Cost Comparison of Fan-out Wafer-Level Packaging to Fan-out Panel-Based Packaging

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Abstract

Fan-out wafer-level packaging (FOWLP) offers many significant benefits over other packaging technologies. It is one of the smallest packaging options, but unlike fan-in wafer-level packaging, the IO count of FOWLP is not limited to the area of the die. Given these advantages, FOWLP continues to grow in popularity.

While the cost of FOWLP is usually reasonable, there are still opportunities for future cost reduction. Many FOWLP suppliers are exploring panel-based manufacturing instead of the current wafer-based approach. Since many more packages can fit on a large panel than on a wafer, the cost per package can be reduced. The surface area of a 370mm x 470mm panel is 1,739 sq.cm. compared to 706 sq.cm. for a 300mm wafer. This means more than twice as many packages can be manufactured on a single panel. However, this does not mean that the cost per package will be cut in half. Many of the costly manufacturing activities do not depend on the surface area of the panel or wafer and they will not be affected by a larger panel.

This paper analyzes the current cost of FOWLP activities and highlights which activities will benefit from a move to panels. An analysis of each manufacturing activity is presented comparing the cost impact of panel versus wafer. The total potential cost savings is also presented.

Key words

Packaging cost, Fab-out wafer-level packaging, Panel based fan-out packaging

I. Introduction

There are a large number of factors that affect the manufacturing cost of an electronic package. Some of these cost drivers are based on the characteristics of the package. Package size, IO count, number of re-distribution layers (RDL), etc. can have a significant impact on cost. However, some of cost drivers are based on the specific manufacturing process. For both fabrication and assembly activities, the size of the manufacturing panel or wafer is a key driver for overall cost.

The sections below discuss the potential cost impact of using a rectangular panel instead of a round wafer for fan-out packaging. Manufacturing costs can be divided into three categories: material costs, the cost of batch activities, and the cost of individual package activities.

A. Material Cost

The cost of the permanent material that becomes part of the package will not be affected by the size of the manufacturing panel/wafer. This includes the mold compound, die adhesive, and RDL materials (dielectric, plated copper, etc.) However, another significant material cost is waste. Since packages are rectangular and current FOWLP manufacturing uses a round wafer, there may be more waste using a wafer than using a panel.

B. Cost of Batch Activities

Batch activities can be defined as activities which are done on an entire wafer or panel at once, or on a batch of wafers/panels. If the equipment cost and throughput are the same for a wafer as on a panel, the cost will be directly proportional to the number of packages on the panel/wafer. However, that is only the case if the throughput and equipment cost per wafer is the same as the throughput and equipment cost per panel. For many activities, the equipment cost for panels may be higher and the throughput may be slower. Therefore, it is difficult to make a single cost reduction assumption regarding the potential cost savings for all batch activities. Each batch activity has to be explored on its own before drawing any conclusions.

C. Cost of Individual Package Activities

Activities that fall into this category are die bonding, electrical testing, and singulation. The cost of these activities will not be significantly affected by moving from a wafer to a panel.

II. Baseline Results

Figure 1 shows a table of the cost components that make up price. While there are many cost components that go into price, only direct cost is typically measured. The remaining cost components are applied as a percentage of direct cost. For mature technologies, competitive market forces drive the indirect and overhead costs to be predictable and consistent. A supplier with high relative overhead must either reduce their overhead or exit that market. As a market matures, only suppliers that can deliver products at a competitive price will survive. However, for new technologies such as FOWLP and panel based fan-out packaging technology, the indirect and overhead costs may vary widely even though the direct costs will be similar across suppliers. For example, the equipment cost and throughput of compression molding is approximately the same for everyone, but the overhead cost of a brand new factory may be very different from the cost of an established and partially depreciated factory.

Cost Component	Description		
Direct Cost	**Measured Cost – May be done at the activity level or at the factory level**	**Activity Based Cost Model Result**	PRICE
Indirect Cost	Factory cost that is not directly associated with an activity. Support, quality, manufacturing engineering, utilities, plant, etc.	While all 4 of These vary widely, they are usually applied as a percentage on direct cost.	
Overhead	Company cost that needs to covered. Typically G&A, marketing, engineering, etc.		
Profit Margin	Usually a percentage on total cost		
Risk Factor	A higher than usual margin allocated to new technologies		

Figure 1 – Cost Versus Price

The most accurate method for measuring direct cost is activity based costing. With activity based costing, a process flow is divided into a series of activities, and the total cost of each activity is calculated. The cost of each activity is determined by analyzing the following attributes: time required, amount of labor required, cost of material required (consumable and permanent), tooling cost, all capital costs, and yield loss associated with the activity. When this paper refers to process step assumptions, it is referring to these attributes: the throughput of the step, the cost of the equipment, etc.

The graph in figure 2 shows an example of the type of output that can be obtained from activity based cost modeling. These are the detailed model steps for the first part of an imaging process for an RDL activity. The X-axis shows the name of the step; the Y-axis shows the type of cost that is contributing to each step.

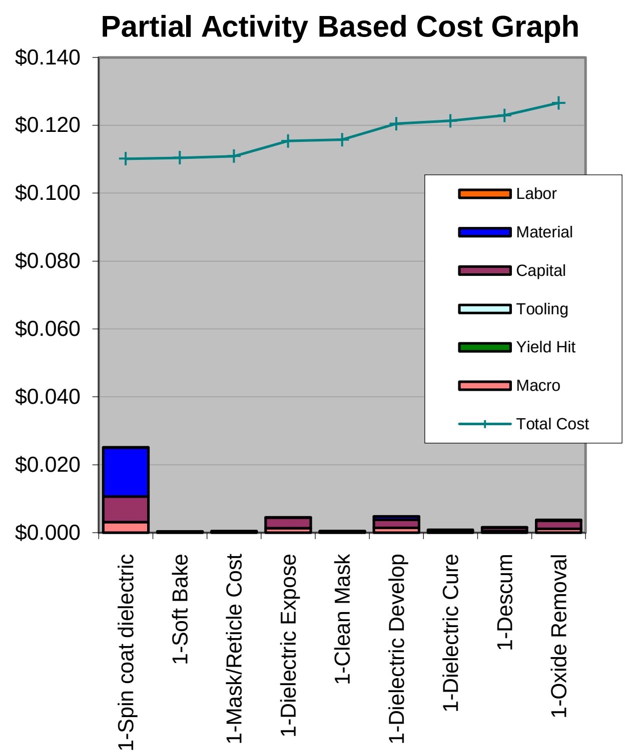

Figure 2 – Activity Based Cost Graph (partial process)

The pie chart in figure 3 shows the cost breakdown of a 10x10 mm FOWLP. This pie chart calculates the direct manufacturing costs of each category as a percentage of the total direct cost. This chart is the baseline that will be used to evaluate the potential cost impact of converting to a panel from a 300mm wafer.

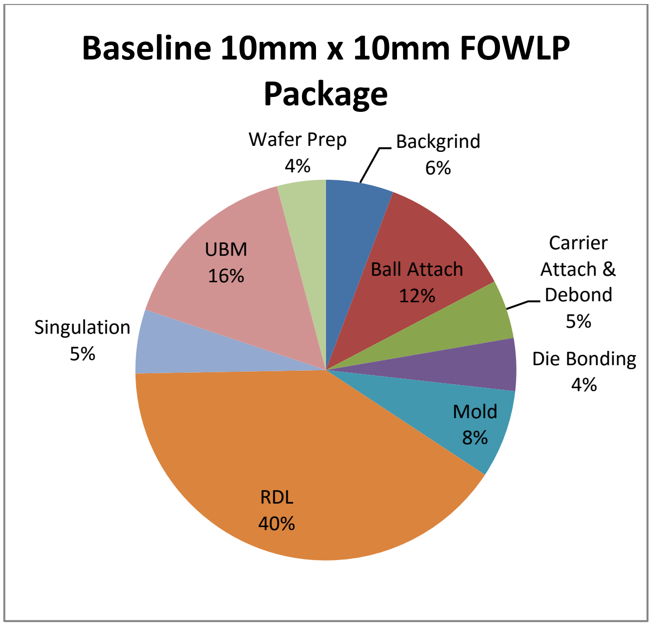

Figure 3 – 10mm x 10mm FOWLP Package Cost

III. Effect of Panel Processing

To understand the potential savings, this section will analyze each of the main process flow segments and describe the potential cost impact of using a panel instead of a wafer. Given that there is still significant uncertainty regarding the size of the panel, the cost of equipment to process that panel, and the throughput of that equipment in terms of panels per hour, a range of estimated savings is provided for each category. Below are the assumptions used for this comparison:

- Package size: 10mm x 10mm
- Package to package spacing: 120 microns
- Edge scrap: 3 mm
- 400 IOs
- 1 RDL
- UBM included
- FOWLP wafer size: 300mm
- Panel size: 370mm x 470mm
- 608 packages per wafer
- 1,575 packages per panel
- Equivalent line and spacing rules
- Equivalent equipment utilization

These assumptions (such as assuming that similar line and spacing rules can be achieved in both cases) were chosen to isolate the impact of the manufacturing panel size on cost. Moving from a typical FOWLP technology, which is largely a semiconductor fabrication-based process, to an organic package process similar to flip chip or wire bond PBGAs would have significant different costs driven by differences in materials, achievable design rules, yield, and significantly different process flows. However, many of those cost differences would not be based on the size and area of the production panel.

A. Wafer Preparation

The wafer preparation covered in this cost analysis includes thinning and singulation of the incoming silicon wafer. Since this activity does not depend on whether a wafer or panel is used for manufacturing, converting the manufacturing process to a panel will have no impact on this cost.

- Minimum expected savings – 0%
- Average expected savings – 0%
- Maximum expected savings – 0%

B. Carrier Attach and Debond

The cost of carrier attach and debond should improve in proportion to the higher package count on a panel. Since the carriers are reusable, the cost of this activity is almost all capital cost. It is reasonable to assume that the throughput per panel will be almost as fast as the throughput per wafer. This results in a maximum improvement of 61%.

- Minimum expected savings – 30%
- Average expected savings – 50%
- Maximum expected savings – 61%

C. Die Bond

Die bonding is done once per package, and the cost per package will not be impacted by moving from a wafer to a panel.

- Minimum expected savings – 0%
- Average expected savings – 0%
- Maximum expected savings – 0%

D. Mold

The two main cost drivers for this activity are the capital cost of the compression mold equipment and the cost of the mold compound. Assuming the equipment cost and throughput are the same, the capital cost will improve by 61%.

There will also be less mold material wasted in a rectangular panel compared to a round wafer even if the package to package spacing and edge scrap assumptions are the same. For a 10x10mm package, 14% of the re-constituted wafer area is wasted. However, only 10% of the panel area is wasted. This results in a 4% material cost improvement based on reduced waste. Combining these savings gives the following estimated savings

- Minimum expected savings – 10%
- Average expected savings – 14%
- Maximum expected savings – 17%

E. RDL

RDL creation is the highest cost category. The main cost drivers are capital and material costs. The capital cost per package should improve with a panel compared to a wafer, but not as much as the maximum of 61% highlighted in the mold and carrier attach and debond analyses. It is not reasonable to assume that the equipment cost and throughput per panel will be the same as the cost and throughput per wafer. In particular, if the imaging is done with a stepper, the throughput per package will be approximately the same with a panel versus a wafer since more exposures will be required on a panel. There may be some improvement based on better optimization of the minimum number of exposures required for a rectangular panel versus a round wafer. The time required to perform the pure batch processes such as sputtering and plating should be the same, but the equipment cost may be higher and the panel capacity may be lower compared to batch processing for wafers.

One of the highest cost materials is the photoimagable dielectric. This is currently most often spin coated on wafers, but a dry film version will likely be used for panels. Dry film photoimageable dielectric tends to be more expensive than its liquid counterpart, but application to a wafer wastes a significant amount of material. Spinning on the dielectric can waste up to 95% of the liquid. Dry film dielectric comes in sheets, so a 300mm x 300mm rectangular sheet must be used for round wafers. At least 23% of this sheet is wasted due to the geometric mismatch. Using a panel will significantly reduce the waste if a dry film dielectric is used, since both are rectangular.

Given the above, we will assume that the capital cost will improve by a maximum of 30.5%. As discussed in the mold analysis, the maximum capital cost improvement is 61%, but that is only if all the equipment costs and throughputs remain the same. The dielectric material cost makes up 60% of the total material cost, so a reduction in dielectric waste will be significant. Using the dry film with minimal waste compared to liquid will result in a total cost savings of 6%. The amount of sputtered and plated material will be largely unaffected by using a panel.

- Minimum expected savings – 10%
- Average expected savings – 15%
- Maximum expected savings – 20%

F. UBM

The under bump metallization cost drivers are similar to the RDL cost drivers with respect to material costs and capital costs. We will assume the same range of improvement.

- Minimum expected savings – 10%
- Average expected savings – 15%
- Maximum expected savings – 20%

G. Ball Attach

The material cost for ball attach will be unaffected by the move to a panel. However, the capital cost of this activity should improve since ball attach is a batch process. The throughput per wafer should be approximately the same as the throughput per panel, but the equipment cost to handle panels will be somewhat higher than wafers. The maximum expected savings below assumes that the capital cost is reduced by 61%, and the average expected savings assumes that the capital cost is only improved by 40%.

- Minimum expected savings – 15%
- Average expected savings – 20%
- Maximum expected savings – 30%

H. Backgrind

The majority of the backgrinding cost is capital. As discussed previously, the capital cost may improve by 61% if equipment cost and throughput is the same. However, since the backgrind area of the panel is larger than the wafer, the throughput will be slower.

- Minimum expected savings – 30%
- Average expected savings – 40%
- Maximum expected savings – 51%

I. Singulation

Singulation cost is driven by the perimeter of the package and will be unaffected by the move to a panel.

- Minimum expected savings – 0%
- Average expected savings – 0%
- Maximum expected savings – 0%

IV. 10mm x10mm Package Comparison

Applying the assumed savings by category to the baseline 10mm x 10mm package gives the following total results:

- Minimum expected savings – 11%
- Average expected savings – 17%
- Maximum expected savings – 22%

The pie chart in figure 4 shows cost breakdown using the average expected savings assumptions.

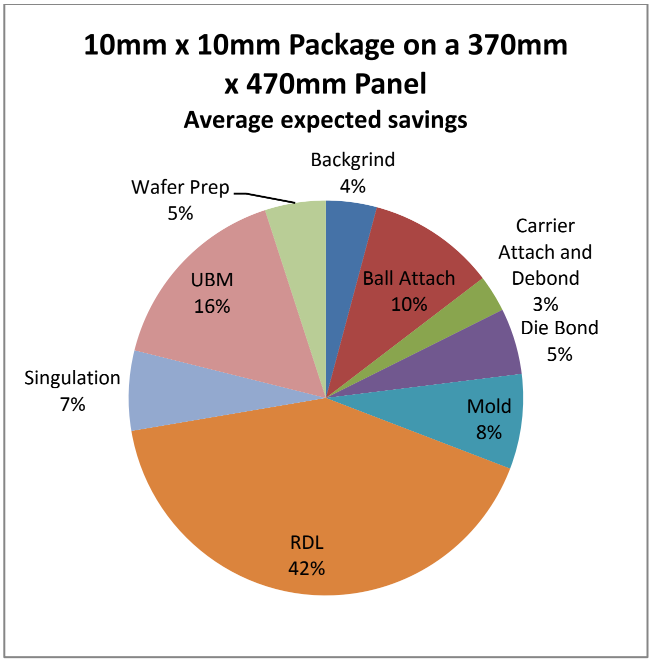

Figure 4 – 10mm x 10mm Panel based Fan Out Package Cost

V. Sensitivity Analysis

The table in figure 5 shows how the potential cost savings of panel based fan-out is affected by the size of the package. The manufacturing assumptions described in section III are kept constant, and only the package size and IO count are varied.

	10x10 mm Package	15x15 mm Package	20x20 mm Package	25x25 mm Package	30x30 mm Package	35x35 mm Package	40x40 mm Package
Packages per Wafer	608	256	148	88	52	40	32
Packages per Panel	1575	720	414	252	180	130	99
Packages per Panel / Packages per Wafer	259%	281%	280%	286%	346%	325%	309%
Average Expected Cost Decrease with a Panel	17.2%	19.7%	19.6%	20.3%	25.3%	23.7%	22.4%

Figure 5 – Potential Cost Savings Sensitivity to Package Size

This shows that more cost savings can be realized with a larger package size. The improved cost for a larger package is directly proportional to the relative difference in the number of packages per panel versus the number of packages per wafer.

However, this improvement is not consistent for every package size. The number of packages per panel or wafer is a discrete number based on the package-to-package and edge scrap spacing rules. The overall efficiency of the total package area compared to the total panel/wafer area will not increase or decrease at the same rate. In the 15x15 mm versus 20x20 mm example, the 20x20mm case is a slightly better fit for the wafer compared to the panel, resulting in slightly less relative savings.

VI. Conclusion

Following are the key conclusions of this analysis.

- The two most dominant cost drivers that differentiate the cost of FOWLP from panel based fan-out processing are reduction in material waste and the increase in the number of packages per panel. Of these two, the most significant is the increase in packages per panel. Material waste reduction is largely a result of a rectangular panel versus a round wafer.

- The average expected cost reduction for a 10mm x 10mm package is 17% even though a panel may have more than 2.5X more packages. If the cost of every activity scaled in proportion to the increased number of package per panel, the cost savings would be 61%. However, the lower value of 17% is due to the fact that not every cost will be affected.

- Additional savings will be realized for larger packages. However, the savings will not increase linearly due to the differences in efficiency of the package layout on the panel and wafer.