Wet Chemical Processing with Megasonics Assist for the Removal of Bumping Process Photomasks

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Abstract

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 to contain the entire bump structure.

Akrion Systems engineers have developed a novel, single-wafer, thick PR strip process with the goal of reducing cost-of-ownership (CoO) for this step in advanced packaging process flows. Using organic solvents plus a unique megasonics capability, this process provides 40% or greater reductions in process times and the associated chemical consumption when compared to traditional processes.

Background

Thick, negative tone resists are more transparent to exposure light wavelengths than standard Novolak positive tone resists and can be exposed by the lithography process much faster (~1 x 10^4 cross-linking chemical events are driven by 1 photochemical event vs. 100 – 1000 chemically amplified resists, or 1:1 for traditional positive tone resists) [1]. Therefore exposure times can be shorter, post-exposure bake steps can be shorter, and delays before or after exposure is not necessary, saving photolithography time and CoO. And, due to more complete cross-linking throughout the resist, the resist mask profiles are truer [1].

Chemically amplified, positive tone, i-line photoresists have also become popular for the thick pattern applications found in Cu pillar and micro-bump formation. The benefit of chemical amplification is similar to that seen with the reaction chemistry of negative tone resists. With chemical amplification, during exposure one photon can trigger the reaction of hundreds (if not thousands) of acid-catalyzed deprotection reactions, rather than one proton to decompose one photoactive compound molecule system used for DNQ/Novolak systems [2]. These resists are also transparent enough to allow photons to penetrate throughout the depth of the mask and generate the reactions [3].

A known drawback to the negative tone resists is that the solvent strip times of the highly cross-linked resist masks are much longer than for typical positive tone resists. *Flack et.al.* [1] noted resist strip times of 5 minutes for two positive resists used in their experiments vs. 50 minutes for the AZ-100nXT negative tone resist, using AZ400T at 80°C. Long strip times or special stripping requirements are also noted on the data sheets of the other major suppliers of negative resists. A similar issue is seen with the chemically amplified positive tone resists as well, vs. non-chemically amplified positive resists.

Based on these thick resist removal challenges, a variety of methods have been developed to reduce the cost, time and chemical consumption required to perform this process. Akrion Systems engineers have developed a fully single-wafer process in which the rate of reaction of solvent and photoresist is increased by a combination of heat and a proprietary form of megasonic agitation.

Experimental

Single-wafer, megasonics assisted processes for stripping thick, micro-bump photoresist

masks have evolved from previous work on stripping chemically amplified, DUV resist in front end semiconductor applications [4].

A two-step process has emerged as the most efficient way to remove resist up to 60 µm thick. In the first step a period of solvent exposure at 60 – 80°C and low wafer spin speed is used to begin swelling and dissolving the thick photoresist layer. This is followed by a second solvent exposure step using aggressive, front side megasonic energy to promote polymer chain scission throughout the bulk of the photoresist layer. Following this step, a DI water rinse and spin dry step are sufficient to completely remove the solvent, dissolved photoresist and any polymer residues. The process may be optimized for time and temperature based on the resist thickness and solvent stripping chemistry used. A flow chart of the typical process is shown in Figure 1.

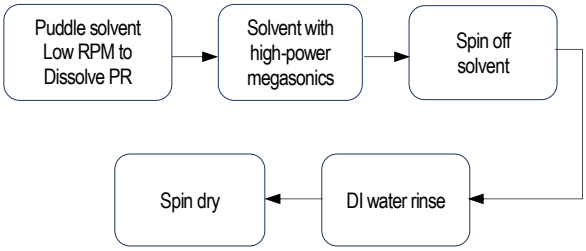


Figure 1. Flow chart of the thick photoresist removal process

The megasonic energy transferred into the meniscus of chemical solvent on the surface of the wafer plays a very important part in driving the reaction between solvent and photoresist, in two ways. The agitation provided by the megasonics helps drive the polymer chain scission reaction once the photoresist swells and starts to dissolve. It also helps to decrease the fluid boundary layer nearer to the surface of the wafer, driving the removal of surface residues similar to the illustration of particle removal phenomenon shown in Figure 2.

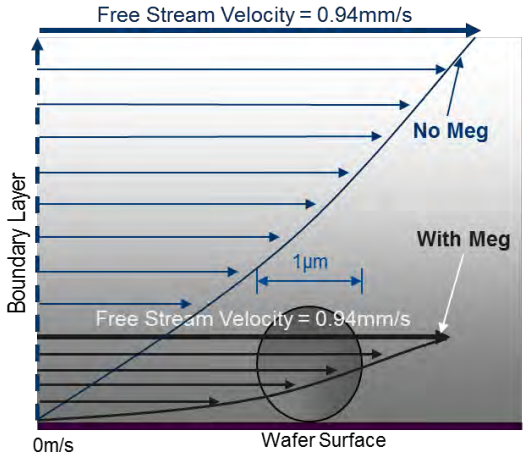


Figure 2. Megasonics impact on fluid boundary layer [5]

The megasonics assisted single wafer process was employed in the development of resist removal steps for two thicknesses of negative tone, JSR photoresist masks used to form mushroom cap and pillar bump structures. The process chamber layout and key components of the Akrion Systems Velocity[4] system used for this work are shown in Figure 3.

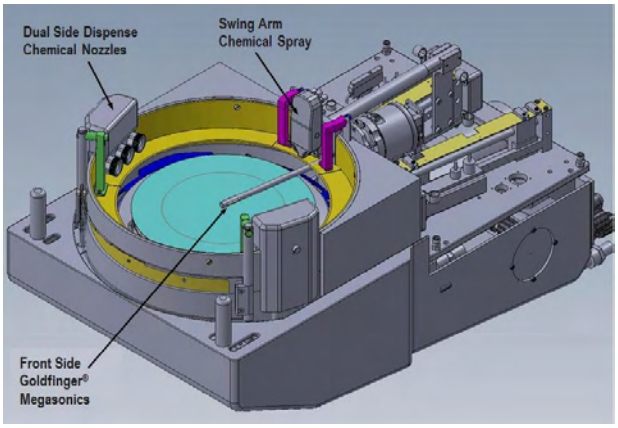


Figure 3. Chamber layout of the Velocity[4] system

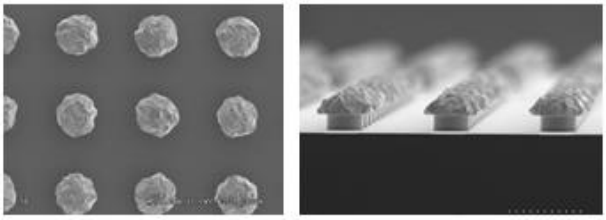
Negative Tone Resist Results

In the first of the JSR resist strip processes, recipes were developed similar to the flow chart in Figure 1 above, with and without the megasonics used in the resist removal step. The notable parameters for each of the processes are shown in Table 1 and SEM images of the resulting structures are shown in Figure 4.

Parameter	w/ Megs	w/o Megs
Bump dia.	50 µm	50 µm
Photoresist	JSR THB-126N, 20 µm thick	JSR THB-126N, 20 µm thick
Solvent	Dynaloy AP7700	Dynaloy AP7700
Temp., Flow	60°C, 1.0 Lpm	60°C, 1.0 Lpm
Solvent feed	Side nozzle w/megs	Topside oscillating
Megasonics	XT 1.0, 100 W	none
Strip time	90 sec. to clear	150 sec. to clear

Table 1. JSR 20 µm strip process parameters

With megasonics and 90 second strip time



Without megasonics and 150 second strip time

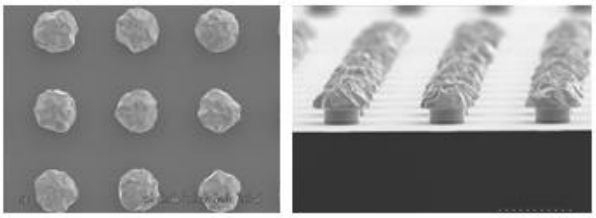


Figure 4. JSR 20 µm Process results

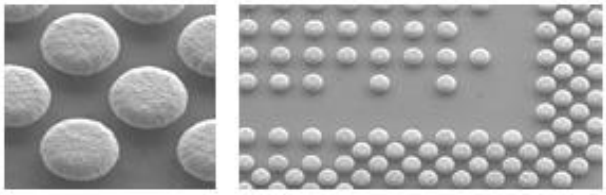
In the 20 µm, JSR THB-126N resist stripping process, the megasonics agitation at 100W power provided a process time reduction of 60 seconds, or 40%, and a corresponding solvent usage reduction of 1 liter per wafer, also 40%, before reclaim.

The second JSR resist strip process was developed in a similar way, with a comparison of the achievable process times with megasonics and with a legacy process not using megasonics. The notable parameters for each of the processes are shown in Table 2 and SEM images of the resulting structures are shown in Figure 5.

Parameter	w/ Megs	w/o Megs
Photoresist	JSR THB-151N, 50 µm thick	JSR THB-151N, 50 µm thick
Solvent	Dynaloy AP7880-C	Dynaloy AP7880-C
Temp., Flow	65°C, 0.7 Lpm	65°C, 1.0 Lpm
Solvent feed	Side nozzle w/megs	Topside oscillating
Megasonics	XT 1.0, 100 W	none
Solvent strip time	135 sec. to clear	180 sec. residue remaining

Table 2. JSR 50 µm strip process parameters

With megasonics and 135 second strip time



Without megasonics and 180 second strip time

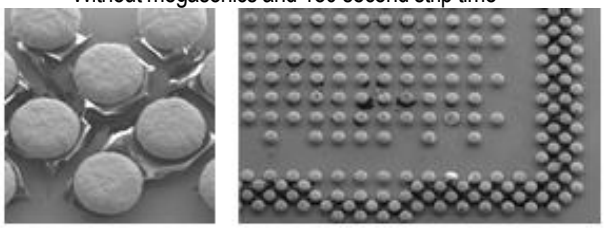


Figure 5. JSR 50 µm Process results

In the 50 µm, JSR THB-151N resist stripping process, the megasonics agitation at 100W power provided a process time reduction of at least 60 seconds (since a large amount of residue remained in the dense bump areas of the non-megasonics samples). Chemical usage reduction was at least 1.5 liters per wafer, before reclaim, or 50% of the solvent consumed per wafer.

It should be noted that typical process times for removing non-chemically amplified positive tone photoresists are in the range of 30 – 40 seconds for resist thicknesses of 15 – 20 µm. This range is based on a process developed for removal of a 17 µm thick RDL mask composed of AZ P4620 photoresist.

Chemically Amplified Positive Resist Results

Similar process development was undertaken for a pair of photoresist masks composed of TOK PMER P-CR4000, a chemically amplified positive tone i-line resist developed for thick,

bump formation applications. For this work masks from two bumping processes were chosen, one at 20 µm thickness and the second at 40 µm thickness.

Again the same basic process flow as noted in Figure 1 was used. In this case non-megasonics comparisons were not made, but an interesting comparison can be made between the 20 µm and 40 µm processes. Process parameters are shown in Table 3 and SEM images of the resulting structures are shown in Figure 6.

Parameter	20 µm PR	40 µm PR
Bump size	20 µm H x 10 µm D	30 µm H x 20 µm D
Photoresist	TOK PMER P-CR4000	TOK PMER P-CR4000
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

Table 3. TOK resist strip process parameters

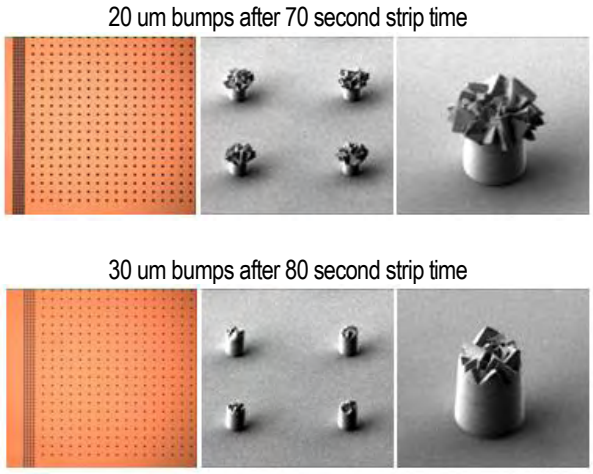


Figure 6. TOK resist strip process results

The TOK chemically amplified, positive resist masks required slightly shorter solvent stripping times for similar resist thicknesses than the negative tone resists. It is interesting to note the delta in process time required between the 20 µm and 40 µm mask removals. A 14% longer process was required to remove a 100% thicker coating of photoresist, suggesting that a somewhat fixed time period is required to initiate the solvent reaction within the photoresist mask, independent of thickness. The authors suspect that a higher solvent temperature will significantly increase the rate of reaction and reduce the overall process time in both cases. This will be studied in upcoming work, together with process development on the stripping of 100 µm thick masks of the same TOK photoresist.

Conclusions

Akrion Systems has effectively applied their proprietary single-wafer megasonics technology to reduce the CoO of thick photoresist stripping process steps. For negative tone photoresist masks in the 20 µm to 50 µm range, the reductions in process time and chemical consumption per wafer can reach 40% or greater vs. a typical single wafer spray process. The same megasonics assisted process method applies to thick, chemically amplified, positive tone resist masks, shown in this paper for the 20 µm to 40 µm range, and will be extended to 100 µm thick masks, at the upper limits of bumping process requirements.

References

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