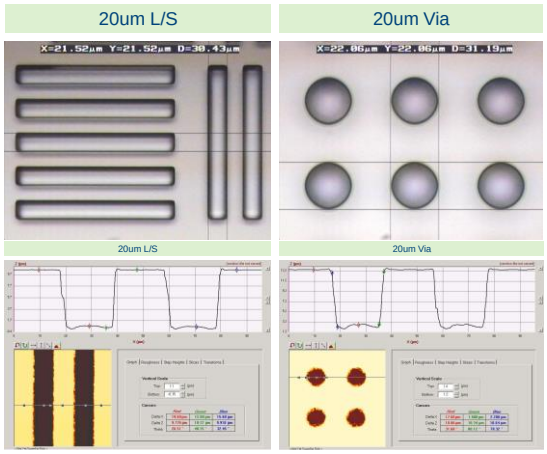

Figure 6: L/S and via characterization.

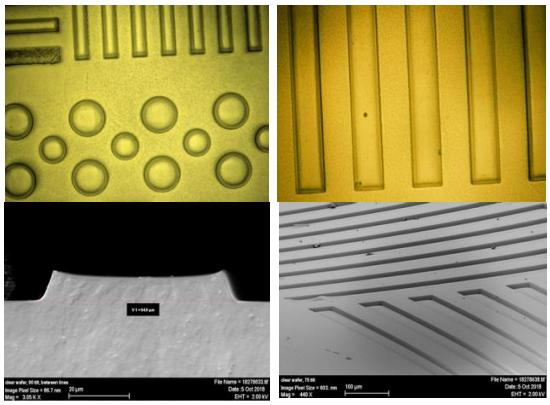

Figure 7: Optical and SEM images of patterns on stamp.

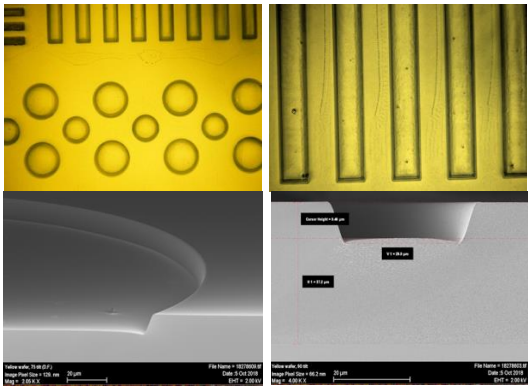

Figure 8: Optical and SEM images of patterns imprinted on Material A.

CONCLUSION

Material A is a class of advanced multifunctional temporary bonding materials with heterogeneous integrated properties that was introduced in this work. This material showed various unique properties such as low softening temperature, curability by UV irradiation, and laser-responsive in a single-component material. The good laser response as a bonding and laser release layer was successfully demonstrated. In addition, the capability of Material A in an embossing process was presented as well. The study showed that a line/space and via with a feature size of 10 µm or higher can be well transferred to Material A from template material. Future study on smaller feature size transfer is currently ongoing and will be presented in the future work.

ACKNOWLEDGEMENTS

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