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Topside Anti-reflective Coating Process and Productivity Improvements on KrF Lithography

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ABSTRACT

Topside anti-reflective coatings (TARC) are used in microelectronics fabrication to control standing wave formation during the patterning process. By changing the phase of the light that is reflected from the substrate, interference effects of thin photoresist films are minimized. Filtering and dispensing these fluids have proven to be difficult, as they are prone to micro-bubble formation due to surfactant additives. Surfactants will encapsulate micro-bubbles that form during filtration and dispense. The acidity of TARC is also of concern with regards to resist dark loss, especially at point of dispense.

Minimization of TARC process defects is of paramount significance in a manufacturing environment. Reduced defect levels can increase overall yield and tool availability. In this study, we examined reducing the volume of trapped air and the resist dark loss associated with TARC acidity to prevent the formation of defects. Due to the inherent material properties of TARC, the handling, chemical priming, preventative maintenance, pump type, filter type and size, vent interval, filtration rate, idle/periodic dispense frequency methodology, and on-wafer dispense methodology must be considered to prevent in-film and surface defects associated with micro-bubbles and the TARC acidity.

Defect reduction and increased tool availability was accomplished by examining and optimizing tool hardware and functionality, examining and optimizing filter media and size, examining and optimizing pump purge/vent sequences and frequency, improving overall pump knowledge, improving filter change procedure and maintenance, and understanding and reducing dark loss issues associated with acidity of TARC chemical.

Keywords: topside anti-reflective coating, defects, dark loss, productivity, micro-bubble, surfactant, flares

1. INTRODUCTION

Anti-reflective coatings (ARC) are an essential part of photolithography with the continual shrinking of pattern geometries. ARCs reduce reflectivity at resist interfaces thus providing better line width control with minimal loss of resist performance. The reflectivity is reduced by either attenuating light that passes through the ARC or by matching the index of refraction of the ARC to the resist system at the exposure wavelength employed.[1] ARCs come in two varieties: bottom anti-reflective coatings (BARC) and topside anti-reflective coatings (TARC). TARC reduce reflectivity by destructively interfering the incident light reflected from the TARC/resist interface with the incident like reflected from the TARC/air interface as represented in Figure 1. The destructive interference is effective if you choose a film thickness for the TARC that has an optical path-length of $\lambda/4$ of the exposure wavelength and a refractive index for the TARC that produces equivalent reflectance of light from the air and from the resist side of the interface. TARC can also help protect resist layers from airborne contamination and assist the uniformity of the develop process due to its excellent wettability. TARC's ph can be tuned to slightly acidic, which counters typical residual base contamination in the atmosphere[2]. TARC contain surfactants to improve uniformity and coatability of the spin-on process at the thin layers required (440Å for KrF process). TARC is a water-soluble chemical, which can be rinsed off in aqueous-based developer solution. Since TARC is a non-absorbing, it does not impose any exposure penalty and does not degrade the contrast of the resist[1].

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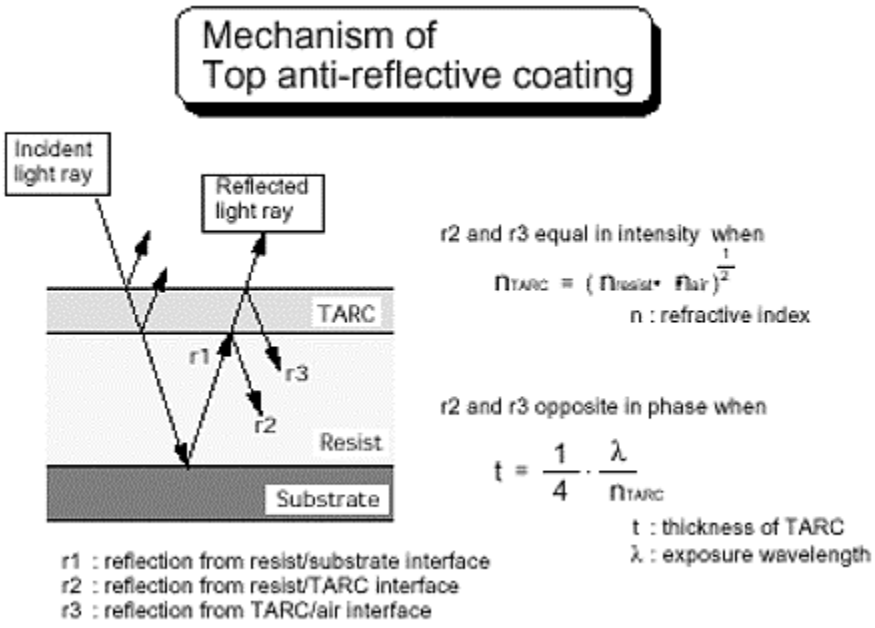

Figure 1: Depiction of Mechanism of Reflectance in Substrate/Resist/TARC Scheme

The chemical properties of TARC, its acidity level and the fact that it contains surfactants, have proven to make filtering and dispensing this fluid difficult. The chemical is prone to micro-bubble formation due to the surfactant additives. The surfactants will encapsulate micro-bubbles that form during filtration, dispense, and possibly chemical manufacturing. These micro-bubbles, if dispensed as in-film bubbles would lead to micro-lensing effects that would affect critical dimensions of features in that area. The buildup of micro-bubbles within the dispense pump often leads to dispense issues, such as double dispenses. These dispense issues would lead to a variety of macro coat defects. The acidity of TARC is also of concern with regards to resist dark loss, especially at point of dispense.

The inclusion of TARC in a production scheme can be of substantial manufacturing benefit if you can minimize the defects induced by this process. To reduce the TARC process induced defects, you must consider the following: chemical handling, chemical priming, coater preventative maintenance, pump type, filter type and size, pump vent interval, pump filtration rate, idle/periodic dispense frequency methodology, and on-wafer dispense methodology.

In this study, we examined reducing the volume of trapped air produced during filtration and dispense and the resist dark loss associated with TARC acidity to prevent the formation of on-wafer defects. Defect reduction and increased tool availability was accomplished by examining and optimizing tool hardware and functionality, examining and optimizing filter media and size, examining and optimizing pump purge/vent sequences and frequency, improving overall pump knowledge, improving filter change procedure and maintenance, and understanding and reducing dark loss issues associated with acidity of TARC chemical.

2. EXPERIMENTAL

2.1 Materials

Topside anti-reflective material was NFC 540 from JSR Micro Inc. The photoresists used for defect experiments and resist/TARC interactions were Rohm and Haas Electronic Materials UV217, ShinEtsu SEPR402, and JSR M296Y.

2.2 Lithographic Process

Tokyo Electron Limited (TEL) CLEAN TRACK™ ACT8™ tracks were used for chemical apply, bake, and development. These systems were equipped with either TEL/Mykrolis RDS (two-stage motor driven dispense pump) or Iwaki T-100 pumps (single stage diagram pump) for TARC supply. ASML KrF 850 scanners were used for the KrF exposure.

The process test monitors (PTM) wafers consist of a 140 nm thermal oxide on top of 2 microns of epitaxial Si. The resists were spin-coated on these substrates followed by a bake specific to the resist type. The TARC film of 44 nm thickness was formed by spin coating over the resist film. No post TARC apply bake was used. KrF exposure was performed, with illumination conditions shown in Table 1 below. A resist specific post-exposure bake was performed. A 3 to 4 sec pre-develop puddle rinse was used to strip the TARC coating in the develop module. Develop with 2.38 wt% tetramethylammoniumhydroxide (TMAH) solution was used to develop the KrF resists.

Table 1: Masking Conditions

Resist	NA	Sigma	PAB	Mask type	PEB	Pre-dev rinse	Dev puddle time
M296Y	0.60	0.50	130C/90sec	Contact	130C/90sec	3 sec	Double 41.1sec/12.4 sec
SEPR402	0.54	0.60	100C/90sec	Line/space	110C/90sec	4 sec	Single 34.4 sec
UV217	0.54	0.60	130C/60sec	Line/space	125C/60sec	4 sec	Single 34.4 sec

2.3 Measurement

The film thickness was measured with a UV-1250 (KLA-Tencor). The pattern defects were measured with an AMAT Compass.

3. RESULTS AND DISCUSSION

3.1 Effect of TARC acidity on underlying resist layer

The standard application coat process for TARC, primarily due to the high concentration of surfactant additives, is a static center dispense; this methodology was employed to minimize micro-bubble formation due to surface energy effects during the TARC deposition. The pattern defect results from PTM wafers would occasionally have a characteristic symmetrical center defect of approximately 2~3 mm size. It was theorized for some time that the defect in Figure 2 and Figure 3 was related to micro-bubble buildup within the pump that effected dispense condition; with this in mind, significant purging of chemical system was often the action taken to mitigate the defect occurrence. This solution was not always predictable and the defect sometimes disappeared without any associated action.

Upon further investigation of an excursion, it was found that the defect was not only a thickness variation in the TARC coating, but that the underlying resist had been affected. CD SEM investigations of the defect showed that there was significant resist dark loss at point of dispense. During this investigation, it was also found that there was a TARC batch-to-batch correlation to the defect occurrence dates; given the fab consumption of TARC, a new batch was entering the fab every seven to ten days. Variations in TARC batch acidity, pH, and resist dark loss were found and are presented in Table 2 below; ultimately the most acidic batches were leading to the center dark loss defect. The dispense condition was changed as an engineering solution. It was found that changing dispense position to 6mm off-center combined with a slightly dynamic recipe (15 rpm during dispense) gained the process significant margin even for the most acidic of batches. Stringent controls were also placed on the chemical supplier in regards to batch acidity, pH, dark loss, line/space profile, and shelf life of raw materials.

Table 2: NFC 540 Chemical Lot to Lot Variations

NFC540 Lot	Film Loss (% by cross section)	% Dark Loss	Acidity mmol/g	Relative profile change from previous batch (200nm L/S)
A	41.66	5.08	0.15	Standard
B	50.18	5.11	0.14	Significant profile change
C	45.30	5.26	0.14	No change
D	70.37	5.89	0.16	Very significant profile change

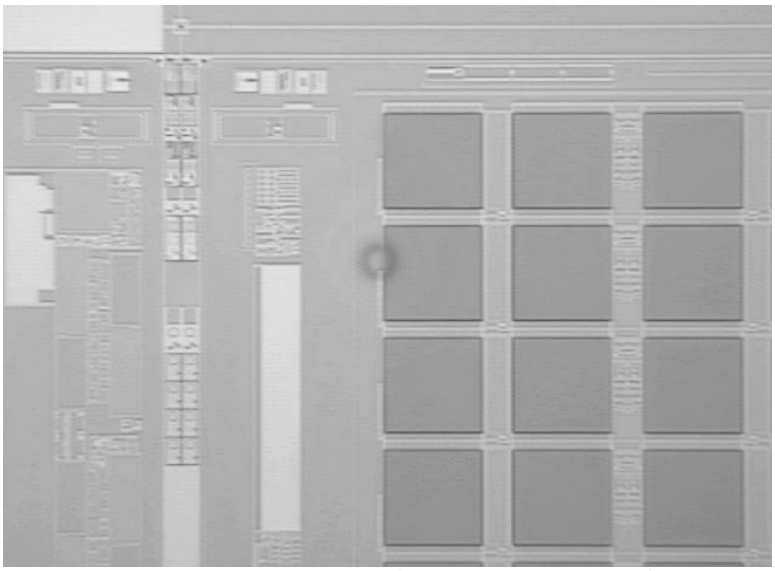

Figure 2: Microscope picture of resist dark loss center defect

Figure 3: Microscope picture of resist dark loss center defect

3.2 Effect of periodic purge/vent sequence on buildup of air bubbles in pump

Even under the best operating conditions, it was found that air bubbles built-up in the TARC dispense pump over several hundreds of dispenses. This buildup of air within the dispense pump would effect dispense conditions significantly. The buildup caused delays of dispense start, dispenses of macro bubbles that lead to coating flares, and double dispenses. It was known from historical precedence that if you significantly purged the pump using N_2 pressure to push TARC chemical through the entire dispense system that these dispense issues would be corrected. Since this action required manual intervention, produced a decrease in tool availability, and forced a significant amount of chemical to go to drain, it was not ideal. As part of this study, it was attempted to automate this purge sequence to increase tool availability, remove the human factor, and decrease chemical waste.

The RDS pump, which is a two-stage pump, has the capacity to purge the dispense pump, vent the filter chamber, and perform a nozzle dispense in separate steps through the pump recipe settings without effecting next product dispense. It was decided to use this functionality to our benefit. The defect test monitor for the layer that ran most heavily on the tool was chosen and a change to the pump recipe was made. Increases to the purge volume and vent time of the pump recipe associated with this layer's wafer flow were made in order to perform a significant purge/vent sequence. Results of this change are presented in Figure 4 and Figure 5; this monitor ran roughly ever 24 hours and was successful in reducing the issues of micro-bubble buildup, with minimal chemical waste, and no lost productivity and wasted man-hours.

Long-term wafer flow recipe management of this solution was a concern; so it was decided to use the dummy dispense software on the ACT system to produce the same effect. Given the fact that the TARC was the only chemical dispense within the cup, two separate dispense conditions were able to be setup: a normal production dispense for dispensing during idle time using the recipe-specified line item within the dummy condition recipe and a separate significant vent/purge sequence dispense set to a specified production wafer count using the resist1 line item within the dummy condition recipe. Given proper choice of wafer count, equivalent results to test monitor methodology was achieved.

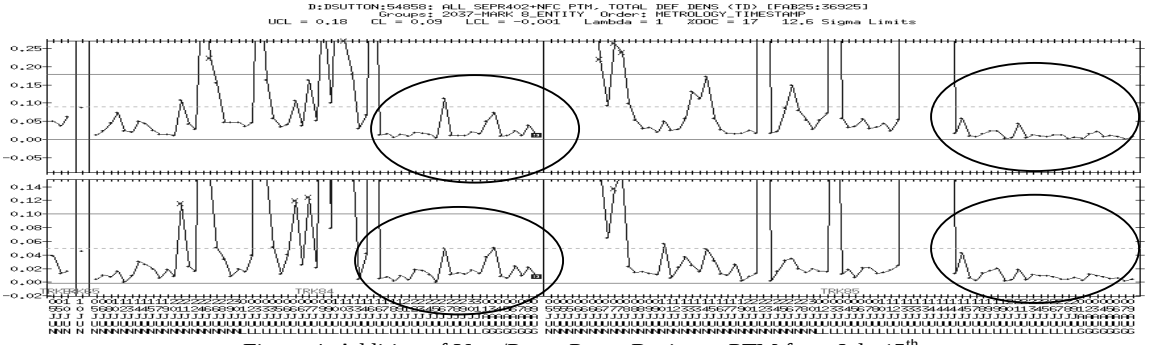

Figure 4: Addition of Vent/Purge Pump Recipe to PTM from July 15th

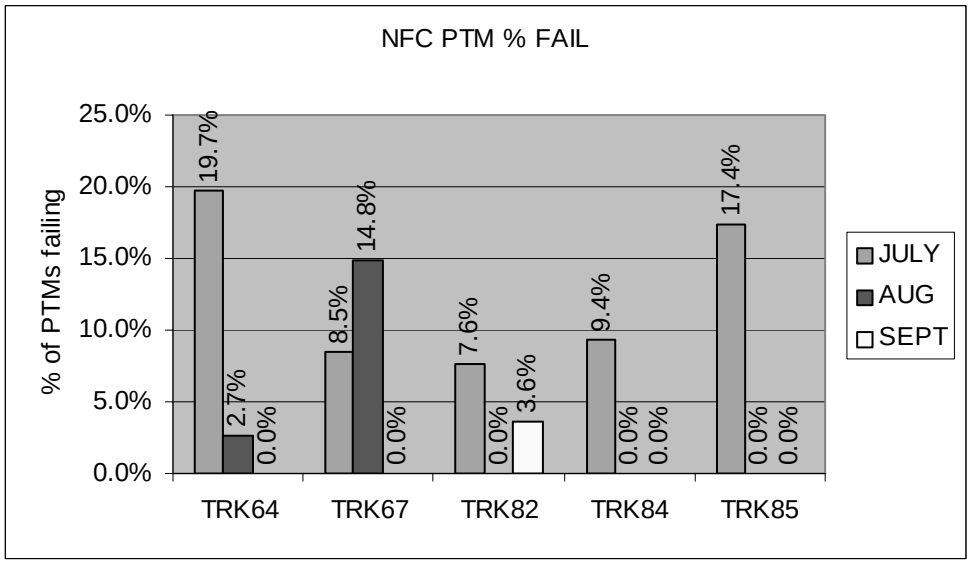

Figure 5: PTM failure rates associated with TARC issues

The T-100 pump, which is a single-stage diagram pump, does not have the same capacities as the RDS pump to purge the dispense pump, vent the filter, and dispense to nozzle in separate steps—it is a simple, but reliable system, which has a manual vent on the filter housing and no true dispense pump purge. With this system though, the same real concerns about buildup of micro-bubbles over time in the filter housing turning into macro-bubbles that would effect dispense and productivity remained. Tokyo Electron Limited worked to add an engineering fix to this problem by adding an auto-vent value to the system. The auto-vent was attached to the drain line of the filter housing and the software was modified such that when the track performed a dummy dispense, the value to nozzle tip would remain closed but the auto-vent value would open allowing us to push the recipe specified volume through the filter to drain and thus venting the filter housing.

3.3 Effect of increasing overall pump knowledge

The issues of micro-bubble buildup occurred on both the systems which were configured with T-100 pumps (10 ACT8 single block tracks, 1 TARC coat cup) and also the systems which were configured with RDS pumps (3 ACT8 double block tracks, 2 TARC coat cups), but were much more prevalent on the RDS configured systems. The RDS configured systems were a much later track addition to the fab floor compared with the T-100 configured systems. The RDS compared to the T-100 was also a more complex dispense system (two-stage pump and electronic dispense value). These two facts lead to several issues.

It was found during the study, that the process of record (POR) pump recipe for the RDS configured systems was operating at a filtration rate (0.5mL/s) that was outside the TEL/Mykrolis RDS recommended maximum filtration rate of 0.3mL/s for TARC chemistries. Given the RDS filtration sequence (feed pump pushing chemical through filter while dispense pump is pulling chemical through filter), this higher filtration rate creates pressure differentials across the filter which are prone to micro-bubble formation in surfactant containing chemistries. It was also found in the POR that the feed pump fill time was set significantly higher (10 seconds) than required (3 seconds) for this viscosity material. The higher feed pump fill time setting increased the overall cycle of the RDS dispense sequence. The two RDS pumps (one for each TARC cup) on the double block systems shared a common reservoir via a t-union coming off the chemical reservoir. As throughput improvements were made on these systems during the same timeframe as this study, a situation arose where this longer than required pump cycle time allowed the feed pump fill sequence of pump1 to effect the dispense pump purge sequence of pump2 (pulling chemical from the dispense pump of pump2 rather than the chemical reservoir)—leaving the dispense pump of pump2 in a negative pressure state which greatly affected dispense start condition of the next production dispense. This issue's cause and effect were initially missed by the maintenance engineers due to a lack of understanding of this new dispense systems; the maintenance engineers significantly increased the electronic value open delay beyond recommended setting to correct for this negative pressure situation. This issue was ultimately corrected by changing the feed pump fill time to recommended settings, thus reducing the overall pump cycle and preventing the pump sequences from affecting one another. Also, a pump training class was provided by TEL to the maintenance engineers to improve their understanding of this new dispense system—this improved knowledge allowed for more accurate, quicker understanding of root cause of future TARC dispense issues.

3.4 Effect of filter type, design, membrane size, and installation procedure on micro-bubble formation

When TARC chemical was initially added into Spansion Fab 25 manufacturing process a sixteen-stack polytetrafluoroethylene (PTFE) 0.05 micron filter membrane was used which was the standard filter for all photolithography resist dispenses at the time. This filter had good longevity (it was changed out annually during a PM), but had a significant issue concerning time to recovery associated with a filter change; at its worst, it would take up to one week to fully recover back to historical baseline defect performance after a filter change. It is believed that TARC chemicals, due to high surfactant additives, do not completely wet the PTFE material quickly, which caused bubble nucleation and shedding[3]. Many experiments were performed around filter type and membrane size to find a filter with good initial wetting, minimal time to recovery, and good longevity.

3.4.1 Filter type, design, and membrane size

The following filters were examined: 0.1 micron 16 stack polysthersulfone (PES), Pall 0.05 and 0.07 micron 16 stack high density polyethylene (PE) Falcon filter, Mykrolis 0.05 micron 16-stack ultra-high molecular weight polyethylene (UPE) filter, Mykrolis 0.03 micron cartridge ultra-high molecular weight polyethylene surface modified membrane (PCM) filter, Pall 0.04 micron 16-stack p-Nylon filter, Pall 0.07 micron cartridge PE EZD-2 filter, Pall 0.02 and 0.04 micron cartridge p-Nylon EZD-2 filter. Ultimately, the time to recovery was substantially better with p-Nylon material compared to the alternatives (1~2 hrs versus 12~24 hours) and even though longevity of p-Nylon is shorter it still outweighed thr alternatives. A pore size of 0.04 micron was chosen over the 0.02 micron filter because no significant benefit was found at the filtration rates being used and the single-stage T-100 pumps could not overcome the pressure differential associated with this media size without substantial issue to dispense quality and filter integrity. The acidity of TARC is known to chemically interact with p-Nylon and eventually lead to a shorter filter lifetime. Longevity experiments with p-Nylon in contact with TARC showed lifetimes of 4~6 months; due to the PM structure, the decision was made to replace the p-Nylon filter every 105 days. Finally, the cartridge filter design was chosen because it allowed for pre-wetting the filter (with TARC chemistry) prior to installation which also further reduced the down time associated with TARC filter change.

3.4.2 Installation Procedure

With the finalization of the filter choice, the remaining work was on ensuring filter change to filter change time to recovery repeatability by producing a best known method (BKM) procedure that the maintenance engineers could follow during PM. The following is that BKM:

NFC Filter Change Procedure (for PM Checklist)

1. Pre-Soak Filter Procedure:
    a. Fill the new filter assembly from the resist nozzle using the 8CC dummy dispense recipe 4x. Then use smaller dispenses to top off; it holds approx 42ml when completely full.
    b. Put the filter caps on the 3 filter ports.
    c. Allow the filter to soak for a minimum of 1 hour.
    d. After 1 hr of pre-soak, top off with NFC again making sure it is completely full before installing.

2a. Filter Install - Iwaki
    a. Remove the old filter and discard in appropriate trash bin.
    b. Remove the caps from the new pre-soaked filter and install on to the pump.
    c. Purge with 8CC a minimum of 10x or until all air is out of lines.
    d. Dummy Dispense a 3CC production pump recipe.

2b. Filter Install - RDS
    a. From the sub-op panel, select Pump Maintenance and the appropriate module and resist nozzle.
    b. Select CLOSE ALL VALVES, then RUN.
    c. Remove old filter and discard in proper trash bin.
    d. Remove the caps from the new pre-soaked filter and install on to the pump.
    e. After the filter is installed, select OPEN ALL VALVES under Pump Maintenance on the sub-op panel for 120 seconds.
    f. Perform the following Dummy Dispenses:
        1.) Dummy Dispense with recipe FILT CHG NFC 1 for 10 times (vent).
        2.) Dummy Dispense with recipe FILT CHG NFC 2 for 3 times (purge).
        3.) Dummy Dispense with recipe FILT CHG NFC 1 for 3 times (vent).
        4.) Dummy Dispense with recipe FILT CHG NFC 3 for 3 times (prime).
    g. Check the output of the pump for air. Repeat the above sequence if any air in noted at the output of the pump.
    h. Dummy Dispense a 3CC production pump recipe.

3. Verify
    a. Verify NFC volume is to spec using a production recipe, adjust if necessary.
    b. Verify good dispense START, STOP, and SUCKBACK using a production recipe. Adjust if necessary.
    c. Verify the START dispense does not suckback into the nozzle before flowing.
    d. Verify the dispense STOP has a slight meniscus above nozzle tip end before the suckback starts, this will help reduce flares.
    e. Verify SUCKBACK is approximately 1.5 mm from the nozzle tip.

With the adoption of this BKM, we have had excellent first time process test monitor pass results post filter change.

4. CONCLUSIONS

In this study, reducing the volume of trapped air produced during filtration/dispense and the resist dark loss associated with TARC acidity were accomplished, which significantly prevented the formation of on-wafer defects. Defect

reduction and increased tool availability was realized by examining and optimizing tool hardware and functionality, examining and optimizing filter media, membrane size, and filter design, examining and optimizing pump purge/vent sequences and frequency, improving overall pump knowledge, improving filter change procedure and maintenance, and understanding and reducing dark loss issues associated with acidity of TARC chemical.

5. ACKNOWLEDGMENTS

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6. REFERENCES

1. Wolf, S; Tauber, R. N.; *Silicon Processing for the VLSI Era, Volume 1*, Lattice Press, Sunset Beach, 2000
2. Brunner, T.; Chen, Z.; Chen, K.; Scheer, S.; Proc. SPIE 2005, 5753, 268
3. Boski, J.; Clarke, M. E.; *Recommendation for Filtration and Dispense of Anti-Reflective Coatings (ARC)*, Mykrolis Application Note MA074