Cost-of-ownership comparison of single-wafer processes for stripping copper pillar bump photomasks

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Keywords: Photoresist stripping, chemically amplified photoresist, negative tone photoresist, megasonics, single-wafer, bumping process, copper pillar, micro-bump, cost-of-ownership

Introduction

A new generation of negative tone and chemically amplified positive tone photoresists by TOK, JSR, Dow Chemical and others has gained momentum for advanced packaging applications. Resist thickness requirements are increasing to the 40-100 µm range as Cu pillars and micro-bumps are adopted, to accommodate the tighter pitches required in the newest multi-chip package designs. In order to form the pillars, the resist mask must be thicker than the height of the pillars to contain the entire bump structure.

In recent work by Akrion Systems and A*Star IME process engineering personnel, a new method was developed for stripping the thickest chemically amplified resist masks, and was tested on resist masks up to 100 µm thick. Using organic solvents in a high temperature spray, combined with a unique megasonics capability, this process has provided 40% or greater reductions in process times and the associated chemical consumption when compared to the existing best known method (BKM). This new single-wafer process was then compared with the BKM for removal of 20 µm and 40 µm resist masks. The comparison focused on the relative cost-of-ownership (CoO) of these two processes.

Background

The stripping and removal of thick photoresist (PR) of 20µm thickness or more has traditionally been problematic [1]. The problem is compounded when the PR is of the highly cross-linked negative tone or chemically amplified positive tone variety [2]. Typically performed in tanks through wafer immersion, a variety of wet bench designs have been employed for PR removal. These batch methods appear to offer greater throughput as multiple wafers of up to 25 per cassette can be processed at one go. The promise of high throughputs plus relatively low tool costs makes wet benches the popular choices for PR stripping. In reality, when a number of wafers coated with thick PR are immersed in the organic solvent chemistry at the same time, the PR removal occurs through a "lift-off" process that leads to the peeling off of the thick PR layer in small pieces instead of through total dissolution in the organic chemistry. Thick layers of PR may simply peel off and float on top of the solvent solution, clog up recirculation lines and filters. In order to completely remove thick PR, multiple tanks of the solvent solution in series are commonly used. In addition, frequent re-work of wafers may be required in order to remove all the residues from the wafer surface. The cost of misprocessing the wafers can significantly add to the cost of ownership (CoO) of the wet bench process. As a result, the single wafer processing tools such as those offered by Akrion Systems offer the best remedy to removal thick PR from wafer surface, one wafer at a time. The single wafer processing environment offers the most exact and precise removal of thick PR in a controlled environment.

The process engineering goal in developing single wafer processes for PR stripping is to minimize process times to maximize system productivity. Stripping process times longer than 2.5 - 3 minutes erode the cycle time benefits of single wafer tools and severely impact the CoO of the process step. A two-step, megasonics assisted process has emerged as the most efficient way to remove resist up to 60 µm thick, and has been used by packaging customers for some time. With solvent reactant temperatures of 60 – 80°C and the process flow shown in Figure 1, the process may be optimized for time and temperature based on the resist thickness and solvent stripping chemistry used.

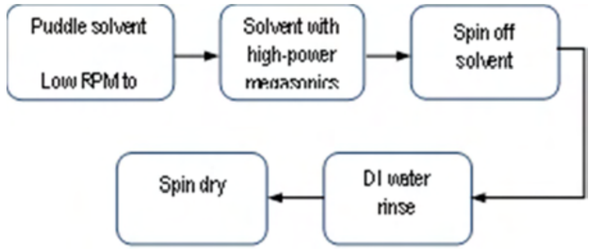


Figure 1. Flow chart of the typical thick photoresist removal process with megasonics assist

The contribution of megasonics technology to the stripping process for thick, highly cross-linked photoresist, shortening process times and reducing chemical consumption by 40 – 50%, has been reviewed in previous publications [3].

At the upper end of resist thicknesses used in bump formation today, this original megasonics assisted process is challenged. Scientists from A*Star-IME and Akrion Systems worked together to optimize the stripping process for a 100 µm resist mask comprised of TOK PMER P-CR4000, a chemically amplified, positive tone, i-line resist developed for thick, bump formation applications, patterning 70 µm high bumps (100 µm width, 80 µm pitch). A 7 minute process on a legacy single wafer tool at A*Star-IME was reduced to 180 seconds on their Velocity[4] (140 seconds chemical process time + rinse + dry), with chemical process temperature of 65°C, at the upper limit of this particular tool. Through a series of development steps on a similar Velocity tool at the Akrion Systems applications lab, the team was able to arrive at a 135 second process (95 seconds chemical process time + rinse + dry). A summary of the various development steps and corresponding chemical process times is shown in Figure 2. Pre- and post-process SEMs are shown in Figure 3. A DMSO based PR strip solvent by Cheil Industries was used for this development.

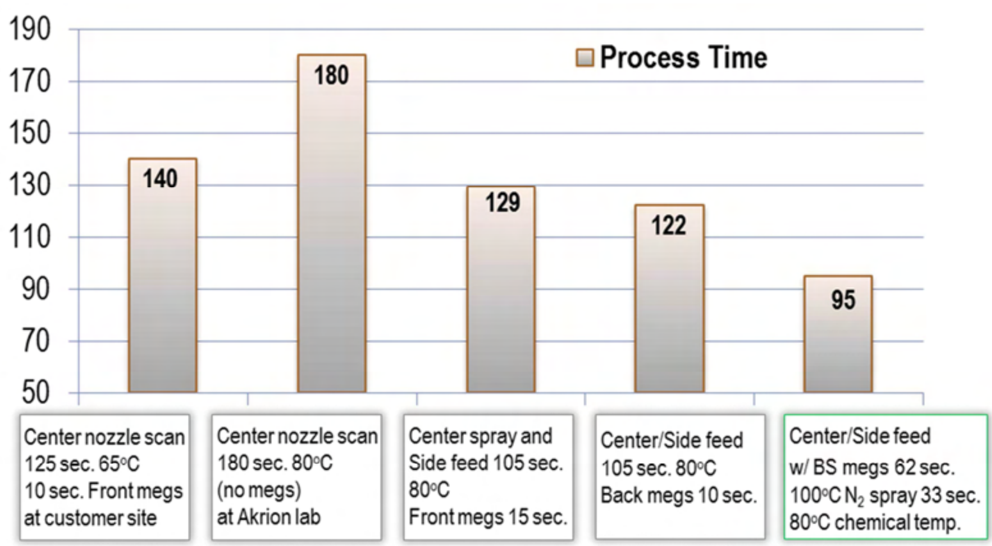
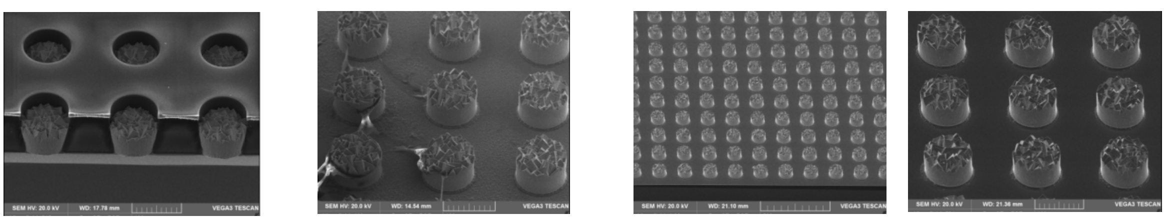


Figure 2. Chemical process times corresponding to steps in development of the strip process for 100 µm TOK resist



Pre-SEM of 100 µm mask Marginal results – 140 seconds Clean results with final process

Figure 3. Pre-and Post-SEM pictures of the 100 µm TOK resist and strip process results

To achieve the final clean results, a new two-step process was developed, as shown in Figure 4. Spray and side dispense chemical feed to the front side of the wafer was used in the first step, in conjunction with backside megasonic energy transmission. The purpose of step one was to begin the decomposition of the polymer chains of the photoresist. In step two, the same solvent chemistry (DMSO based, Cheil Ind.) at 80°C was sprayed with greater velocity and at higher temperature using a nitrogen spray at 100°C. In this case the physical force of the spray, heat energy of the chemical and of the spray work together to complete the decomposition, break apart the photoresist, and completely remove it down to the surface of the wafer.

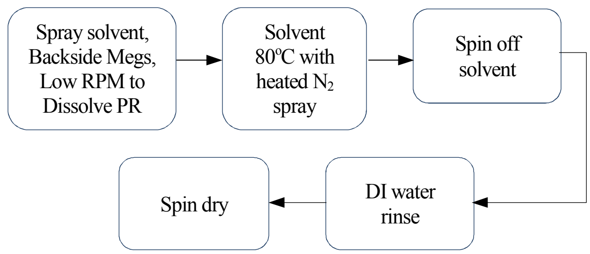


Figure 4. Flow chart of a revised process for stripping very thick PR films

Experimental

After reaching the process time reduction of 31% achieved with the newly developed hot N_2 spray process for 100 µm resist, the team sought to apply the same approach to similar 20 µm and 40 µm TOK masks. The same basic process flow as noted in Figure 4 was used as the method for stripping these resist masks, and the same DMSO based solvent product by Cheil Industries was used. The process conditions shown in Table 1 were decided upon after coupon testing to optimize the new process for clean results. SEM images of the resulting bump conditions are shown in Figure 5.

Table 1. Parameters of the hot N_2 spray process for two thicknesses of TOK resist strip

Parameter	20 µm PR	40 µm PR
Bump size	6 µm H x 30 µm ø	10 µm H x 30 µm ø
Photoresist	TOK PMER P-CR4000	TOK PMER P-CR4000
Solvent	Cheil (w/DMSO)	Cheil (w/DMSO)
Temp., Flow	80+ °C, 1.22 Liters	80+ °C, 0.83 Liters
Total use w/reclaim	0.32 Liter	0.20 Liter
Solvent feed	Hot N_2 spray, side nozzle backside megs	Hot N_2 spray, side nozzle backside megs
Megasonics	Backside	Backside
Strip time	**42** sec. to clear	**60** sec. to clear

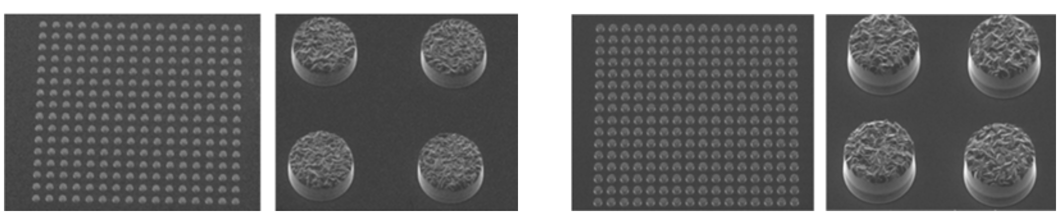


Figure 5. TOK resist stripping cleared process results for 20 µm and 40 µm bumps

In previous work with similar bump sizes and the same resist thicknesses [3], the process times required to clear the resist films were 70 seconds and 80 seconds for the 20 µm and 40 µm TOK masks, respectively, using the previous BKM process. Therefore the process time improvements with the hot N_2 spray process are 40% and 25%, respectively. It should be noted that the earlier bumps patterned with the 20 μm resist mask were mushroom style and not pillars. This may account for part of the 40% improvement in process time for the 20 μm resist.

Results and Discussion

Using the process conditions and required process times of both processes to produce clean results on the bump structure wafers, a comparison of cost-per-wafer of the processes was made. The earlier BKM allows somewhat lower chemical flow rate, but at longer total process times. A cost-per-wafer comparison for the two processes is shown in Table 2.

Table 2. Cost per wafer calculations for the legacy and new PR strip processes for 40 μm TOK resist

40μm TOK PR Strip ITEMS		UNITS	Legacy BKM Process Arkion Systems Velocity 6 80°C Solvent + Megs	New PR Strip Process Velocity 6 Hot N2 Spray + Megs	Comments
-1	1.1. System Price	US$	$2,000,000	$2,000,000	Budget price per system
	1.2. Depreciation	Year	5	5	
	1.3. Footprint	M²	9.2	9.2	
	1.4. Consumable Parts	US$	37450	37450	
-2	2.0 Total Process Time	Seconds	120	100	
	2.1. WPH at Proces Time	WPH	142	155	
	2.2. Yield	%	100.00%	100.00%	
	2.3. Utilization	%	95.00%	95.00%	Fab dependent utilization rate
	2.4. Net WPH	Wafers Processed/HR	134.9	147.25	(2.1)*(2.3)
	2.5. Mach/Man Ratio	Tools/Tech	3	3	
	2.6. Avail. Hours	HRS/YR	8,322	8,322	Annual Hrs. x Equipment dependent uptime
	2.7. Net Output	PCS/YR	1,122,638	1,225,415	(2.4)*(2.6)
-3	**Fixed Costs**		400,000	400,000	
	3.1. Depreciation	US$/YR	400,000	400,000	(1.1)/(1.2)
-4	**Variable Costs**		4,382,332	3,680,288	
	4.5. Energy (EL,Air,WA..)	US$/YR	4,044.49	4,044.49	typical kWH = 4.05, cost = $0.12/kWH
	4.6. Chemical Cost	US$/YR	4,378,287.42	3,676,243.50	typical US$/liter =15.00, calculation incl. reclaim
-5	**Total Annual Cost (3+4)**	US$/YR	4,782,332	4,080,288	
-6	**Total Unit Cost (5/2.7)**	US$/Wafer	**4.26**	**3.33**	

Cost per wafer calculations indicate that the newly developed process provides savings per wafer of 22%, primarily due to the process time reduction and reduction in stripping solvent required per wafer. An efficient single wafer process for thick photoresist removal also provides an alternative to the conventional immersion processes.

Conclusions

Akrion Systems and A*Star IME scientists have effectively collaborated to apply proprietary single-wafer process technology to reduce the cost-per-wafer of the thick photoresist stripping process. The results apply to chemically amplified, positive tone resist masks, and negative tone photoresist masks, in the 20 μm to 100 μm range. In the case of the 40 μm mask, where new and old processes were compared, the new process combining megasonics and heated N_2 spray for chemical feed, provides a cost per wafer savings of 22%.

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