Considerations for the Use of Application-Specific Photoresists

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ABSTRACT

In recent years, photoresist suppliers have migrated to offering a full palette of resist chemistries and processes which are specifically tailored for particular pattern types and / or exposure processes. Thus we now see designations such as "contact resist", "isolated line resist", "dense line resist", "attenuated phase shift resist", etc. This specialization offers the lithographer more choices for continual performance improvement and optimization, but implementation of multiple resist platforms in manufacturing can be problematic. In this paper, we examine the design criteria and efficacy of pattern- and application- specific photoresists versus a generic "multi-purpose" material, and identify some of the trade-offs which can be expected when employing these resists. Generalized ideal resist behaviors are presented for different pattern criteria, including proximity bias. Both experimental and simulation results are given.

Keywords: Keyword: photoresist, isolated line, dense line, contact hole, DUV, I-Line, contrast, develop

1. INTRODUCTION

The rapid evolution of semiconductor technology over the past 15 years has been fueled in large part by advances in photolithography. Improved lens design and manufacturing capability has leveraged the fundamental physics governing the formation of the aerial image, which carries the mask information to the wafer. Thus we have realized concurrent wavelength reduction and numerical aperture increases with overall improved image control across the full field at ever-decreasing critical dimensions (CD). This decrease in CDs has been further facilitated by the physics of phase shift masks, optical proximity correction, and off-axis illumination. The role of chemistry, however, has been equally vital, as improved photoresist chemical systems have worked in conjunction with the improved aerial image to allow manufacturing at k_1 factors previously thought impossible. For instance, I-line resists, once thought incapable of running 350 nm processes are now routinely doing 300 nm processes and in some cases being proposed for 250 nm processes.

Today's leading-edge six level metal 180 nm CMOS logic processes feature 25-30 masking layers patterned by a mix-and-match combination of I-line and DUV exposure tools. Table 1 shows representative pattern layers and the associated photoresist requirements fulfilled by the 2 I-Line and 2 DUV resists. Within five years, leading edge factories will likely feature I-line, DUV, and 193 nm wavelengths, thus adding to the complexity of the overall photoresist arsenal. As each new lower wavelength technology proliferates, photoresist suppliers have introduced appropriate chemistries with the requisite optical absorption and sensitivity properties. The result has been a significant growth in the number of different chemistries which they must offer. Figure 1 shows the growth in number of photoresists offered at any given time by a representative supplier for each of the exposure wavelengths. The total number of resists appears to follow a type of Moore's Law, nearly doubling every five years. Resist supplier roadmaps have become an exceptionally complex menu of niche products, with both wavelength and pattern-specific offerings.

An interesting trend resulting from these chemistry improvements has been the migration from "one size fits all" resist chemistries to pattern-specific formulations[1-2]. This has been enabled by a number of innovations and improvements including polymer synthesis and molecular weight fraction isolation, new photoactive compound (PAC) and photoacid generator (PAG) types, as well as an improved overall understanding of the complex structure-property relationships which dictate the diffused latent image and subsequent dissolution rate versus exposure function. For chemically-amplified DUV resists, the composition trend has been away from simple [polymer, PAG, solvent] to specific molecular weight resin distributions featuring multiple acid-labile protecting groups, mixtures of different transparency PAGs, and a variety of base additives dissolved in solvent mixtures. Chemists are now better able to tailor resist performance for a given thickness on a specific substrate/reflectivity, and have even begun optimizing by pattern type.

As shown in Table 1, in the case of DUV lithography today, critical mask levels typically include active, gate, local interconnect, contact, and first metal. The exact CD and minimum pitch of these layers are of course product-specific, but in general, a resist strategy distinction has often been proposed between memory and random logic designs. Cost-competitive memory designs require the smallest possible bitcell layout and thus force patterning of minimum pitch features, while random logic designs do not feature the periodicity which allows small pitch. It is important to note, however, that memory designs often include critical periphery circuitry which is largely isolated, and the trend in system-on-a chip integration is to include both memory and logic functionality in the same design. Thus the bifurcation of “isolated” and “dense” line resist types is somewhat inappropriate. Nevertheless, this differentiation is often highlighted by photoresist suppliers, and deserves exploration. We explore here the optimum generalized characteristics for imaging such feature types.

2. EXPERIMENTAL

Experimental data was obtained, unless otherwise noted, using 0.61 μm thick JSR Microelectronics resist, processed with a softbake of 130C for 90sec, a PEB of 130C for 90 sec, using conventional illumination at NA = 0.60 and σ = 0.65. Simulations were conducted using PROLITH v 6.04 from FINLE Technologies.

3. RESULTS

One of the most critical determinants of DUV resist performance is the diffusion of photogenerated acid during the post-exposure bake. The role of acid diffusion and its convolution with reaction kinetics has been discussed extensively in the literature, and can be simulated using a variety of physical models, but is not explored in this study. Instead we focus solely on the effect of develop contrast, using the well established Mack development model[3].

Two photoresists with significantly different dissolution characteristics were compared for imaging of 200 nm isolated and 1:1 L/S lines. Top SEM data for best energy through focus are given in Figure 2. The corresponding cross section images are shown in Figure 4. It can be seen that for isolated images, Resist A gives a larger DOF than Resist B, but the situation is reversed for printing 400 nm pitch 1:1 L/S pairs. The Mack model dissolution profiles are given in Figure 3, where it can be seen that Resist B features a significantly higher develop rate contrast.

These results indicate that a lower develop contrast results in a larger DOF for isolated features, so a simulation study was conducted to determine how generally applicable this design point is. A comparison was made of the process window for 250, 180, and 150 nm features, on either 500 nm or 1000 nm pitch. For each feature type, the resist develop contrast, N, was varied from 2 to 20. The resulting exposure latitude versus DOF plots are shown in Figure 5. It can be seen that in all cases, regardless of target linewidth or proximity, the exposure latitude at best focus improves with increasing develop contrast. Since exposure latitude is directly proportional to the slope of the aerial image, and higher contrast develop profiles increase the effective slope more, this result is not surprising. It can also be seen that for all 500 nm pitch features, the DOF improves with increasing develop contrast. The situation is different, however, for isolated lines, where the preferred contrast for maximum DOF increases from 2 at 250 nm to 3 at 180 nm to 5 at 150 nm. The normalized image log-slope (NILS) value decreases steadily as linewidth decreases, and there appears to be a critical NILS for which a very low contrast resist will simply not resolve the image. The ratio R_{max} / R_{min} plays a somewhat lesser role in determining process window than does the contrast. For 150 nm isolated lines at a contrast of N = 5, the ratio was varied from 50 to 10,000 with only small changes in EL or DOF resulting.

These results can be interpreted in terms of the aerial images shown in Figure 6. The process latitude which is obtained depends upon the position of the aerial image conjugate point relative to the mask edge. As the linewidth gets smaller, the conjugate point moves further away from the mask edge. Note that for dense lines, the conjugate point always corresponds to the half pitch[2]. The higher the develop contrast, the closer the isofocal point is to the conjugate.

The proximity bias (1000 nm pitch CD - 500 nm pitch CD) is shown in Figure 7 for the three feature sizes at various develop contrast values[4]. In general, higher contrast resist results in greater bias, but depends upon the target CD. 250 nm features, for instance show 0 bias for a develop contrast of approximately 8, while 150 nm isolated features size larger than the 500 nm pitch feature regardless of contrast.

In Figure 8, a develop contrast comparison has been made for the case of alternating phase shift exposure of 150 nm isolated and 500 nm pitch and 250 nm isolated and 500 nm pitch features. Again, the higher contrast resist always gives EL improvement, but maximum DOF is achieved at lowest contrast for 250 nm isolated lines, but at relatively high contrast (N = 10) for 150 nm isolated and 500 nm pitch features.

4. SUMMARY

In the last several years, photoresist formulation differentiation has been made in terms of feature proximity without much consideration for exactly what feature size or pitch is desired. Obviously the photoresist has no cognizance of what type of feature on what pitch it is printing, it merely responds to the light intensity it samples via its dissolution rate function. We have attempted here to build a generalized framework for consideration of develop contrast optimization. The ultimate goal for the resist chemist would be to mate a set of aerial images through focus with a customized dissolution rate profile to maximize the depth of focus for a specific feature. This is a lofty goal and it faces practical limitations due to the myriad different types of features typically found on a given product mask layer. Nevertheless, there appears to be a level of validity for favoring a particular develop contrast for a specific pattern type. In general, a lower contrast material will give a larger DOF at best dose than a higher contrast material, but the lowest contrast is not always superior in this regard, especially at very low k1 values, where the NILS value is < 1.0. The choice of resist also depends upon the assumed tool/process error budget consumption, since larger exposure latitude may be required in some cases, and this will always be afforded by a higher contrast photoresist.

Finally, while measurable process latitude improvements may in some cases be realized by using a custom resist per layer, there are practical cost of ownership limitations to the number of different materials which can be implemented in a manufacturing environment. This is particularly true if the photoresists require different bake conditions, which can dramatically effect the availability of the track for production as bakeplates equilibrate to temperature setpoints. Additionally, the time required to daily qualify resist processes as well as new batches of multiple materials takes away from production time, and ultimately, in the absence of full automation, more chemicals represent increased opportunity for human error associated with managing multiple chemicals. Some amount of tool-level dedication can alleviate the challenges associated with multiple resist platforms, but in the case of DRAM production, tools are often dedicated to lots, not levels, thus increasing the difficulty.

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Table 1. Typical 180 nm CMOS Logic Process Photoresist Requirements

Layer	l (nm)	Resist	Thickness (nm)	Requirements
Active	248	D_1	700	Semi Iso Space resolution
S/D	365	I_1	3000	High transparency, photospeed
Gate	248	D_2	500	Semi Iso Line resolution, ARL compatable
Local Interconnect	248	D_1	700	Semi Iso Space / Contact resolution
V_t adjust	365	I_2	1000	High photospeed
Contact	248	D_1	800	Hole resolution
First Metal	248	D_1	800	Dense Line/Space resolution
First via	248	D_1	800	Hole resolution
Metal 2-N	365	I_2	1000	Dense Line/Space resolution
Via 2-N	365	I_2	1000	Att PSM surface inhibition
Final Metal	365	I_2	1500	High transparency, photospeed
Passivation	365	I_1	3000	High transparency, photospeed

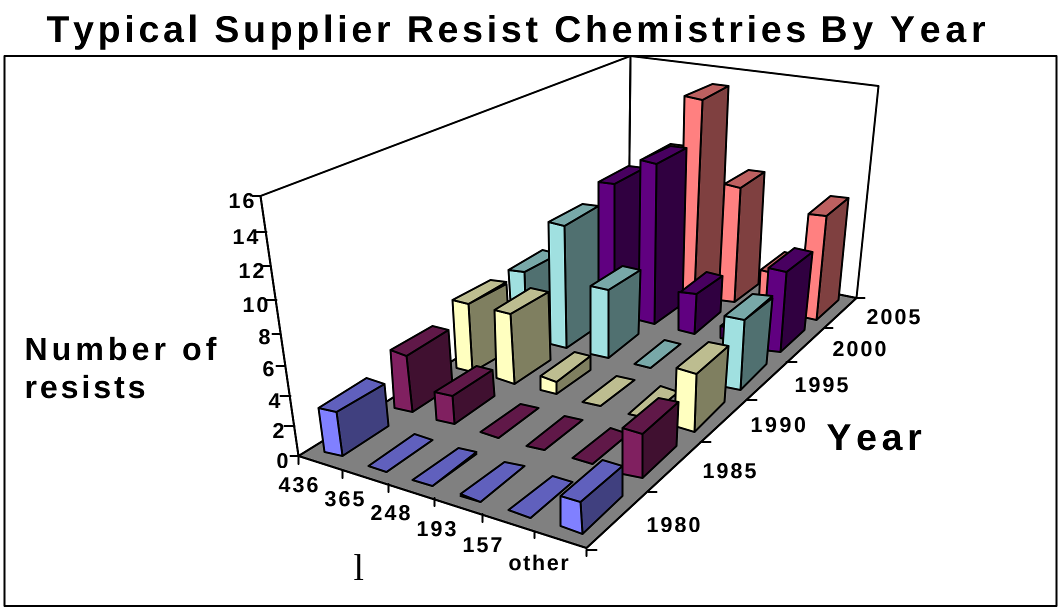

Figure 1. Growth in the number of different resists offered by a typical supplier since 1980, grouped by exposure wavelength.

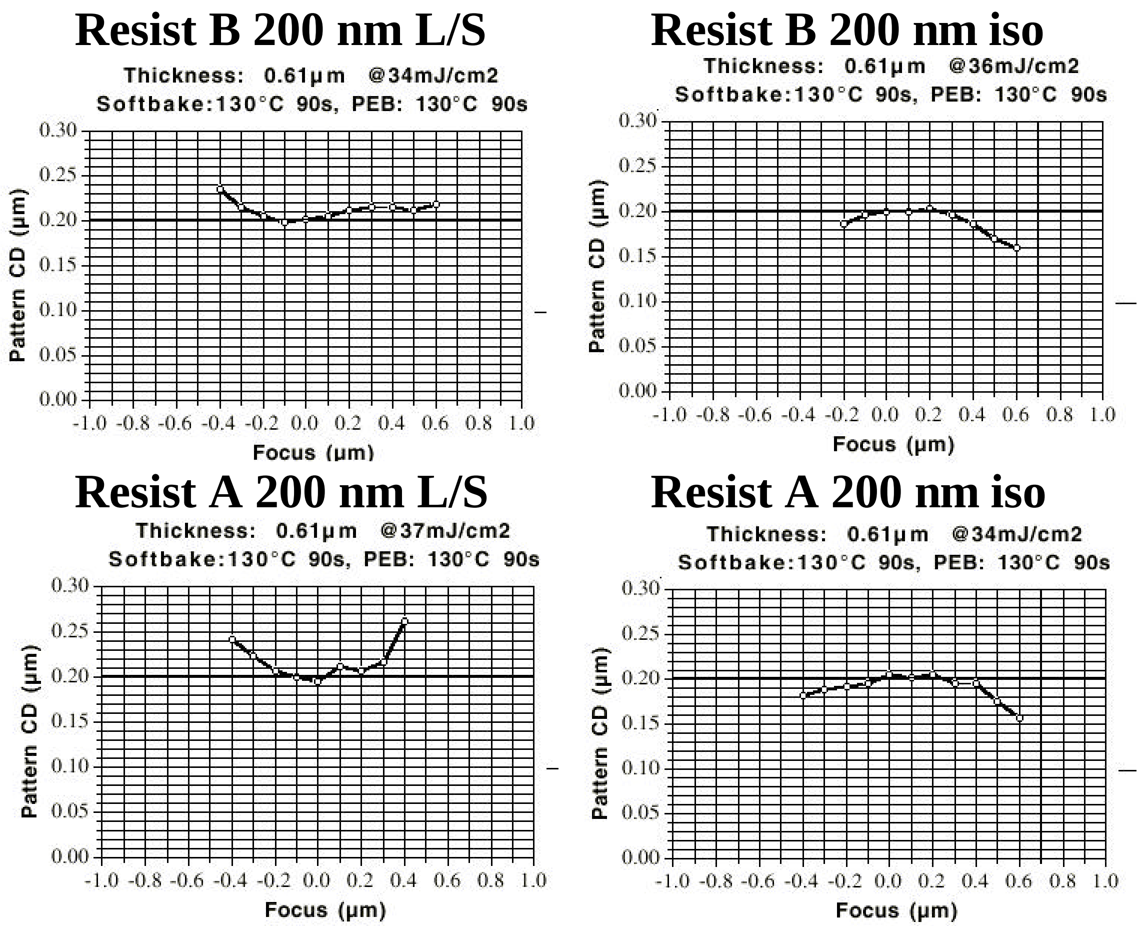

Figure 2. Comparison of 200 nm isolated (right) and dense (left) focus windows at exposure shown for two JSR resists.

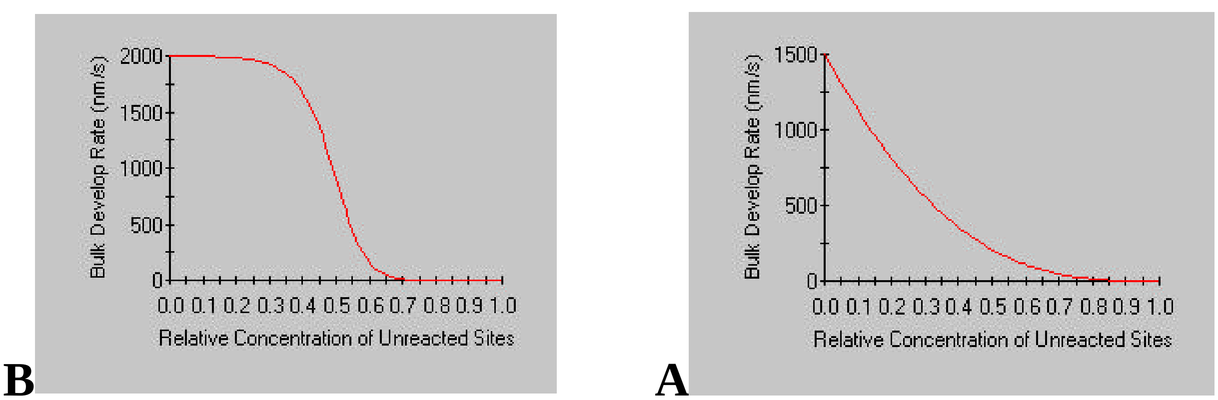

Figure 3. Dissolution rate profiles for the two resists.

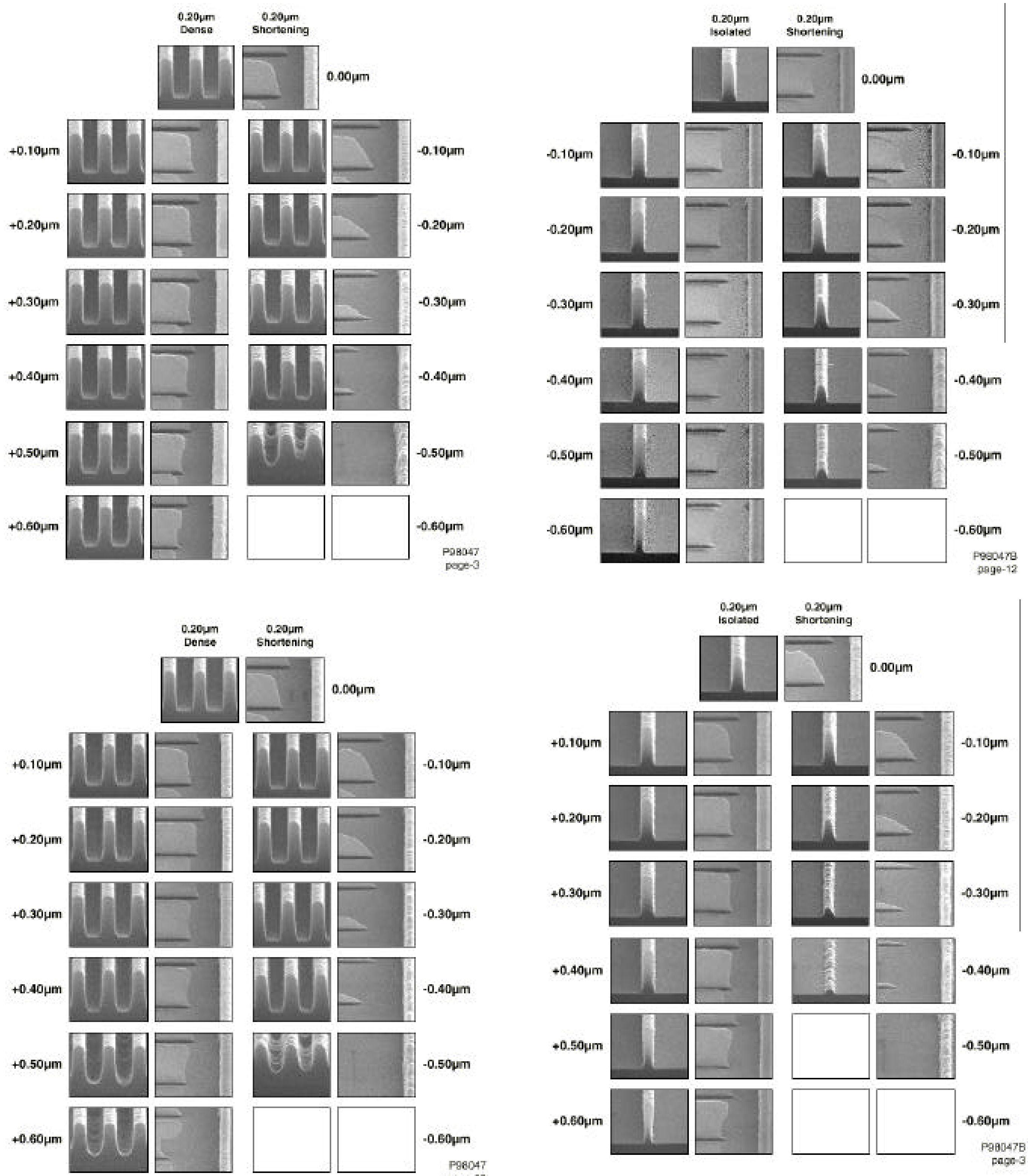

Figure 4. SEM photographs corresponding to the SEM data in Figure 2. Top = Resist B, Bottom = Resist A.

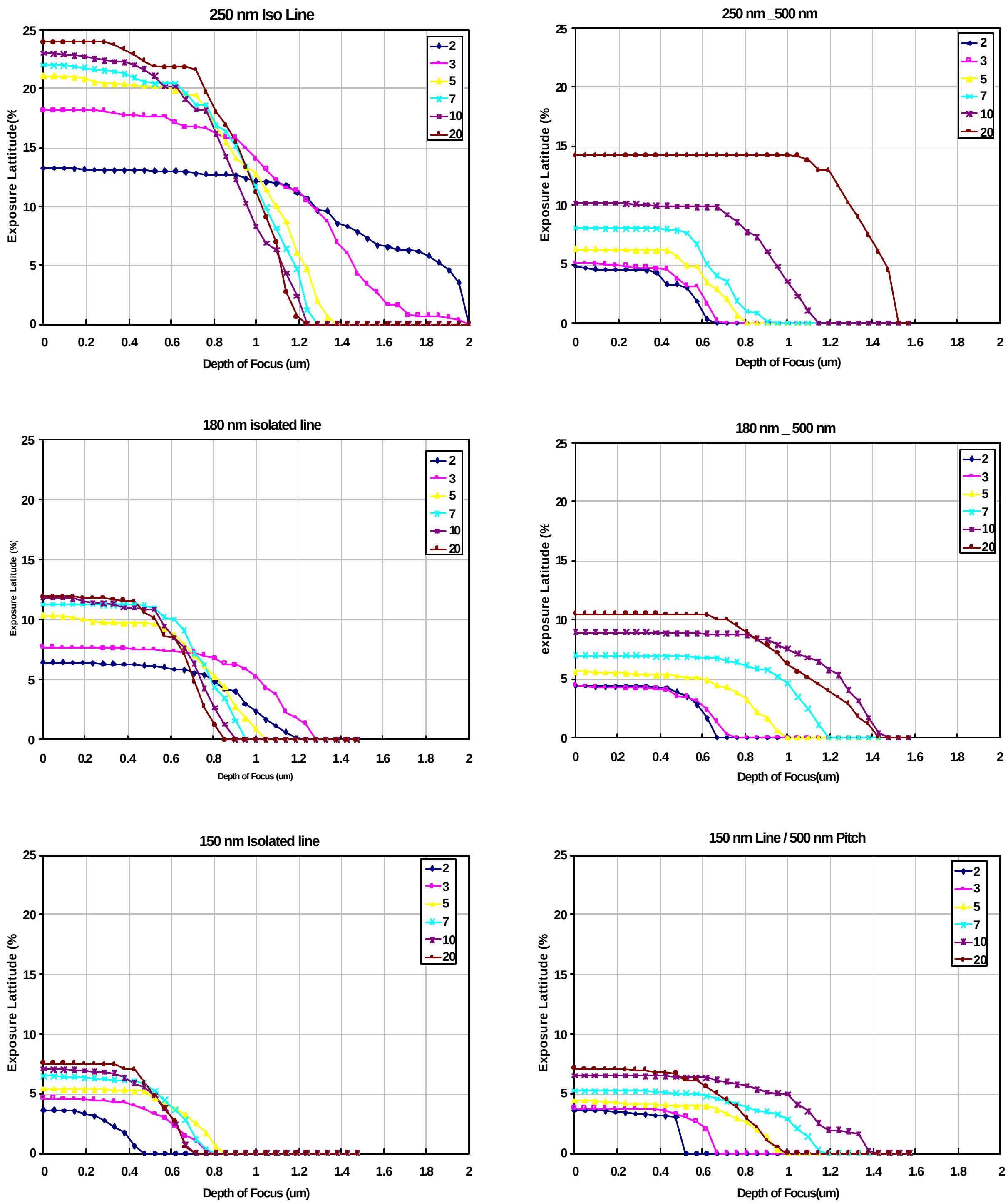

Figure 5. Comparison of exposure latitude versus DOF plots for 250, 180, and 150 nm features on 1000 and 500 nm pitch. Develop contrast value as indicated.

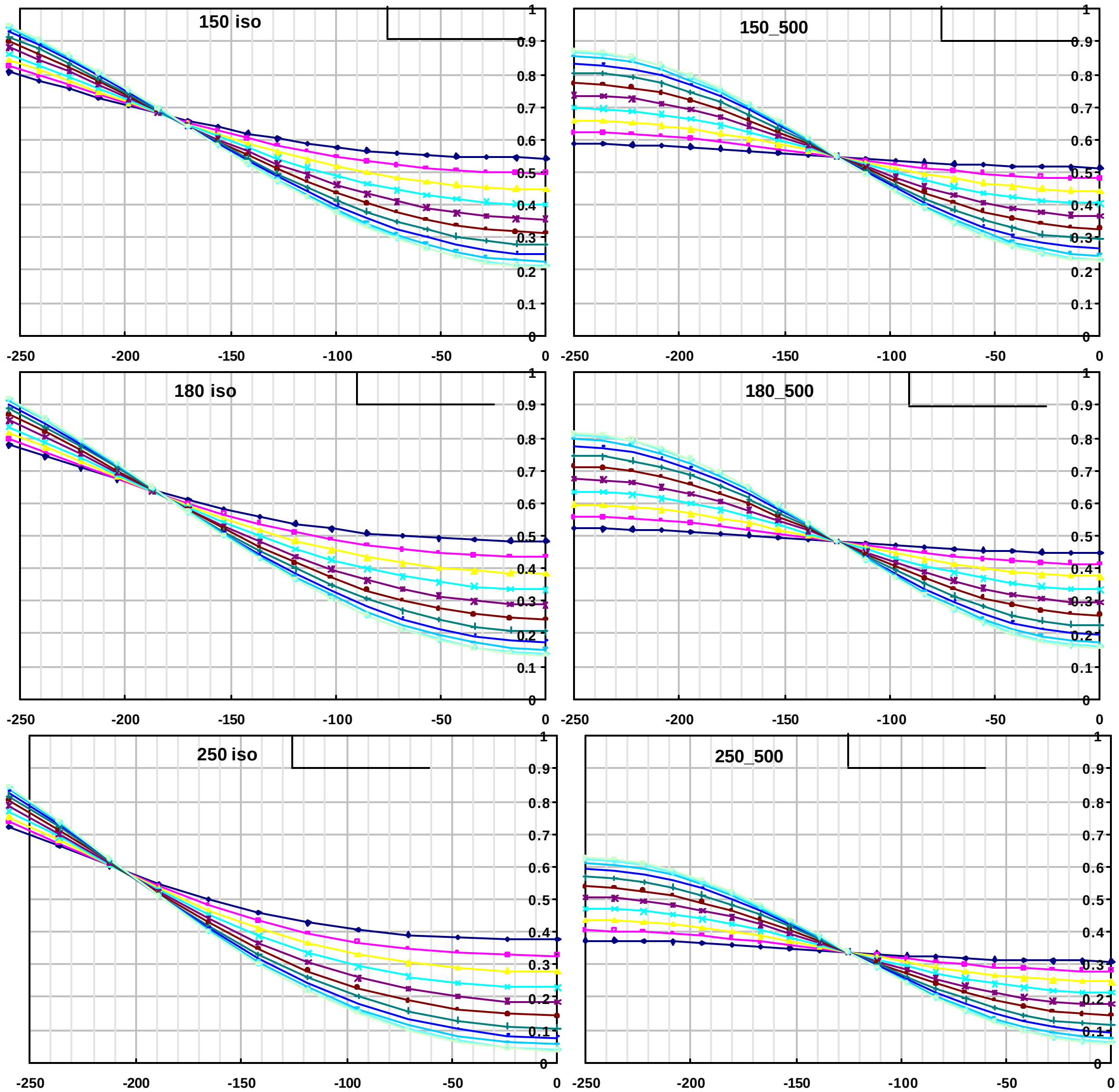

Figure 6. Aerial images through focus corresponding to the lines from Figure 4. Edge of chrome is shown at top of each graph. X axis is mask position, Y axis is light intensity.

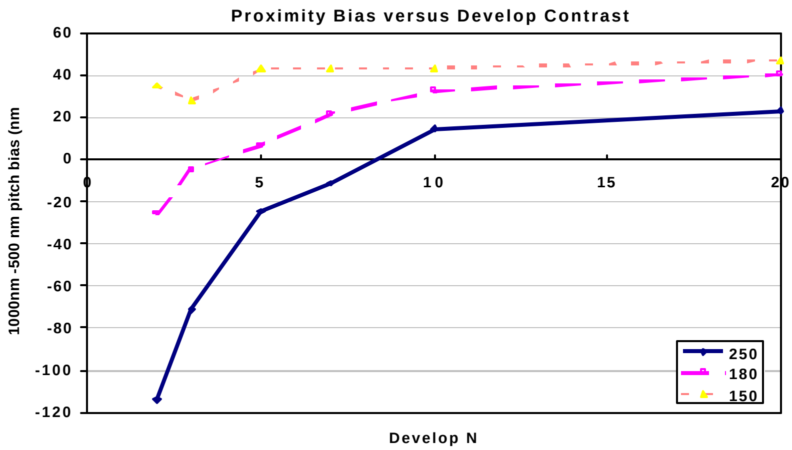

Figure7. Comparison of proximity bias for 250, 180, and 150 nm features as a function of develop contrast.

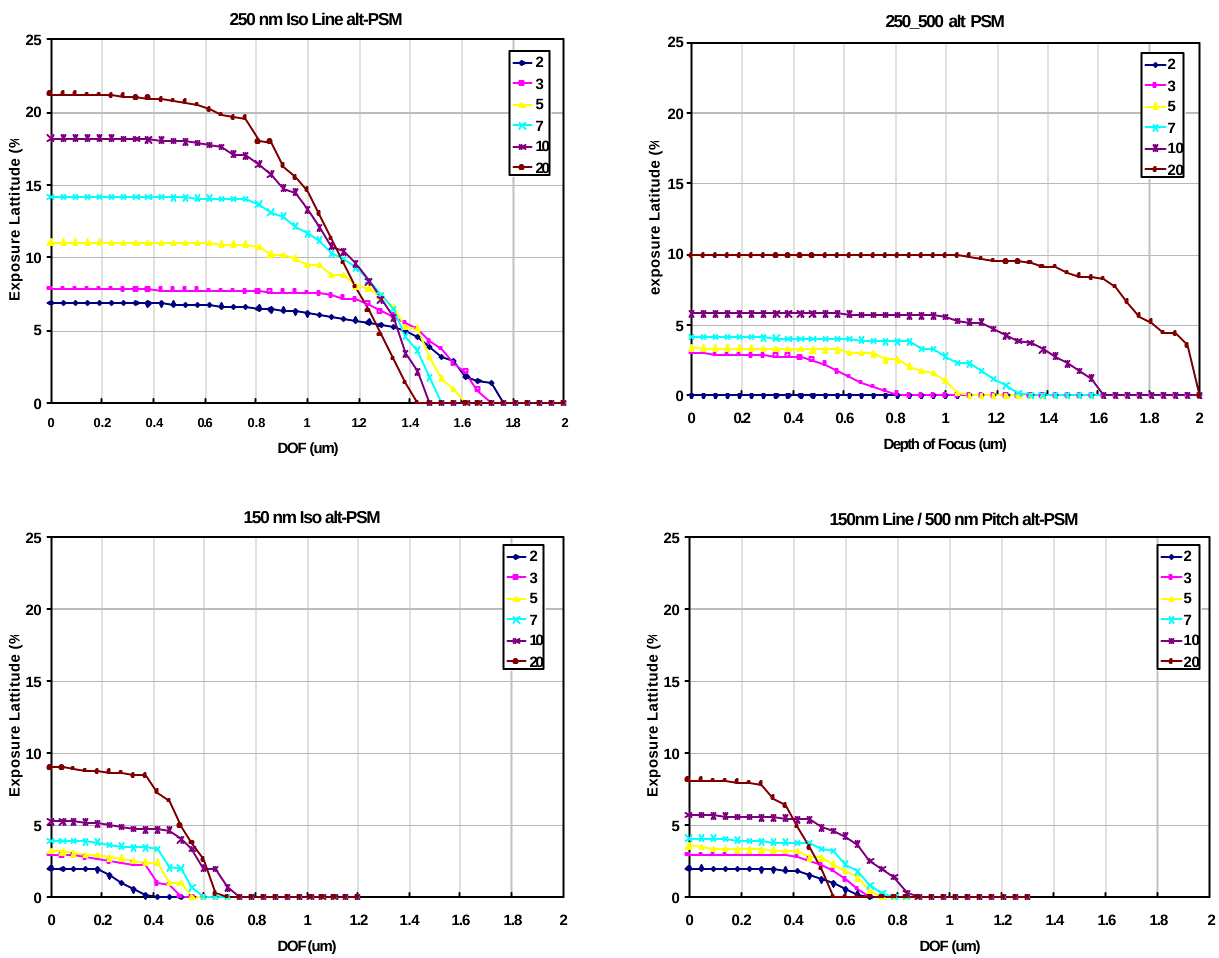

Figure 8. Comparison of exposure latitude versus DOF plots for 250 and 150 nm features on 1000 and 500 nm pitch using alternating phase shift exposure at NA = 0.50 and sigma = 0.30.