Comprehensive Study of Thermal Impact on Warpage Behaviour of FOWLP with Different Die to Mold Ratio

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***Abstract*—One of the challenges in processing Fan Out Wafer Level Package is the warpage of the Molded Wafer. Some of the fabrication processes such as lithography, coating, etching, and plating could not process wafer with high warpage. Therefore, the molded wafer should have as low a warpage magnitude as possible.**

In this paper, we study the warpage behavior of the molded wafer with different die to mold ratio. Further work is done on evaluating the impact of different chuck temperatures during the debonding process for the wafer with the highest warpage. The debonding process involved removing the molded wafer from the metal carriers, removing the thermal release tape from the molded wafer, and subjecting the molded wafer to series of thermal treatments to reduce the final warpage of the molded wafer.

Keywords- Fan-out wafer level package (FOWLP), Warpage, Die to Mold Ratio, Mold 1st process.

1. INTRODUCTION

In today's semiconductor packaging, fan-out wafer level package (FOWLP) is still one of the most cost-effective and rapidly evolving technologies since the transition into heterogeneous integration [1, 2]. It uses the method of placing known good dies onto the reconstituted wafer. There are many challenges with this packaging technology, and the wafer warpage is one of these challenges [3]. The primary cause of the wafer warpage is due to material mismatch of the coefficient of thermal expansion (CTE) from the molding compound and the silicon dies [4]. Wafer warpage will impact the downstream processes such as backgrinding; and re-distribution layer (RDL) process both in handling the warped wafer and the quality of the process [5]. It is essential to have low wafer warpage during processing for the FOWLP assembly process [6].

Molding was done over the dies mounted on a metal carrier laminated with thermal release tape. The molded wafer with metal plate was sent through a debonding system whereby it was debonded from the metal plate through a thermal process where heat is applied, activating the thermal sensitive tape thus separating molded wafer from the metal plate. The thermal tape was peeled off from the molded wafer before it went through a series of thermal treatments to minimize the warpage of the molded wafer. The warpage of the FOWLP was measured for each configuration variation and analysis. The impact of the temperature during the separation and thermal treatment process was studied to determine the best process condition to produce the lowest possible warpage magnitude. Wafer with different die-to-mold ratio were prepared and subjected to different temperatures to study the thermal impact on the warpage behaviour of FOWLP.

2 TEST VEHICLE DESIGN

Variables such as different die sizes, package sizes, fan-out ratio, and overmold thickness were evaluated. Die sizes are 7x7x0.3mm and 5x7x0.3mm. Package sizes are 8x8mm, 9x9mm, 10x10mm, 6.5x9mm, and 5.5x8.5mm. Fan-out ratio are 1.31, 1.34, 1.65, 1.67, and 2.04. Overmold thicknesses are 0.125mm and 0.2mm. Figure 1 shows the schematic of the test vehicle. Table 1 tabulated the various test vehicles that have different die to mold ratio.

A wafer with higher die to mold ratio is expected to have higher warpage, and this may need further evaluation to understand how to reduce the warpage in order for the molded wafer to handle the subsequent fabrication processes.

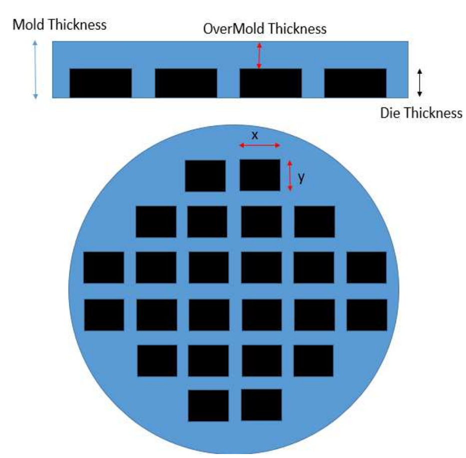


Figure 1: Schematic diagram of FOWLP

Table 1: Test Vehicle's information

Test Vehicle	Die Size (mm)		Pitch (mm)		Overmold Thickness (mm)	Fan-Out Ratio (FOR)
	X	Y	X	Y		
TV1	7	7	10	10	0.125	2.04
TV2	7	7	9	9	0.125	1.65
TV3	7	7	8	8	0.125	1.31
TV4	5	7	6.5	9	0.125	1.67
TV5	5	7	5.5	8.5	0.125	1.34
TV6	7	7	10	10	0.2	2.04
TV7	7	7	9	9	0.2	1.65
TV8	7	7	8	8	0.2	1.31
TV9	5	7	6.5	9	0.2	1.67
TV10	5	7	5.5	8.5	0.2	1.34

3. TEST VEHICLE FABRICATION PROCESS

Mold 1st approach was used to fabricate the FOWLP. The dies are picked from dicing tape and placed on a metal plate that has been laminated with thermal released tape, as shown in Figure 2. Compression molding is carried out on the metal plate populated with dies. Figure 3 shows the molded wafer on a metal plate. The molded wafer is subjected to post mold cure before it is debonded from the metal plate through a debonding process. Figure 4 showed the debonded mold wafer. The whole fabrication process of test vehicle is illustrated in Figure 5.

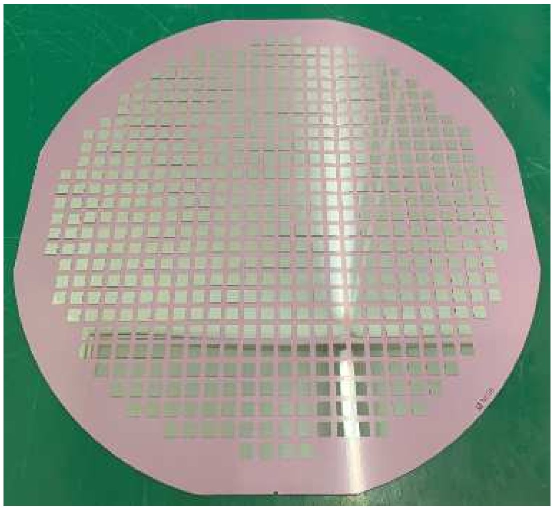


Figure 2: Metal Plate populated with dies

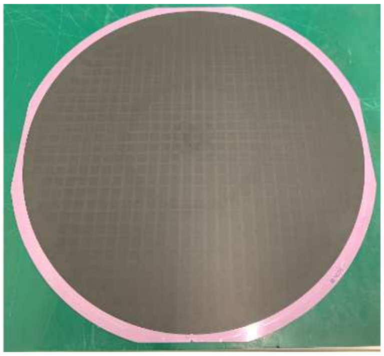


Figure 3: Molded wafer on metal plate

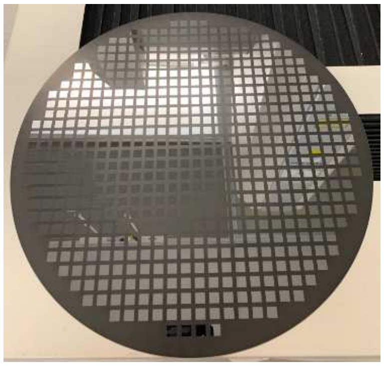


Figure 4: Debonded Mold Wafer

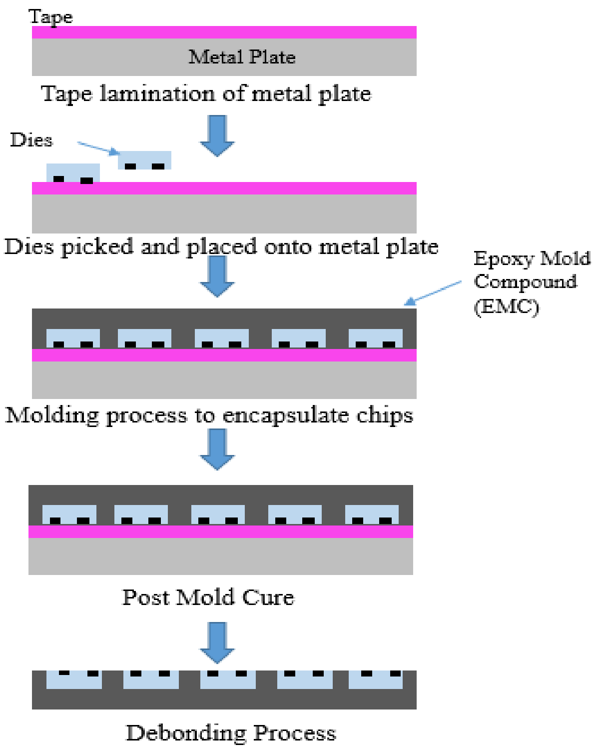


Figure 5: Fabrication process of Test Vehicle

4. DEBONDING PROCESS

ERS ADM330 is used for the debonding process. The molded wafer is secured on the metal plate with thermal release tape. Figure 6 shows the three chucks on the TriTemp slide system that are used to debond the molded wafer from the metal plate and subject it to further thermal inputs to manipulate the warpage outcome of the molded wafer. The system will peel off the thermal release tape from the molded wafer before sending it to the second and third chuck.

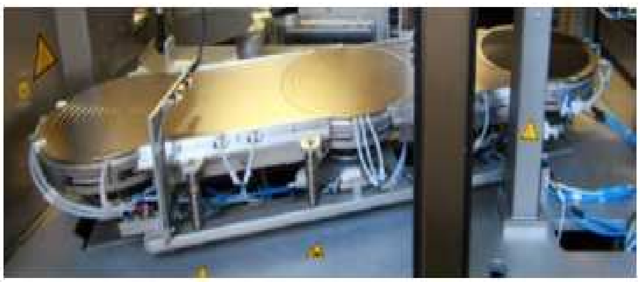


Figure 6: TriTemp slide system in ERS ADM330 debonding machine

The 1st chuck is set to the release temperature of the thermal release tape, and it will remain fixed for the whole DOE study. The last chuck is set at room temperature as the molded wafer needs to cool down to room temperature for the warpage measurement. The temperature of the cooling chuck will have a different setting to determine the thermal impact on the warpage of the debonded molded wafer.

The chuck is capable of maintaining the set temperature within +/- 2°C. Temperature uniformity across the chuck surface helps in ensuring good uniform thermal input to the molded wafer during the debonding process. Contactless transportation through the TriTemp slide system is crucial in reducing the warpage of the molded wafer. This transport mechanism differentiates this machine from other debonding systems. The slider system uses a tilt mechanism to allow the wafer to slide from one chuck to another. No non-uniform heat dissipation is encountered when handling hot wafers, which is typical to pick and place (use of end-effector). Figure 7 shows the process flow in the debonding machine.

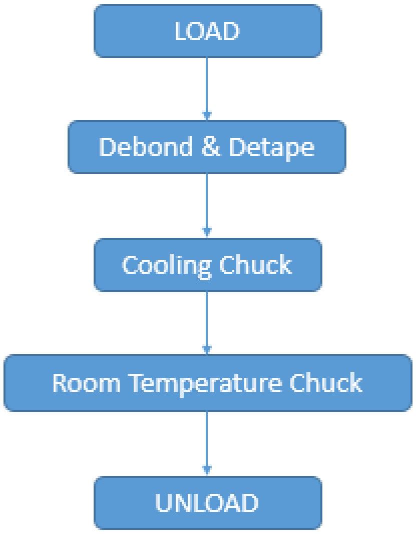


Figure 7: Process in the debonder

The Test Vehicles 1 to 10 are subjected to a debonding temperature of 180°C and cooling temperature of 50°C to determine the warpage response. The Test Vehicle with the highest warpage magnitude will be subjected to various cool chuck temperatures.

5. WARPAGE MEASUREMENT APPROACH

Nikon confocal scope is used to measure the warpage of the test vehicle after the debonding process. The scope will measure the warpage of the wafer across three axes, as shown in Figure 6. The average warpage magnitude will be used for the response on the DOE matrix with different temperatures. Figure 7 shows the typical warpage plot using the Nikon confocal scope.

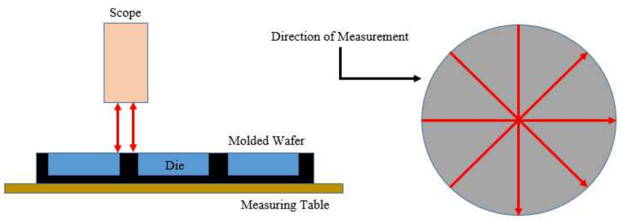


Figure 6: Warpage Measurement approach

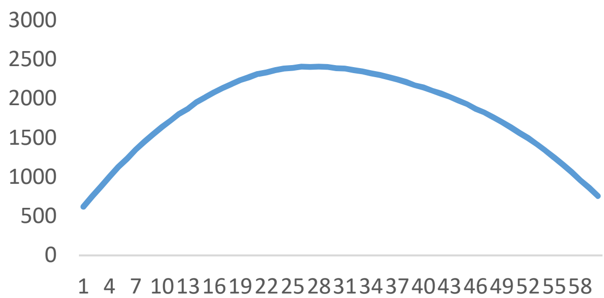


Figure 7: Warpage plot of molded wafer

6. WARPAGE MEASUREMENT RESULTS AND OBSERVATIONS

All the test vehicles had been fabricated, debonded, and measurement of warpage done. Table 2 showed the warpage results for all test vehicles.

Table 2: Warpage Measurement for all Test Vehicles

Test Vehicle	Die Size (mm)		Pitch (mm)		Average Warpage (mm)
	X	Y	X	Y	
TV1	7	7	10	10	0.443
TV2	7	7	9	9	0.396
TV3	7	7	8	8	1.731
TV4	5	7	6.5	9	0.730
TV5	5	7	5.5	8.5	0.937
TV6	7	7	10	10	0.562
TV7	7	7	9	9	0.851
TV8	7	7	8	8	1.717
TV9	5	7	6.5	9	0.942
TV10	5	7	5.5	8.5	1.357

The wafer from TV 3 & 8 encountered an issue on the TriTemp slide, making it unable to slide properly. Both these test vehicles had the highest warpage with more than 1.7mm. Figure 8 shows the wafer was not able to stop at the centre of the chuck during the sliding process. This issue was resolved by having a higher tilting angle of the slide system. Figure 9 shows the tilting angle of the slide system. The higher angle helped in increasing the inertia force to slide the wafer further and faster along the slide system. Figure 10 shows the wafer stop at the chuck's centre after increasing the tilt angle of the slide system.

Figure 8: Wafer not stopping at chuck's centre

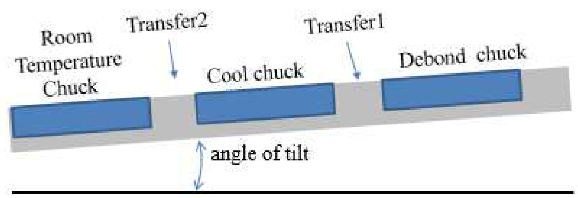


Figure 9: Tilt angle of the TriTemp slide

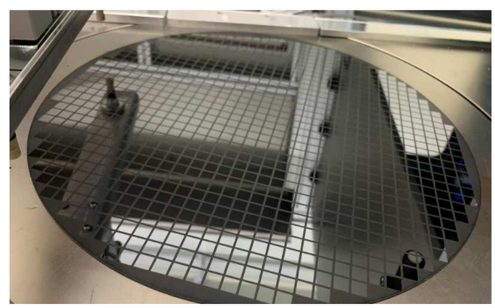
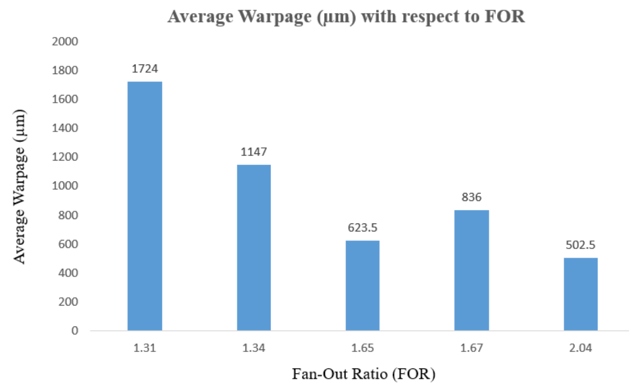


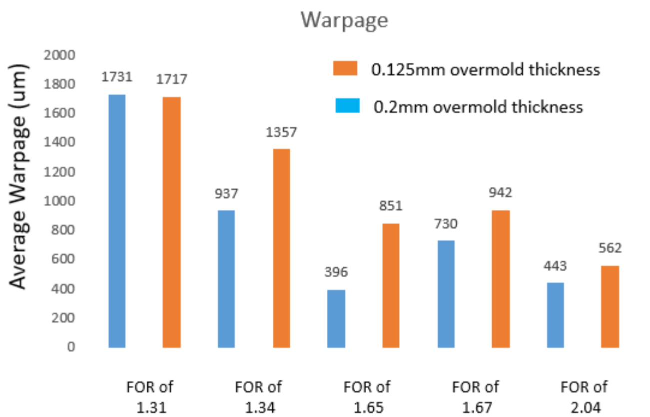
Figure 10: Wafer stopped at chuck's centre

Further analysis of the warpage data revealed that the smaller Fan-out ratio has the highest wafer warpage, as shown in Graph 1.



Graph 1: Average Warpage with respect to FOR

The overmold thickness had an impact on the wafer warpage, as shown in Graph 2. Higher overmold thickness generally exhibits higher warpage.



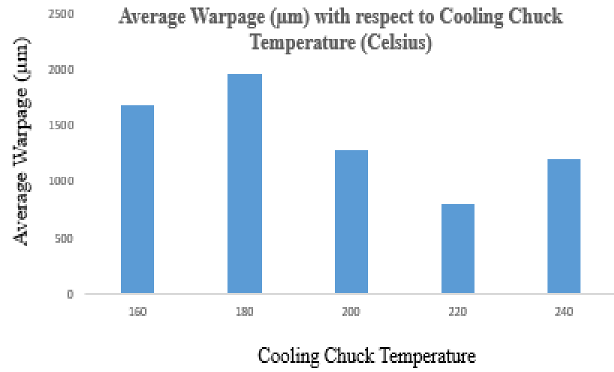
Graph 2: Warpage with respect to overmold thickness

TV10 with the rectangular die was selected for further study using different temperatures on a cooling chuck while maintaining room temperature for the last chuck. A wafer with rectangular die and of different x and y pitch may behave differently from a wafer with square die and equal x & y pitch. Table 3 tabulated the different cooling chuck temperatures used in the study.

Table 3: Information of cooling chuck temperature

Number	Cooling Chuck Temperature (Celsius)
1	160
2	180
3	200
4	220
5	240

The TV10 was subjected to different cooling chuck temperatures as listed in Table 3. The warpage of the wafer is measured after the debonding process. The warpage results are shown in the Graph 3. The warpage of the molded wafer achieved the targeted ≤ 1.5mm with cooling chuck temperature above 200ºC. This may indicate that cooling chuck temperature beyond 200ºC leads to optimum polymer relaxation compared to other temperatures.



Graph 3: Average warpage with respect to cooling chuck temperature

7. CONCLUSION

A comprehensive warpage study of FOWLP was conducted and indicated the following findings:

1. Higher overmold thickness increased the warpage magnitude,
2. A smaller fan-out ratio generally has a higher warpage magnitude.
3. A higher tilt angle of the TriTemp slide in debonder system is necessary to ensure smooth debonding and warpage adjustment process
4. The temperature setting on the debonder system needs to be optimized to ensure the warpage magnitude is ≤ 1.5mm

8. ACKNOWLEDGMENT

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9. REFERENCES

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