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Effect of Silicon Die Condition on the Breaking Load Performance of a Dam and Fill Semiconductor Package

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

A semiconductor package has a silicon die on which an integrated circuit (IC) is fabricated. The die is singulated from a single wafer using processes like mechanical sawing or laser grooving. These processes have impact on the final condition of the silicon die after wafer singulation. This paper discusses a study on the effect of the die condition on the breaking load of a package with a dam and fills structure. The encapsulation material of this type of package has lower modulus when compared with the epoxy mold compound material used in most molded packages. The package breaking load was determined using 3-point bend test for two sets of packages. The first set of packages was assembled with silicon die produced using mechanical sawing. The second set was assembled with die produced using laser grooving. Results of the 3-point bend test showed that the breaking load of the package with die from mechanical sawing is higher compared with the package assembled with die from laser grooving. The study revealed that that the silicon die condition has significant effect on the robustness of the final package where the die is used.

Keywords: Package breaking load; mechanical sawing; laser grooving; silicon die; 3-point bend test; dam and fill.

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1. INTRODUCTION

Robust semiconductor package is desired in electronic device applications. The package has to be strong enough to resist package damage under bending loads or other mechanical forces applied during package assembly manufacturing and even in actual device use. The package has a silicon die that is produced using different dicing processes. These processes influence the die condition or die surface and edge quality. Currently two dicing technologies have established themselves, which can be divided in mechanical blade sawing and laser-based processes with nanosecond lasers. Mechanical sawing with diamond blades has been used for a long time but as the wafer material is getting thinner and the chip size smaller, this classical process is replaced by laser-based dicing processes. The mechanical load and the relatively large kerf width are serious disadvantages of a mechanical dicing process. The diamond blades are basically not suitable to cut thin wafers in the range of 100 µm or less, because they cannot resharpen themselves at the thin wafer edge. [1]. Though using diamond saw blade is a low-cost process, chipping and crack or mechanical damage tend to occur due to mechanical stresses induced by the diamond blade [2,3]. For a nanoscale Cu/low-k wafer, inter-layer dielectric (ILD) and metal layers peelings, cracks, chipping, and delamination are the most common dicing defects by traditional diamond blade saw process [4].

With the challenges associated with mechanical sawing, dicing using laser technology has emerged. Laser technology offers a micromachining process which is much more competitive than diamond blade saw. This wafer dicing process by laser ablation, in which material is removed via evaporation and melt ejection under irradiation of laser pulses, results in diminished kerf width, reduction in top-/bottom-side chipping and cracking and high throughput over mechanical blade dicing [4,5,3]. Even with the improvement offered by laser technology in dicing process, damage or weakening of the silicon die is still possible [6]. The heat-affected zone (HAZ), a term used to encompass the damage caused to a material during and after irradiance by a laser pulse, impacts the die strength [7]. In recent years, dicing using plasma technology has been explored to further improve the dicing process [8,5,6].

Knowing that the condition of the die is influenced by the dicing process used, its effect on the package breaking load performance needs to be investigated. In semiconductor packages like Quad Flat No Lead (QFN), there are reliability challenges [9] and one of them is package crack that can be caused by handling, electrical test operations, shipping and surface mount technology (SMT) printed circuit board (PCB) assembly [10]. In this study, another type of package that uses dam and fill structure (Fig. 1) was considered to understand the difference in the breaking load of such package having silicon die produced using mechanical sawing with that of the same type of package but having die produced by laser grooving. The encapsulant of this type of package has lower modulus compared with the epoxy mold compound used in other packages such as QFNs. It means that the material is less rigid or easy to deform. The dam and fill process consists of building a wall (dam) around the area to be encapsulated using a high-viscosity adhesive that does not slump between dispensing and curing. The cavity created by the dam is then filled with a low-viscosity version of the same adhesive or encapsulant [11]. Dam and fill dispensing typically encapsulates wire bonds and die [12]. Dam-and-fill materials offer high package reliability and reduced warpage [13]. The breaking load or the resistance of the package against package crack can be measured using 3-point bend test.

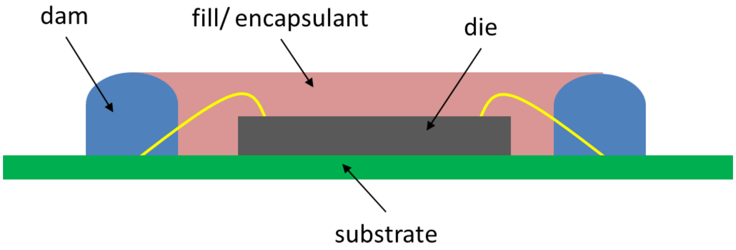

Fig. 1. Dam and fill semiconductor package

2. METHODOLOGY

The semiconductor package analyzed in this study has a total thickness of 0.48 mm with a tape substrate of 0.16 mm thickness. This package has a silicon die attached to the tape substrate using die attach adhesive in a dam and fill structure described previously. The dam and fill area covers approximately 6.6 x 7.6 mm. There were two sets of packages tested. The first set of packages was assembled with silicon die produced using mechanical sawing. The second set was assembled with die produced using laser grooving.

The package breaking load testing was done using the Instron MicroTester equipment shown in Fig. 2. It has a load cell that measures the amount of force applied to the specimen in a 3-point bend setup described in Fig. 3. The equipment used in this study was checked in terms of calibration validity to ensure accuracy of the force measurements. The package is supported at the bottom by two stationary anvils and force is applied from the top with the upper loading anvil. The distance between the fixed anvil supports or the span was set at 5 mm. The package sample was oriented with the dam and fill area facing downward (dead bug orientation). Then the tape substrate would be in contact with the loading anvil during the application of force. Force was applied at the center of the package and the maximum force was recorded. The breaking force was considered as the force where a first load drop could be seen in the load-displacement curve. Using statistical analysis, the package breaking load results from the two sets of package samples were then compared.

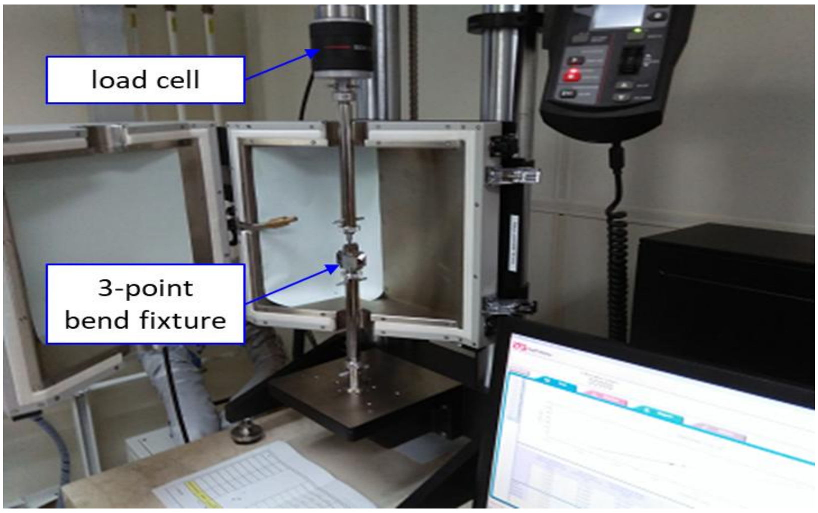

Fig. 2. Instron MicroTester (Model 5948)

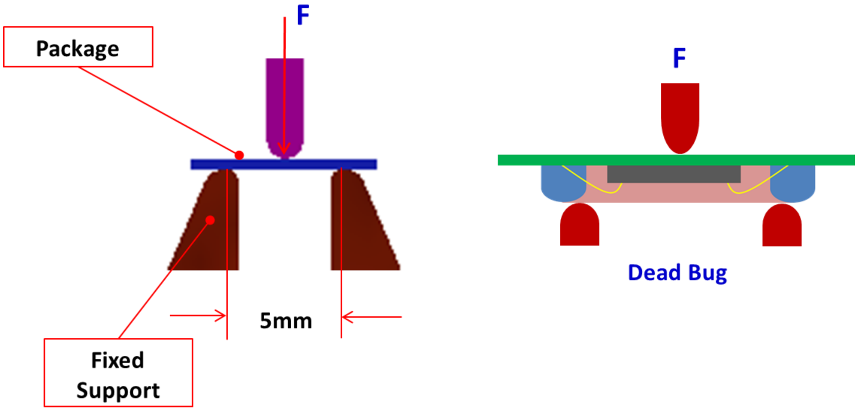

Fig. 3. Package 3-point bend test setup

3. RESULTS AND DISCUSSION

The package breaking load result with die produced by mechanical sawing is shown in Fig. 4. As the load or force applied increases, a load drop could be seen. This drop in the recorded load implies that the package breaking point is reached and the package is already damaged. The load drop observed is not as noticeable as those of the other packages using epoxy molding compound as package encapsulation. For those packages, a big drop could be observed as the more rigid epoxy molding compound breaks under bending load. Dam and fill materials in the package considered in this study have much lower modulus than the epoxy mold compound materials used in most Quad Flat No Lead (QFN) or Ball Grid Array (BGA) packages. From the package 3-point bend test results, the average breaking load calculated was around 7.6 N for dam and fill package with die from mechanical sawing.

On the other hand, the package breaking load result with die produced by laser grooving is shown in Fig. 5. The average breaking load calculated was around 5.5 N. It can be observed that the load-displacement curves in Fig. 5 are similar to the curves in Fig. 4. The only obvious difference is that the load at which the drop occurs is lower in Fig. 5 for the dam and fill package assembled with die produced by laser grooving.

Comparison using a box plot shown in Fig. 6 clearly indicates that package breaking load is higher with die produced using mechanical sawing. This comparison result agrees with the previous study [7] where the die strength obtained by laser dicing is far lower than blade, which indicates that severe thermal damages have been generated. Thermal damage to the chip induced by laser ablation results in die strength degradation. Ablative laser dicing processes [8] employ nanosecond pulsed lasers for cost and throughput considerations but they can cause severe thermal damage to separated dies leading to lower-than-expected die strength for thin and ultra-thin dies. This appears to be the case in this study where the die weakening is

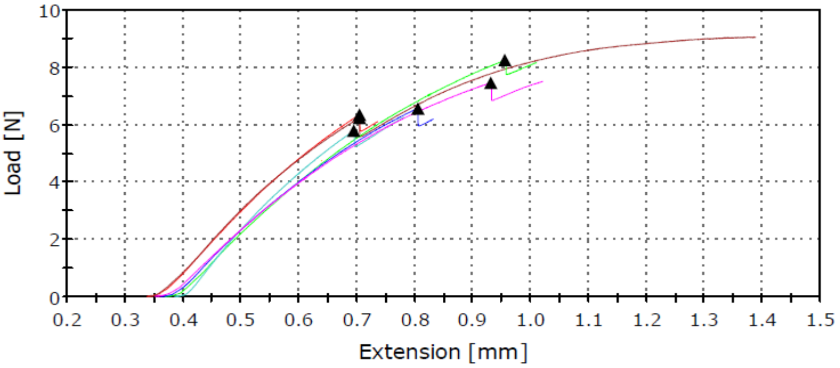

Fig. 4. Force vs package deflection for package assembled with die produced by mechanical sawing (average breaking load = 7.6 N)

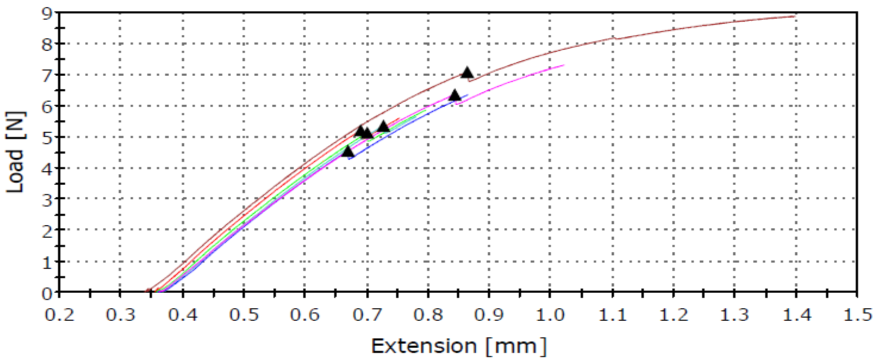

Fig. 5. Force vs package deflection for package assembled with die produced by laser grooving (average breaking = 5.5 N)

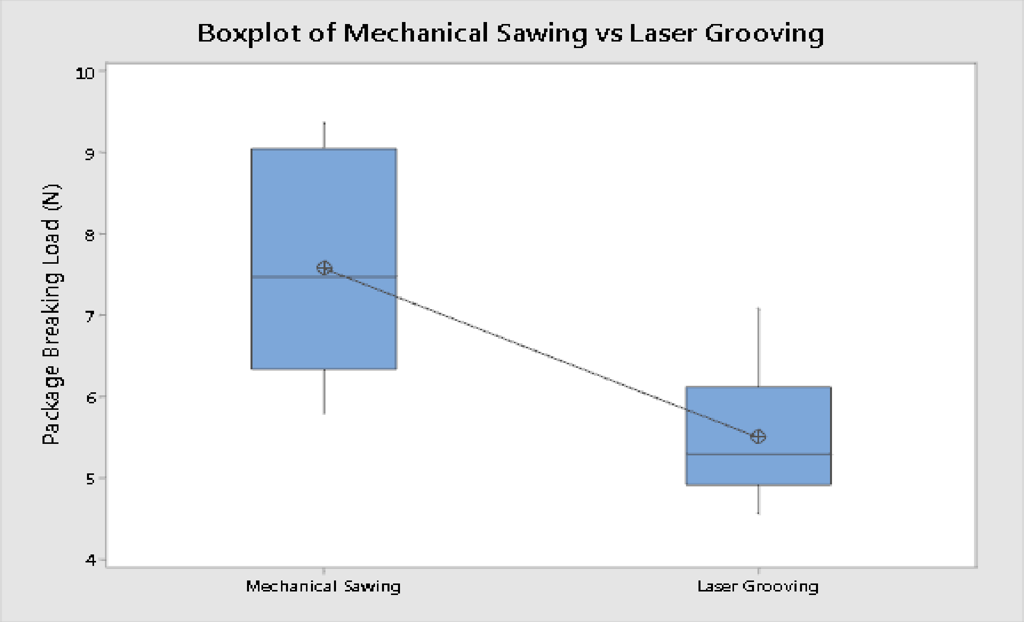

Fig. 6. Boxplot of the package breaking load comparison (mechanical sawing vs laser grooving)

manifested in the lower package breaking load of the dam and fill package. The results showed that a dam and fill package assembled with weaker die would also result in a weaker package. Thus, it is important to use a process that would not weaken the silicon die to ensure that the resulting dam and fill package would be able to withstand higher bending loads in actual applications.

4. CONCLUSION

Package bend testing results revealed that the breaking load of the package assembled with die from mechanical sawing is higher compared with that of the package with die from laser grooving. This difference in the package breaking load shows that the die condition has significant effect on the robustness of the final dam and fill package. The laser grooving has weakened the die more than mechanical sawing and this indicates that severe thermal damages have been generated. The die strength degradation is understood to be related to the laser induced heat-affected zone (HAZ) size and defect density. From this study, it can also be concluded that it is important to use a dicing process that results in higher die strength. Other types of semiconductor packages that are having encapsulation material (encapsulant) with higher modulus such as QFN could be considered in futures studies. This is to investigate if the silicon die condition would still have significant impact on the package breaking load of more rigid packages.

DISCLAIMER

The products used for this research are common and predominantly used products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because there is no intent to use these products as an avenue for any litigation but just for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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