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

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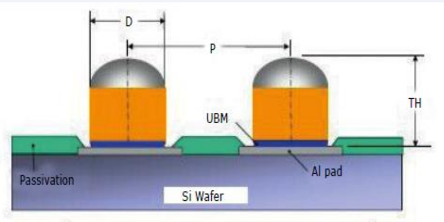
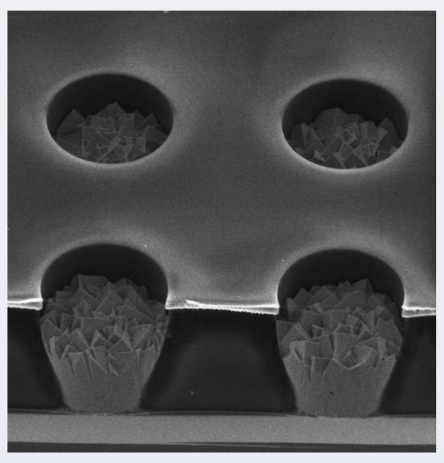
INTRODUCTION

- A new generation of negative tone and chemically amplified positive tone photoresists has gained momentum for patterning Cu pillars with micro-bumps as bump densities increase
- Why the new photoresist products?
  - PR must fully enclose the pillars prior to reflow
  - As PR thickness reach **40 ~ 100µm** chemical amplification or negative tone polymers are more responsive to UV exposure than standard Novolak resists – generating more complete cross-linking
- Stripping the PR becomes a greater challenge
  - The standard batch immersion stripping approach encounters issues
    - "Lift-off" of photoresist can occur – undissolved PR fouls baths and re-adheres to wafers
    - Wafer rework and fouled baths impact process CoO
- A **Cost Effective single-wafer PR Stripping Solution** can be achieved by improving productivity and reducing chemical consumption



Feature	Dimension
Pitch (P)	50-100um
Cu Pillar Diameter (D)	20-50um
Total height (TH)	30-45um

TI / Amkor copper pillar bump design rules (Courtesy of Texas Instruments and Amkor)



SEM image of 70 µm height pillars prior to reflow (courtesy A*Star IME)

BACKGROUND

- In previous work process scientists from Akrion Systems and A*Star IME developed a novel process to strip 100 µm TOK chemically amplified resist used to pattern 70 µm Cu pillars
- The commonly used single wafer process for stripping thick photoresists has proven effective for films up to 60 µm thick (Figure 3)

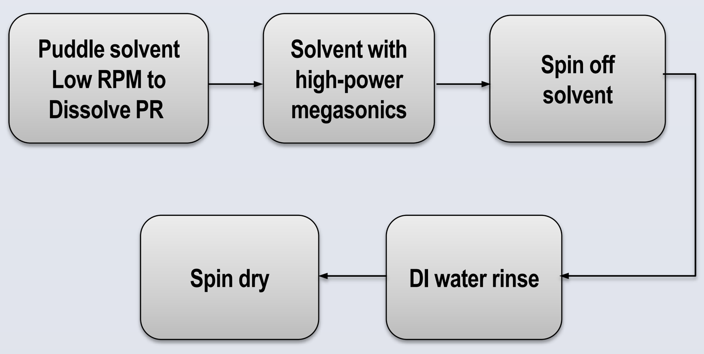
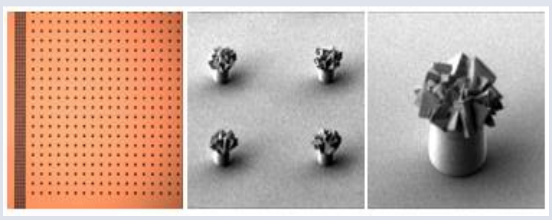
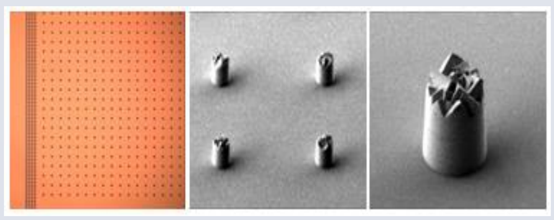


Figure 3 – flow chart and sample results for legacy process, thick PR strip

Parameter	20 µm resist	40 µm resist
Bump size	20 µm H x 10 µm D	30 µm H x 20 µm D
Photoresist	TOK PMER P-CR4000, 20 µm thick	TOK PMER P-CR4000 , 40 µm thick
Solvent	Microposit 1165	Microposit 1165
Temp., Flow	70°C, 1.0 Lpm	70°C, 1.0 Lpm
Solvent feed	Side nozzle w/megs	Side nozzle w/megs
Megasonics	XT 1.0, 100 W	XT 1.0, 100 W
Strip time	70 sec. to clear	80 sec. to clear

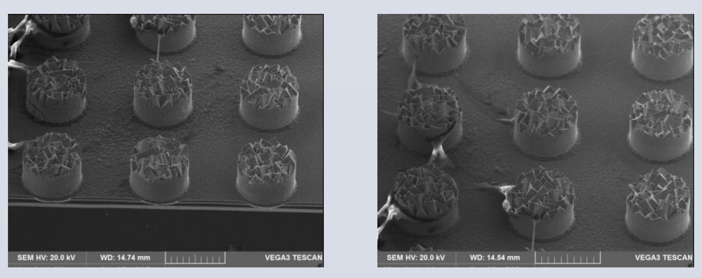


20 µm bumps after 70 second strip time

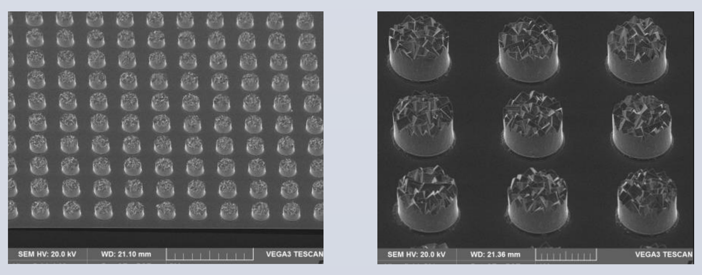


30 µm pillars after 80 second strip time

- When scaling this process up to strip a 100 µm resist pattern of the same material a 140 second time-to-clear provided marginal results and further optimization was required (Figure 4)
  - Chemical process time of 95 seconds was achieved (initial customer process was 7 min.)
  - Splits with NMP-based and DMSO based products were run equivalent results



Marginal results at 140 seconds – resist remaining



Clean results with final process at 95 seconds

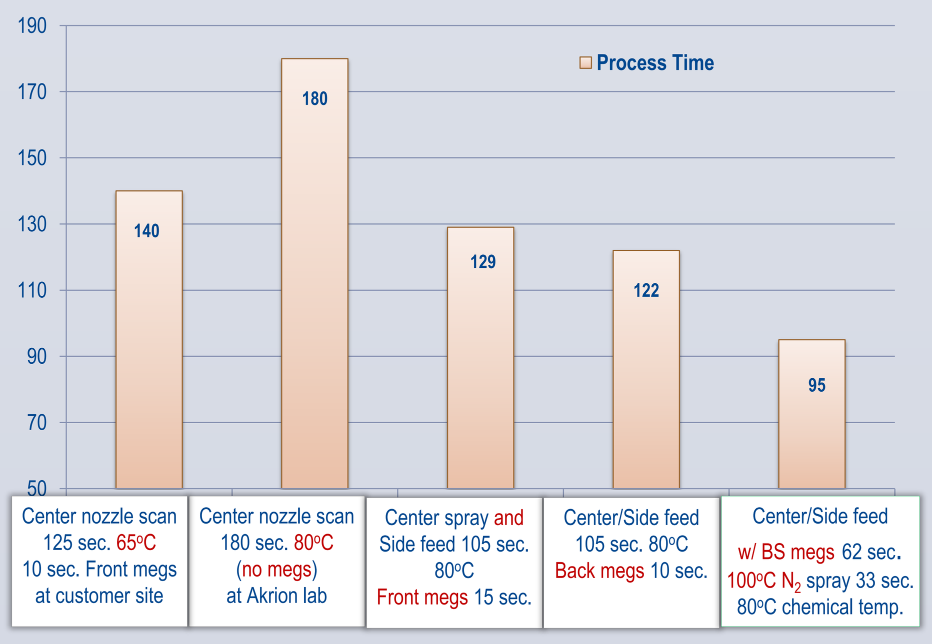


Figure 4 – Development of a new process to strip the 100 µm TOK PMER P-CR4000 resist

- The newly developed process incorporates megasonics during the first chemical stripping step and N_2 spray heated to 100°C in the second step to accelerate the chemical (Figure 5)
  - The 95 second strip process represents a 31% improvement over the best result achieved previously

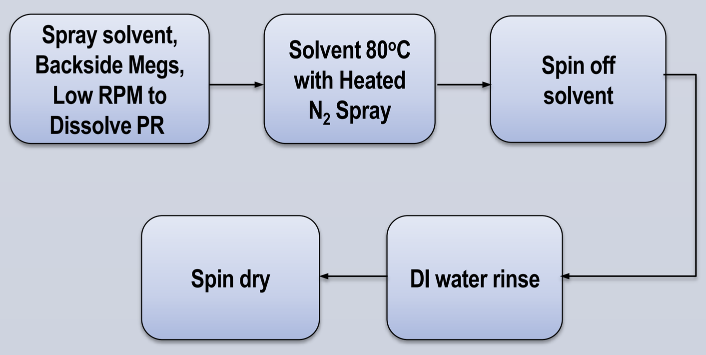
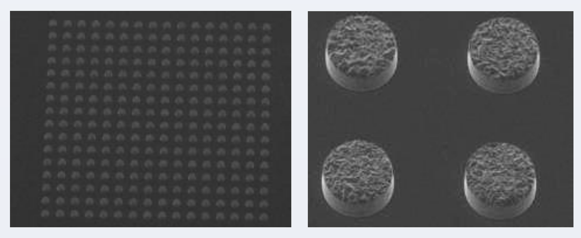


Figure 5 – flow chart of the revised process to shorten 100 µm resist strip

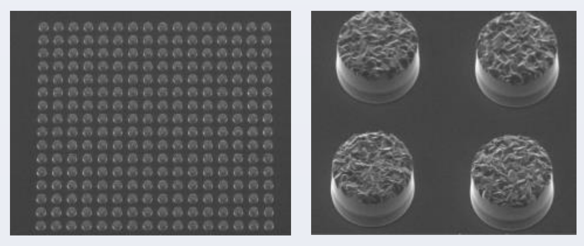
EXPERIMENTAL

- Based on the process time reduction achieve on 100 µm resist with the new process using hot N_2 spray the team sought to apply the same approach to the 20 µm and 40 µm resist
- The same DMSO based product as with the 100 µm process development was used and after development with coupons the process conditions and results shown in Figure 6 were achieved

Parameter	20 µm resist	40 µm resist
Bump size	10 µm H x 25 µm D	20 µm H x 25 µm D
Photoresist	TOK PMER P-CR4000, 20 µm thick	TOK PMER P-CR4000 , 40 µm thick
Solvent	Cheil StarStrip	Cheil Star Strip
Temp., Flow	80+ °C, 2.0 Lpm	80+ °C, 2.0 Lpm
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



10 µm bumps after 42 second strip time



20 µm bumps after 60 second strip time

Process parameters and results for the Hot N_2 spray PR strip of 20 and 40 µm TOK PMER P-CR4000 resist

- Process times were reduced from 70 seconds and 80 seconds to clear for the 20 µm and 40 µm resist, respectively to 42 seconds and 60 seconds, reductions of 40% and 25%
- Note that in the second test the bumps patterned by the 20 µm resist were pillars and not mushrooms, probably accounting for some of the 40% improvement

RESULTS AND DISCUSSION

- A comparison of the cost-of-ownership was made for the original single-wafer process versus the newly developed process using heated N_2 spray together with megasonics
  - The legacy process runs at lower chemical flow rates, but with longer overall process times
  - With a well designed reclaim capability and shorter process times the new process achieves lower cost per wafer
  - The new process provides a 22% cost per wafer savings primarily due to the reduction in solvent consumption per wafer
- The newly developed and more efficient single-wafer process provides a viable alternative to immersion stripping of photoresists up to 100 µm thick

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	$2,000,000	Budget price per system
	1.2. Depreciation	Year	5	5	
	1.3. Footprint	M^2	9.2	9.2	
	1.4. Consumable Parts	US$	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**	

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 40 µm case the new process, combining megasonics and heated N_2 spray with chemical feed, a cost per wafer savings of 22% was achieved

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