Cost Comparison of Temporary Bond and Debond Methods For Thin Wafer Handling

Amy J. Palesko, Chet A. Palesko
SavanSys Solutions LLC
Austin, Texas

Abstract
Miniaturization and increased performance demands are driving the industry to explore 2.5D and 3D packaging. Although progress has been made in recent years, many barriers remain. One primary cost driver for 2.5D and 3D processes is the temporary bond and debond method used for thin wafer handling. Various solutions are appearing on the market, but there is not a single method taking the lead as the obvious best choice. Many factors must be considered when looking at the total cost of a thin wafer handling solution. In this paper, we will use cost modeling to carry out detailed cost and yield trade-offs for temporary bond and debond methods. Instead of concentrating on one proposed solution that is available on the market, we will analyze a range of solutions, focusing on variables such as tool cost, material cost, throughput, and yield. With this analysis, we will determine the most significant cost drivers within the temporary bond and debond process and propose process details for a reasonable solution.

Introduction
The cost model used for conducting trade-offs and exploring key cost drivers in this paper is a generic model. A process flow was designed to cover the basic process steps required for any temporary bond and debond process, while leaving out extra steps that are required for only one or two particular methods. The variables that can be adjusted within the generic process flow are diverse enough to allow for values that represent different methods.

This cost model was designed to study the key cost drivers of the temporary bond and debond process, but it is not intended as a detailed survey of all methods available today. In the results section, this paper addresses various features of the entire process (e.g. how higher temperature may affect yield, what the impact of stress applied at debond may be) without tying those features to a specific technology. By looking at an overview of key variables—tool cost, material cost, throughput, and yield—the goal of this cost comparison is to provide both technology vendors and users with an understanding of the key drivers that affect total wafer cost.

Activity Based Cost Modeling
Activity based cost modeling and parametric cost modeling are the two dominant cost modeling methods. Parametric cost modeling is done by statistically analyzing a large number of actual results and creating a model that matches as closely as possible. This "black box" approach, as an extrapolation based on historical data, is only appropriate for modeling processes that change slowly over time or cannot be decomposed into individual activities.

For reliable and dynamic trade-offs, activity based cost modeling is the most accurate cost modeling method because individual activities are characterized and analyzed. The total cost of any manufacturing process is calculated by dividing the process into a series of activities and totaling the cost of each activity. The cost of each activity is determined by analyzing the following attributes:

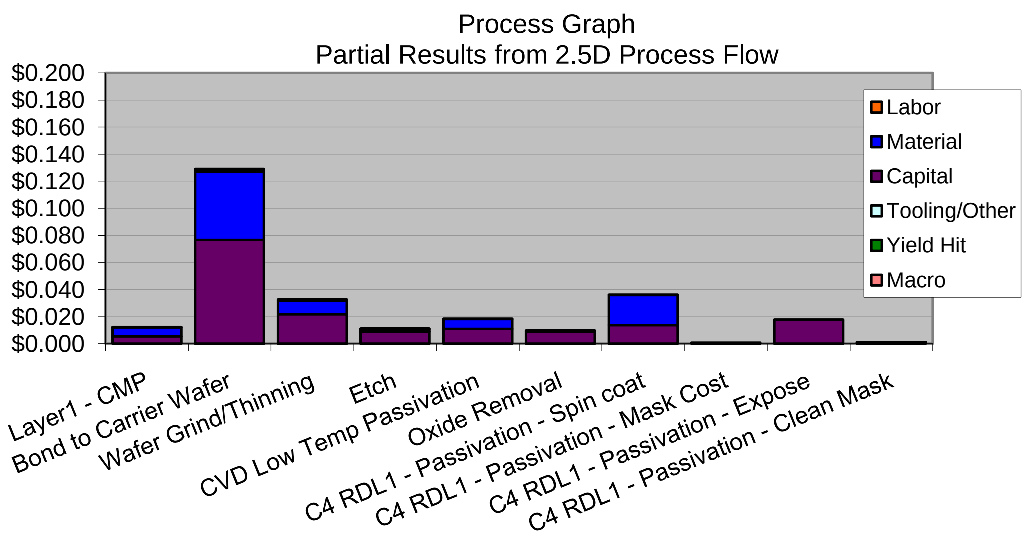
- The time required to complete the activity
- The amount of labor dedicated to the activity
- The cost of material required to perform that activity—both consumable and permanent material
- Any tooling cost
- The depreciation cost of the equipment required to perform the activity
- The yield loss associated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

Activity based cost modeling is also well suited to comparing different technologies and manufacturing processes. The total cost of a product can be divided into the following three categories:

- Direct manufacturing cost
- Allocated factory overhead
- Profit margin

The direct manufacturing cost is easy to quantify and reasonably consistent across the industry. However, factory overhead and profit margin vary significantly between different manufacturing sites and companies. By using activity based cost modeling, the specific differences in manufacturing cost can be determined by comparing the direct manufacturing costs. This “relative” cost modeling makes it much easier to understand the cost impacts—good or bad—of design decisions and technology tradeoffs.

The graph below shows a partial example of an activity based cost graph for a 2.5D process flow. Each activity contributes cost in at least one of the six categories shown. The steps shown in the graph below are the steps immediately before and after bonding the device wafer to a carrier wafer. In this series of steps, the primary cost drivers are material and capital, as seen by the blue and purple bars.



Results

The generic process flow used to study key cost drivers in the temporary bond and debond process is summarized below.

- Wafer preparation (apply adhesive) – The equipment cost and throughput of this step are based on typical spin-on activities; the variable adjusted in this step is the material cost, to account for the cost of a temporary bond/debond adhesive.
- Temporary bond device wafer to carrier wafer – This step contains no variables; this study focuses on changing the cost and throughput of the debond equipment only, although those same variables could be applied to temporary bonding equipment as well.
- Wafer mount (prep for debond) – This step has no changing variables, and represents a process with high throughput on an inexpensive piece of equipment; it also includes a material cost adder. This step represents a simple process such as mounting the wafer stack on dicing tape prior to debond.
- Debond from carrier wafer – This step has three variables which are adjusted for the cost driver analysis: throughput, equipment cost, and material cost.
- Yield hit – This step accounts for the yield of the entire temporary bond and debond process

The process flow is assumed to be carried out on a fully processed, 300mm device wafer (for a 2.5D application) that costs $700. Overhead and profit margin are applied to the base wafer cost, but not to the temporary bond and debond activities. This means that the numbers presented in this paper are a comparison of direct costs, rather than price. Finally, all scenarios presented assume highly automated lines. In a real factory, there may be potential cap ex and load balancing issues to consider from an equipment standpoint.

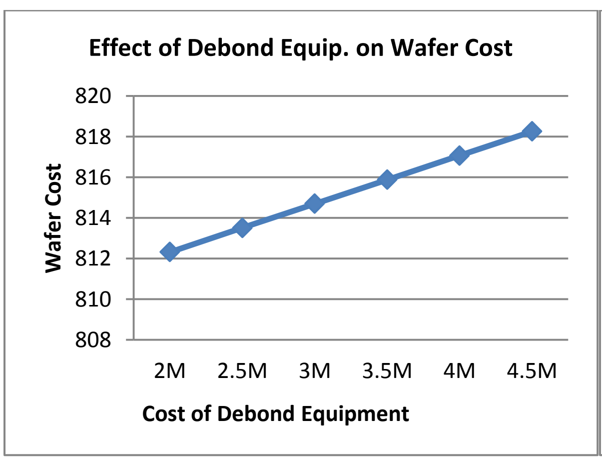
To summarize, the only variables changed in this process are: adhesive material cost, debond equipment cost, debond throughput, and yield. There is also a material factor that can be added for debond as a cost per wafer. In most scenarios, this variable remains static, and is only used to account for unique debond scenarios which required specialized materials or activities.

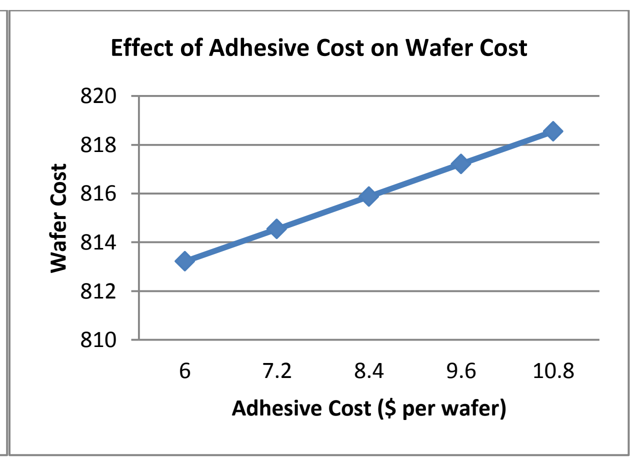
A cost model representing a real temporary bond and debond method would have more process steps than the basic ones listed above. There are often numerous steps required for bond and debond activities alone, including but not limited to wafer preparation, solvent application, simple bakes, and cleaning steps. By using a simplified version of the model, high level, key cost drivers that will generally apply to all process flows can be analyzed. To understand subtler differences, cost models based on each proprietary bonding method would have to be constructed.

Before carrying out detailed trade-offs, a sensitivity analysis was run on the four primary variables. The first two graphs below display the linear cases of changing equipment and adhesive material cost while holding all other variables steady.

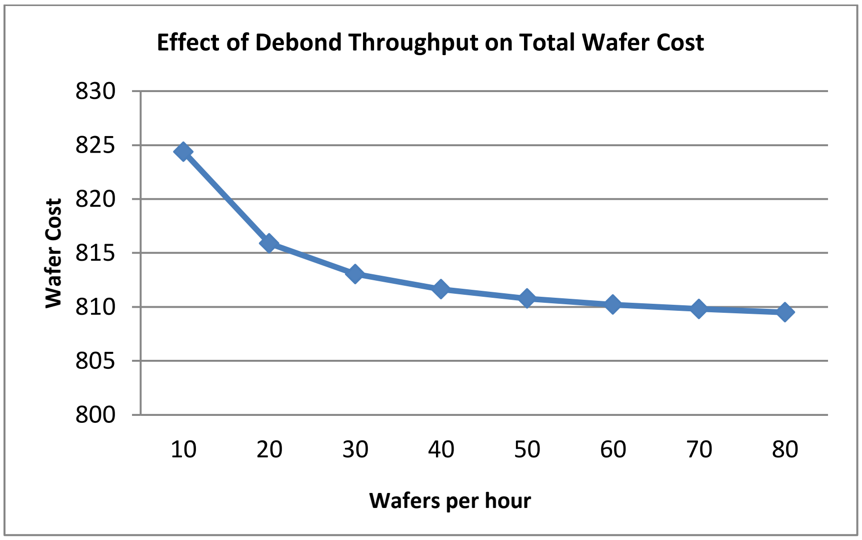
There are multiple factors that may affect adhesive cost. Different formulations and chemicals will be more or less expensive; the amount of material required for a particular type of bond process will affect the material cost associated with that step; some temporary bond processes require two materials, with both either layered on to the device wafer, or one applied on the device wafer and the other on a temporary carrier [1]. Considering all of these factors, material costs may vary widely. For the purpose of this cost model, the adhesive cost per wafer was calculated based on a reasonable amount of material dispensed per wafer [2], and a range of prices from $400 to $900 per liter of adhesive.

In contrast to the adhesive material cost, the reason for a higher or lower debond equipment cost is straight-forward. Tools with better capabilities, whether due to increased throughput or better yields or another factor, will cost more. In the cost model used, the equipment is assumed to depreciate over five years.

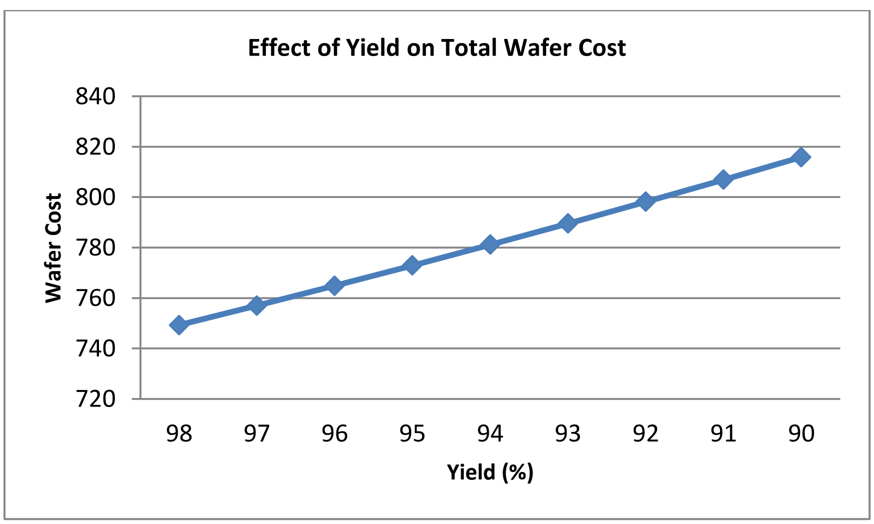




The effect of throughput on wafer cost is graphed below. Unlike the other variables, the impact here can be seen as a curve, rather than as a linear relationship. This is because the impact on the total wafer cost is based on minutes per wafer, but the conventional unit for throughput for a tool tends to be expressed in wafers per hour (wph). A change from 10 wph to 20 wph is the difference between 6 minutes per wafer and 3 minutes per wafer, which is a major change. However, an increase from 50 wph to 60 wph is only the difference between 1.2 minutes per wafer and 1 minute per wafer. Therefore, increasing the wph by 10 does not necessarily have a linear impact on the final wafer cost. The graph clearly indicates that there are greater cost benefits to be gained from increasing throughput from 10 and 20 wph up to 40 or 50 wph. Once the throughput reaches the level of 50 wph, there are diminishing returns as throughput increases.



The final sensitivity analysis focuses on yield. Similar to the material and equipment cost graphs on the previous page, the relationship here is linear. However, where a single change in one of those previous variables created a difference of 1 or 2 dollars, every percentage change in yield has a 7 or 8 dollar effect on the total cost of the wafer.



Based on the results of all of these sensitivity analyses, it's clear that yield is a key cost driver. There are many factors within the temporary bond and debond process that may affect yield, depending on the method selected. For example, thermal slide debond may impact yield based on the heat required. Chemical debond processes can affect yield due to the chemicals used, which may degrade the dicing tape the wafer is mounted on [3]. Processes that require a vacuum during debond may create defects due to pockets created in the adhesive [4]. Some methods of debond will create more stress on the thinned wafer, or there may be a period of time when the thinned wafer is not supported sufficiently during a cleaning step. These are only some of the ways in which yield may be affected during the temporary bond and debond process.

Trade-Offs

In this final section, a variety of trade-offs were carried out to compare the impact of changing multiple variables at once. With four variables to adjust (and the option of adding a debond material cost adder), there are hundreds of combinations to consider. To limit the number of combinations, all variables were adjusted within a limited range, with about five or six choices for each. Yield has been limited to a range of 95% to 97%, which this paper assumes to be achievable once the process reaches maturity. Due to the fact that yield is a major cost driver, three of the four scenarios in this section focus on yield. The basic question these trade-offs are designed to answer is: when does it make sense to pay more?

<u>Scenario 1 – More expensive material lowers throughput, increases yield</u>

This scenario describes a situation in which more expensive material is used to increase yield, but at the expensive of throughput. The cost of the debond equipment is $3M, and there are no additional material cost adders in the debond step.

Debond Throughput (wph)	Adhesive Cost ($/wafer)	Yield	Total Wafer Cost
60	6	95%	$764.67
60	7.2	95%	$765.93
40	8.4	95.5%	$764.33
40	9.6	95.5%	$765.58

Note that a small increase in the adhesive material cost may result in a lower total wafer cost, even with a loss of throughput, but increasing the adhesive cost too much will outweigh the benefit of the yield improvement.

<u>Scenario 2 – Equipment throughput and cost versus yield</u>

In this scenario, equipment cost is increased and throughput is lowered to achieved better yields. The adhesive cost is the same for all scenarios, and there are no additional debond material costs applied.

Debond Throughput (WPH)	Equipment Cost	Yield	Total Wafer Cost
40	3M	95.5%	$761.81
30	4M	96%	$760.47
20	4M	96.5%	$759.55

Note that even when investing in a tool that is more expensive by one million dollars and has a slower throughput, an increase of 0.5% yield still results in a lower total wafer cost. Even when the throughput decreases further, to achieve even higher yield in the last row, the final wafer cost is still improved. These examples highlight the importance of yield when considering equipment costs and specs.

<u>Scenario 3 – Debond throughput versus equipment cost</u>

This scenario compares a more expensive piece of equipment with a high throughput and a slower, less expensive tool. Material cost and yield remain the same, and there is no addition material cost adder due to debond.

Debond Throughput (WPH)	Equipment Cost	Yield	Total Wafer Cost
80	3M	95%	764.09
40	2M	95%	764.7

These results are interesting because they reveal that the total wafer cost is affected by less than a dollar even when the throughput is cut in half due to a shift to less expensive debond equipment.

<u>Scenario 4 – Equivalent costs at different yields</u>
In the preceding three scenarios, examples were selected where at least two or three variables were kept the same. In this final table, examples were selected at four yield points where the total wafer cost was as close to $761 as possible. As this paper has already established, yield is a dominant cost driver. This table was created to determine if it was possible to achieve equivalent costs even at different yields. A total wafer cost approaching $761 did not result from any of the scenarios tested at 95% yield, so that option is not included in the table below.

Debond Throughput (WPH)	Debond Equipment Cost	Adhesive Cost ($/wafer)	Yield	Debond Material Cost Adder ($/wafer)	Total Wafer Cost
40	3M	6	95.5%	1	$761.81
30	4M	7.2	96%	1	$761.72
20	4M	7.2	96.5%	1	$760.79
20	4M	9.6	97%	3	$761.4

Rows one, two, and three are straightforward, in that more expensive material and more expensive equipment were required to achieve better yields, always at the expense of throughput. The final option highlights the impact of two material cost increases, one being a more expensive adhesive, and the second being an additional material cost required due to specialized debond activities designed to improve yield.

Summary

An activity based cost model was designed to study the key cost drivers of the temporary bond and debond process. Instead of looking in detail at the numerous temporary bond and debond methods currently on the market, this cost model was used at a higher level to study the impact of a few key variables applicable to all methods: adhesive cost, debond equipment cost, debond throughput, and yield.

Based on a sensitivity analysis of each variable, it was concluded that adhesive and debond equipment cost both have a linear effect on the total wafer cost, while changes in debond throughput do not impact the total wafer cost with as much magnitude after a throughput of approximately 50 wph is achieved. Yield also affects the total wafer cost with a linear trend, and a change in 1% results in 7 or 8 dollars per wafer.

Trade-offs were then carried out using this basic cost model to compare different scenarios in which multiple variables were changed. The key conclusion that can be drawn from these trade-offs is that despite the major impact of yield changes, there are still scenarios in which extra costs to achieve better yield did not necessarily result in an improved total wafer cost.

References

[1] R. John, “Low Cost, Room Temperature Debondable Spin on Temporary Bonding Solution: A Key Enabler for 2.5D/3D IC Packaging,” The Institute of Electrical and Electronics Engineers, Incorporated, 2013.

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[4] J. Hermanowski, “Thin Wafer Handling – Study of Temporary Wafer Bonding Materials and Processes,” IEEE International Conference on 3D System Integration, 2009.