Photoresist strip using advanced single-wafer process technology

By Laura Mauer, Scott Kroeger [Veeco Precision Surface Processing], and Amy Lujan [SavanSys Solutions]

Photoresist strip is a key lithography step in many electronics packaging process flows. There are a variety of photoresists and processes available depending on the lithography requirements. In addition, there are different methods for stripping the negative dry film photoresist that is typically used for advanced packaging applications.

The focus of this analysis is the Veeco Precision Surface Processing WaferStorm® tool featuring ImmJET™ high-performance immersion and single-wafer spray process technology. The tool and chemistry are introduced, along with a cost analysis of the key variables of the strip process. The cost modeling portion, conducted by SavanSyS Solutions LLC, includes a comparison of the Veeco tool to other available processes, such as batch immersion and spray tools.

The approach to understanding the cost elements associated with each technology is activity-based cost modeling. In this methodology, a process flow is broken down into activities, and the cost components of each activity–including labor, material, capital, tooling, and yield–are analyzed. The goal of this analysis is to evaluate the ImmJET technology, and to understand the key cost drivers associated with photoresist strip.

Background

A thick photoresist pattern is required for the formation of tall bump structures, shown in **Figure 1**. Dry film resist provides the advantage of uniform resist thickness across the entire wafer, eliminating the need to do multiple coatings and edge bead removal. However, since these are negative working polymers, they are highly cross-linked and more challenging to remove. The complete removal of the film and cleaning of the surface is critical to the yield of the next step, which is etching of the underlying metal seed layers.

A successful process results from the proper choice of tool technology, solvent, and process to completely remove the dry film without any residuals that would block subsequent etching. Wet benches are commonly used for photoresist stripping processes. A batch of wafers is loaded into an immersion station with heated chemistry for a long soak. Typical wet-bench configurations include multiple soak tanks. The first immersion station is the "dirty" tank where the bulk of the resist saturates the solvent. The second tank typically involves a "cleaner" solvent process after which the wafers are transferred to a final rinse tank before drying. Single-wafer spray systems have also been used as an alternative to batch processes. However, the length of time for the spray process is quite long for these highly cross-linked dry film resists and, though this process can be effective at removing the resists, the cost-of-ownership is too high to be feasible in a high-volume manufacturing process. Here, we present a new high-performance immersion and spray process technology, called ImmJET, which combines an optimized immersion step and single-wafer spray process to produce high-yield results at a low cost-of-ownership.

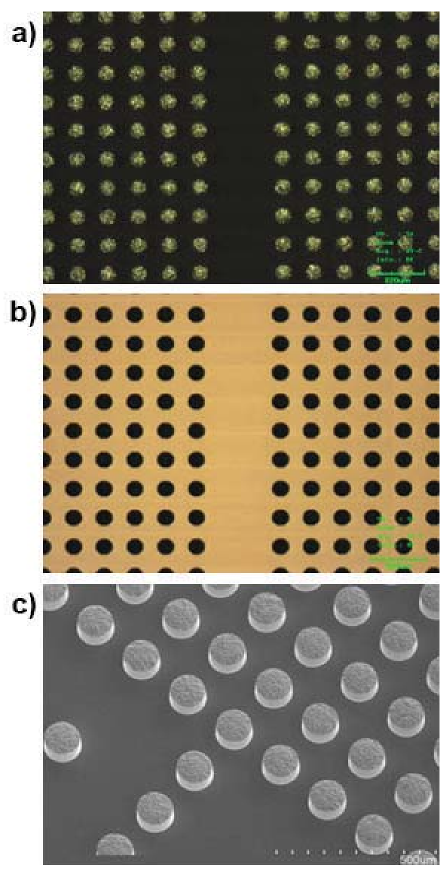

Figure 1: Optical images a) Pre-dry film resist strip; b) Post-DFR strip; c) SEM image post-DFR strip.

Process flow

The combination of two process techniques (sequenced immersion and single-wafer spray) in a single system provides unique capabilities for photoresist and dry film strip. Each wafer is soaked under precisely controlled conditions in a heated, recirculating, solvent immersion bath with a nitrogen environment. Sequencing is based on the downstream process times, ensuring each wafer is soaked an equal length of time. With the appropriate selection of chemistry for the composition and thickness of the dry film, the soaking time allows for swelling and dissolution of the highly cross-linked resist. The process sequence is shown in **Figure 2**.

Following the sequenced immersion step, the surface of the wafer remains solvent-wet during transfer to the single-wafer spin process station. The use of a high-pressure chemical fan spray enhances the removal of residuals, ensuring a clean, resist-free surface. The wafer is then transferred to a

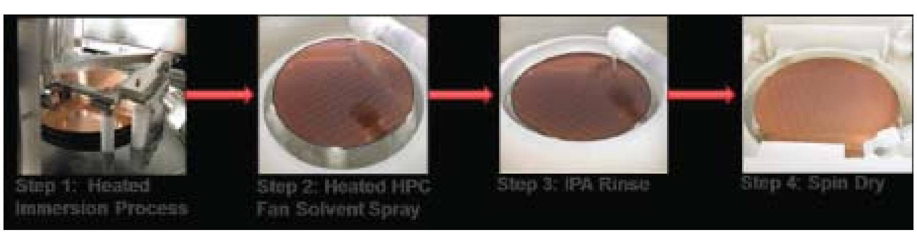

Figure 2: Dry film strip process sequence.

spin-rinse-dry station where the surface is completely cleaned and becomes particle-free using an IPA rinse.

Because there are numerous types of dry film resists, the selection of a solvent appropriate for the film being dissolved is important. For the work reported in this paper, a Dynastrip™ solvent technology was selected given its compatibility with all advanced packaging applications, such as plated bumps and redistribution line metallurgies. This family of chemistries has excellent performance with dry film resists, as well as wet spin-on resists. The Dynastrip solvent is compatible with copper, all solder types, and with the underlying passivation layers. Because it can be recirculated within the equipment, and has a high bath loading capability, it contributes to a low cost-of-ownership, as is demonstrated in the cost analysis section of this paper. It should be noted that other chemistries have been used successfully. However, there are differences in the chemical costs, chemical life, and process parameters.

One of the significant operational cost drivers using a wet bench or traditional single-wafer process is the frequency of filter changes caused by the significant buildup of partially dissolved resist material in the system. To address this, ImmJET technology includes a Triple Strainer that collects this material. The Triple Strainer is automatically flushed with solvent to clear the buildup of residuals. With two strainers in tandem, one strainer can be actively processing while the other is self-cleaning, thereby enhancing process efficiency and eliminating the cost for filter replacements.

Cost-of-ownership

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 analyzed. These considerations include the time required for the activity, labor dedicated to the activity, material costs (both consumable and permanent), tooling costs, all capital-related costs, and yield loss.

The goal of the study was to compare ImmJET to three industry standard methods: wet bench, batch spray, and single-wafer strip equipment. A summary of the initial analysis is shown in **Figure 3**. Because the wet bench is the most commonly used of the three alternatives, the scope of the cost analysis presented in this study compares the new solution versus a traditional wet bench strip approach (**Figure 3**). This analysis focuses on a single-step in a process flow, so rather than adding or removing steps, as often happens when two technologies are compared, all of the adjustments are within the parameters of a single step. Industry data was used to determine the parameters for the current industry method, such as equipment price, bath refresh rate, and throughput. However, because every factory is different, in addition to selecting baseline assumptions for the industry method, a sensitivity analysis was

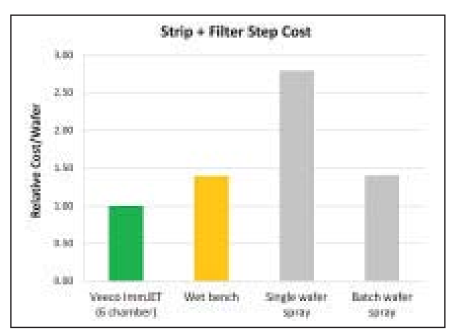

Figure 3: Cost-of-ownership comparison.

carried out on key variables to understand their impact on cost (**Table 1**).

Cost model assumptions include the following: 1) Direct costs only—no overhead or pricing margins; and 2) Factories are assumed to be well-balanced and fully utilized. **Table 2** shows the cost breakdown of wet bench technology relative to the ImmJET 6-chamber tool, which is the more cost-effective of the two. The type of contributing cost is also included. Note that the percentage of cost for the new technology is split almost evenly between material and capital. This is because the equipment price is more expensive than a traditional wet bench, but less material is required to clean the same number of wafers. The wet bench is a more material-heavy process, not only due to the larger bath, but due to the filter requiring continual replacement – and the filter represents a material cost.

Sensitivity analysis

The analysis of baseline assumptions revealed that the wet bench is more expensive than the 6-chamber ImmJET tool. To verify these findings, material costs (related to both the bath and the filter) were analyzed for sensitivity. There are multiple ways to look at chemical costs with regard to a process that uses a substantial volume of chemical as a consumable. This analysis looks at the trade-offs from the perspective of the number of wafers cleaned by a set number of gallons, and also by the refresh rate of a bath for a set number of wafers. It should be noted that the yield for both processes was assumed to be the same. Because the use of single-wafer processing typically results in higher yield than a batch process, the results in this analysis are conservative.

The two charts in **Figure 4** show the cost of the strip step for the 6-chamber tool compared to a wet bench, at different refresh rates. The blue circle indicates the baseline assumptions. These charts make it clear that even if the 10-gallon refresh rate is a high assumption and fewer gallons can be used to completely clean 500 wafers, the

	Relative Throughput (wph)	Relative Equipment Cost	Relative Chemical Cost	Bath Loading	Other
ImmJET 6 chamber	1.00	1.00	1.00	500 wafers in 6.2 gal of material at $80/gal	Triple strainer with self-cleaning capability
Wet bench	0.32	0.33	1.61	500 wafers in 10 gal of material at $80/gal	Filter changed every 1000 wafers at $100 per filter

Table 1: Cost model assumptions (ImmJET vs. wet bench).

Breakdown of Strip + Filter Steps	Labor	Material	Capital	Strip + Filter
ImmJET (6 chamber)	1%	49%	50%	**1.00**
Wet bench	2%	60%	38%	**1.39**

Table 2: Strip + filter costs by activity.

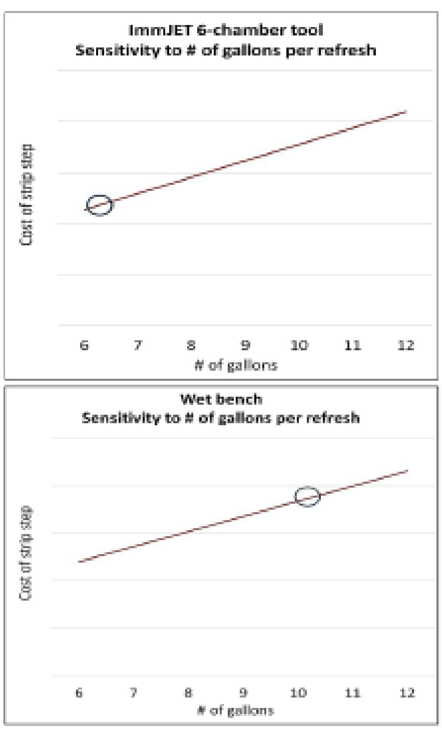

Figure 4: Cost sensitivity to chemical usage. (Note: y-axis scale is the same for both charts.)

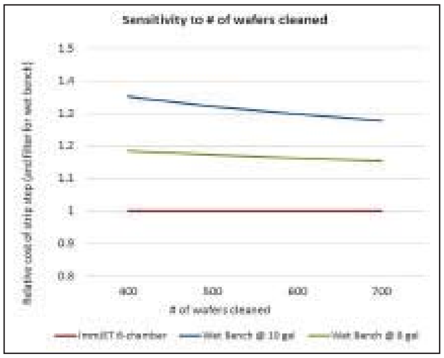

Figure 5: Cost sensitivity to number of wafers cleaned.

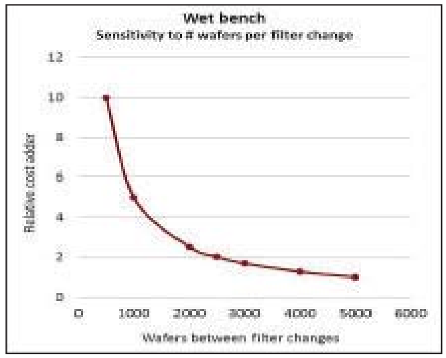

Figure 6: Cost sensitivity to filter change frequency.

wet bench is not cost-effective at even 8 or 7 gallons.

Figure 5 assumes a baseline chemical amount and varies the number of wafers cleaned. Our solution is proven to clean 500 wafers in 6.2 gallons of material. This chart indicates how the cost would further be affected by an increase or decrease in the number of wafers. The new immersion and spray process technology shows a clear cost advantage. A lower cost wet bench at 10 gallons may only compete in long-term cost-of-ownership if a bath refresh of 8 gallons is able to successfully clean more than 700 wafers.

Figure 6 indicates the contribution to cost when having to replace a filter regularly for a typical wet bench. The cost adder indicates how much of a $100 filter is amortized over the cost of each individual wafer, depending on the number of wafers cleaned between filter replacement.

Summary

The new immersion and single-wafer spray process technology evaluated combines the advantages of sequenced immersion and single-wafer spray within one tool. This enables a cost-effective method for stripping of dry film resists. Activity-based cost analysis conducted by SavanSys Solutions LLC, confirms the use of this technology to be less costly than the conventional batch wet bench. Improved bath life, efficient chemical usage, and significant reduction in filter changes provide the cost savings.

Acknowledgment

ImmJET and WaferStorm are registered trademarks of Veeco.

Biographies

Laura Mauer received her BS in Electrical Engineering from New York U. and her MS in Electrical Engineering from Syracuse U.; she is currently CTO at Veeco Precision Surface Processing; email lmauer@veeco.com

Scott Kroeger received his BA from Miami U. and his MBA from Case Western Reserve U. and is currently VP of Marketing at Veeco Precision Surface Processing.

Amy Lujan received her BS in Chemistry from The College of William & Mary and is currently VP of Business Development at SavanSys Solutions.