Cost Analysis of a Wet Etch TSV Reveal Process

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Through silicon via (TSV) technology is a key design element being incorporated into more and more advanced packaging designs today. TSVs offer distinct benefits in form factor and improved performance and can enable new, innovative designs not previously possible. To scale this valuable technology and spark industry adoption, there is a need to refine and optimize the TSV reveal process to reduce costs in every step.

Veeco's Precision Surface Processing Business Unit (PSP) has introduced a wet etch tool and process that reduces the number of steps and the cost of the TSV reveal process. A SavanSys cost model was built to analyze and compare the Veeco process with the current industry TSV reveal process of record (POR) (dry etch). This knowledge portal entry provides a cost comparison between these two process methods and highlights key cost drivers.

TSV Reveal Process

The TSV middle process appears to be the preferred integration scenario. Figure 1 shows the sequence for the reveal process after the wafer has been bonded to a carrier and gone through an initial grinding to thin the bulk of the silicon wafer. The step we are focusing on for this discussion, the Silicon etch for the TSV reveal, is highlighted in the yellow box.

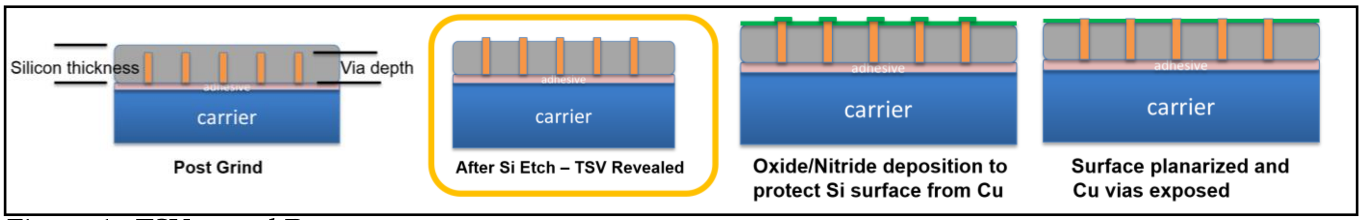


Figure 1. TSV reveal Process

After the mechanical grinding process to remove the bulk of the silicon, an additional thinning process is required to safely reveal the vias, while also eliminating the surface roughness and defective silicon resulting from the grinding process. This final etch and surface conditioning can be done with either a combination of CMP and plasma dry etching, or wet chemical etching. CMP is typically not used alone to do the actual reveal of the vias due to the potential for Cu contamination of the silicon when the copper is exposed during the polishing process.

CMP processes use expensive slurries and critical post-cleaning steps to remove the slurry particles and other contaminants. Plasma processes usually require expensive equipment and etching gases along with much higher consumable and maintenance costs. The plasma etch process also requires a separate wet cleaning step following etch.

Alternatively, Veeco's advanced wet etch equipment and process, replaces the four tools used in the dry etch POR (CMP, plasma etch, clean, and silicon thickness measurement). The key to making the wet etch process most economical is eliminating the CMP step in the sequence. The Veeco two-step wet etch process, performed in a single tool, accomplishes this in a simpler, less costly process.

The first step in the wet process uses a high-rate silicon etch to contour and smooth the silicon surface to within ~2 µm of the TSVs. This first step eliminates grinding marks and compensates for the non-uniformities in the silicon to be etched. Following this step, the chemistry is changed to the SACHEM

Reveal Etch™ to precisely uncover the vias since this etchant is selective to silicon and does not etch the oxide liner covering the TSVs. Etching is controlled by integrated measurement of the silicon before and after the processes using Veeco's Profile Match Technology™.[i]

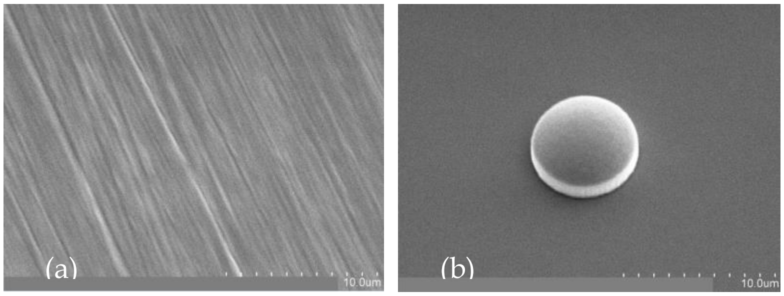


Figure 2. SEM images to illustrate surface roughness
(a) Post Grind and smoothing (b) Post TSV reveal

Veeco Profile Match Technology measures the incoming silicon thickness and determines the etch profile based on the TSV depth data and reveal height requested. The ability of the etch profile control to compensate for radial variations in the silicon thickness results in a more uniform reveal height, and thereby reduces the amount of reveal required. Lower reveal heights translate into lower passivation deposition and then, less final CMP to expose the Cu surface.

Activity Based Cost Modeling

Cost modeling was used to understand the key cost drivers of the TSV reveal process and to compare the two etching methods. Activity based cost modeling is a detailed, bottom-up approach to understanding cost. A process flow is broken down into individual activities, and the cost considerations for every activity are accounted for.

Table I. Direct Cost Components Used in Activity Based Cost Modeling

Direct Cost Components	**Description**
Time required for the activity	Used to calculate labor and equipment cost
Labor dedicated to the activity	Usually a percentage of a person combined with activity time
Material required to perform the activity	Consumable and permanent materials; directly added to total cost
Tooling	Not usually relevant for med/high volume products
Equipment Depreciation	Calculated using equipment availability time, number of years of depreciation, and time for process step
Yield loss	Usually defects per million opportunities for assembly models, and defects per area for fabrication models

Cost Analysis and Trade-Offs

From the perspective of breaking down cost into process flow sections, the TSV reveal process begins with bonding to a carrier wafer, proceeds through a variety of grinding and CMP steps that occur before and after the dry etch, and includes CVD passivation after the vias are revealed. A few metrology steps are included as well. For the purpose of this cost analysis, the total reveal process cost and the direct reveal (wet or dry etch) process cost will both be considered.

It is helpful to consider how the TSV reveal steps fit into a larger process flow. With a better understanding of how much or how little cost a particular section of a process flow contributes, better design and cost decisions can be made.

Figure 3 shows a direct cost breakdown of a generic interposer-based process. In this process flow (die on interposer on substrate) is considered, TSV-related processes account for over half of the total cost. This percentage is heavily dependent on the other design parameters, such as what kind of assembly is used, how many redistribution layers (RDLs) are required, and so on. However, even with the caveat that many variables are at play, it is clear that any processes related to TSV–whether creation or reveal–are significant.

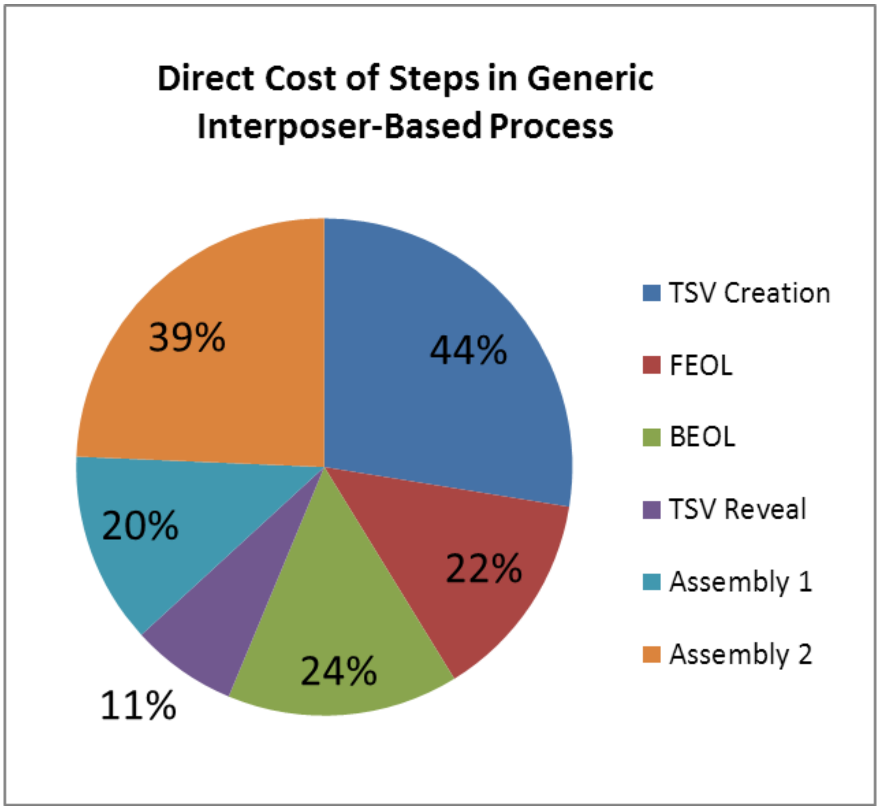
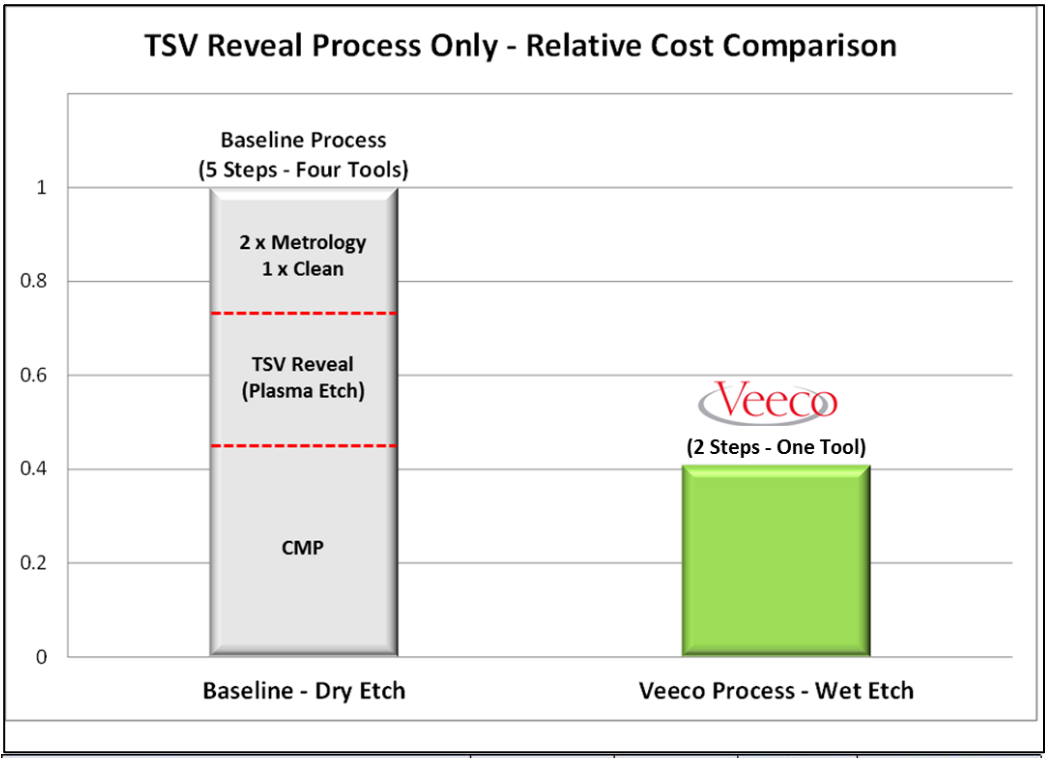


Figure 3. Direct Cost of Steps in Generic Interposer-Based Process

With TSV reveal accounting for about 10% of the cost of the entire process flow, it is clear that total product cost can be significantly impacted by even this small subset of steps.

Figure 4 summarizes a baseline cost comparison between wet etch and dry etch, focusing only on the individual steps that make up the direct TSV reveal step(s). The equipment costs, throughputs, and material costs associated with both process flows are based on industry standard data. Because every factory is different, utilizing different tools, different chemistries, and different protocols, the sensitivity analyses presented later are important for understanding the impact of different variables within each type of reveal process. It should be noted that the yields for both processes were assumed to be equal. Potential defect reductions may be obtained that would add to the cost benefits.



Reveal Process Only	Capital	Material	Other (Labor)	Step Cost (Normalized)
Baseline - Dry Etch (Five Steps)	66.2%	32.4%	1.4%	**1.00**
CMP	34.7%	64.1%	1.2%	0.46
TSV Reveal (Plasma Etch)	90.7%	7.8%	1.5%	0.26
2 Metrology Steps + 1 Clean	94.9%	3.5%	1.6%	0.28
Veeco Process - Wet Etch (One tool)	78.6%	17.9%	3.5%	**0.41**

Figure 4. Direct TSV Reveal Process Step Comparison

The total wet or dry reveal cost is presented as a normalized cost, while the individual cost contributors in each step and category are presented as percentages. Even without a comparison of absolute values, a few conclusions can immediately be drawn.

First, given this set of baseline assumptions, the process utilizing a two-step reveal etch that combines the activities in the baseline is less than half the cost of the baseline process. Second, this type of comparison makes it easy to identify where cost is coming from in each step, rather than just identifying the cost of each step. Within the baseline process flow, the plasma etch process contributes a high capital cost, while the CMP step contributes a high material cost. In the two-step reveal process for wet etching, most of the cost comes from the cost of the equipment. This is not a surprising result, as it eliminates complicated steps and simplifies the process into just one tool.

When investigating the cost of a new technology, this type of cost comparison is not enough: a more robust analysis must be carried out. Making a single set of baseline assumptions and drawing conclusions does not account for the vast differences between processes and factories. Sensitivity analysis is important to understand the impact of individual variables. Etch rate was selected for sensitivity analysis for the purpose of this entry. Additional variables such as material cost and equipment cost could be tested as well.

Etch Rate
One of the key variables in both processes is throughput, which is directly dependent on etch rate. The following two charts illustrate how the cost of the reveal steps change as the etch rates change.

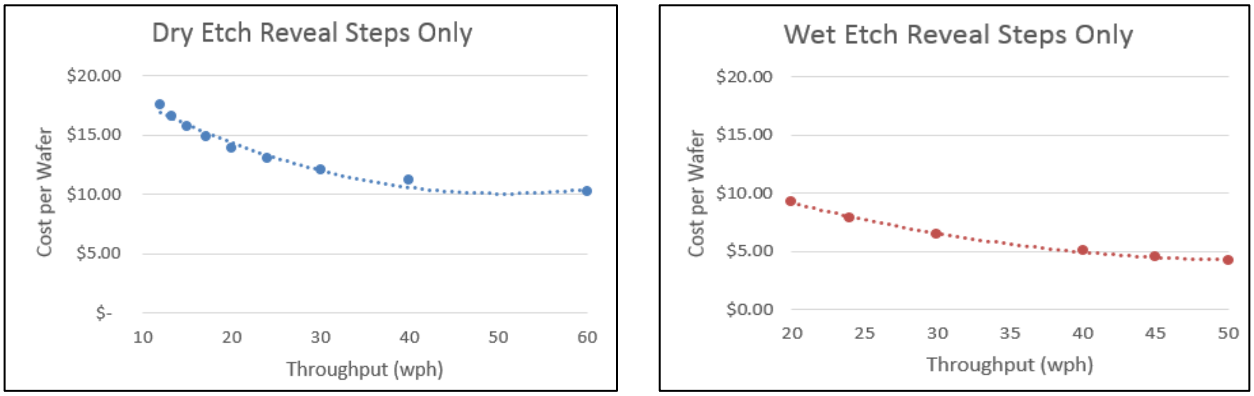


Figure 5. Etch Rate Sensitivity Analysis

An improvement in etch rate has a significant impact on the cost of both processes. This is a helpful comparison to consider, as a factory planning to invest in a new piece of equipment may want to understand the cost impact if there are barriers that prevent the best throughput from being achieved. Sensitivity analysis helps with this decision. The charts reveal that even a less than ideal throughput with the wet etch process does not prevent the process from being cost effective.

Equipment and Material Sensitivities
The graphs charting the sensitivity of the wet etch process to both equipment cost and material usage are shown in Figure 6. They each have an expected, linear impact. Changing the equipment price affects the reveal step by about a dollar per wafer with a million dollar price change. This is not surprising, considering that capital is about 80% of the cost of this novel wet etch reveal process. Material cost within the wet etch tool is calculated as a per wafer material usage, so any change in the dollars per wafer input has the same impact on the dollars per wafer resulting cost, as seen in the graphs below. The material cost would change if either the price of the chemicals increased, or the amount of chemical required increased.

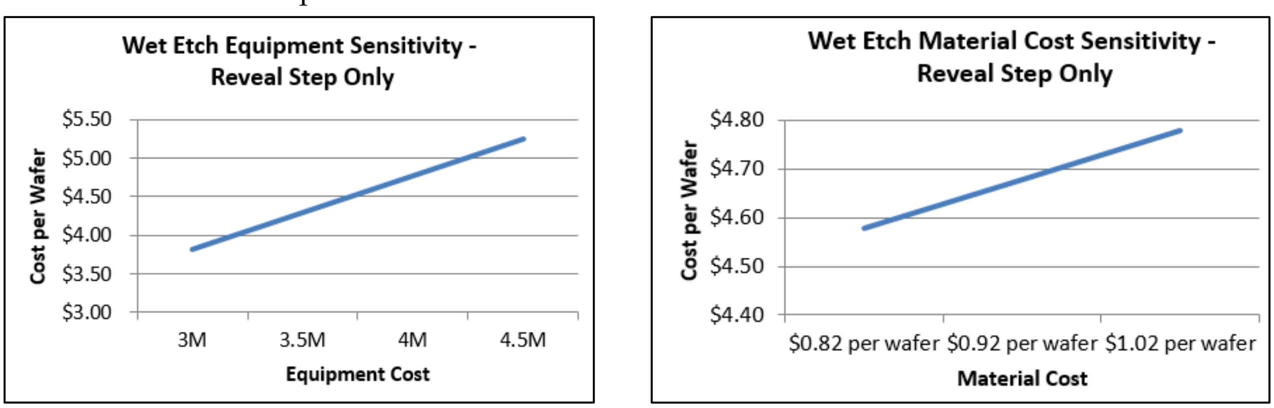


Figure 6. Equipment and Material Price Sensitivities

Conclusion
The Veeco wet etch process replaces four tools used in the dry etch process (CMP, plasma etch, clean, and silicon thickness measurement), simplifying the process by incorporating a streamlined, two-step process in one wet etch tool.

Activity-based cost modeling conducted by SavanSys was used to carry out a baseline cost comparison of the wet etch and dry etch processes. The cost contributors in both cases were identified, and the wet etch process was revealed to be more cost-effective. Sensitivity analysis showed that the wet etch process carries a cost advantage in many cases.