

Footing Reduction of Positive Deep-UV Photoresists on Plasma Enhanced ARL (PE ARL) SiON Substrates

Lori Anne Joesten^a, Matt Moynihan^a, Tracy Lindsay^a, Michael Reilly^a, Kathy Konjuh^b, David Mordo^b, Ken MacWilliams^b, and Srini Sundararajan^b

^aShipley Company, 455 Forest Street, Marlborough, MA 01752
^bNovellus Systems, Inc., 3970 North First Street, San Jose, CA 95134

ABSTRACT

Chemically-amplified positive DUV photoresists are well known to exhibit small profile deviation at the resist substrate interface, commonly called footing, when processed on substrates like silicon oxynitride (SiON), titanium nitride (TiN), and boron phosphorous silicate glass (BPSG). Severe footing can cause etch problems resulting in critical dimension (CD) non-uniformity and degraded lithographic performance. The objective of this paper is to examine possible solutions to footing on SiON substrates by focusing on three main areas: photoresist formulation, photoresist processing and substrate manipulation.

The differences in photoresist formulation lead to various footing results. Three Shipley™ DUV photoresists, APEX-E 2408™ POSITIVE DUV PHOTORESIST, UV5™ POSITIVE DUV PHOTORESIST and UV6™ POSITIVE DUV PHOTORESIST are examined to benchmark the performance on a baseline 300Å SiON film deposited on silicon. The formulation study is designed to discover the main differences in the photoresist that cause different amounts of footing by examining four areas: photo-acid generator (PAG) type, PAG loading, additive loading and polymer type.

Photoresist processing is studied to understand the main impact of several different processing steps on footing. The studies are performed with one or more of the following Shipley Positive DUV Photoresists, APEX-E 2408, UV5 and UV6 with a 300Å SiON film. The main process steps examined are developer time, photoresist thickness, and softbake and post-exposure bake (PEB) temperature. Prime temperature and dehydration bake after prime are also examined. The develop studies are performed to determine if longer develop times or would erode the foot. Photoresist thickness is examined to determine if the foot size is affected by the position on the swing curve. Softbake and PEB are examined to determine if manipulating bake conditions reduces footing. The substrate priming and dehydration bake studies are performed based on success in minimizing footing on BPSG by using a dehydration bake after prime.¹

The properties of the substrate are closely examined to determine the effect on interfacial footing for APEX-E 2408 and UV6. Although SiON ARL layers have been shown to offer significant improvements in photoresist patterning and yield,² DUV resist performance can be further improved by reducing the amount of footing. Factors that can contribute to the amount of footing include substrate type, surface treatment, substrate thickness and substrate reflectivity. The surface treatments examined include an oxide cap, a 10-second Post-Ash and several nitrous oxide plasma treatments, which vary the gas flow, power, and time.

The studies on SiON film thickness and reflectivity show the greatest effect on photoresist footing. By changing the SiON film thickness from the reflection minimum of 300Å to the reflection maximum of 550Å, the footing is reduced by more than half for APEX-E 2408 and nearly eliminated for UV6. The use of a nitrous oxide plasma treatment reduces the foot by more than a factor of three. The combination of a surface treatment with the reflection maximum of 550Å completely eliminates all traces of footing for APEX-E 2408 and UV6. This work demonstrates that there is an interaction between the surface induced foot and the effective optical dose (reflectivity). Clearly, the purpose of an ARL is to minimize CD swing by reducing reflectivity. A 300Å SiON baseline film has a swing ratio of 5.3% for UV6 which increases to 17.7% for a 550Å SiON film. This study gives additional information to minimize the overall CD variation caused by both footing and CD swing.

1. INTRODUCTION

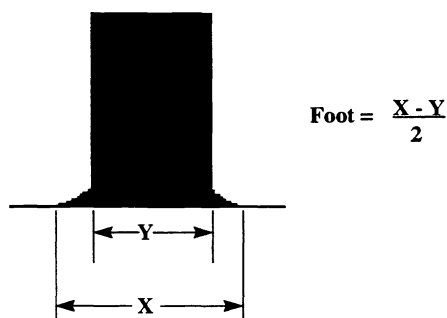
Critical dimension (CD) control is a key parameter for sub-quarter micron DUV lithography. Thin film interference (TFI) effects have a dramatic impact on CD control. Fortunately, TFI effects can be minimized in many ways, including the application of an inorganic anti-reflective layer, such as SiON. SiON substantially reduces the resist-substrate interface reflections and thereby provides a means to achieve excellent CD control. Unfortunately, many chemically-amplified DUV resists are contaminated by the formation of amines at the SiON surface.³ This contamination leads to footing and, hence, poor CD control and resolution.

Methods to improve the foot include using a barrier layer between the photoresist and substrate, changing the photoresist chemistry to reduce its sensitivity to basic contaminants or treating the substrate surface to reduce its basicity. This paper examines the effects of resist chemistry, processing and substrate surface on footing.

2. EXPERIMENTAL

The equipment set for photoresist processing consists of a TEL MK8 coat and develop track, a GCA XLS 7800 Stepper with KrF Laser and a 0.53 NA lens (0.74σ). A Prometrix SM300 is used for all resist film thickness measurements. The SiON films are deposited using a Novellus Concept Two Sequel System. The SiON film thickness is measured on a KLA-Tencor UV-1250SE. The process and substrate manipulation work uses one or more of the following Shipley DUV photoresists and developers: APEX-E with MEGAPOSIT® MF®-702 DEVELOPER, UV5 and UV6 with MEGAPOSIT® LDD-26W DEVELOPER. The main response for all experiments is footing. The size of the foot is determined by measuring the linewidth just above the foot, measuring the linewidth at the substrate and then subtracting the two numbers and dividing by two (see Figure 1). This results in a measurement of the foot per side of the resist line. JMP statistical software is used in the analysis of the formulation designed experiment and of the surface treatment response surface methodology.

Figure 1: Measurement of Footing

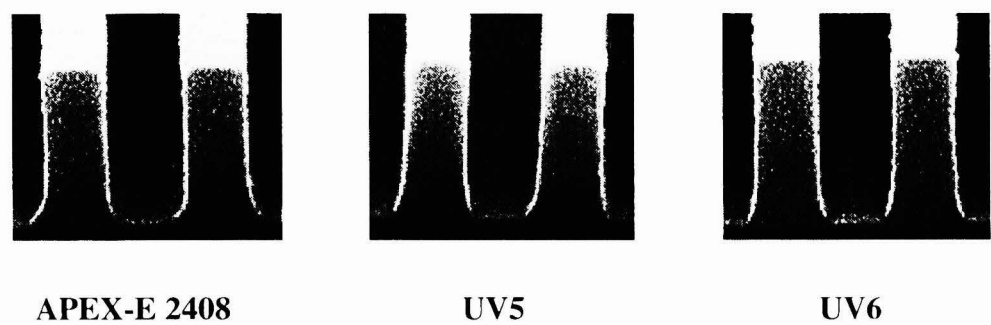


3. RESULTS AND DISCUSSION

3.1 Solutions Through Photoresist Formulation

The interaction between SiON substrates and Positive DUV chemically-amplified photoresists may result in footing. Several of Shipley's DUV resists are examined in order to benchmark the degree of footing on a baseline SiON film of 300Å. The resists examined include APEX-E, UV5 and UV6, as shown in Figure 2. The results of the initial benchmark indicate that APEX-E has the largest foot, followed by UV5, with UV6 showing the best performance.

Figure 2: 250 nm 1:1 Lines/Spaces on 300Å SiON



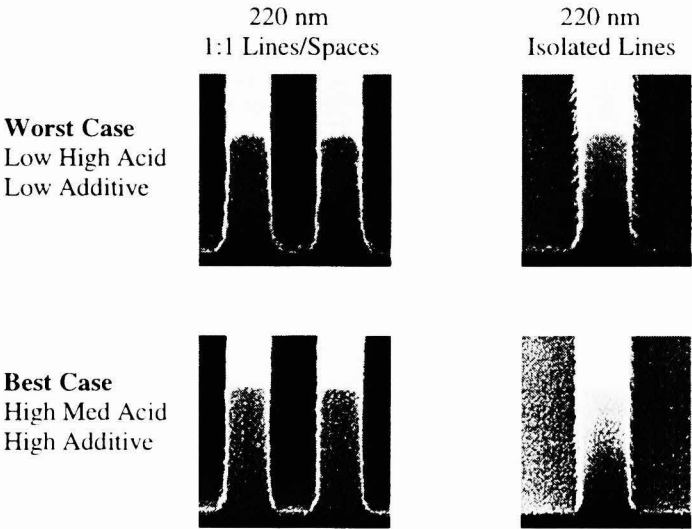
In order to understand the fundamental differences in footing between the resists, a formulation experiment is designed. The experiment focuses on four main areas: photo-acid generator (PAG) type, PAG loading, quencher loading and polymer type. The experiment is a full factorial design and the factors and levels are shown in Table 1.

Table 1: Formulation Design of Experiment

FACTOR	LEVEL 1	LEVEL 2
PAG Type	Medium Strength Acid	High Strength Acid
PAG Loading	Low	High
Additive Loading	Low	High
Polymer Type	Medium Acrylate	Medium-High Acrylate

The JMP analysis of the formulation experiment indicate that the two main factors that affect footing are additive loading and PAG type. Footing is reduced by increasing the additive loading and by using the medium strength acid. In chemically-amplified photoresist, there is an equilibrium between the acid and the base in the exposed region. When basic contamination is introduced at the substrate surface, the equilibrium shifts, resulting in more deactivated acid at the substrate interface.³ By introducing more additive into the resist system and using a medium strength acid, the equilibrium can be better maintained throughout the exposed region. The net result is a reduction in the foot. Although the results of the experiment show that the use of higher additive loading (best case) has a 2X reduction in footing over the worst case, the footing is still too large for practical applications. Figure 3 shows the best and worst cases for 220 nm 1:1 lines/spaces and isolated lines.

Figure 3: 220 nm 1:1 Lines/Spaces and Isolated Lines on 300Å SiON

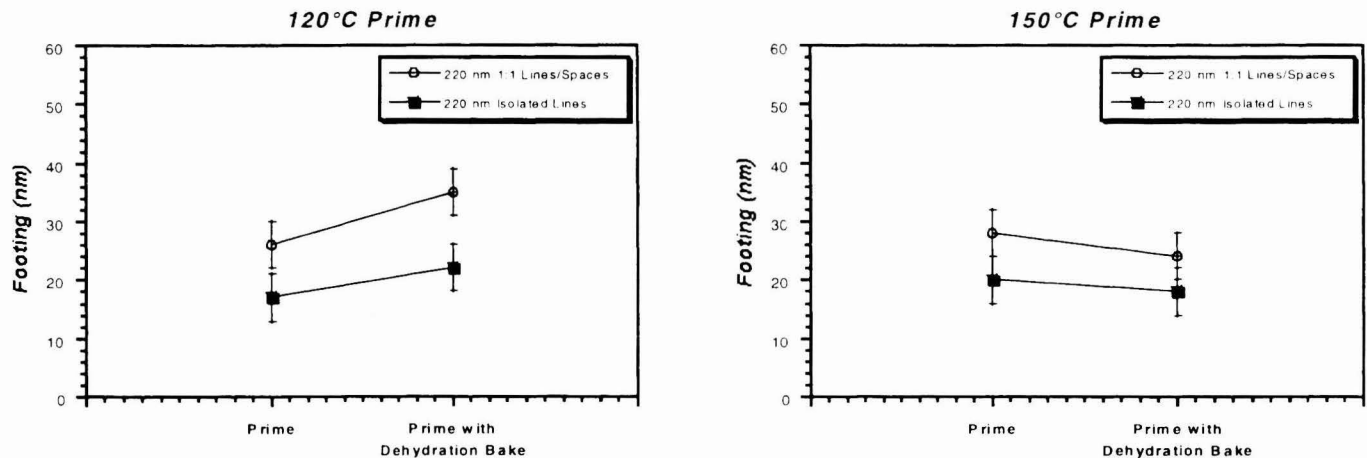


3.2 Solutions Through Photoresist Processing

3.2.1 Prime Temperature and Dehydration Bake

The effects of prime temperature and dehydration bake are examined based on improvements in footing shown with BPSG.¹ The experiment examines the effects of two different prime temperatures with and without a high temperature dehydration bake following prime for UV6 on a 300Å SiON film. The results are inconclusive. At a prime temperature of 120°C, a dehydration bake of 175°C appears to make the footing worse. A prime temperature of 150°C shows similar footing as the 120°C prime, but in this case the dehydration bake has no effect. The results are displayed in Figure 4.

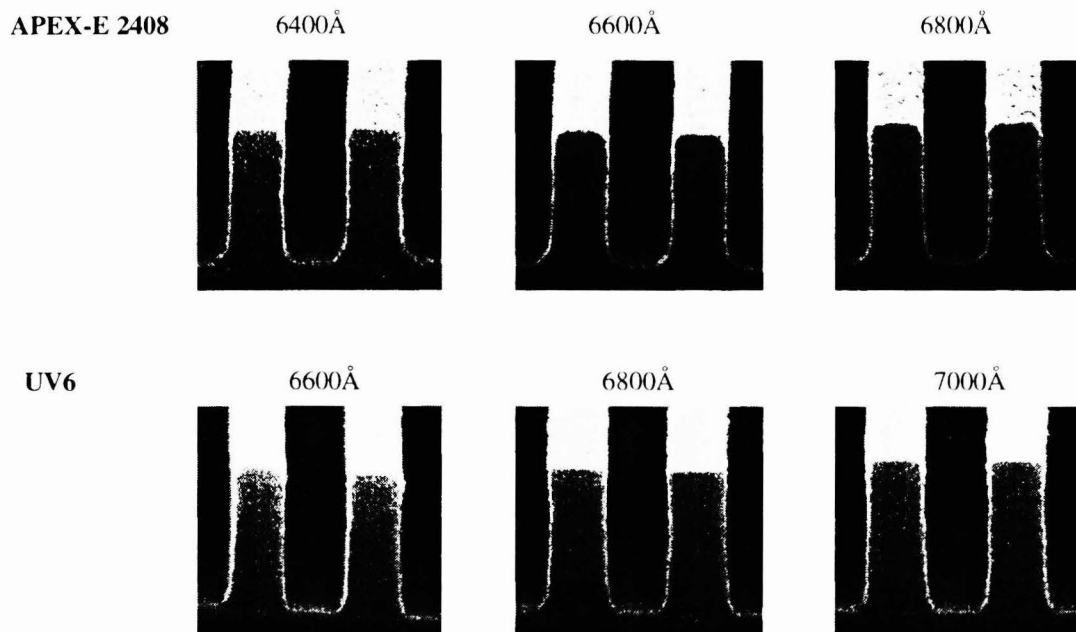
Figure 4: The effect of Dehydration Bake on footing at a 120°C and a 150°C Prime



3.2.2 Photoresist Thickness

The photoresist profile can be manipulated by changing the resist thickness in relation to the swing curve. Therefore, it is attempted to manipulate the foot by changing the resist thickness for APEX-E and for UV6. A total of three film thicknesses are examined for each resist. The results indicate no change in footing, as seen in Figure 5.

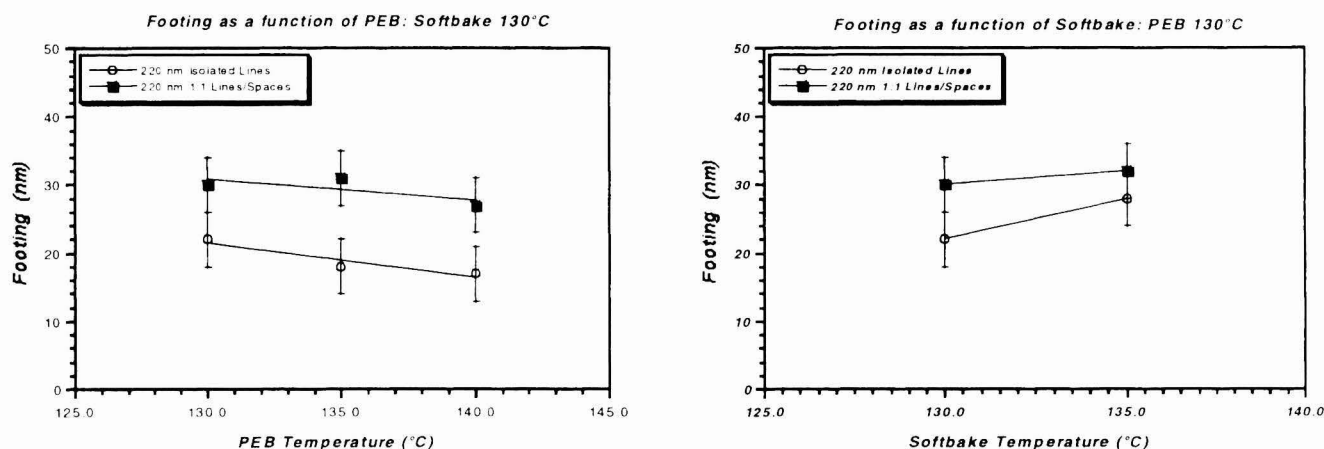
Figure 5: Footing vs. Resist Thickness, 250 nm 1:1 Lines/Spaces on 300Å SiON



3.2.3 Softbake and Post-Exposure Bake

The effect of changing softbake and post-exposure bake (PEB) on footing is examined for UV6. Manipulating the softbake/PEB temperature differential changes the amount of acid diffusion such that an increase in PEB temperature results in more acid diffusion. Increasing the diffusion may result in more acid being available to deblock the polymer at the substrate surface, thereby eliminating footing. The study consists of four runs, three at a fixed softbake of 130°C where the PEB is equal to or greater than the softbake temperature and one run at a 135°C softbake and a 130°C PEB. The results of the experiment indicate that increasing the PEB only marginally affects the footing. The improvement is insignificant in that it is within the measurement error of ± 5 nm. The manipulation of bake temperatures offers no solution to footing. Figure 6 shows the effects of softbake and the effects of PEB on the footing of UV6.

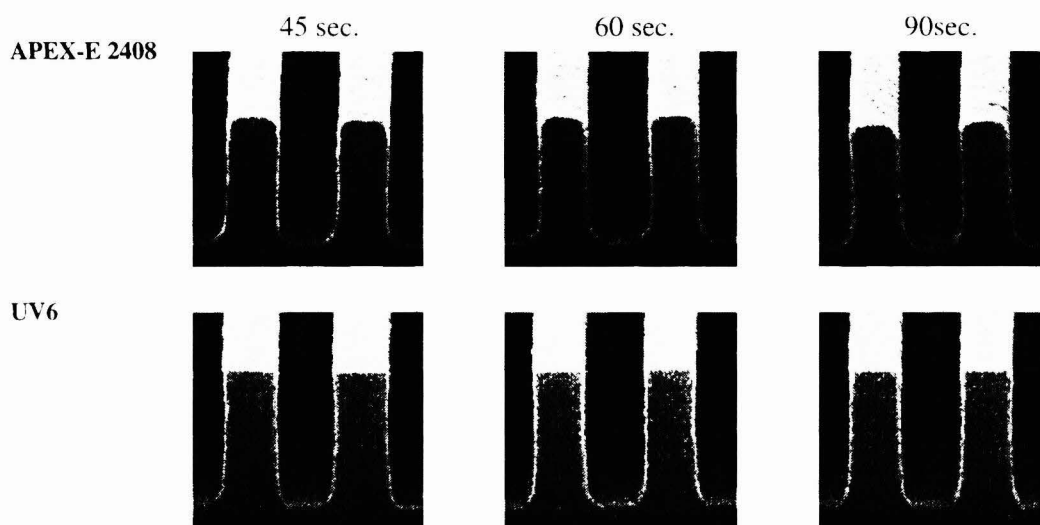
Figure 6: Effects of Softbake and PEB on footing for UV6, 220 nm 1:1 Lines/Spaces and Isolated Lines on 300Å SiON



3.2.4 Develop Time and Normality

The develop step is examined to attempt to find a solution to footing with a more aggressive develop process such as longer develop times. APEX-E and UV6 are examined with single puddle develop times of 45, 60 and 90 seconds. This approach shows no solutions to footing. The results for develop times are displayed in Figure 7.

Figure 7: Develop Time vs. Footing, 250 nm 1:1 Lines/Spaces on 300Å SiON

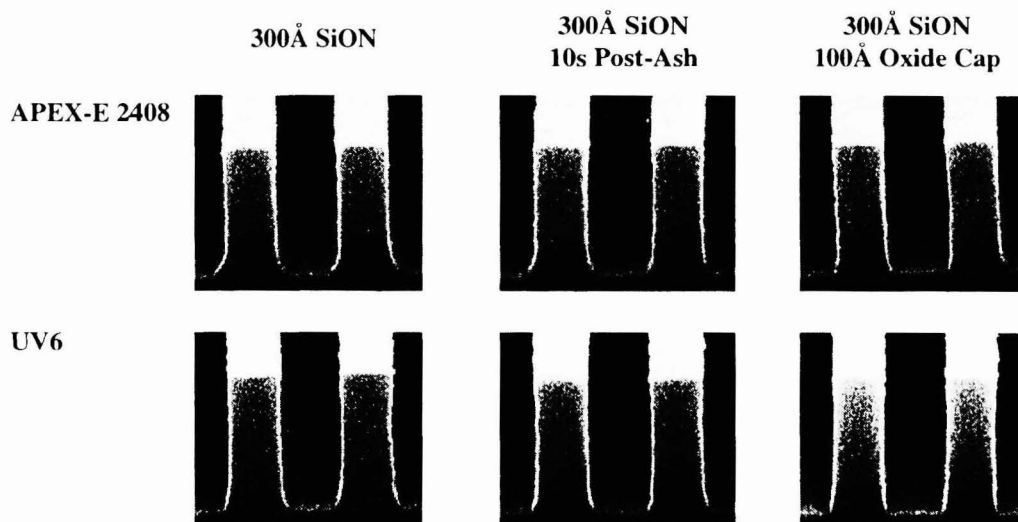


3.3 Solutions Through Substrate Manipulation

3.3.1 SiON Oxide Capping

The use of an oxide cap is examined to determine if a barrier to the substrate surface reduces footing. This is accomplished in one of two ways. First, a 100Å cap of silane-based oxide is deposited over the baseline 300Å SiON film and second, a post ash treatment is performed on the surface of the baseline SiON film. The post-ash treatment is a 10 second burn of the film and is believed to result in a thin oxide layer. APEX-E, UV5 and UV6 are examined on both the 100Å oxide cap and the post-ash treatment. The results, as seen in Figure 8, indicate that the post-ash treatment gives a 2X improvement in footing, over a baseline SiON film, for all resists. The 100Å oxide cap results in a 3X improvement in footing for APEX and UV5 and more than a 5X improvement in footing for UV6. The different substrate surfaces are analyzed to determine any differences in composition which would lead to different amounts of footing. The analysis shows a large amount of carbon contamination on the film, making it difficult to determine differences in the films.

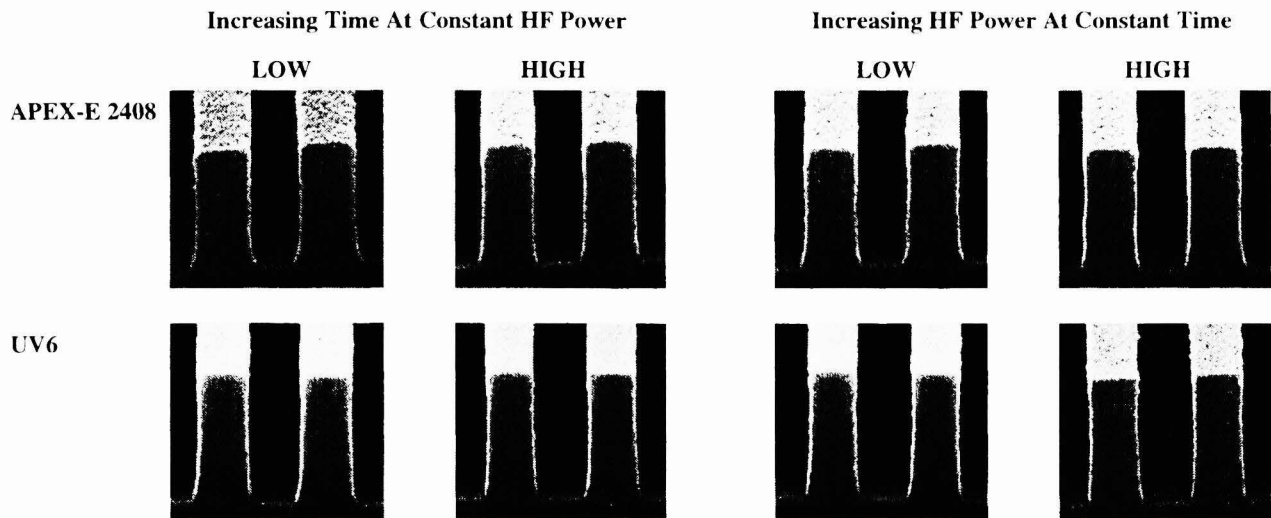
Figure 8: Oxide Capping, 250 nm 1:1 Lines/Spaces



3.3.2 Nitrous Oxide Plasma Surface Treatments

Nitrous oxide plasma treatments on a 300Å SiON film are also examined. The treatments involve nitrous oxide flow, high frequency power and time. A nitrous oxide plasma treatment is also thought to form a thin oxide on the surface, the exact composition of the films is not known as surface analysis has proven difficult. The study examines the effectiveness of the plasma treatments and also how footing is manipulated with changing power and time at a constant nitrous oxide flow. APEX-E and UV6 are examined for each condition in the experiment. The factors of time and power each have three levels using a central composite orthogonal response surface design. In general, the nitrous oxide plasma treatments result in at least a 2X improvement in footing over a baseline film. The results of the response surface indicate that a longer treatment yields the most significant improvement in footing. The effect of power is minimal but does indicate a slight trend that increasing power will decrease the foot. Figure 9 displays the results of the nitrous plasma RSM.

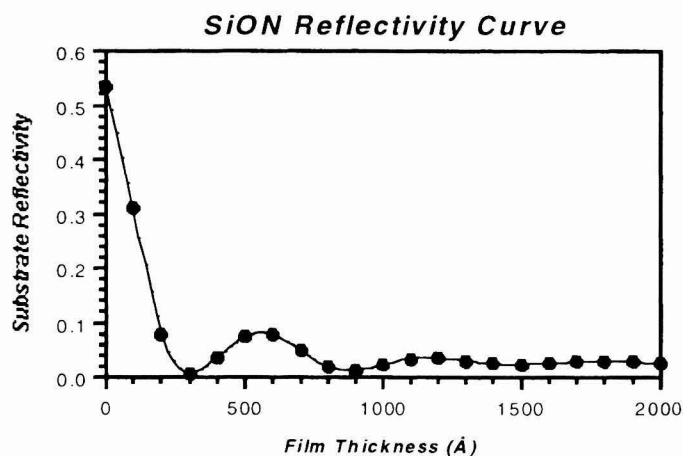
Figure 9: Nitrous Oxide Plasma Surface Treatments, 250 nm 1:1 Lines/Spaces



3.3.3 SiON Film Thickness and Reflectivity

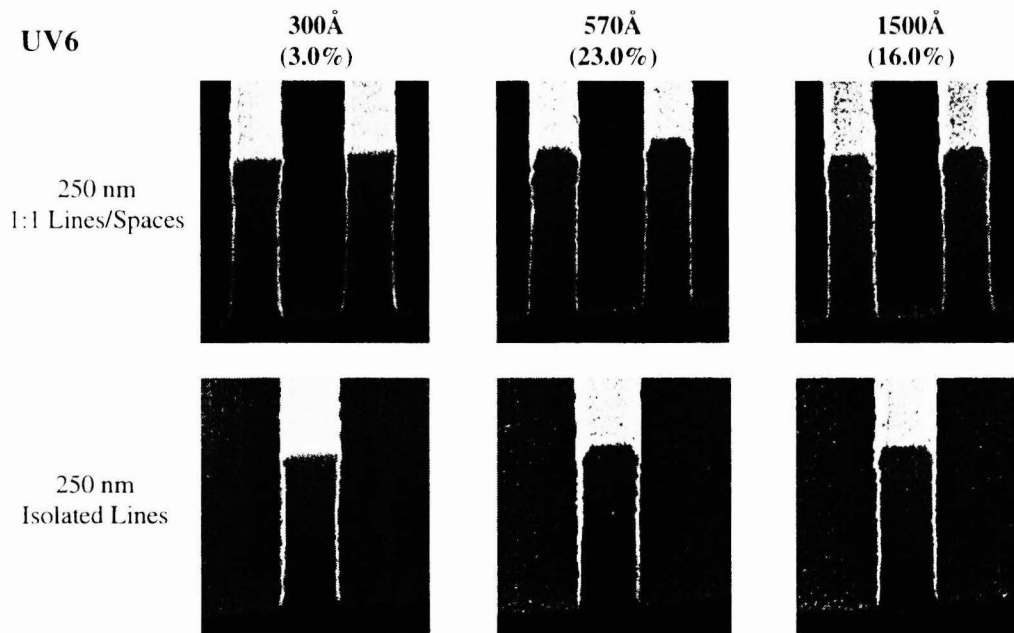
A SiON film with fixed n and k values produces a distinct reflectivity curve, shown in Figure 10. The curve shows a damped sinusoidal dependence of reflectivity on thickness because of its high absorptance.

Figure 10: SiON Reflectivity Curve



Changing the position on this reflectivity curve by varying SiON thickness affects the profile of the photoresist.⁴ Footing is examined on three SiON substrates of different thickness with fixed n and k values: 300Å (minimum), 570Å (maximum) and 1,500Å (minimum). The resulting trend is that footing decreases with increased SiON reflectivity. The results for UV6 are shown in Figure 11. At the 1,500Å film thickness, a local minimum of 16% reflectivity, a 2X improvement in footing results over the 300Å film, which has a reflectivity minimum of 3.0%. At 570Å, a reflectivity maximum of 23%, a 4X improvement in footing is achieved over the 300Å film.

Figure 11: Footing vs. SiON Film Thickness, 250 nm 1:1 Lines/Spaces and Isolated Lines



An additional experiment is performed to determine if the degree of footing is dependent upon the total reflectivity, the standing wave phase at the substrate interface or a combined effect of the two. The experiment consists of five runs varying reflectivity from 1.0% to 22.0%. The resulting substrates have similar n and k values, except for the 267Å film of 1% reflectivity, and have a phase relationship relative to the reflectivity minimum at 300Å varying from -0.67 to 2.68 radians. The reflectivity curves are shown in Figure 12.

The footing results for UV6, as seen in Figure 13, show a non-linear behavior with the phase on the reflectivity curve. As reflectivity increases from 1.0% to 5.0% the footing appears to worsen, moving from a descending midpoint (267Å) to a minimum (300Å) on the reflectivity curve. The footing then improves with increasing reflectivity and film thickness, moving from the minimum (300Å) through two ascending mid points (350Å and 422Å) to the maximum (556Å). The results show that there is a dependence of footing on the phase of the standing wave at the substrate interface. As our substrate thickness changes in the direction of negative phase, instead of an undercut profile occurring, as seen by Mack,⁴ the relative increase of light intensity at the interface results in a reduction in footing. The difference in data can be explained by the fact that there is a foot on the profile at the zero phase (300Å) for SiON and so a reduction in the size of the foot is observed instead of an undercut. The data is not strictly sinusoidal and the behavior of which might also depend upon total reflectivity in this low reflectance regime, but the minimal data set does not allow a firm conclusion. However, it does appear that working at a thickness slightly below the reflection minimum results in a reduction in footing with minimal change in reflection control. Working at a local reflectivity maximum also significantly eliminates traces of footing.

Figure 12: Reflectivity Curves

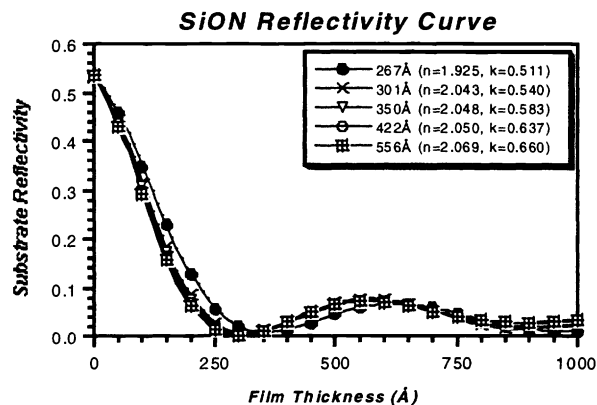
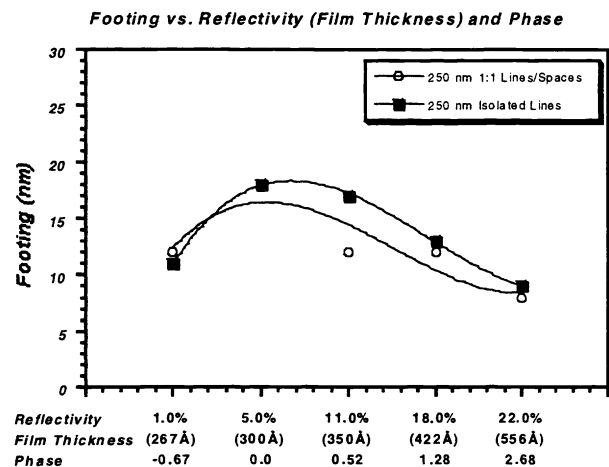


Figure 13: Footing vs. Reflectivity and Phase
250 nm 1:1 Lines/Spaces and Isolated Lines

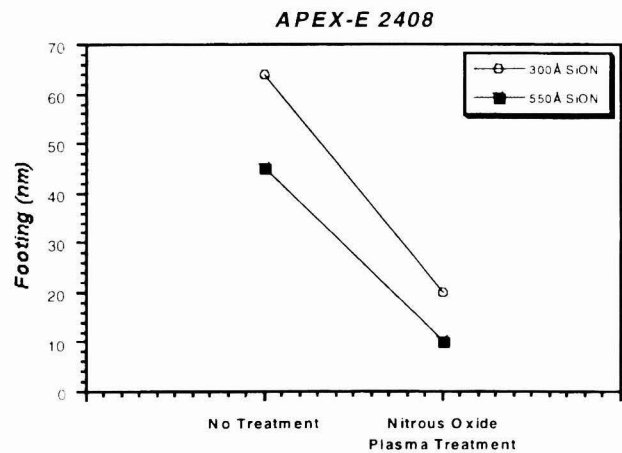


3.3.4 SiON Film Thickness and Surface Treatment

The position on the SiON reflectivity curve has the greatest effect on footing, nearly eliminating the problem for UV6 and significantly reducing it for APEX-E when using a local reflection maximum, a film thickness of 550Å. However, the best and most appealing solution would occur around a reflection minimum. In this experiment two different effects are being examined: one, confirming the improvement in footing when using a 550Å film and, two, attempting a solution with a nitrous oxide plasma treatment. The experiment consists of four conditions, 300Å SiON with and without treatment and 550Å with and without treatment. UV6 and APEX-E are studied. The results are displayed in Figure 14. UV6 shows a 2X improvement in footing from an untreated wafer to a nitrous oxide plasma treated wafer. The greatest improvement is found for the 550Å, in that no footing occurs on the 550Å plasma treated SiON and very little footing occurs on the 550Å *untreated* SiON. The results for APEX-E indicate that the surface treatment has the greatest effect on footing, showing a 4X reduction in footing, whereas the 550Å SiON film only results in a 2X reduction in footing. The 550Å nitrous oxide plasma treated film virtually eliminates all traces of footing for APEX-E.

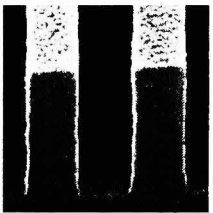
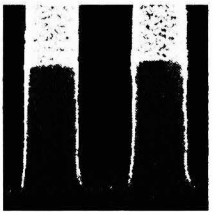
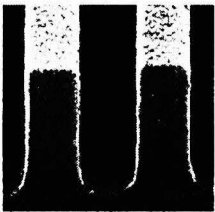
Figure 14: Footing vs. Surface Treatment and Film Thickness, 250 nm 1:1 Lines/Spaces

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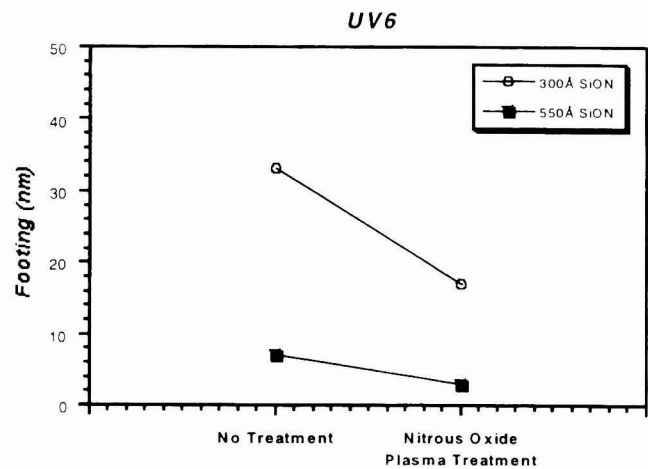


No Treatment

Nitrous Oxide
Plasma Treatment

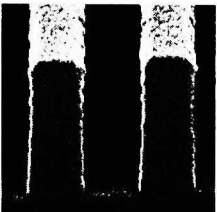
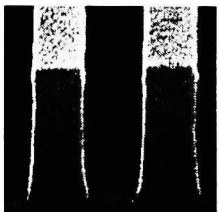
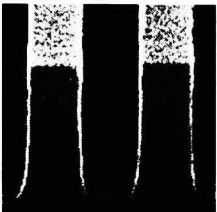


UV6



No Treatment

Nitrous Oxide
Plasma Treatment



The best footing results are obtained by using an SiON thickness resulting in a local reflection maximum with a nitrous oxide plasma surface treatment. It is expected that when moving from a reflection minimum of 300Å to a reflection maximum of 550Å, thin film effects may cause CD control issues and degrade lithographic performance. Figure 15 displays the CD swing curve for UV6 on 300Å SiON, 550Å SiON and silicon. The swing ratio for UV6 on silicon is 39.0%, which is reduced to 5.3% for the 300Å SiON. The 550Å SiON film still provides a fair amount of reflection control at a swing ratio of 17.7%. The lithographic performance for UV6 shows some differences between the 300Å and the 550Å films. The 550Å SiON film does show slightly better focus latitude, 0.2 - 0.4 μm , greater than the 300Å film for the 200 nm lines/spaces and the isolated lines, most likely due to the improvement in footing. Figure 16 displays the focus latitude comparison for UV6 on 300Å and 550Å SiON.

Figure 15: UV6 CD Swing Curve

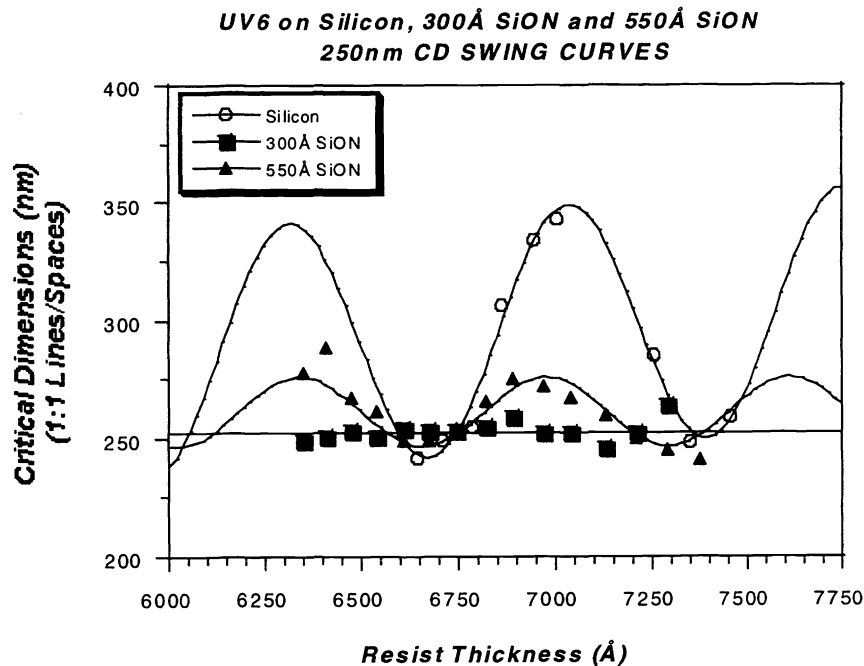
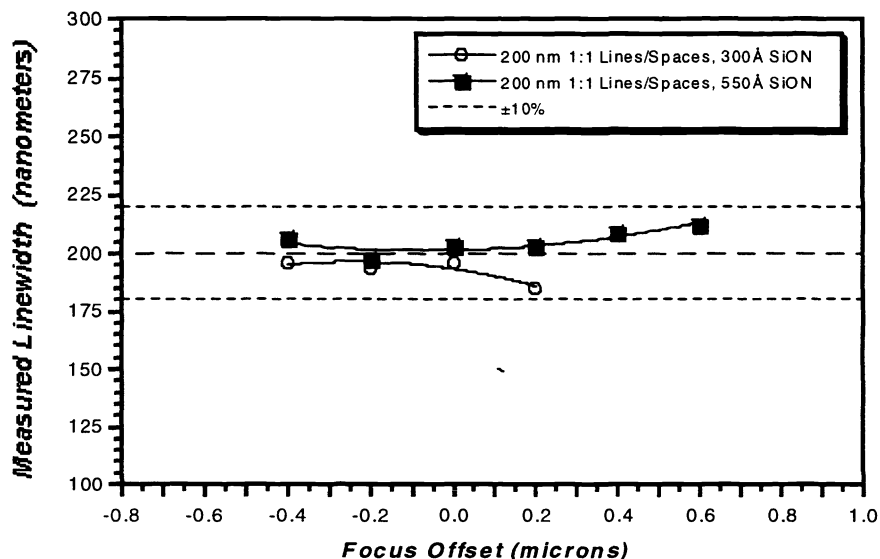


Figure 16: UV6 on 300Å and 550Å SiON; 200 nm 1:1 Lines/Spaces, Focus Latitude
**200nm 1:1 Lines/Spaces
FOCUS LATITUDE PLOT**



4. CONCLUSIONS

Photoresist formulation, processing and substrate manipulation are studied to examine possible solutions for positive chemically amplified resists footing on SiON substrates. The most significant improvements are realized through substrate manipulation. The two most significant factors are the SiON film thickness, as related to reflectivity and phase of the standing wave at the interface, and the nitrous oxide plasma surface treatments; when used in combination they can eliminate most if not all traces of footing at the substrate interface. While the use of a more reflective SiON may not provide the best substrate in terms of reflection control, it does reduce footing. A balance is realized between CD non-uniformity due to footing and CD non-uniformity due to reflection control. Nonetheless, solutions to footing are being explored through variations of plasma treatments for the 300Å film and also through photoresist formulation.

5. ACKNOWLEDGMENTS

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- 102 **Chemically amplified ArF resists based on cleavable alicyclic group and the absorption band shift method [3333-10]**
N. Shida, T. Okino, K. Asakawa, T. Ushirogouchi, M. Nakase, Toshiba Corp. (Japan)
- 111 **Design and study of water-soluble positive- and negative-tone imaging materials [3333-11]**
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- 122 **Optimization of etch conditions for a silicon-containing methacrylate-based bilayer resist for 193-nm lithography [3333-13]**
T. Steinhäusler, A. H. Gabor, D. White, A. J. Blakeney, Olin Microelectronic Materials, Inc.; D. R. Stark, D. A. Miller, G. K. Rich, V. L. Graffenberg, K. R. Dean, SEMATECH
- 132 **Thermal stability of silicon-containing methacrylate-based bilayer resist for 193-nm lithography [3333-14]**
D. White, B. T. Beauchemin, Jr., A. J. Blakeney, T. Steinhäusler, Olin Microelectronic Materials, Inc.
- 144 **Lithographic performance of a dry-etch stable methacrylate resist at 193 nm [3333-15]**
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- 154 **Dual-wavelength photoresist for sub-200-nm lithography [3333-16]**
S. Hien, G. Czech, W.-D. Domke, H. Raske, M. Sebal, I. Stiebert, Siemens AG (FRG)
- 165 **Progress in 193-nm top-surface imaging process development [3333-17]**
J. M. Hutchinson, V. Rao, G. Zhang, A. R. Pawloski, C. A. Fonseca, J. Chambers, S. M. Holl, S. Das, Intel Corp.; C. C. Henderson, D. R. Wheeler, Sandia National Labs.
- 176 **Processing of acrylate-based 193-nm resists: influence of physico-chemical properties [3333-18]**
B. P. Mortini, SGS-Thomson Microelectronics (France); C. Rosilio, CEA-CENS (France); A. Prola, P. J. Paniez, France Telecom-CNET
- 188 **Negative-tone TSI process for 193-nm lithography [3333-19]**
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- 195 **Effect of the dissolution contrast on the process margin in 193-nm lithography [3333-20]**
M. Takahashi, S. Kishimura, T. Naito, T. Ohfuji, M. Sasago, Association of Super-Advanced Electronics Technologies (Japan)

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- 206 **Chemical and lithographic aspects of organic deep-UV BARCs [3333-21]**
M. Padmanaban, W.-B. Kang, K. Kimura, Y. Nishiwaki, G. Pawlowski, H. Tanaka, Clariant Japan K.K.
- 219 **Positive bilayer resists for 248- and 193-nm lithography [3333-22]**
R. Sooriyakumaran, G. M. Wallraff, C. E. Larson, D. Fenzel-Alexander, R. A. DiPietro, J. Opitz, D. C. Hofer, IBM Almaden Research Ctr.; D. C. LaTulipe, Jr., J. P. Simons, K. E. Petrillo, K. Babich, M. Angelopoulos, IBM Thomas J. Watson Research Ctr.; Q. Lin, A. D. Katnani, IBM Microelectronics Div.
- 228 **Deep-ultraviolet antireflective coating with improved conformality, optical density, and etch rate [3333-23]**
D. J. Guerrero, J. D. Meador, G. Xu, Brewer Science, Inc.; H. Suzuki, Y. Sone, Nissan Central Research Institute (Japan); V. Krishnamurthy, J. Claypool, J. E. Lamb III, Brewer Science Inc.
- 236 **Choice of amines as stabilizers for chemically amplified resist systems [3333-24]**
L. Ferreira, S. Malik, T. R. Sarubbi, A. J. Blakeney, B. Maxwell, Olin Microelectronic Materials, Inc.
- 245 **Positive- and negative-tone water-processable photoresists: a progress report [3333-25]**
S. Yamada, D. R. Medeiros, K. Patterson, W.-L. K. Jen, T. Rager, Q. Lin, C. Lenci, Univ. of Texas at Austin; J. D. Byers, SEMATECH; J. M. Havard, D. Pasini, J. M. J. Fréchet, Univ. of California/Berkeley; C. G. Willson, Univ. of Texas at Austin

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C. L. Henderson, S. A. Scheer, P. C. Tsiartas, B. M. Rathack, Univ. of Texas at Austin; J. P. Sagan, R. R. Dammel, Clariant Corp.; A. Erdmann, Fraunhofer Institute for Silicon Technology (FRG); C. G. Willson, Univ. of Texas at Austin
- 268 **Probabilistic model for the mechanism of phenolic polymer dissolution [3333-27]**
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- 278 **Extension of 248-nm optical lithography: a thin film imaging approach [3333-28]**
Q. Lin, A. D. Katnani, T. A. Brunner, C. DeWan, C. Fairchok, IBM Semiconductor Research and Development Ctr.; D. C. LaTulipe, Jr., J. P. Simons, K. E. Petrillo, K. Babich, D. E. Seeger, M. Angelopoulos, IBM Thomas J. Watson Research Ctr.; R. Sooriyakumaran, G. M. Wallraff, D. C. Hofer, IBM Almaden Research Ctr.
- 289 **Study of bake mechanisms by real-time in-situ ellipsometry [3333-29]**
P. J. Paniez, A. Vareille, P. Ballet, France Telecom-CNET; B. P. Mortini, SGS-Thomson Microelectronics (France)
- 301 **Can sub-0.18- μ m FEOL be realized in production with KrF DUV? [3333-30]**
W. Gehoel-van Ansem, P. Zandbergen, Philips Research Labs. (Netherlands); J. de Klerk, Philips Semiconductors (Netherlands)

- 313 **Resist edge roughness with reduced pattern size [3333-31]**
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- 324 **Inorganic bottom ARC SiOxNy for interconnection levels on 0.18- μ m technology [3333-32]**
Y. Trouiller, N. Buffet, T. Mourier, Y. Gobil, CEA-LETI (France); P. Schiavone, France Telecom-CNET; Y. Quere, CEA-LETI (France)

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- 336 **Novel antireflective structure for metal layer patterning [3333-33]**
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- 347 **Advance of resist profile control in multilayer resist process for sub-150-nm lithography [3333-34]**
Y. Kimura, H. Endo, A. Endo, Oki Electric Industry Co., Ltd. (Japan)
- 357 **Comparisons of critical parameters for high- and low-activation-energy deep-UV photoresists [3333-35]**
W. Conley, C. P. Babcock, Cypress Semiconductor Corp.; N. R. Farrar, H.-Y. Liu, Hewlett-Packard Co.; B. Peterson, K. Taira, JSR Microelectronics, Inc.
- 366 **Application of plasma-polymerized methylsilane for 0.18- μ m photolithography [3333-36]**
C. Monget, France Telecom-CNET; C. Y. Lee, Intel Corp.; O. P. Joubert, France Telecom-CNET and CNRS-LPCM-IMN (France); G. R. Amblard, CNET/SGS-Thomson (France); T. W. Weidman, D. Sugiarto, Applied Materials; J. Yang, Intel Corp.; F. Cormont, France Telecom-CNET; R. L. Inglebert, Univ. d'Orléans (France)
- 376 **New design principle for the PACs of novolak resists [3333-52]**
S. Jha, A. Reiser, Polytechnic Univ.
- 384 **Design of i-line photoresists capable of sub-quarter-micron lithography: effects of novel phenolic resin with controlled end group [3333-39]**
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- 401 **Improved simulation of photoresists using new development models [3333-156]**
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- 417 **Novel negative photoresist based on polar alicyclic polymers for ArF excimer laser lithography [3333-78]**
S. Iwasa, K. Nakano, K. Maeda, E. Hasegawa, NEC Corp. (Japan)

- 425 **Improving the performance of 193-nm photoresists based on alicyclic polymers** [3333-114]
K. Patterson, U. Okoroanyanwu, T. Shimokawa, S. Cho, Univ. of Texas at Austin; J. D. Byers, SEMATECH; C. G. Willson, Univ. of Texas at Austin
- 438 **New water-processable chemically amplified resists: three steps, two tones, one solvent** [3333-159]
G. D. Darling, Active Materials Inc. (Canada); A. M. Vekselman, AIM Co. (Canada); S. Yamada, Univ. of Texas at Austin

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- 448 **Novel ArF photoresist system using acrylic polymers** [3333-47]
B.-C. Ho, J.-F. Chang, T.-C. Liu, J.-H. Chen, Industrial Technology Research Institute (Taiwan)
- 454 **Novel single-layer photoresist containing cycloolefins for 193 nm** [3333-61]
J.-H. Park, D.-C. Seo, K.-D. Kim, S.-Y. Park, S.-J. Kim, H. Lee, Korea Kumho Petrochemical Co., Ltd.; J.-C. Jung, C.-K. Bok, K.-H. Baik, Hyundai Electronics Industries Co., Ltd. (Korea)
- 463 **Design of an etch-resistant cyclic olefin photoresist** [3333-90]
R. D. Allen, J. Opitz, T. I. Wallow, R. A. DiPietro, D. C. Hofer, IBM Almaden Research Ctr.; S. Jayaraman, K. A. Hullihan, L. F. Rhodes, B. L. Goodall, R. A. Shick, BFGoodrich
- 472 **Resist cluster formation model and development simulation** [3333-101]
K. Kamon, K. Nakazawa, A. Yamaguchi, N. N. Matsuzawa, T. Ohfuji, M. Sasago, Association of Super-Advanced Electronics Technologies (Japan); K. Kanzaki, S. Tagawa, Osaka Univ. (Japan)
- 484 **Recent advantages of bilevel resists based on silsesquioxane for ArF lithography** [3333-118]
T. Morisawa, N. N. Matsuzawa, S. Mori, Y. Kaimoto, M. Endo, T. Ohfuji, K. Kuhara, M. Sasago, Association of Super-Advanced Electronics Technologies (Japan)
- 493 **Theoretical calculations of silylation reaction of photoresists** [3333-119]
N. N. Matsuzawa, S. Mori, T. Morisawa, Y. Kaimoto, M. Endo, T. Ohfuji, K. Kuhara, M. Sasago, Association of Super-Advanced Electronics Technologies (Japan)
- 503 **Negative-type chemically amplified resists for ArF excimer laser lithography** [3333-121]
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- 512 **Acid-sensitive arylether-protected poly(4-hydroxystyrene) derivatives for chemically amplified deep-UV positive resists** [3333-137]
P. R. Varanasi, K. M. Cornett, A. D. Katnani, IBM Microelectronics Div.
- 524 **New antireflective coatings for 193-nm lithography** [3333-158]
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- 534 **Improved positive surface modification resist process for 193-nm lithography** [3333-50]
M. Endo, T. Matsuo, S. Mori, T. Morisawa, K. Kuhara, M. Sasago, Association of Super-Advanced Electronics Technologies (Japan); M. Shirai, M. Tsunooka, Osaka Prefecture Univ. (Japan)

- 546 **Standard developer available ArF resist and performance [3333-57]**
Y. Uetani, H. Fujishima, Y. Miya, I. Takemoto, Sumitomo Chemical Co., Ltd. (Japan)
- 554 **Tailoring of isolation structures with top-surface imaging process by silylation [3333-74]**
H.-G. Kim, M.-S. Kim, C.-K. Bok, B.-J. Park, J.-W. Kim, K.-H. Baik, D.-H. Lee, Hyundai Electronics Industries Co., Ltd. (Korea)
- 562 **Influence of salting-out effect in ArF resist development [3333-81]**
Y. Yoshida, T. Kumada, A. Sasahara, A. Oshida, H. Adachi, Mitsubishi Electric Corp. (Japan)
- 571 **Lithographic characteristics of 193-nm resists imaged at 193 and 248 nm [3333-88]**
J. Opitz, R. D. Allen, T. I. Wallow, G. M. Wallraff, D. C. Hofer, IBM Almaden Research Ctr.
- 579 **New approaches to production-worthy 193-nm photoresists based on acrylic copolymers [3333-89]**
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- 587 **High-silicon-concentration TSI process for 193-nm lithography [3333-117]**
S. Mori, T. Morisawa, N. N. Matsuzawa, Y. Kaimoto, M. Endo, T. Matsuo, K. Kuhara, T. Ohfuji, M. Sasago, Association of Super-Advanced Electronics Technologies (Japan)
- 595 **Dry etching resistance of methacrylate polymers for ArF excimer laser lithography [3333-120]**
T. Ohfuji, M. Endo, M. Takahashi, T. Naito, T. Tatsumi, K. Kuhara, M. Sasago, Association of Super-Advanced Electronics Technologies (Japan)
- 601 **Dissolution-rate analysis of ArF resist polymers based on the percolation model [3333-122]**
A. Yamaguchi, S. Kishimura, N. N. Matsuzawa, T. Ohfuji, Association of Super-Advanced Electronics Technologies (Japan); T. Tanaka, S. Tagawa, Osaka Univ. (Japan); M. Sasago, Association of Super-Advanced Electronics Technologies (Japan)
- 611 **Rapid simulation of silylation and the role of physical mechanisms in profile shapes [3333-123]**
M. A. Zuniga, E. H. Croffie, A. R. Neureuther, Univ. of California/Berkeley
- 625 **Feasibility of a CVD-resist-based lithography process at 193-nm wavelength [3333-149]**
C. Y. Lee, S. Das, J. Yang, Intel Corp.; T. W. Weidman, D. Sugiarto, M. Nault, D. Mui, Z. A. Osborne, Applied Materials
- 634 **Line-edge roughness in sub-0.18- μ m resist patterns [3333-151]**
S. C. Palmateer, S. G. Cann, J. E. Curtin, S. P. Doran, L. M. Eriksen, A. R. Forte, R. R. Kunz, T. M. Lyszczarz, M. B. Stern, MIT Lincoln Lab.; C. M. Nelson, Motorola and SEMATECH

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- 644 **Material design and lithographic performance of novel hydroxystyrene-copolymer-based DUV negative resists [3333-68]**
T. Kudo, K. Aramaki, S. Masuda, G. Pawlowski, Clariant Japan K.K.
- 655 **Compatibility of chemically amplified photoresists with bottom antireflective coatings [3333-75]**
H. Yoshino, T. Itani, S. Hashimoto, M. Yamana, T. Yoshii, H. Tanabe, NEC Corp. (Japan)

- 666 **Minimizing photoresist dispense volumes on organic antireflective layers: the effects of chemistry and coating methodology on defect size and density [3333-80]**
A. E. Bair, A. M. Davis, B. D. Lantz, J. R. Johnson, C. R. Spinner III, SGS-Thomson Microelectronics; S. Tanner, V. J. Marcos, H. Matsui, DNS Electronics
- 672 **Recent advances in increasing the thermal flow resistance of acetal-derivatized polyhydroxystyrene deep-UV matrix resins [3333-83]**
J. M. Kometani, F. M. Houlihan, A. G. Timko, O. Nalamasu, E. Reichmanis, S. A. Heffner, M. E. Galvin, Lucent Technologies/Bell Labs.
- 680 **Photoacid generation in chemically amplified resists: elucidation of structural effects of photoacid generators using new acid-sensitive dyes for monitoring acid generation [3333-85]**
J. F. Cameron, J. M. Mori, T. M. Zydowsky, D. Kang, R. F. Sinta, M. King, Shipley Co. Inc.; J. C. Scaiano, G. Pohlers, S. Virdee, T. Connolly, Univ. of Ottawa (Canada)
- 692 **Development of DUV resist formulations with excellent performance on metal substrates [3333-86]**
M. M. Rajaratnam, J. F. Cameron, J. H. Georger, D. Kang, G. Prokopowicz, R. F. Sinta, J. W. Thackeray, Shipley Co. Inc.
- 706 **Structural basis for high thermal stability of a resist [3333-96]**
S. Malik, A. J. Blakeney, L. Ferreira, M. A. Toukhy, J. Ferri, Olin Microelectronic Materials, Inc.
- 715 **Monitoring and controlling synthesis of bottom antireflective coating materials by in-situ FT-IR technique [3333-99]**
S. Ding, J. Shan, D. N. Khanna, Clariant Corp.
- 726 **Effects of underlayer on performance of bilayer resists for 248-nm lithography [3333-107]**
K. Babich, A. Callegari, K. E. Petrillo, J. P. Simons, D. C. LaTulipe, Jr., M. Angelopoulos, IBM Thomas J. Watson Research Ctr.; Q. Lin, IBM Microelectronics Div.
- 735 **Photoacid generators in chemically amplified resists [3333-109]**
Y. Suzuki, Toyo Gosei Co., Ltd. (Japan); D. W. Johnson, MicroChem Corp.
- 747 **Monitoring photoacid generation in chemically amplified resist systems [3333-115]**
U. Okoroanyanwu, Univ. of Texas at Austin; J. D. Byers, SEMATECH; T. Cao, S. E. Webber, C. G. Willson, Univ. of Texas at Austin
- 758 **Advanced negative resists using novel aminoplast crosslinkers [3333-116]**
A. Afzali, J. D. Gelorme, L. L. Kosbar, IBM Thomas J. Watson Research Ctr.; M. O. Neisser, W. Brunswold, C. Feild, M. Lawson, R. Varanasi, IBM Microelectronics Div.
- 768 **Conductive bilevel resist system based on polysilphenylenesiloxane and polyaniline for nanometer lithography [3333-135]**
K. Watanabe, M. Igarashi, E. Yano, Fujitsu Labs. Ltd. (Japan)
- 776 **Photoresists using tetrahydropyranyl- and tetrahydrofuranyl-protected styrene maleic anhydride half-ester polymers [3333-138]**
W.-S. Huang, IBM Microelectronics Div.; R. Sooriyakumaran, IBM Almaden Research Ctr.; R. W. Kwong, A. D. Katnani, IBM Microelectronics Div.
- 786 **New dry-developable chemically amplified photoresist [3333-143]**
J.-B. Kim, H. Kim, Korea Advanced Institute of Science and Technology

- 794 **Diffusion of photoacid generators by laser scanning confocal microscopy [3333-153]**
P. L. Zhang, LSI Logic Inc.; S. E. Webber, J. Mendenhall, Univ. of Texas at Austin; J. D. Byers, SEMATECH; K. K. Chao, LSI Logic Inc.
- 806 **Water-castable bottom antireflective coatings [3333-157]**
P.-H. Lu, S. Mehtsun, J. P. Sagan, R. R. Dammel, Clariant Corp.; I. A. McCulloch, M. Kang, Hoechst Research and Technology; H. Tanaka, K. Kimura, Clariant Japan K.K.

Part Two

POSTER SESSION: DUV PROCESSING

- 820 **Control of acidity of the substrate for precise pattern fabrication using a chemically amplified resist [3333-41]**
I. Satou, S. Yabe, M. Watanabe, T. Taguchi, Oki Electric Industry Co., Ltd. (Japan)
- 830 **New development model: aggregate extraction development [3333-43]**
T. Yamaguchi, H. Namatsu, M. Nagase, K. Yamazaki, K. Kurihara, NTT Basic Research Labs. (Japan)
- 837 **Proximity-bias swing: origin and characterization [3333-44]**
P. Zandbergen, W. Gehoel-van Ansem, Philips Research Labs. (Netherlands); J. de Klerk, Philips Semiconductors (Netherlands); G. Vandenberghe, IMEC (Belgium); F. Linskens, Shipley Europe (Netherlands)
- 845 **Examination of develop puddle time and its effects on lithographic performance [3333-53]**
M. S. Markowski, Shipley Co. Inc.
- 860 **Application of a bilayer silylated resist process in volume production [3333-54]**
R. Franzen, A. Grassmann, M. Kirschinger, T. Schedel, H. Wiedenhofer, M. Witte, Siemens AG (FRG)
- 869 **Enhancement of process latitude by reducing resist thickness for KrF excimer laser lithography [3333-59]**
M. Asano, Y. Maruyama, T. Koike, K. Chiba, E. Shiobara, T. Ikeda, Toshiba Corp. (Japan)
- 880 **Analysis of resist pattern collapse and optimization of DUV process for patterning sub-0.20- μ m gate line [3333-71]**
J. Y. Yu, G.-M. Jeong, H. Huh, J. J. Kim, S.-P. Kim, J.-K. Jeong, H.-S. Kim, LG Semicon Co., Ltd. (Korea)
- 890 **Lithographic evaluation of deep-UV photoresists for 0.25- and 0.18- μ m technology design rules [3333-79]**
G. R. Amblard, CNET/SGS-Thomson (France)
- 909 **Etch integration issues in the development of deep submicron contacts utilizing DUV resist and organic BARC [3333-91]**
V. Ramanathan, S. Chen, K. Lai, M. R. Brongo, N. Samarakone, Rockwell Semiconductor Systems
- 916 **Effect of processing on surface roughness for a negative-tone chemically amplified resist exposed by x-ray lithography [3333-95]**
G. W. Reynolds, J. W. Taylor, Ctr. for X-ray Lithography/Univ. of Wisconsin-Madison

- 924 **Real-time amine monitoring and its correlation to critical dimension control of chemically amplified resists for sub-0.25- μm geometries** [3333-97]
W. Conley, C. P. Babcock, J. A. Lilygren, C. P. Sandstrom, Cypress Semiconductor Corp.; N. R. Farrar, Hewlett-Packard Co.; J. Piatt, D. Kincad, B. Goodwin, O. Kishkovich, J. Higley, P. Cate, Extraction Systems Inc.
- 931 **Process and performance optimization of bottom antireflective coatings** [3333-98]
S. Ding, P.-H. Lu, J. Shan, E. Gonzalez, S. Mehtsun, S. S. Dixit, D. N. Khanna, Clariant Corp.
- 941 **Deposition of trace metals to a wafer surface from lithography materials** [3333-100]
R. W. Ramage, Intel Corp.; R. Vos, M. Meuris, M. Lux, IMEC (Belgium)
- 953 **High-performance profiles and characteristics of a chemically amplified resist** [3333-110]
H. Mochizuki, H. Tomiyasu, Y. Kameyama, M. Tsukamoto, T. Niinomi, Y. Tanaka, J. Fujita, T. Ochiai, Mitsubishi Chemical Co. (Japan)
- 960 **Footing reduction of positive deep-UV photoresists on plasma-enhanced ARL (PE ARL) SiON substrates** [3333-112]
L. A. Joesten, M. L. Moynihan, T. K. Lindsay, M. Reilly, Shipley Co. Inc.; K. Konjuh, D. Mordo, K. P. MacWilliams, S. Sundararajan, Novellus Systems, Inc.
- 972 **Advanced ARCH resist** [3333-125]
N. R. Bantu, J. Marshall, T. Holt, D. Perry, D. Khan, Olin Microelectronic Materials
- 987 **Lithographic performance of recent DUV photoresists** [3333-126]
B. Streefkerk, K. van Ingen Schenau, C. Buijk, ASM Lithography B.V. (Netherlands)
- 997 **Top-surface imaging through silylation** [3333-127]
S. V. Postnikov, M. H. Somervell, C. L. Henderson, S. Katz, C. G. Willson, Univ. of Texas at Austin; J. D. Byers, SEMATECH; A. Qin, LSI Logic, Inc.; Q. Lin, IBM East Fishkill
- 1009 **Lithographic and chemical contrast of single-component top-surface imaging (TSI) resists** [3333-131]
J. R. Bohland, Shipley Co. Inc.; J. Chambers, S. Das, Intel Corp.; T. H. Fedynyshyn, Shipley Co. Inc.; S. M. Holl, J. M. Hutchinson, V. Rao, Intel Corp.; R. F. Sinta, Shipley Co. Inc.
- 1017 **Novel approach to surface imaging** [3333-144]
M. A. Spak, F. Mohr, R. Bradbury, R. R. Dammel, Clariant Corp.; J. W. Weigold, S. W. Pang, Univ. of Michigan
- 1024 **Resist residue generated on TiN topographic substrates in positive chemically amplified resists** [3333-147]
H. Wada, A. Usujima, Y. Yanagishita, K. Nakagawa, Fujitsu Ltd. (Japan)
- 1031 **Photoresist and the photoresist/wafer interface with a local thermal probe** [3333-148]
D. S. Fryer, J. J. dePablo, P. F. Nealey, Univ. of Wisconsin/Madison
- 1040 **Process effects resulting from conversion to a safe-solvent organic BARC** [3333-150]
J. C. Cox, L. Welsh, D. Murphy, Texas Instruments Inc.; R. J. Eakin, P. Silvestre, R. R. Dammel, S. Ding, B. Williams, D. N. Khanna, Clariant Corp.

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- 1052 **Effect of resin molecular weight on novolak dissolution** [3333-38]
H.-Y. Shih, H. Zhuang, A. Reiser, Polytechnic Univ.; P. M. Gallagher-Wetmore, Phasex Corp.
- 1061 **Effects of a visualization dye in a thick film photoresist** [3333-42]
K. H. Jensen, S. A. Ficner, Clariant Corp.
- 1069 **Resin fractionation effect for photoresist performance** [3333-58]
T. Yamada, Y. Saito, K. Itoh, Nagase Electronic Chemicals Ltd. (Japan)
- 1081 **Novolak resin analogs for resist applications** [3333-62]
S. F. Wanat, K. H. Jensen, P.-H. Lu, D. S. McKenzie, Clariant Corp.
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