Cost and Yield Analysis of RDL Creation in Fan-out Wafer Level Packaging

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Abstract

This paper will break down the cost of the activities that make up the entire RDL process. The activities that account for the creation of an RDL include dielectric application, the use of photolithography to define the metal layers, and metallization steps. A typical series of RDL creation steps will be presented, and possible variations to the process will be included. Sensitivity analysis of variables within key steps will be carried out. Additionally, the contribution of an RDL to total package cost is also included.

Activity based cost modeling will be used for the analysis. With this type of cost modeling, a process flow is divided into a series of activities, and the total cost of each activity is accumulated. The cost of each activity is determined by analyzing the following attributes: time required, labor required, material required (consumable and permanent), capital required, and yield loss.

The goal of this analysis is to understand which portions of RDL creation contribute significant cost, and how changes in the process may increase or reduce cost. These conclusions will also be applicable to the entire fan-out wafer level packaging process because RDL creation is a significant portion of the total cost of a fan-out package.

Key words

Cost, fan-out, RDL, yield

I. Introduction

The fan-out wafer level packaging (FOWLP) process continues to be an area of interest and growth for the advanced packaging industry. While cost and yield analyses have already been carried out with a focus on the entire fan-out process, the contribution of redistribution layer (RDL) creation to total cost has not been explored in depth.

There are multiple styles of FOWLP available on the market today—some have the die placed first and some have the RDL created first. In some, the die is placed face up, while in others, the die is placed face down. While those styles have different processes and unique cost and yield drivers, one cost driver they all have in common is RDL creation. In some cases, the process steps that go into creating an RDL may account for a full half of the total number of steps in the entire process flow. The chart in Fig. 1 shows an example of the cost contribution of the segments of a die-first face down fan-out process. In this case, for a single RDL in a medium-sized package, the cost contribution is a third of the total process cost.

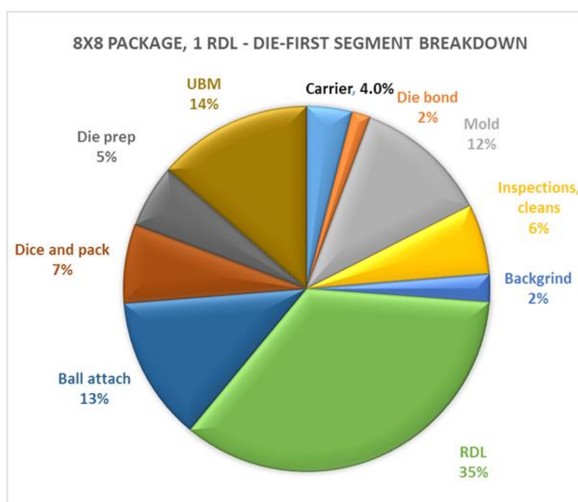


Figure 1 – Die-first Segment Breakdown

II. Activity Based Cost Modeling

This analysis uses activity based cost modeling. Activity based cost modeling is a bottom-up approach to cost. A process flow is broken down into discrete steps, or activities, and the various types of cost associated with each activity are accounted for. The types of cost are:

- The time required to complete the activity
- The amount of labor dedicated to the activity
- The cost of material required to perform that activity – both consumable and permanent material
- Any tooling cost
- The depreciation cost of the equipment required to perform the activity
- The yield loss associated with the activity

III. RDL Process Flow and Cost Drivers

RDL creation is typically a series of imaging and plating steps. The activities captured by the RDL creation process as defined in this analysis start with a dielectric layer, then a metal layer, and conclude with another dielectric layer.

Some fan-out packages may have more than one RDL. The activities described below will not change in that case; some of them will just be carried out multiple times. One RDL layer will typically require two dielectric layers, two RDL layers will require three dielectric layers, and so on. The activities listed in Tables 1 and 2 describe the creation of a single RDL.

Table 1. Activities in RDL Creation

Cost Model Step Name	
Spin coat dielectric	These are the lithography steps to apply and then image a photoimagable dielectric; these steps conclude with some metrology and cleaning to prepare for the metal application.
Soft Bake	
Mask/Reticle Cost	
Dielectric Expose	
Clean Mask	
Dielectric Develop	
Dielectric Cure	
Descum	
Oxide Removal	
Thickness Measure	
Warpage Measure	
Warpage Adjustment	
Inspection	
Bake	
Sputter Barrier (Ti)	A seed layer is sputtered before photoresist application to define the areas which should be plated.
Sputter Seed (Cu)	
Coat PR	
Mask Cost PR	
Expose PR	

There are a total of forty activities listed in these two tables, which represent about half of the steps involved in a one-die, one-RDL process flow. The fact that there are so many steps required for RDL creation means there are many steps where variations may occur. There is not a single method for creating an RDL. The one selected for this cost model reflects a generic RDL creation as would be carried out on a traditional bump line using photoimagable polyimide. An alternative process would be a dual damascene process. Additionally, there may be variations within individual steps. This process assumes a spin-on, photoimagable dielectric, but a dryfilm may be used, or a process flow that supports a non-photoimagable dielectric.

Table 2. Activities in RDL Creation (Cont'd)

Cost Model Step Name (process cont'd)	
Clean Mask PR	A few cleaning steps occur, then the metal is plated to form the RDL, the resist is stripped, and some final metrology and cleaning take place. This step accounts for the yield fall-out from the lithography process. A final yield hit step is included to account for the yield impact of the lithography.
Develop PR	
Descum 1	
Inspection (Optical)	
Plate RDL	
Strip Resist	
Thickness Measure	
Etch Seed	
Etch Barrier	
SRD	
Descum 2	
RDL Clean	
Yield Hit	
Spin coat dielectric	Final lithography steps to apply and define the top layer of dielectric.
Soft Bake 2	
Mask/Reticle Cost	
Dielectric Expose 2	
Clean Mask 2	
Dielectric Develop 2	

The two tables below break down the cost contribution of different steps within RDL creation. The top cost drivers are the photoimagable dielectric, the photoresist, the sputtering, and the plating steps.

Table 3. Cost Contribution of RDL Steps

Step Name	% of RDL cost
Spin coat dielectric	14.03%
Soft Bake	0.22%
Mask/Reticle Cost	0.38%
Dielectric Expose	3.44%
Clean Mask	0.30%
Dielectric Develop	3.63%
Dielectric Cure	0.66%
Descum	1.23%
Oxide Removal	2.85%
Thickness Measurement	0.04%
Warpage Measurement	0.11%
Warpage Adjustment	0.19%
Bake	0.06%
Sputter Barrier (Ti)	6.92%
Sputter Seed (Cu)	6.92%
Coat PR	9.61%
Mask Cost PR	0.38%
Expose PR	5.16%
Clean Mask PR	0.30%

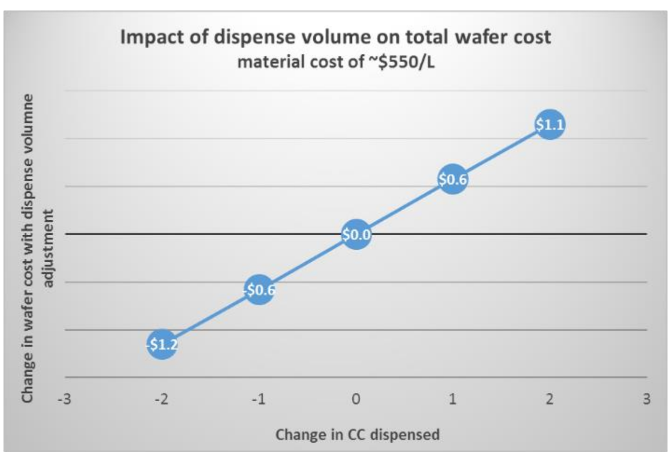
Table 4. Cost Contribution of RDL Steps (Cont'd)

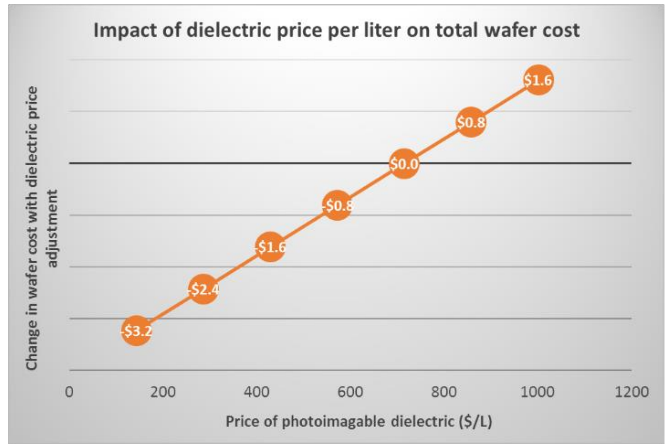
Step Name	% of RDL cost
Develop PR	3.63%
Descum 1	1.23%
Plate RDL	4.65%
Strip Resist	1.28%
Thickness Measurement 2	0.04%
Etch Seed	1.52%
Etch Barrier	1.52%
SRD	0.13%
Descum 2	1.23%
RDL Clean	2.85%
Yield Hit	1.28%
Final-Spin coat dielectric	14.21%
Final-Soft Bake 2	0.22%
Final-Mask/Reticle Cost	0.38%
Final-Dielectric Expose 2	3.49%
Final-Clean Mask 2	0.31%
Final-Dielectric Develop 2	3.67%
Final-Dielectric Cure 2	0.67%
Final-Descum 2	1.24%

IV. Sensitivity Analysis

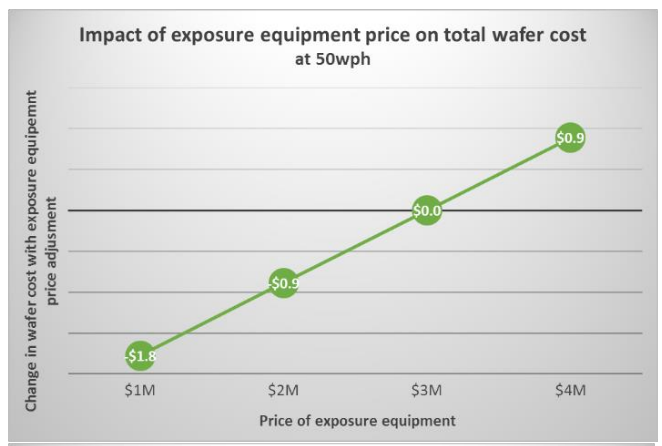
Application of the dielectric, which includes the dielectric material cost, is the most expensive step. The next most expensive step is spin-coating the photoresist for the metal layer, and after that, the sputtering, exposure, and plating steps related to metallization. The sensitivities explore the dielectric step, the exposure step, and the sputtering steps.

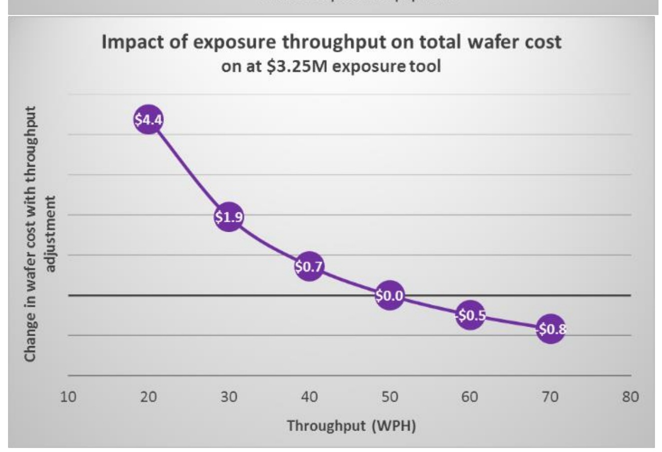
The first two charts focus on the expensive photoimagable dielectric. The sensitivity of the price and the dispense amount is tested.



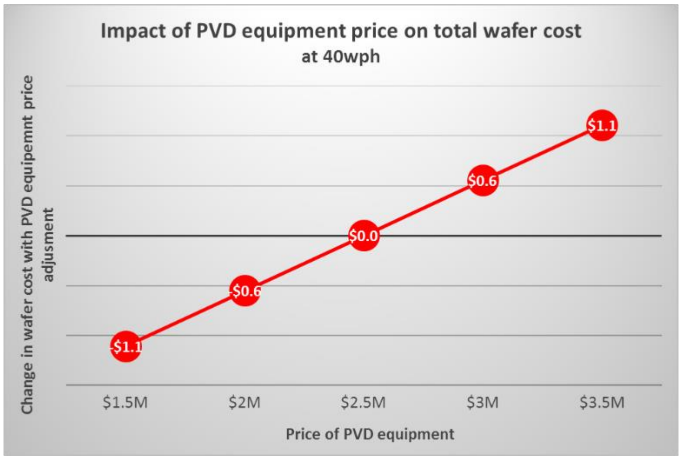


The second two charts focus on exposure equipment throughput and price. The equipment needed for a fan-out WLP process will depend largely on line and space requirements and properties of the materials being imaged. If a stepper is required, the price will be on the higher end; if an aligner can be used, the capital cost may be lower. The price of the exposure equipment has an expected, linear relationship to package cost. The impact of throughput is also notable, though an increase of ten wafers per hours has a much greater impact when going from twenty to thirty, versus going from sixty to seventy.





While depositing the seed layer prior to plating the RDL is not the most expensive step of RDL creation, it is still a cost contributor for the fan-out WLP process, primarily due to equipment price. The following chart shows the impact of the equipment price.



V. Yield Analysis

A key element of cost is yield. To discuss yield, the cost of the entire package must be considered. There are a variety of steps in the fan-out process that may introduce defects; RDL creation is one of them. Depending on whether a die-first or die-last process is being employed, defects introduced during RDL creation may be costly.

A. Die-first FOWLP

Table 5 shows the impact of defects introduced during RDL creation for a small, medium, and large design. The same defect density settings were tested for each design, but this results in a different effective process yield in each case, so the resulting final yield is listed as a reference. The impact on cost is shown as a percent increase. The first row, which has zero additional defects and zero percent, is the baseline. Note that the 0.0 defect density assumption does not mean there are no defects in the entire process—there are defect density assumptions throughout the baseline process already. The first row only refers to zero new defects on top of the baseline.

The larger the package and die size, the more notably the resulting cost is affected. There are two reasons for this. First, the same level of defect density will impact differently sized packages differently. Defect density is the probability that a defect will occur in a 1cm2 area. The model assumes that one defect anywhere within the package area will cause that package to be scrapped. The larger the package is, the more likely that a defect will occur somewhere within the package area.

Second, a $5000 incoming wafer is assumed in all cases. This same wafer diced into different die sizes means the larger die bring a more expensive cost into the larger package. Therefore, any larger packages that have to be scrapped will include the loss of a more expensive die.

Table 5. Impact of Defects on Die-first FOWLP

Additional Defects per cm^2	***4mmx4mm package, 2mmx2mm die***	
	Resulting Total Yield	***% Cost Increase from Baseline***
0.00	99.6%	0.00%
0.02	99.3%	0.32%
0.04	99.0%	0.63%
0.06	98.7%	0.95%
0.08	98.4%	1.26%
Additional Defects per cm^2	***8mmx8mm package, 5mmx5mm die***	
	Resulting Total Yield	***% Cost Increase from Baseline***
0.00	98.5%	0.00%
0.02	97.3%	1.24%
0.04	96.0%	2.45%
0.06	94.8%	3.68%
0.08	93.6%	4.88%
Additional Defects per cm^2	***12mmx12mm package, 9mmx9mm die***	
	Resulting Total Yield	***% Cost Increase from Baseline***
0.00	96.7%	0.00%
0.02	94.0%	2.67%
0.04	91.3%	5.28%
0.06	88.7%	7.83%
0.08	86.2%	10.31%

B. Die-last FOWLP

A similar analysis to the die-first analysis above was carried out for die-last, but the results are more complicated because the results are heavily dependent on whether the defect is introduced before or after die placement, which means during or after RDL creation. If a defect is introduced during RDL creation, only the cost of the processing will be lost (under the assumption that die are placed only on known good locations).

In this analysis, instead of adjusting the size of the die and package, the focus is on the change in total cost depending on whether the defect is introduced before or after die placement. The design evaluated is an 8x8 package with a 5x5 die and 300 I/Os. The incoming die comes from a $5000 wafer, and the cost to bump and dice that wafer is included in these results.

The results show clearly that the cost impact of a defect introduced after die placement is more dramatic than that of a defect added during RDL creation and discovered before die placement.

Table 6. Impact of Defect Timing in Die-last FOWLP

Additional defects per cm2	***Total Yield***	***% Cost Increase if defect occurs after die placement***	***% Cost Increase if defect occurs before die placement***
0.00	98.53%	0.0%	0.00%
0.02	97.25%	1.0%	0.11%
0.04	95.98%	2.0%	0.22%
0.06	94.86%	3.0%	0.34%
0.08	93.65%	4.1%	0.45%

VI. Conclusion

The creation of an RDL is a key cost contributor in a fan-out package. Depending on the details of the design, the steps that go into creating an RDL may represent half of the entire process flow. Therefore, any reduction in the cost of an RDL will have an impact on the total cost of the package.

Steps within the RDL process that contribute the highest cost are the application of a photoimagable dielectric, the application of photoresist, sputtering, and the plating steps. Sensitivity analysis was carried out to show the impact on total wafer price when key variables within those steps were adjusted. Yield analysis was also carried out to show how total package cost is affected by a defect introduced during RDL creation.