Metal Layer Process Characterization: Statistical and Computation Methods for Handling, Interpreting and Reacting to In-Line Critical Dimension Information

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ABSTRACT

A common challenge faced in many photolithographic processes is the patterning of photoresist on reflective substrates such as aluminum. One effect of the reflectivity of such substrates is linewidth variation known as reflective notching which severely impacts process latitude and device reliability. In recent years, strongly absorbing intermediate layers or ARCs, both organic and inorganic, have seen widespread implementation to control reflective notching. However, a more cost effective and immediate solution to reflective notching would be the application of a fast, high resolution dyed version of an i-line, g-line resist optimized for linewidth control over reflective topography. AMD's Fab 15 solution to reflective notching was the implementation of Shipley's 3617M™ photoresist for all non-ARC metal layers. The process was qualified, implemented and monitored for two weeks at which time in-line data indicated: 1) a downward shift in the metal linewidths, 2) increased critical dimension variation, and 3) a critical dimension distribution statistically different from the previous photoresist process. This paper will present the methods used for handling, interpreting and reacting to in-line metal critical dimension data. Actual production data will be compared to PROLITH/2™ simulated results, and corrective actions identified as well as lessons-learned summarized.

Keywords: photolithography, reflective notching, topography, process latitude, CD variation, in-line data, simulation

1. Introduction

Linewidth variation over highly reflective topography is a chronic problem for semiconductor lithography processes. With this challenge comes the need to optimize photolithography processes to achieve the widest, most robust process windows. In general, positive photoresist and monochromatic light sources used in optical steppers can cause pattern degradation due to thin film interference and light scattering effects [1]. Thin film interference effects such as standing waves are caused by the propagation of light through a thin film of partially absorbing material (the resist) coated on a substrate which is somewhat reflective [2,3]. The effects of substrate reflectivity on photoresist range from reflective notching of the patterned image to critical dimension (CD) control issues, where reflectivity changes may cause a shift in the absolute energy required to hit desired CDs. These effects have resulted in the use of anti-reflective coatings (ARC) or dyed resists on highly reflective levels such as metal.

It was determined that the most cost-effective solution for AMD's Fab 15 facility to address the effects of substrate reflectivity on photoresist was the implementation of a dyed resist specifically formulated for our applications. The resist is Shipley 3718JM™ resist. The 3718JM resist processes for metal-1 and metal-2 were set up at two different E_0 swing curve minimum points. The strategy behind establishing the metal processes at two different E_0 minimum targets was to reduce the exposure at metal-1 by using a thinner resist layer, while using higher exposure and a thicker layer of resist at metal-2 to avoid scumming due to the larger topography. When using a target resist thickness that is at the minimum or maximum of an E_0 swing curve, the resultant CD is less sensitive to thin film interference effects [3].

The dye used in 3718JM reduces the light scattering both within the resist and from the substrate. This results in better CD control, but the reduced sidewall angle of the resist profile makes the focus window quite narrow. As light travels through resist it is absorbed and therefore, the top of the resist receives a higher exposure dose than the bottom. This leads to "positive" sloped profiles, i.e., resist lines are narrower at the top than the bottom. The defocusing of the aerial image as it travels through resist can also lead to a different profile shape at the top versus bottom of the resist. This change in sidewall profile through focus can be readily observed on a focus-exposure matrix. The resist profile imaged at positive focus (focus at or above the top of the resist) shows a significant resist "foot," or a rounding of the profile at the bottom, whereas at negative focus (focus at or below the bottom of the resist) the resist profile is rounded at the top. If the depth of focus is limited by resist profile degradation (as is often the case), the extra degradation of a dyed resist can cause reduced depth of focus.

Since the implementation of the 3718JM dyed resist at AMD, Shipley has introduced a new series of dyed resists, the MEGAPOSIT® 3600M™ series photoresists. These dyed resists have been implemented in various CMOS and BiCMOS facilities. The photoresists were engineered for extremely high throughput processing on reflective substrates and boast control of reflective notching and CD variation while simultaneously providing good process latitude, excellent sidewall profiles, and high thermal stability. Based on Shipley's reported SPR3600M resist characteristics and AMD's needs, conversion to this new series of resists from 3718JM was investigated.

The anticipated benefits for converting to the 3600M series photoresist were:

1. Improved CD control and a wider process window due to focus latitude.
2. Consolidation of resist processes for metal-1 and metal-2.
3. Reduced misprocess due to resist process consolidation.

The specific 3600M series resist implemented in Fab 15 Photo was 3617M. All of the original 20 soft-starts used in the qualification indicated good CD control with wafer electrical test (WET) and SORT results comparable to the existing 3718JM process. The new resist process was qualified, implemented in production and closely monitored for two weeks, at which time in-line data indicated a downward shift in the metal linewidths (especially at metal-2), increased critical dimension variation, and a critical dimension distribution statistically different from the previous photoresist process (for both metal-1 and metal-2).

In this paper we will discuss the implementation results of Shipley 3617M, including methods used for handling, interpreting and reacting to in-line critical dimension data. In addition, we will investigate the effects of swing curves, develop rate, focus offset, and stepper controls. Comparing actual production data to simulated results using PROLITH/2 we will deduce the optimized process parameters for the 3617M resist, quantify the parameters through the running of split lots, and verify the resist's statistical stability.

2. INITIAL 3617M QUALIFICATION

TEL Mark V tracks were used to HMDS vapor prime, spin coat, and proximity soft bake the resist on bare silicon wafers. The initial setup of the process consisted of running E_o vs. thickness swing curves for both the 3718JM and SPR3617M. As mentioned earlier, among the anticipated benefits of converting to the 3617M resist was to use the same thickness for both metal-1 and metal-2. As a result, most of the testing was done at the metal-2 thickness of 18,500Å. Thickness was measured using a Prometrix SpectraMap-300.

A 2^3 full factorial DOE with two center points, centered around the Shipley recommended process, was conducted. The factors investigated were soft bake, post exposure bake (PEB), and develop time. The responses evaluated were Eo, Esize, Esize/Eo, % exposure latitude, isolated-dense bias, and focus latitude (all for an isolated 0.8µm CD target on bare Si substrates).

The DOE was run using an ASML PAS 2500/40, i-line 5X reduction stepper interfaced to a TEL Mark V track. The stepper uses monochromatic illumination at a wavelength of 365nm with a numerical aperture of 0.4 and partial coherence of 0.54.

The wafers from the DOE were post exposure baked, developed and post develop baked on the TEL. The develop process uses an E^2 nozzle for dispensing an AMD formulated developer, Contrast 2000 (C2000). Where possible, the TEL Mark V and ASML PAS 2500/40 were utilized in an in-line cluster mode. Critical dimensions were measured after develop using a Hitachi S-6700 low voltage, scanning electron microscope.

Results of this initial work indicate that 3617M resist has improved sidewall angles through focus with less rounding at the top of the lines. Based on repeat runs at the best and center processing conditions the following process conditions were used to set up the new 3617M process: soft bake = 95° C, PEB = 115° C, and develop time = 75sec.

Once the process was qualified and approved, the 3617M resist was implemented in production. The differences between the 3718JM and 3617M resist processes are outlined in Table 1.

Table 1. 3718JM vs. 3617M resist processes (bare silicon)

Parameter	3718JM metal-1	3718JM metal-2	SPR3617M metal-1/-2
metal resist thickness	16,600Å (5600 rpm)	18,500Å (4500rpm)	18,500Å (3390 rpm)
soft bake temp (ºC) / time (sec)	100 / 60	100 / 60	95 / 60
PEB temp (ºC) / time (sec)	110 / 45	110 / 45	115 / 60
developer	C2000 (0.255N)	C2000 (0.255N)	C2000 (0.255N)
TEL puddle time	90 sec single puddle	90 sec single puddle	75 sec single puddle

3. 3617M IMPLEMENTATION AND PERFORMANCE

The new resist was implemented into production after all of the original 20 soft-starts indicated good CD control with wafer electrical test (WET) and SORT results comparable to the existing 3718JM process. The new resist process was qualified, implemented in production and closely monitored for two weeks. After this time period the in-line data indicated a downward shift in the metal linewidths (especially at metal-2), increased critical dimension variation, and a critical dimension distribution statistically different from the previous photoresist process (for both metal-1 and metal-2). See Figure 1.

To statistically quantify the mean and variance changes for in-line CD data and wafer electrical test (WET) data before and after conversion to 3617M resist, the t-test procedure was performed and results were analyzed using the t-statistic. The parameters analyzed were metal-1 CD (MMEFICD), metal-2 CD (MMZFICD), metal-1 open (M1OPEN), metal-2 open (M2OPEN), metal-1 resistance (RSMETAL1), metal-2 resistance (RSMETAL2), and the ratio of metal open to metal resistance (M1RS1, M1RS2). Results are shown in Table 2.

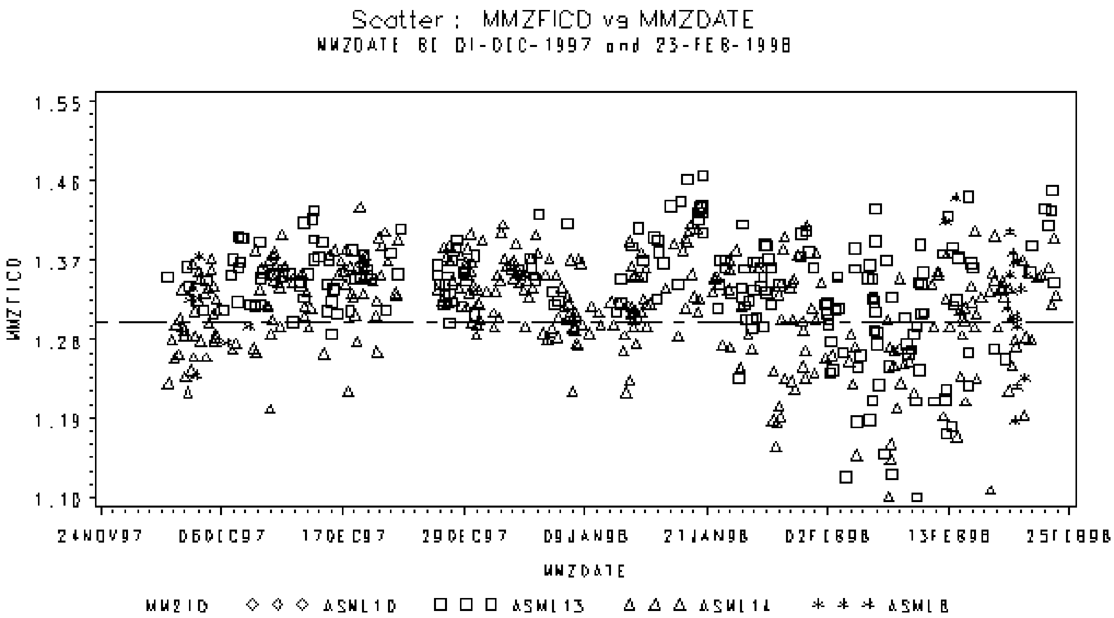


Figure 1. In-line data showed an unexpected downward shift in critical dimensions at metal-2.

Table 2. Statistical Analysis

In-line CD Data

resist	MMEFICD mean	MMEFICD std dev	MMZFICD mean	MMZFICD std dev
3718JM	1.084	0.0354	1.337	0.0422
3617M	1.068	0.0519	1.302	0.0798

WET Data

resist	M1OPEN mean	M1OPEN std dev	M2OPEN mean	M2OPEN std dev
3718JM	60.99	2.19	49.60	1.244
3617M	62.37	1.93	48.87	1.537

resist	RSMETAL1 mean	RSMETAL1 std dev	RSMETAL2 mean	RSMETAL2 std dev
3718JM	82.36	1.6	35.09	0.761
3617M	81.68	1.6	35.07	0.734

resist	M1RS1 mean	M1RS1 std dev	M2RS2 mean	M2RS2 std dev
3718JM	1.31	0.033	1.337	0.0422
3617M	1.35	0.034	1.302	0.0798

Based on statistical comparison of the two resist processes and resultant in-line data, the 3617M resist was not demonstrating the CD control expected based on initial qualification results. Fortunately, the low CD lots did not demonstrate a significant impact at WET and SORT and the low lots seem to have yielded well despite the difference in CDs. However, in response to the statistical analysis of the data the metal process was proactively converted back to the 3718JM process.

4. 3617M POST-QUALIFICATION EXPERIMENTS

Following implementation of the 3617M resist, and the associated downward shift in metal linewidths and increased CD variation, an initial investigation into possible root causes of the trend included:

- Running a split lot (No. 1) between metal deposition tools and developer cups.
- Running a split lot (No. 2) between metal deposition tools and the 3617M and 3718JM resists.
- Quantifying resist thickness variations on the TEL between the 3617M and 3718JM resists.
- Completing an isolated vs. dense line study on metal substrates deposited using two different deposition tools.

AMD's Fab 15 manufacturing facility uses the Varian 3280 (VAR1), Varian 3290 (VAR2), Eclipse Mark II (MRC) and Anelva sputtering systems to deposit various metal films. During the time frame in which the 3617M CD excursions were discovered, several sputtering targets were changed on the metal deposition tools.

Split Lot No. 1

To identify any differences in CDs between TEL track develop cups and the 3718JM and 3617M resists, a two-way split lot was run. As the CD excursions were most prevalent at the metal-2 layer, 10,000Å Al/1,000Å Ti was deposited to reflect a metal-2 film stack.

Similar to the initial qualification of the 3617M resist, this lot was processed on an ASML stepper interfaced with a TEL Mark V wafer track. Electrical after etch CDs were recorded. Results are summarized below in Table 3.

Table 3. Average FICD (μm)

metal dep tool	dev cup 1	dev cup 2
Eclipse Mark II	1.39	1.40
Varian 3290	1.24	1.33

No CD differences were observed for wafers processed on the Eclipse Mark II. However, there is a .09μm difference between the two develop cups for the wafers processed on the Varian 3290. As no obvious commonality was observed from this experiment, a root cause for the erratic CDs was not identified with this split.

Split Lot No. 2

A second split lot was run to further isolate the root causes of the erratic metal CDs. This lot was split into 4 groups: 3617-MRC, 3718-MRC, 3617-VAR, and 3718-VAR. All four groups were processed on an ASML2500/40 i-line stepper interfaced to a Mark V TEL track.

The electrical after etch CDs for all four groups were on target (target=1.30μm). Production in-line CDs are monitored and measured electrically using a Prometrix Lithomap EM1. This tool calculates linewidth data from the sheet resistance, design length, and the voltage across several resistors of varying dimensions. Since all four groups did not deviate significantly from the target CD, the split lot did not identify a source for the erratic CDs (see the FI electrical data in Table 4).

Resist Thickness Uniformity

A total of 50 bare silicon wafers were coated on a TEL Mark V track. Twenty-five of the wafers were coated with the 3617M resist process, 18,500Å, and the other 25 wafers were coated with the 3718JM resist process, 18,500Å. Each wafer was measured on a Prometrix Spectramap-300 probing 49 sites. The mean, range and standard deviation were plotted for each wafer in the same order they were processed on the TEL. No significant difference in uniformity was observed between the two resists.

Isolated vs. Dense Line Study on Metal Substrate

This study was conducted on bare metal substrates with no underlying topography. The wafers were processed with approximately 10,000Å of Al on 1,000Å of Ti on 3,500Å of CVD oxide. The wafers were generated using both the Varian and MRC metal deposition tools.

The wafers were processed on an i-line ASML stepper interfaced to a TEL track and used a Benchmark Technologies Q-Cleave test reticle. This test reticle includes dense and isolated lines ranging from 0.4µm to 2.0µm (wafer dimensions). Table 5 is a summary of the processing parameters for each wafer.

Table 4. Four-Way Split Lot (CDs in µm)

split	iso	dense	iso-dense	FI electrical
3617-MRC	1.70	1.44	0.26	1.27
3617-VAR	1.73	1.48	0.25	1.30
3718-MRC	1.76	1.47	0.29	1.33
3718-VAR	1.66	1.47	0.20	1.34

Table 5. E_0 and Line Profile Study

wafer #	soft bake (ºC)	PEB (ºC)	develop time (sec)	metal tool	resist type	E_0 (mJ/cm^2)
G5	95	115	75	VAR	3617	60
C1	95	115	75	MRC	3617	60
E0	95	115	60	VAR	3617	70
B4	95	115	60	MRC	3617	70
C0	100	110	90	VAR	3718	55
A2	100	110	90	MRC	3718	55

A focus-exposure matrix was run on each wafer, at 150 by 15mJ/cm^2 for 3617M and 110 by 10mJ/cm^2 for 3718JM; best focus for the system was -0.3µm, and was varied by 0.4µm increments. All wafers were developed using an E^2 nozzle, single puddle process.

Top-down CD measurements are shown in Table 4. End-on SEM pictures of the 1.0µm nominal isolated and dense resist lines were also obtained from each of the wafers. The desired outcomes from the SEM cross-sections were to identify differences between isolated and dense lines, metal deposition tools, resist types, and various develop times.

From the cross-sections, undercutting of the resist lines was observed at higher exposures. This undercutting is especially prevalent on the 3617M resist using the 75sec puddle. The results of this experiment indicate that the 3617M, 75sec develop process has improved sidewall profiles through focus, however, undercutting is observed at the higher exposures. With the 3718JM resist at lower exposures scumming was observed, but very little undercutting was seen (even at the highest exposure). Little difference was seen among the iso-dense print bias results for the two types of metal deposition tools (see Table 4).

Focus/Exposure Data

Electrical CD data was collected for the processing parameters summarized in Table 6. This data was entered into ProDATA™ and process windows were calculated for each coat and develop processing condition. See Figure 2 for some example results. Like the end-on SEM pictures, the electrical CD data also indicates improved focus latitude with the 3617M resist, but little or no improvement in exposure latitude using the 75 second develop process.

Table 6. Process Windows

soft bake (ºC)	PEB (ºC)	develop time (sec)	resist type	focus latitude	% exposure latitude
95	115	75	3617	3µm	18%
95	115	60	3617	3µm	33%
100	110	90	3718	2µm	25%

5. SIMULATED CHARACTERIZATION

PROLITH/2 version 5.07 (FINLE Technologies) was also used to help determine root causes for the wider FICD distribution seen with the 3617M process versus the 3718JM process. The goals of the simulation effort were to:

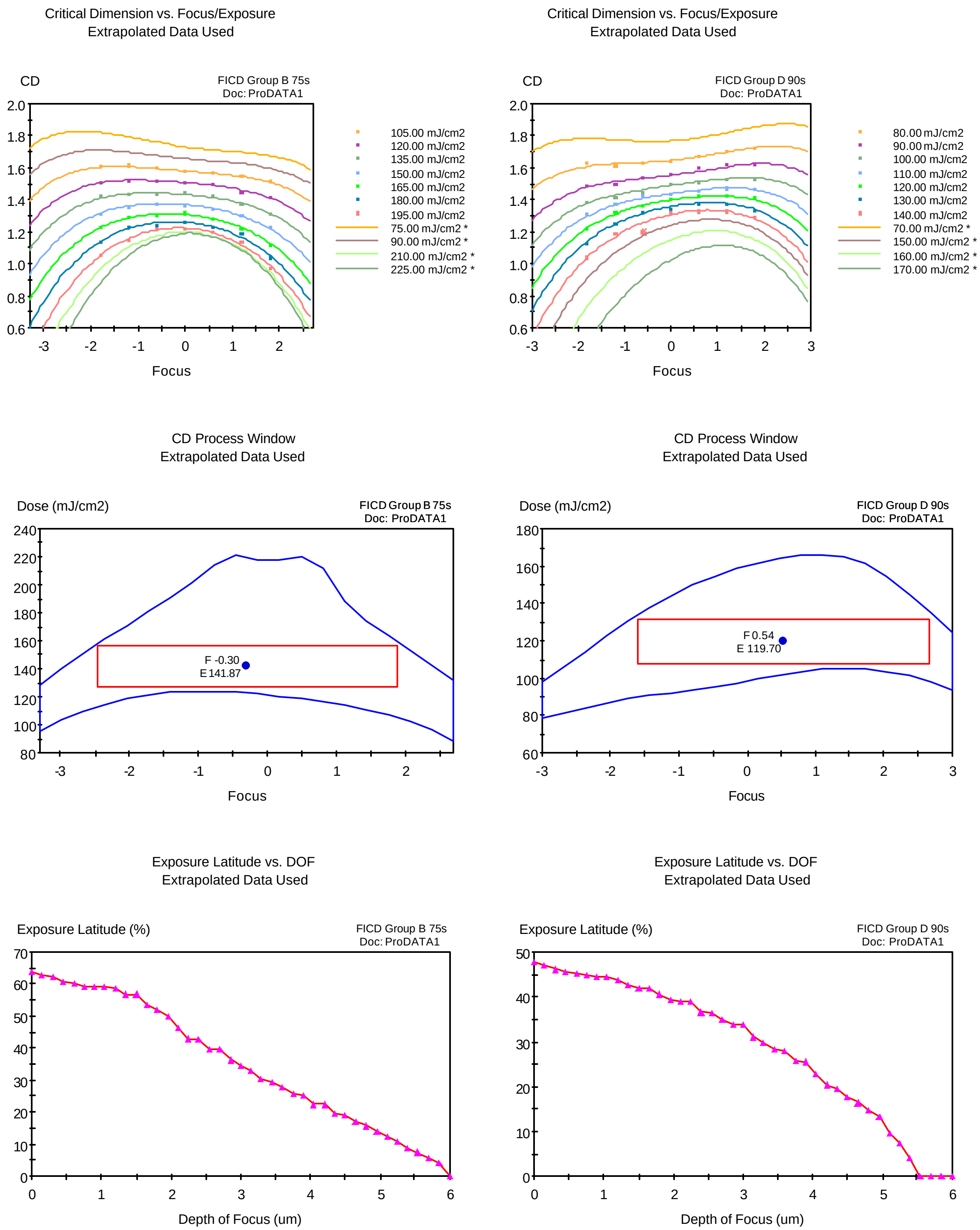
- Understand why 3617M exhibits sidewall undercutting.
- Gain an understanding of what causes the small metal CDs and increased variation using the 3617M resist.
- Understand thin film interference and its effect on CD control.

The first step in process modeling is to adjust input parameters to more accurately match a given set of experimental conditions. Before these adjustments, lithography simulators typically do not match experimental results due to differences in resist thickness measurement, dose calibration, and development parameters. For this paper, PROLITH/2 input parameters were adjusted using the Thornton-Mack method [4]. The tuning parameters that this method describes are:

- Index of refraction
- Exposure rate constant, C
- Development parameters - R_{min}, R_{max}, n, m_{th}
- CD metrology parameters
- Lens aberrations

The process defined in the Thornton-Mack paper suggests that many of these tuning parameters can be adjusted using an E_0 swing curve on bare silicon. Once the process is matched on bare silicon, using the same adjustments the model can accurately predict the behavior of other processes on differing substrates and under different conditions.

Initial resist modeling parameters were provided by Shipley (see Tables 7 and 8 for a summary of “before and after tuning” parameters). Bare silicon wafers were coated with resist thicknesses varying from 1.6 to 1.9µm for 3718JM and 1.7 to 1.9µm for 3617M. Table 9 gives a complete set of experimental conditions. The dose-to-clear, E_0, was determined for each resist thickness to yield an experimentally determined swing curve. This experimentally determined swing curve was plotted against the simulated swing curve and exhibited a mismatch in both phase and amplitude. To compensate for the shift in phase, the simulated data was adjusted by changing the refractive index. To further match the model to experimental data, the resist C parameter (the exposure rate constant) was tuned to shift the dose of the simulation to match the experiment. Matched swing curves with both parameter adjustments implemented are shown in Figures 3 and 4.



(a) (b)

Figure 2. ProDATA analysis of focus-exposure matrix data for (a) 3617M and (b) 3718JM resists. CD specification limits for the process window calculation were 1.15 – 1.50µm.

Table 7. 3718JM Simulation Parameter Before and After Tuning

parameter	before tuning	after tuning
A (µm^{-1})	1.052	1.052
B (µm^{-1})	0.224	0.224
C (cm^2/mJ)	0.0396	0.0230
refractive index	1.592	1.709

Table 8. 3617M Simulation Parameter Before and After Tuning

parameter	before tuning	after tuning
A (µm^{-1})	0.804	0.804
B (µm^{-1})	0.389	0.389
C (cm^2/mJ)	0.0157	0.0171
refractive index	1.592	1.71

Table 9. Experimental Conditions

Resist	3718JM	3617M
Coat cycle	1600 rpm dispense for 3 sec, 2 ml of resist, 18 sec spin at variable spin speed	1600 rpm dispense for 3 sec., 2 ml of resist, 18 sec spin at variable spin speed
Soft bake	60 sec proximity bake @ 100ºC	95 sec proximity bake @ 95ºC
PEB	45 sec proximity bake @ 110ºC	60 sec proximity bake @ 95ºC
Development	AMD C2000 developer, (0.255 N TMAH), 75 sec single puddle	AMD C2000 developer, (0.255 N TMAH), 75 sec single puddle

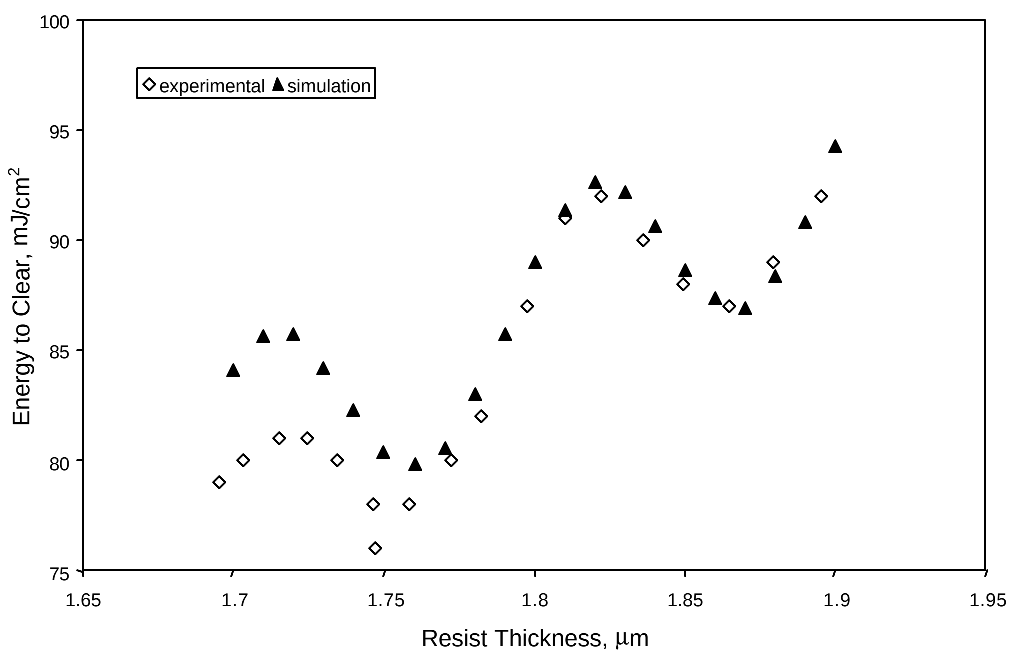


Figure 3. Swing curves of dose-to-clear comparing experimental and tuned simulations for 3617M resist on bare silicon.

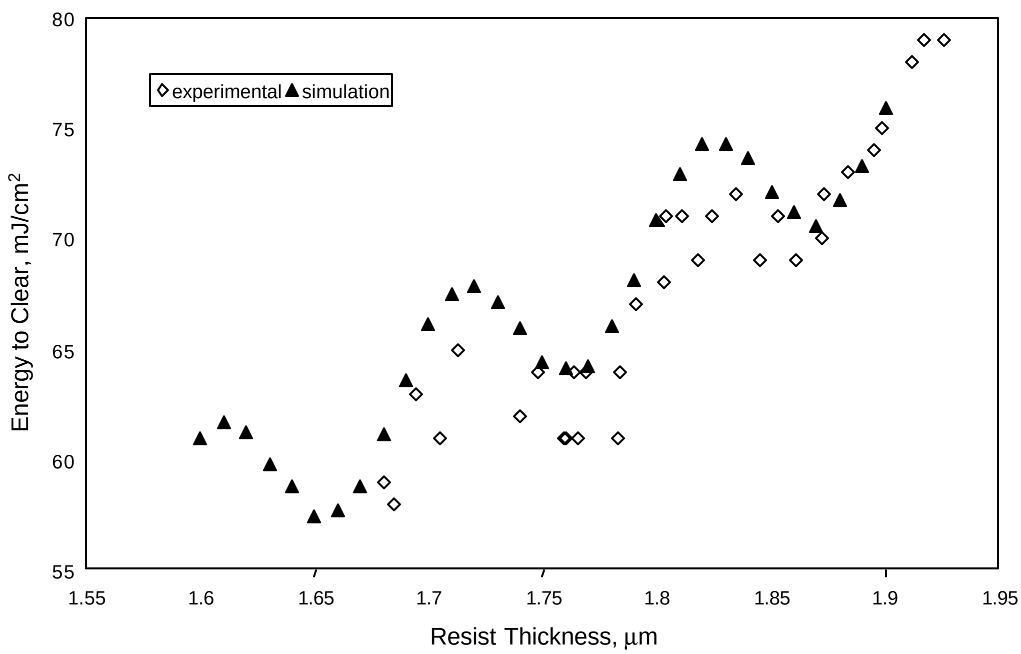


Figure 4. Swing curves of dose-to-clear comparing experimental and tuned simulations for 3718JM resist on bare silicon.

As was also mentioned by Thornton and Mack [4], other parameters such as stepper lens aberrations and development surface inhibition impact the ability of simulation results to match a given experimental scenario. Measuring the aberration behavior of a lens in-situ is possible [5], but is not practical in our production environment. Thus, as a simple approximation, lens aberrations were assumed to be 0.1 waves of 3rd order astigmatism and 0.1 waves of 3rd order spherical. These values are not out of the question for the 0.4 NA lenses of the vintage used in our steppers, but were chosen as simply educated guesses.

Thornton and Mack suggested using the surface inhibition function as a way of matching the surface shape of the photoresist profile [4]. The resists used in this study, however, exhibit depth-dependent dissolution behavior that goes beyond simple surface inhibition. As was stated earlier, one of the advantages of the Shipley 3617M resist is its superior profile performance, even though the resist is moderately dyed and used at thicknesses near 2 µm. Since this resist is only of moderate contrast, one would expect sloped sidewalls. In fact, initial simulations showed best focus and exposure conditions resulting in resist profiles of 80 - 82°, whereas experimental results produced close to 90° (vertical sidewall) profiles. It seems likely that this resist was engineered to exhibit a depth-dependence to the dissolution behavior that results in better sidewall angles. Such depth-dependence may be manipulated by adjusting the polymer properties to provide a desirable solvent gradient that increases the dissolution rate toward the bottom of the resist.

Without the ability to directly measure the variation of development rate as a function of depth into the photoresist, various relative development rate functions $R_{rel}(z)$ were tried empirically. It was found that, for this resist, the relative dissolution rate function shown in Figure 5 resulted in resist profiles that matched experimental profiles. This $R_{rel}(z)$ function, in conjunction with the parameters of Table 10, were used to simulate the patterning of 1µm lines and spaces in 3617M resist on a metal-2 film stack. Comparison of the cross-sectional simulations with line-end SEM pictures through focus and exposure are shown in Figures 6 and 7. Excellent agreement between simulation and experiment is observed for both critical dimensions and resist profile shapes.

Figure 6 also shows an interesting phenomenon of resist undercutting at high exposure (the 180mJ/cm^2 SEM picture). Apparently, the increasing development rate with depth into resist that provides vertical profiles at the nominal exposure leads to the undesirable side-effect of undercutting at high exposures. Note that the simulation also predicts this undercutting.

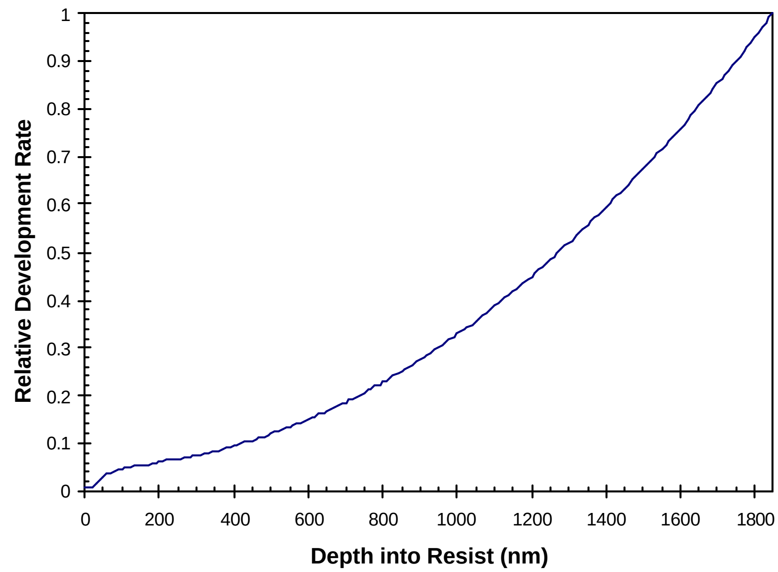


Figure 5. Empirically determined relative development rate function used in matching simulated to experimental resist profiles.

Table 10. PROLITH/2 Input Parameters

Image Model: High NA Scalar	Film Stack:
Wavelength = 365.0 nm	Layer #1: 1000nm Aluminum
Numerical Aperture = 0.40	Layer #2: 350nm Oxide
Reduction Ratio = 5.0	Substrate: Silicon
Image Flare = 0.02	
Partial Coherence = 0.54	Resist System: Positive
	Thickness = 1.850 µm
Mask:	Absorption Parameter A = 0.802 1/µm
Linewidth = 1.000 µm	Absorption Parameter B = 0.389 1/µm
Pitch = 2.000 µm	Rate Constant C = 0.0180 cm^2/mJ
	Refractive Index = 1.712
Focal Position = varied	
Exposure Energy = varied	Development Model: Original Mack
	Max Develop Rate = 360.0 nm/s
PEB Diffusion Length = 70.0 nm	Min Develop Rate = 0.050 nm/s
	Threshold M = 0.55
Development Time = 75.0 sec	Selectivity Parameter n = 2.00

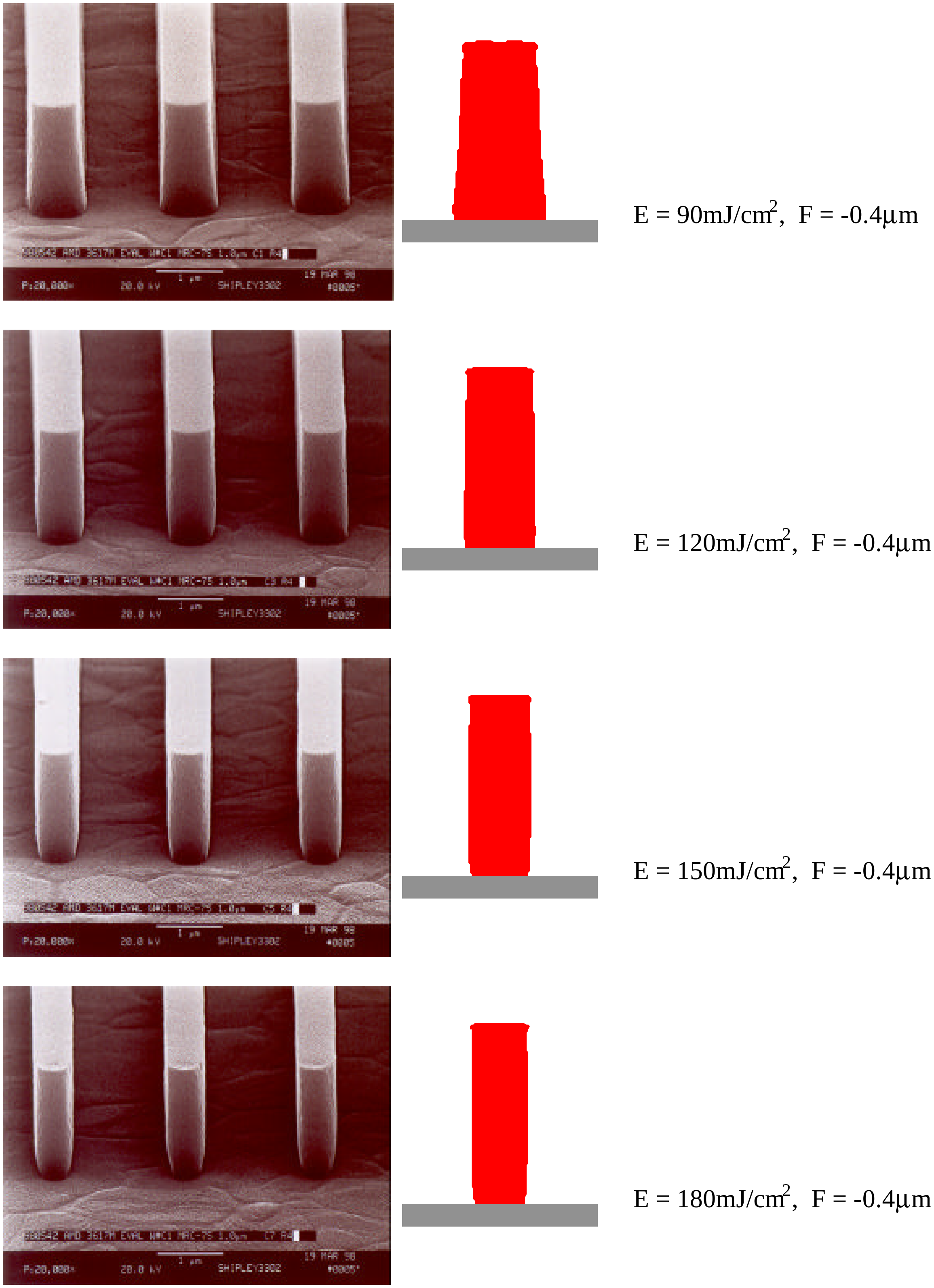


Figure 6. Experimental and simulated resist profiles through exposure on a metal substrate for Shipley 3617M resist.

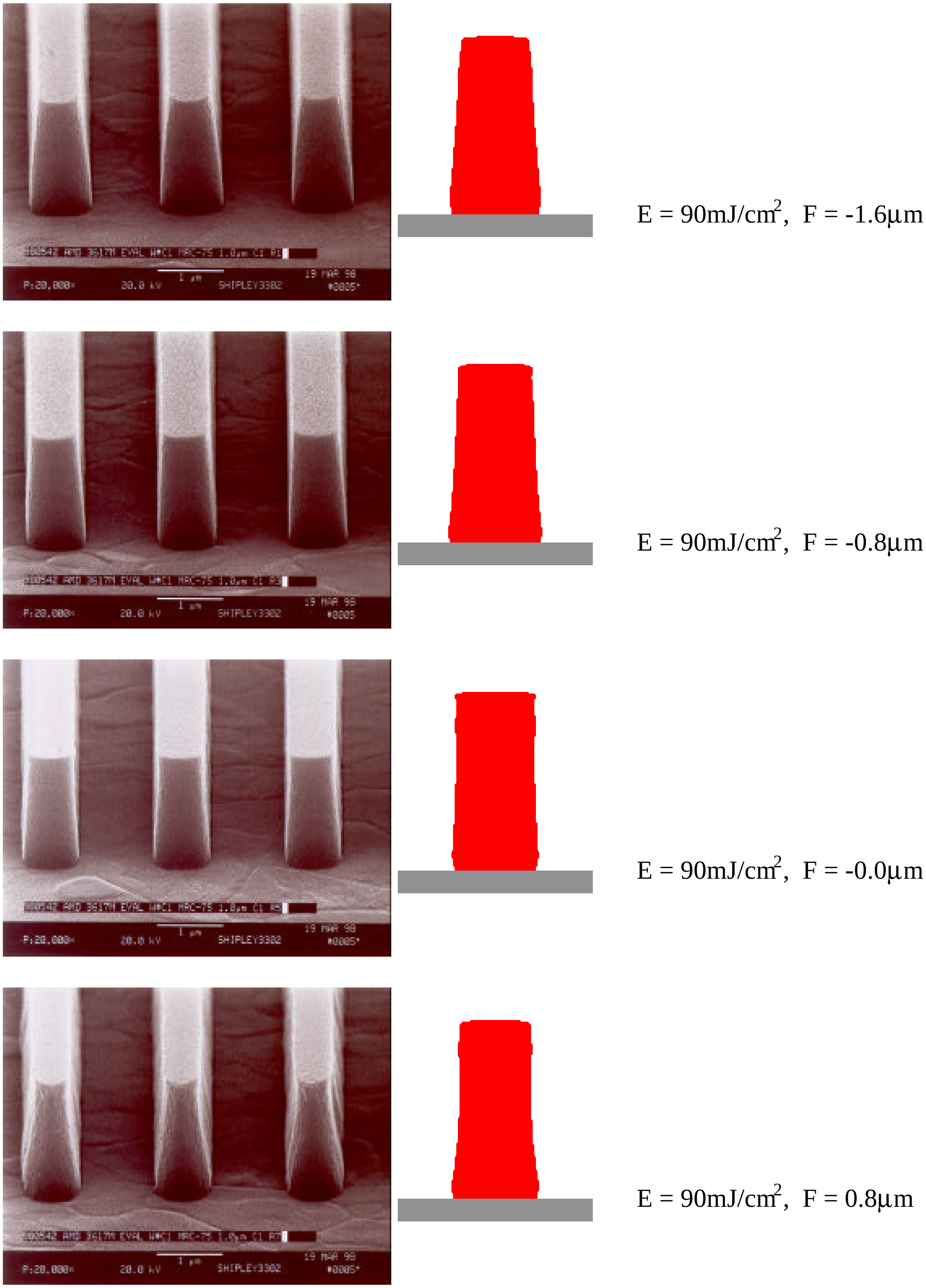


Figure 7. Experimental and simulated resist profiles through focus for Shipley 3617M resist.

6. CONCLUSIONS AND NEXT STEPS

In this paper, AMD's Fab 15 manufacturing facility's planned use of Shipley 3617M photoresist as a solution to reflective notching was presented. Initial qualification, implementation, and performance were detailed, and post-qualification experiments run as a result of in-line critical dimension data abnormalities were addressed. In addition, experimental and PROLITH/2 simulated results were shown.

While initial qualification results and stated product benefits drove Fab 15's implementation of a 3617M resist process, in-line process data quickly indicated a CD control problem. Based on statistical comparison of the 3718JM and 3617M resist processes, and resultant in-line data, the 3617M resist was not demonstrating the CD control expected based on initial qualification results. In response to these factors, the metal process was proactively converted back to the 3718JM resist and an effort was initiated to determine the cause of the CD control problems.

It is believed that the following circumstances contributed to our observed critical dimension data abnormalities:

1. 3617M was initially characterized only on silicon and not on metal.
2. Vertical resist profiles for 3617M were assumed to correlate to a high contrast resist with a wide(r) overall process window (i.e., both improved focus and exposure latitude).

Based upon SEM end-on shots and resist simulations, it is postulated that good profiles were obtained through a careful engineering of resist solvent gradients to control dissolution rates (the resist solvent concentrations cause a "solvent-rich at the bottom/solvent-poor at the top" effect). This gives a depth-dependence to the development rate that results in vertical sidewalls. However, it does not result in improved exposure latitude and this improvement is vital for CD control.

Lithography simulation proved quite useful in clarifying the behavior of the 3617M resist and, in providing direction as to the root causes for the wider FICD distribution observed. For example, the surface inhibition function used in PROLITH/2 indicates an increase in development rate from the top to bottom of the resist which cannot be explained by normal exposure variations. This led to the belief that resist solvent gradient engineering resulted in vertical profiles. Our modeling work allowed for the matching of experimental and simulated data and thereby, a tuning of PROLITH/2 to our manufacturing process. Next steps will include use of the tuned model to provide direction for future experimentation in our continuing effort to determine the best strategy for addressing reflective notching. In addition, the model will be used to investigate the effects of mask bias and focus offsets on FI CD distribution, specifically for metal substrates.

While in this paper we have presented accomplishments to date, there exists ample opportunity and need for future work. The approach taken for the metal layer process characterization detailed herein was as follows: recognition of a manufacturing need, identification of a suitable resist material, initial resist qualification, material implementation and performance monitoring, post-qualification experimentation, and process modeling. This approach presumed that improved sidewall angles correlate to an overall improvement in process latitude (i.e., a wider process window based on both improved focus and exposure latitude). However, a focus on reflective substrate CD control, in conjunction with good profiles, is critical given that process windows and resist profiles are being decoupled in modern resists. Although we have yet to determine all of the factors which contributed to the wider FICD distribution seen with 3617M versus 3718JM resist, it is apparent that the initial 3617M qualification relied too heavily on resist profile criterion and not heavily enough on reflective substrate CD control criterion. Also, factors such as the interaction between the resist process and items including sputtering targets, deposition tools, etc. require a more detailed investigation. These will be additional areas of focus for our continued work.

7. ACKNOWLEDGEMENTS

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