Critical Dimension and Image Placement Issues for Step and Flash Imprint Lithography Templates

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ABSTRACT

Step and Flash Imprint Lithography (SFIL) is an attractive low-cost method for printing sub-100 nm geometries. Relative to other imprinting processes, SFIL has the advantage that the template is transparent thereby facilitating conventional overlay techniques. In addition, the imprint process is performed at low pressures and room temperature, which minimizes magnification and distortion errors. Since SFIL is a 1X lithography technique, the template masks will require very good layer-to-layer overlay accuracy for multiple level device fabrication. To fabricate a transparent SFIL template, processing techniques familiar to existing binary phase shift mask fabrication are utilized. However, in order to fabricate the sub-100 nm features necessary for SFIL templates, thinner resist and chromium are necessary. Initial resolution tests have resulted in features sizes down to ~20 nm with the non-chemically amplified resist, ZEP520. Template to template overlay of <15 nm (mean + 3s) can be achieved if the template fabrication procedure consists of a single 1” template exposed in the center of a 6” x 6” x 0.25” quartz blank.

Keywords: Step, Flash, Imprint, Lithography, Template

1. INTRODUCTION

Step and Flash Imprint Lithography (SFIL) is a technology that can potentially provide sub-100 nm feature resolution without the significant expense of multi-element, high quality projection optics or advanced illumination sources.[1-3] However, since the technology is 1X, the requirements of the imaging template are critical with respect to resolution and positional accuracy. The preferred form factor for SFIL templates is currently under investigation, however, for this study, the templates were configured in a size format of 1” x 1” x 0.25” and are cut from a standard 6” x 6” x 0.25” (6025) quartz mask blank.[4] This format may change as SFIL imprinting tools evolve but the template size in the near term will be smaller than a standard 6025 plate, allowing for the additional advantage of exposing multiple SFIL templates on a single substrate. This fabrication methodology brings about increased complexity for image placement error control over standard single die fabrication techniques. Imaging of the template pattern will typically utilize electron beam exposure technology which has been well known to produce very high resolution lithography and, with current state-of-the-art tools, image placement over a 6” x 6” exposure area can be controlled to better than 40 nm (mean + 3s). Even though e-beam lithography systems typically will exhibit state-of-the-art image placement specifications, the residual or uncorrectable systemic distortions can introduce additional errors when fabricating and overlaying multiple SFIL templates taken from a single 6025 substrate. The 2001 International Technology Roadmap for Semiconductors (ITRS) indicates that the wafer device overlay specification in 2016 (22 nm node) will be 9 nm. This will require an SFIL template-to-template overlay specification of <7 nm, much better than what is currently available with conventional photomask fabrication tools. Although the 1” SFIL template patterning area helps to reduce the effects of scaling errors, positional dependent residual system distortions become more problematic to control.

Typical template fabrication starts with a conventional 6025 quartz photomask plate using established chromium (Cr) and phase shift etch processes and equipment to define features in the quartz substrate. Critical dimension (CD) losses during the etching of the 80 - 110 nm thick Cr layer used on standard photomask blanks make the fabrication scheme impractical for the SFIL high resolution 1X templates. In addition, previous studies indicate that image placement errors of 20 nm are typical for a thick Cr pattern transfer process.[5] However, as the Cr thickness is reduced, the plate distortions from the pattern transfer process should also be minimized. The purpose of this work is to investigate alternative thin Cr films in order to study the limits of the SFIL process both from the standpoint of resolution as well as image placement accuracy and investigate the optimum SFIL template layout on a 6025 quartz substrate for best pattern overlay.

2. METHODOLOGY

Thinner (= 20 nm) Cr layers still suppress charging during the e-beam exposure of the template and have the advantage that CD losses encountered during the pattern transfer of the chrome are minimized. Two electron beam sensitive resists were used in this fabrication process: NEB22, a negative chemically amplified resist, and ZEP520, a positive polymer scission type resist consisting of copolymers of ?-chloromethacrylate and ?-methylstyrene. Although the ZEP520 has a considerably lower sensitivity to electron radiation than NEB22, excellent resolution has been demonstrated.[6] 15 nm of Cr was deposited on the 6025 substrates. For this Cr thickness, initial CD performance information was obtained at resist thicknesses of 180 nm for ZEP520 and 200 nm for NEB22. For image placement measurements, the resist thickness was increased slightly in order to provide the best contrast for the metrology system mark detection when measuring the resist features.

The exposure tool for this work is the Leica VB6HR electron beam exposure system. The system has a 100 keV thermal field emission electron source and utilizes a 780 nm IR laser height sensor to measure and compensate for variations in substrate surface topology. The compensation is necessary in order to correct for major field butting errors that can occur with surface non-planarity, particularly from "sag" due to gravity effects on a 6025 plate. The masks were coated on an EV Group Inc. EV150 coater track system configured to handle the 6025 substrates in an automated cassette-to-cassette mode. The development of the resists was performed either by hand, which is the case for the solvent development of ZEP520, or with an EV160 developer track configured for aqueous base development. After plate processing, CD measurements were performed on a Hitachi S7800 CDSEM with a measurement repeatability of 3.5 nm (3s). Image placement accuracy was measured on a Leica LMS2020 metrology system calibrated to a Leica quartz standard which consistently produces long-term measurement repeatability of 12 nm and short-term repeatability of 10 nm. All image placement data results are from the average of 10 readings for each array configuration and all marks exhibiting poor mark detection were eliminated from the datasets. The resulting error numbers are determined from multipoint analysis. The LMS system also has a plate bow compensation that takes out the effects of plate sag.

3. CD RESULTS

The Sumitomo NEB22 resist process did not provide consistent sub 100 nm features on the initial tests for resolution mainly due to the complex thermal characteristics of the 6025 substrates during the PAB and PEB processes. NEB22 is a chemically amplified photoresist and exhibits as much as 8 nm/^{o}C during the PEB process.[7] Variations in temperature across the 6025 plates during thermal ramp up for bake cycles have a significant effect on CD performance. However, even with this limitation, the resist had sufficient resolution to investigate pattern transfer image placement issues of a clear field mask.

Dark field masks were fabricated using the ZEON Chemicals ZEP520. ZEP520 resist is a positive non-chemically amplified, polymer scission type resist that requires only a softbake for film curing prior to exposure. ZEP520 has shown excellent resolution for direct write applications [8] and also exhibits very high resolution for the thin Cr on quartz process. For initial resolution tests, the quartz substrate was sputter coated with a 15 nm film of Cr that is only used as a hardmask for pattern transfer into the quartz. A 60-100 nm etch depth was selected for the quartz relief pattern that comprises the final template image to be used for the SFIL imprint imaging process. Using an 180 nm ZEP520 film for initial resolution tests, 20 nm semi-dense features were resolved using a develop process of MIBK:IPA for 180 seconds followed by a 30 second IPA rinse and N2 blow dry. Although the features were oversized >10 nm after expose and develop, the CD bias introduced from resist to Cr to final quartz feature benefited the smaller dimensions by pulling them closer to nominal. This CD bias from initial resist feature size to the final quartz etched feature size had a maximum delta of 7.8 nm for a 30 nm line (100 nm space) at 600 µC/cm^2 exposure dose (Fig. 1). 20 nm features were resolved at a 9:1 aspect ratio confirming the high contrast of the ZEP520; however, most of the dense patterns were collapsed during the processing of the resist.

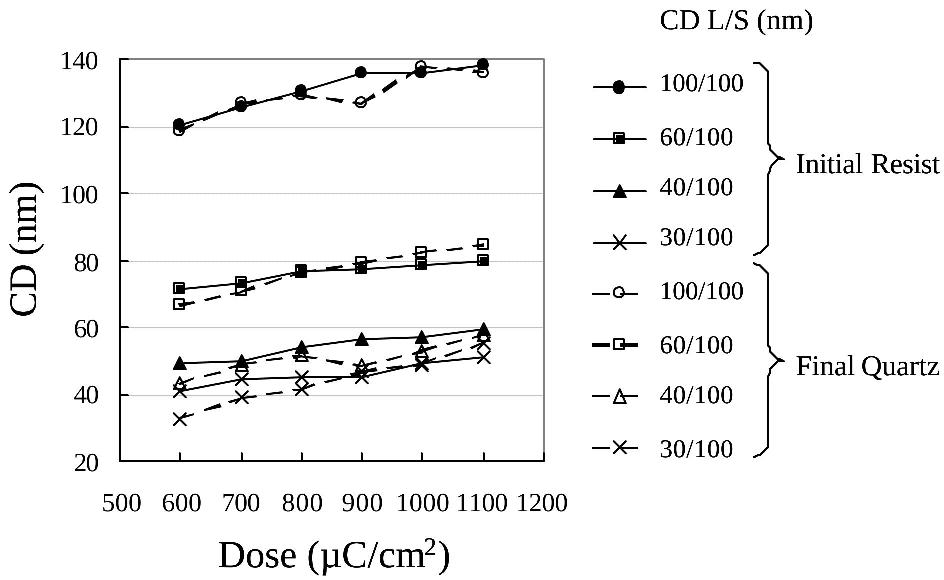
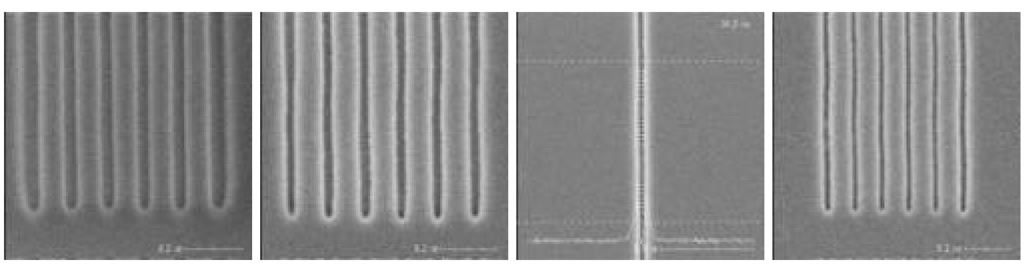


Fig. 1. Plot of initial resist versus final quartz feature critical dimension as measured on a SFIL template with 180 nm ZEP520 on 15 nm chromium on a 6" x 6" x 0.25" quartz plate.

To reliably produce features at the 20 nm coded size and smaller, the resist was thinned to 100 nm with the Cr film maintained at 15 nm. The CD bias improved with the thinner resists as the 30 nm line (100 nm space) exposed at 800 µC/cm^2 measured 38.4 nm after resist develop and O_2 descum (Fig. 2a.) and 23.5 nm after Cr and quartz etch (Fig 2b.). The 30 nm isolated lines measured 24.9 nm (Fig 2c.) indicating very little iso/dense bias for the smaller feature sizes. The smallest features resolved using this process were 20 nm lines at 100 nm spacing yielding a CD of 12.9 nm on the final 60 nm deep etched quartz features at a dose of 800 µC/cm^2 (Fig. 2d.).



a. b. c. d.

Fig. 2. a.) 30/100 nm line/space resist features after exposure and O_2 descum; b.) 30/100 nm line/space features after 15 nm Cr and 60 nm quartz etch; c.) 30 nm isolated line after Cr and quartz etch; and d.) 20/100 nm line/space features etched 60 nm into quartz. All features exposed at 800 µC/cm2.

4. IMAGE PLACEMENT RESULTS

While the fabrication of multiple templates on a single 6025 plate may reduce cost and process throughput, it also introduces additional image overlay complexity. Typical 6025 photomasks fabricated for stepper use are concerned with mask-to-mask image overlay. Provided the masks are produced on the same mask exposure tool, the individual distortions associated with that single tool are not of a critical nature so long as they are repeatable. With the introduction of multiple templates on a single substrate, repeatable distortions due to magnetic fields of components within the exposure chamber and stage mirror surface imperfections associated with electron beam exposure tools now become a significant factor for SFIL template-to-template overlay. These repeatable distortions are commonly referred to as tool "fingerprints". Figure 3a is a 19 x 19 array of 30 um alignment marks patterned in NEB22 resist on a 50 nm chrome-deposited 6025 quartz plate and illustrates a typical fingerprint from the VB6 exposure tool used for this study. The vector errors from the LMS 2020 plot are the residual errors associated with the VB6 tool that cannot be corrected through the normal tool correction algorithms such as X and/or Y scale, orthogonality, trapezium, and magnification. This unique fingerprint is repeatable and follows all four orientations (0, 90, 180, 270 deg) on the LMS. The errors do not show up when comparing the mask-to-mask overlay of multiple substrates written on this system since the distortion errors are very repeatable. Typical mask-to-mask errors from the VB6 using the same substrate and resist process are better than 20 nm (m + 3s) which is within the tool manufacturer specifications.

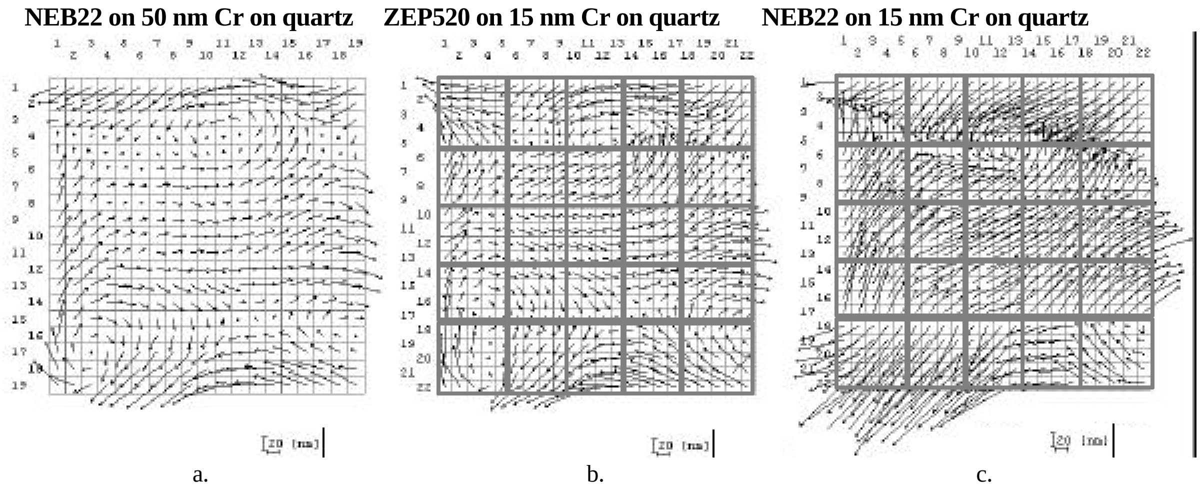


Fig 3. a.) Distortion fingerprint from 19 x 19 array (0.0008% pattern density) of 30 um marks written in NEB22 resist over a 5” x 5” area of 50 nm chrome on a 6025 quartz plate as measured on LMS 2020. b.) Similar distortion fingerprint from 5 x 5 SFIL template array (22 x 22 marks) written over 5” x 5” area with ZEP520 resist on 15 nm Cr. c.) Same 5 x 5 SFIL template array with NEB22 resist on 15 nm Cr. Gray lines indicate boundary of individual 1” SFIL arrays; b) and c) have 0.25% pattern density.

The same VB6 fingerprint of residual errors is evident in Figure 3b when examining the entire 5” x 5” area of 1” SFIL arrays exposed in ZEP520 referencing to the LMS2020 grid. The gray lines delineate the boundaries of the individual 1” SFIL arrays. Although the distortion pattern is similar in vector direction for all the plots in Figure 3a-3c, the magnitude of the errors in Figure 3c are much greater for the SFIL arrays patterned using the NEB22 resist. This increased error magnitude for the NEB22 resist coated substrates is consistent and repeatable over 4 separate runs on two different 6025 mask holder chucks. The increase in the magnitude of errors for the NEB22 resist coated plates 3a and 3c was not anticipated and could possibly be associated with the pattern density (0.0008% for 19 x 19 array vs. 0.25% for the 22 x 22 SFIL array), resist process (chemically amplified vs. non-chemically amplified), and/or exposure dose. Resist charging could also be a factor. The exposure dose for NEB22 is 1.5 orders of magnitude less than the ZEP520 with an associated beam current of 200 pA and 2 nA, respectively, on the VB6 tool. The difference in the error magnitude of plate 3b and 3c adds another complex overlay variable to control when exposing multiple templates on a single 6025 substrate.

Along with the fingerprint distortions of the exposure tool, additional contributors to image placement errors are from stress related to the deposited chrome film used for pattern transfer into the quartz. According to the model generated by Martin, et al., to look at in-plane distortion contributors for SFIL templates, the stress associated with the chrome film has a minor effect (<2 nm over 1” field) on the in-plane distortion (IPD), whereas the plate “sag” contributed the most to IPD.[2] The effects of plate sag on pattern distortion is reduced using the VB6 laser height sensor that measures changes in surface topology and adjusts the field magnification to compensate. There are still residual errors, since trapezium and keystone errors are not corrected on a field-to-field basis. The chrome stress values used by Martin, et.al, to simulate Cr stress induced IPD were 100 MPa for a 20 nm film. However, the amount of stress from a thin sputter deposited film of chrome is very much dependant on the processing conditions for the sputter system and the variability can be high. The deposition system applying the films for this study have produced 10 nm films with a measured stress that averages 600

MPa and with a very high substrate to substrate variation of +-50%. In order to evaluate the effects of the higher stress on an SFIL template IPD, another simulation was run with the stress and thickness of chrome set to 600 MPa and 15 nm, respectively. The simulation results from the increased film stress parameter indicate an increase in the IPD of only 2 nm across the 1" array over the previous simulation results. To examine the effects of chrome thin film stress on 6025 substrates, the Leica LMS error plots of Figure 4a and b show the results of measurements made on a 22 x 22 array of marks distributed over the center 5" x 5" of a 6025 template. Both templates were coated with 15 nm of sputtered chrome and the error plot in Fig. 4a is the position error plot of measurements made before and after the final chrome strip for a 6025 template coated with ZEP520 positive resist. The error plot of Fig. 4b compares the LMS measurements made before and after the RIE pattern transfer of NEB22 negative resist alignment mark features into the chrome film. The pattern density of the exposed alignment mark array is <1%. The scale change caused by chrome stress is small but measurable over a 5" array and the error contributing to a 1" SFIL array positioned in the center of the 6025 plate is 7 and 5 nm (mean + 3s) in X and Y, respectively, for the NEB22 coated plate and 7 nm in both X and Y for the ZEP520 coated plate. These results are overlay errors resulting when comparing the final quartz image to the initial resist pattern on the same substrate. However, the X and Y scaling effects did slightly increase the resist to final image placement errors on the arrays going out to the corners of the 5 x 5. The maximum X and Y errors were 9 and 8 nm, respectively, for the ZEP520 plate and 14 and 15 nm for the NEB22 plate.

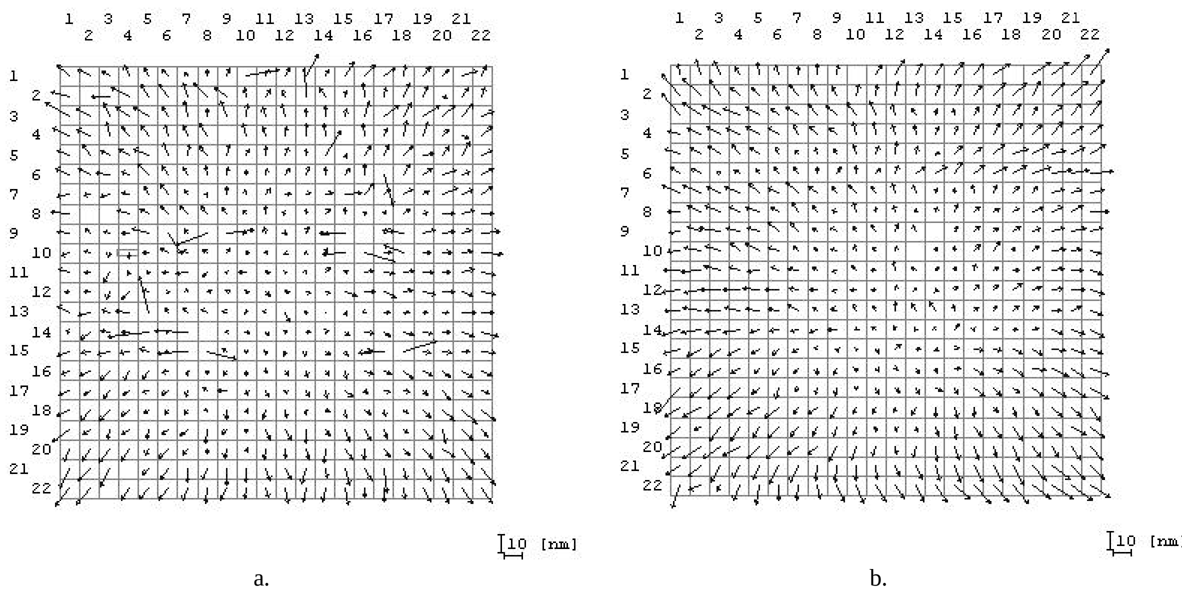
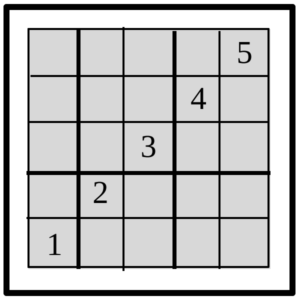


Fig 4. Image placement error plots of a 22 x 22 array written on a 6025 plate over a 5" x 5" area. a.) ZEP520 positive resist template array comparing measured placement errors before and after chrome strip. Scale difference is 0.10 ppm in both X and Y. b.) NEB22 negative resist template array comparing measured placement errors before and after chrome etch. Scale difference is 0.13 ppm in X 0.11 ppm and Y.

To investigate the effects of the combination of residual distortion fingerprint from the VB6 system and Cr film stress-induced IPD on multiple 1" SFIL templates, the SFIL image placement arrays were configured in a 5 x 5 array covering the center 5" square area of the 6025 plate. The arrays were spaced such that the mark spacing is consistent across the entire 5" x 5" area. Each individual 1" SFIL array in the 5 x 5 consists of an array of 17 x 17 marks and each 1" array is exposed entirely prior to moving to the adjacent array. The arrays are sequenced in a serpentine motion from lower left to upper right. Table 1 lists the positional errors associated with the various placements of the SFIL template arrays across the diagonal of the 6025 plate as illustrated by the diagram. It was assumed the center 1" array would have the lowest positional errors and was selected as the reference for comparing the positional accuracy of the other four arrays evaluated. Using the center array as reference, the positional error results for the two corner arrays without correcting for scale and non-orthogonality indicates significant overlay errors as the placement moves outward from the center. By applying corrections, the error terms can be significantly reduced. Corrections could be applied separately for each individual SFIL template, however, even with those corrections the errors would still be as high as 20 nm. Significant numbers of samples would need to be generated for a high confidence level for those corrections and the overlay accuracy still would not be reduced to the level required for the 20 nm lithography node. This also does not address the additional overlay errors that can occur when comparing templates fabricated from multiple 6025 plates.

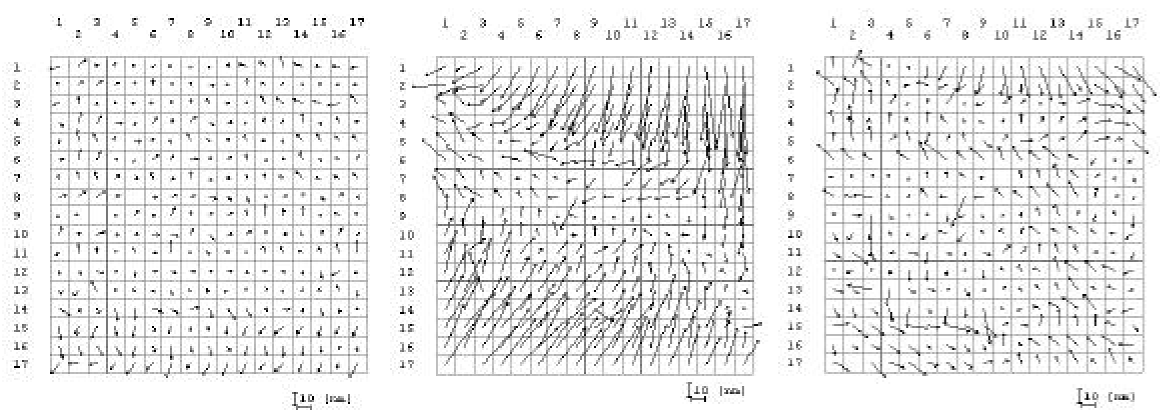


	Uncorrected				Corrected for scale and orthogonality			
	NEB22 Template		ZEP520 Template		NEB22 Template		ZEP520 Template	
Arrays	X	Y	X	Y	X	Y	X	Y
1 to 3	*27.5*	*29.69*	*26.16*	*26.06*	*17.28*	*14.78*	*15.33*	*12.51*
2 to 3	*21.44*	*20.84*	*17.16*	*17.92*	*12.68*	*10.21*	*12.88*	*11.01*
4 to 3	*13.36*	*18.17*	*29.67*	*36.31*	*11.2*	*12.45*	*16.88*	*20.68*
5 to 3	*48.7*	*53.72*	*47.9*	*52.29*	*19.71*	*11.44*	*19.51*	*18.89*

(All values are mean + 3s)

Table 1. Corrected and uncorrected overlay data of templates taken from the upper right and lower left diagonals of a 5 x 5 array of 1” SFIL arrays (17 x 17) as compared to the center 1” array. Data collected for both NEB22 and ZEP520 processed plates.

To evaluate templates written from different 6025 substrates, three arrays from the 5 x 5 SFIL template arrays were selected (center, lower left and upper right) on NEB22 and ZEP520 resist coated plates. In actual practice, having both negative and positive tone resists would be desirable in order to maximize e-beam system throughput efficiency. The center 1” SFIL arrays were measured from both plates and compared to the LMS grid, correcting for scale and non-orthogonality. The errors are very low for both templates; the NEB22 resist-coated plate measured 9 and 4 nm (m + 3s) for X and Y, respectively, and the ZEP520 at 7 nm for X and 3.5 nm for Y. Overlaying the raw measurement data without any corrections applied to the center arrays from the NEB22 and the ZEP520 coated plates reveal errors of 10 and 13 nm in X and Y, respectively (Fig. 5a) and is within the repeatability of the LMS 2020. The residual errors as illustrated by the vector arrows in the plot are random and additional improvements will not be gained by correcting for scale and/or non-orthogonality. If arrays are selected that were written at the corners of the 5” x 5” writing area from the two different 6025 plates, the errors can be considerably larger. Taking the lower left SFIL array of the NEB22 coated substrate and the upper right ZEP520 array and comparing the raw measurement data with no corrections, the positional



a. b. c.

Fig 5. Final quartz image placement error vector plots of 1”, 17 x 17 arrays written on a different 6025 plates. ZEP520 positive resist template referenced to an NEB22 negative resist template (grid) a.) SFIL array written at the center of the 6025 plate, X=10 and Y=13 nm (m+3s), no corrections; b.) Upper right of the ZEP520 5 x 5 array and the lower left of the NEB22 array, no corrections, X=32 and Y=64 nm (m+3s); and c.) Upper right ZEP520 array and the lower left NEB22 array corrected for scale and orthogonality, X=19 and Y=23 nm (m+3s).

errors in X and Y are 32 and 64 nm (Fig. 5b). Again, by correcting for scale and non-orthogonality on each individual 1" SFIL arrays, the errors could be reduced to 19 and 23 nm in X and Y, respectively (Fig. 5c). The random error vectors on the plot of figure 3c indicate much of the error is most likely attributed to the system residual distortions. Unfortunately, when overlaying two individuals 1" arrays from different parts of the substrate, the overlay error of the templates increases due to their being taken from different areas of the distortion fingerprint. In a worse case scenario, the templates "cut" from two different plates processed with the two different resists of the 6025 substrate can be considerable. The combined error when overlaying all five 1" arrays (lower left to upper right) from both the NEB22 and ZEP520 coated plates is 64 and 72 nm (mean + 3s), X and Y respectively. If scale and orthogonality corrections are applied to the data, the errors are reduced to 47 and 26 nm in X and Y, respectively.

5. CONCLUSION

Fabrication of 20 nm resolution SFIL templates can be achieved using Cr and quartz technology. The use of thin Cr has shown not to be a significant factor to pattern overlay provided the deposition process results in a low stress film. The template exposure layout on a 6025 quartz substrate does require careful consideration due to the level of overlay accuracy required for such high resolution templates. To reduce the errors associated with layer-to-layer alignment of SFIL templates, the best overlay achieved would be to use the center 1" area of the 6025 plate. This would reduce the overlay variation that can occur when placing the templates in various areas of the e-beam exposure tool distortion fingerprint without complex tool and/or software compensation. Also, further analysis will be required to investigate how different resist can contribute to variations in mask distortions.

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