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Laser releasable temporary bonding film with high thermal stability

Yong-suk Yang, Kyo-sung Hwang, Robin Gorrell *

3M Korea, 7, Samsung 1-ro 5-gil, Hwaseong-si, Gyeonggi-do, Korea.
**3M Corporation, 6801 River Place Blvd., Austin, TX 78726-9000, United States.*

Abstract

A temporary bonding film using a unique, laser releasable pressure sensitive adhesive construction has been formulated to advance wafer level fan-out process technology development. The film format and excellent thermal and dimensional stability of the temporary bonding film are particularly well suited to address the developing needs of panel level fan-out processes. The development of wafer level packaging process technology provides many benefits, including increased density and performance, greater design flexibility, simplification of the supply chain and process, and improved yield and overall cost of the semiconductor package. Specifically, in the case of fan-out, technology advances allowing wafer thinning to as little as 30 microns, backside patterning, and handling of the wafer or panel during copper RDL processing have become possible.

The thinning and handling processes on the molded wafer or panel are accompanied by large thermal, physical and chemical stresses. These external stimuli, which are difficult to overcome with non-rigid semiconductor materials such as poly-silicone or organic encapsulants, can significantly reduce the yield of these processes. The most effective approach to protecting the semiconductor package substrate from these process stresses is the use of a support carrier. The combination of a rigid carrier and a semiconductor device reduces or eliminates physical stresses in the process and can control the warping and expansion or contraction of the substrate during thermal exposures. Various carrier materials can be used, including thick silicon wafers, glass, ceramics, metals and others, with the choice of carrier dependent on a multitude of factors such as suitability for the carrier release process to be used, carrier coefficient of thermal expansion (CTE), reusability, and cost.

3M's laser releasable temporary bonding film supports bonding between semiconductor device and carrier with excellent adhesion. The benefits of process simplicity and the high level of material heat tolerance achieved with the 3M technology are well aligned with the current direction of packaging technology, with the film format allowing for processing of either wafers or large panels. 3M's laser releasable temporary bonding film employs a glass carrier. Laser scanning through the glass carrier enables separation of the carrier without physical stress, allowing thin materials to be easily removed from the carrier without physical damage. The heat resistance of the 3M temporary bonding film of up to 250°C for an extended period allows precise passivation layer curing and sputtering processes. With the 3M temporary bonding film, process designers will be able to implement package production processes with a wide process margin and exceptional quality.

Key Words: Fan-out WLP, Temporary bonding de-bonding film, RDL-first, RDL-last, Laser releasable film

I. Wafer level packaging and fan-out WLP

Wafer level packaging technologies are being widely adopted in the semiconductor packaging industry based on a variety of benefits, such as enabling smaller package form factors, improved thermal and electrical performance, lower power consumption and lower manufacturing cost. Wafer level packaging technologies have led the market beyond existing packaging technologies such as flip chip ball grid array (BGA) and quad-flat-no leads (QFN) in terms of performance and cost [1]-[2]. The fan-out process has also brought semiconductor micro-patterning technology into the realm of packaging. Redistribution layers (RDL), implemented with micro-patterning technology and the wafer reconstitution/molding process can provide smaller chips and more I/O, greatly contributing to maximizing the performance of the package and reducing the production cost. In the fan-out process, printed circuit board (PCB) interposers are no longer needed. The fan-out process can be divided into RDL-first and RDL-last when considering the RDL build-up process. In the case of an RDL-first process, where the redistribution layers are formed first, and then combined with device chips, the RDL quality does not affect chip loss. This is due the ability to inspect or test the RDL and not populate non-yielding sites. However, the RDL-first process itself is more complicated, requiring a high level of adhesive surface uniformity to achieve good RDL quality [1]-[3].

On the other hand, RDL-last is a process of directly building RDL on a redistribution wafer prepared by picking and placing singulated chips on a temporary carrier that is overmolded with specially formulated, low CTE epoxy molding compound. Cleaning of the adhesive residue after de-bonding is easy and the process itself is simpler than the RDL-first process. However, as shown in Figure 1 below, serious warpage of the mold wafer can occur during curing of the passivation layers, and is one of the biggest difficulties of the current RDL-last process [3].

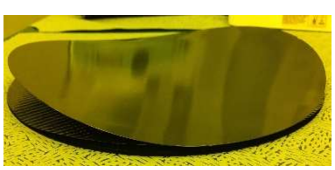


Figure 1, Delamination between a carrier and a device due to severe device warpage during high temperature processing. If the gripping force of the temporary bonding film is insufficient, severe device warpage occurs during the high temperature process.

II. 3M Laser Releasable Temporary Bonding Film

The target format for fan-out technology is transitioning from wafer to panel, particularly at outourced assembly and test facilities (OSATs) that may not have existing wafer processing infrastructure, and where the cost advantage of large panel formats up to 600 x 600 mm is significant when compared to 200 or 300 mm diameter wafers. However, in general, spin-coatable materials that have heretofore been the mainstay of temporary bonding/de-bonding are difficult to apply in panel applications. On the other hand, an adhesive in film format is free from these limitations. Unlike liquid spin-coatable materials, where the bonding material and release material must be applied to the substrate and carrier through a separate process, film-based materials can be easily applied in a simple roll lamination process.

3M has developed a family of glass-carrier based, laser detachable temporary bonding/de-bonding solutions for the fan-out process (RDL-first process and RDL-last process).

Laser releasable temporary bonding film (a multi-layered product described in the next section) provides exceptional panel/wafer grip performance for the RDL-last process. Strong bending that occurs in thick mold wafers can be effectively controlled even at high temperatures over 200 °C. In addition, passivation curing processes requiring up to 230 °C for as long as 4 hours can be carried out. Support for high temperature processing for up to 10 hours is possible if ramp up and ramp down are included.

Laser releasable temporary bonding film (a single layered product) is a laser releasable adhesive film that can be de-bonded with low stress. The laser releasable film supports the RDL-first process with excellent thermal stability and surface roughness uniformity. Pre-aging of the film at 150 ˚C for 30 minutes can increase the adhesion and physicochemical stiffness of the film to the carrier. The maximum thermal stability of the laser releasable layer after thermal aging is up to 300 ˚C. The RDL layer is directly built-up on the adhesive through the metal deposition and patterning processes and the passivation curing process. After the RDL process is completed, the die is placed onto the RDL that was built. The laser releasable temporary bonding film (single layered product) can effectively support the RDL build-up process and die bonding and molding processes without delamination [5].

III. RDL-last (chips first) process

3M Laser Releasable Temporary Bonding Film (multi-layered product) is a 3 in 1 structure as shown in Figure 2 below. Among the three layers, the bonding layer forms the bond to the substrate, and is composed of a high molecular weight thermoplastic elastomer, which shows excellent adhesion to substrates, and with exceptional thermal stability. This allows the temporary bonding film to support multiple passivation curing processes without delamination based on its excellent high temperature wafer grip force. After process completion, the adhesive layer can be fully removed without leaving residue as shown in Figure 3. The middle layer is a core film for providing structural support, and selected to minimize CTE and warpage of the bonded substrate and carrier. The bottom layer is a pressure sensitive adhesive which is bonded to the glass carrier and also provides the laser release function.

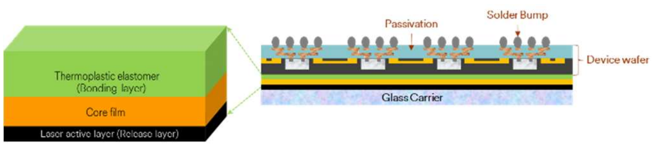


Figure 2, 3M laser releasable temporary bonding de-bonding film (multi-layered product) for supporting RDL-last process

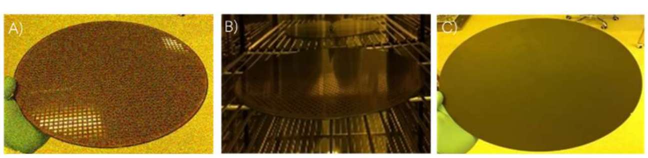


Figure 3, Passivation curing simulation test (230 ˚C X 2hrs X 2 Times) for actual bonding wafer with 3M product, A) Bonded device with carrier by using 3M product, B) Maintaining grip force of 3M product for glass carrier during passivation layer curing process, C) Mold wafer after carrier de-bonding & adhesive peeling; Device wafer without warpage & adhesive residue.

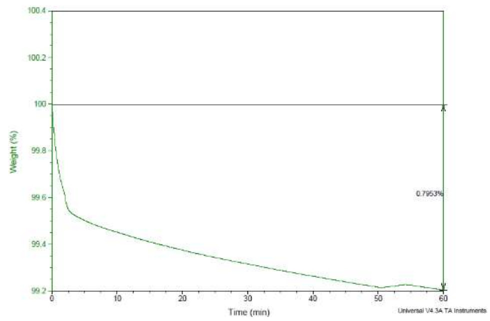


Figure 4, TGA Weight loss analysis of 3M Laser releasable temporary bonding film (multi-layered product): 0.793% @ 230 ˚C for 1hr, N2 Gas

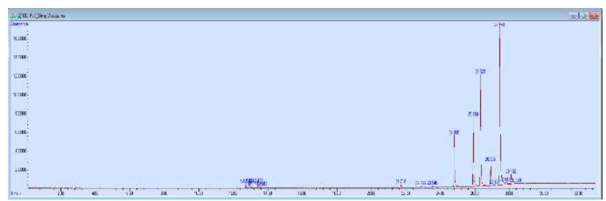


Figure 5, Residue Analysis on mold wafer by GC-Mass

As shown in Figure 3, after a passivation curing simulation test at 230 ˚C for 4 hours, the laser releasable temporary bonding film (multi-layered product) showed excellent wafer bonding performance with strong wafer grip force. Thermal defects were not found on the release layer surface. In addition, the temporary bonding film has demonstrated weight loss values of less than 1% in thermal gravimetric analysis (TGA) after simulated passivation curing as shown in Figure 4.

To check whether adhesive residue remained on the surface of the mold wafer after thermal processing, the mold wafer was cut and put into a capsule containing solvent and then heated at a high temperature for 4 hours. The solvent was analyzed precisely by gas chromatography – mass spectrometry (GC-MS) for the elements constituting the adhesive. As a result of the evaluation, the corresponding elements were not found as shown in Figure 5. We could confirm that the temporary bonding film did not leave adhesive residue after the passivation layer curing process.

IV. RDL-first process

The RDL-first process can enable better RDL quality and lower production cost compared to the RDL-last process. As shown in Figure 6, the RDL-first process builds up the RDL directly on the release adhesive surface, so the adhesive strength and surface roughness can directly affect the quality of the RDL [4].

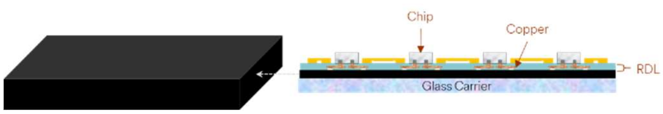


Figure 6, 3M Laser releasable temporary bonding film (Single layered product) for supporting RDL-First process

As shown in Figure 7 below, the laser releasable temporary bonding film (single layered product) has a laser active ingredient dispersed to a nano-scale level and a high molecular weight elastomer binder, providing exceptional thermal stability and excellent laser de-bonding performance. Numerous polar functional groups in the binder resin also play a major role in enhancing interfacial adhesion between the carrier and the film. Extra functional groups that are not involved in carrier attachment can be crosslinked to each other through a pre-aging process under high-temperature to provide higher thermal stability and chemical resistance [5].

The excellent surface uniformity of the laser releasable temporary bonding film (single layered product) allows high quality RDL build-up. Generally, to support the RDL process without any problems, an Ra value of less than 0.5μm is required.

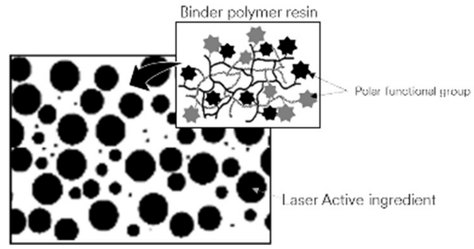


Figure 7, Design concept of 3M laser releasable temporary bonding film (single layered product)

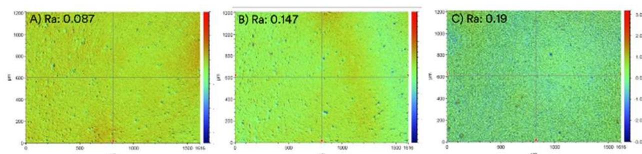


Figure 8, Surface roughness analysis of 3M laser releasable temporary bonding film (single layered product) by Bruker confocal, A) Ra value after glass lamination, B) Ra value after metal deposition (Cu), C) Ra value after thermal aging (@ 210 °C for 2hrs)

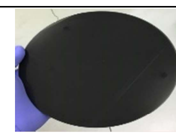
Condition	Reference**	3M Laser Releasable temporary bonding Film
Room Temperature		
Aging for 1hr at 300 °C*		

Table 1, Metal deposition process simulation test of 3M laser releasable temporary bonding film (single layered product) @ 300 °C for 1hr in Air, *Using the flash for clear picture, **Reference sample: Initial version laser releasable film

As shown in Figure 8, the initial surface roughness value of the laser releasable temporary bonding film (single layered product) after lamination onto the carrier is very good at 0.087μm. Even after metal deposition and thermal aging, the Ra value does not exceed 0.2μm, which is also very good. the process for metal deposition is usually carried out under high temperature and vacuum conditions above 200 °C. The high temperature conditions under vacuum can cause much larger damage to the organic material than in the atmosphere. We conducted a thermal aging test for the laser releasable temporary bonding film (single layered product) at 300 °C to simulate this [6].

As shown in the lower right image of Table 1, no delamination or voiding was observed at the interface between carrier and film, despite the high temperature and atmospheric conditions of 300 °C. If the adhesive's adhesion or thermal stability were insufficient, voiding or delamination may occur such as shown in the reference sample. Generally, a 300 °C temperature has been used for simulating the metal deposition process, suggesting that no problems are anticipated in a typical metal deposition process with high vacuum condition of 220 °C [6].

V. De-bonding process with laser scanning

The laser releasable temporary bonding films allow robust carrier de-bonding processes for lasers of various wavelengths. Currently, the temporary bonding films can be successfully de-bonded using 308, 355, and 1,064 nm wavelength lasers. De-bonding is possible without damaging the device with low stress as shown in Figure 9.

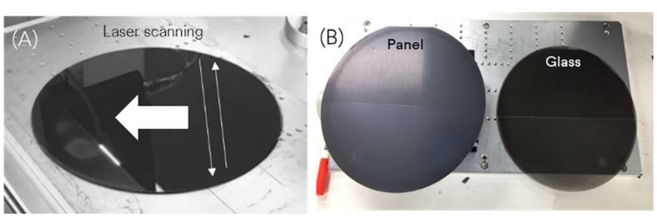


Figure 9, Laser de-bonding processing, (A) Laser scanning, (B) Demounted device wafer from a carrier

In addition, 3M laser releasable temporary bonding films can completely block any leaked laser energy during the de-bonding process. The laser releasable temporary bonding film exhibits superior laser blocking performance compared to spin-coatable materials. We evaluated the laser energy blocking performance of the temporary bonding film for the most intrusive IR laser (1,064 nm wavelength) under conditions equivalent to the actual de-bonding process. For reference, a range of process conditions can be acceptable for the de-bonding process, even with laser equipment of the same wavelength. For example, if the laser beam width is wide, lower energy can be required. In general, a narrow beam is often used in a laser marking process and has a higher energy per unit area than a laser with wider beam width. In this evaluation, we used a beam of narrow width rather than the normally recommended de-bonding conditions to evaluate the laser blocking performance of 3M products under the most severe conditions. Of course, the condition evaluated (0.4mm X 20W) is also a condition that results in acceptable de-bonding.

As shown in Figure 10 and Table 2, a 20 watt laser dosage under the above evaluation conditions was used to carry out the de-bonding process. Unlike the spin coated reference material, the temporary bonding film provided complete shielding from the laser energy as shown by the laser energy detector. The excellent barrier performance of the temporary bonding film to laser energy provides a much wider process margin in the design of the fan-out process, and in selection of materials.

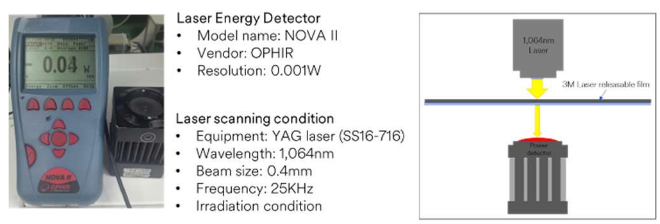


Figure 10, Laser energy blocking performance test, Measure transmittance of laser energy by using Laser energy detector (NOVA II)

Sample	Reference			3M laser releasable temporary bonding film		
Scanning Energy (W)	10	15	20	10	15	20
Detected Energy (W)	3.7	2.7	2.1	0	0	0

Table. 2, Laser blocking performance evaluation result of 3M Laser releasable temporary bonding film

Conclusion

The fan-out process has brought semiconductor micro-patterning technology into the realm of packaging. Redistribution Layers (RDL), implemented with micro-patterning technology and the wafer reconstitution/molding process can provide smaller chips and more I/O, greatly contributing to maximizing the performance of the package and reducing the production cost. Differences in the RDL process, which is the core of the fan-out process, result in differing process simplification, quality, manufacturing yield and cost. No matter the RDL process used, the support of a suitable temporary bonding/de-bonding material is required.

The RDL-first process, which can reduce chip loss and improve RDL quality, is achieved through the use of a single release layer with uniform and low surface roughness, as well as excellent adhesion [4].
In the case of an RDL-last process, with a simpler process enabled by building-up the RDL directly on the reconstituted wafer, it is necessary to employ a multi-layered type material which can prevent the warpage of the device.

The 3M laser releasable temporary bonding film enables the de-bonding process with low stress, and without device damage. The multi-layered film provides outstanding wafer grip force and the thermal stability required for an RDL-last process.

Acknowledgment

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3M Center, Building 224-3N-11
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1-800-251-8634 phone
651-778-4244 fax
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