

Intrafield Distortion Characterization

Brian Martinick
Microelectronic Engineering
Rochester Institute of Technology
Rochester, NY 14623

Abstract-- Distortion of printed photoresist patterns exists in all photolithographic tools and can be generated by numerous factors. These non-correctable overlay errors are the direct result of lens imperfections, machine inaccuracy, and reticle error. Any one of these factors can have extreme effects on pattern placement and quality. This study involved characterizing this anomaly and was the first of its kind at the Semiconductor & Microsystems Fabrication Laboratory (SMFL). Incorporating a unique test reticle, crosshairs were printed on silicon wafers. These features were measured via Manufacturing Electron Beam Exposure System (MEBES) market analysis to reveal any pattern migration. This analysis involves passing the electron stream over the beams of the crosshairs. The resulting signature from electron backscattering showed small movements of the pattern. Mathematical modeling of the raw data extracts correctable errors leaving a residual distortion map. These maps can be used as a figure of merit for the amount of pattern placement distortion within the photolithographic tool.

1. INTRODUCTION

With the ever-decreasing geometry size of integrated circuits, comes the need for extremely tight tolerances of IC fabrication tools. Namely within exposure tools, the amount of tolerable distortion. Distortions of printed patterns can be generated by numerous factors. These non-correctable overlay errors are the direct result of lens imperfections, machine inaccuracy, and reticle error. Any one of these factors can have extreme effects on pattern placement and quality. Several techniques are available to measure distortion and reveal any possible distortion patterns. The most common are external overlay measurements of typical box-in-box structures, and in-situ measurements. These techniques were an acceptable method for revealing distortion problems to ultimately increase yield. However due to advances in lens manufacturing, and tool controls within state-of-the-art exposure tools, the magnitude of these non-correctable errors has become small. This increase in quality has caused us to re-examine the current distortion

measurement techniques and their correlation to product imaging.

Distortion characterization has never been performed on SMFL photolithographic tools. This project will adapt the mentioned techniques to measure intrafield pattern placement distortion and provide valuable insights of the tool's ability to accurately expose patterns.

2. DESIGN AND ANALYSIS

The planned procedure for this investigation was to first design and create a test reticle which contained measurable metrology features. These features were measured for any displacement error creating a reticle error file. Silicon wafers coated with photoresist were then exposed with this reticle. The resulting metrology features printed on the wafer were measured for displacement error in the same manner. Next mathematical modeling of the raw data was incorporated to extract any extra machine correctables. Finally, reticle error was removed leaving a residual distortion vector map.

Designing the reticle involved a selection of measurable metrology features. Features like box-in-box, and horizontal/vertical bars were considered, but metrology tool resources were limited. However the Semiconductor & Microsystems Fabrication Laboratory's (SMFL) Manufacturing Electron Beam Exposure System (MEBES) was capable of measuring crosshair features shown in fig. 1. The MEBES market analysis passes the electron stream over the beams of the crosshairs. The resulting signature from electron backscattering showed small movements of the pattern. Therefore the final design of the reticle contained arrays of clear and dark field crosshairs. Both crosshair types were incorporated to address and charging issues during market analysis. The final layout is shown in fig. 2.

The crosshair design provides a minimum dimension of $2\mu\text{m}$, which approaches the resolution limit of the stepper used for this investigation. The smallest features were of most concern due to the tighter tolerances of overlay as compared to large features. The crosshairs were also spaced $500\mu\text{m}$ apart at the wafer level.

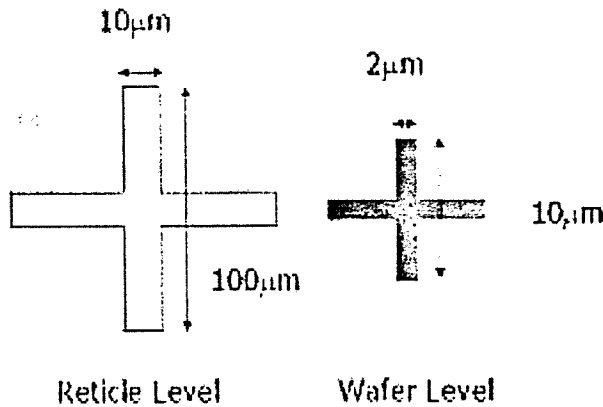


Fig. 1. Crosshair Dimensions

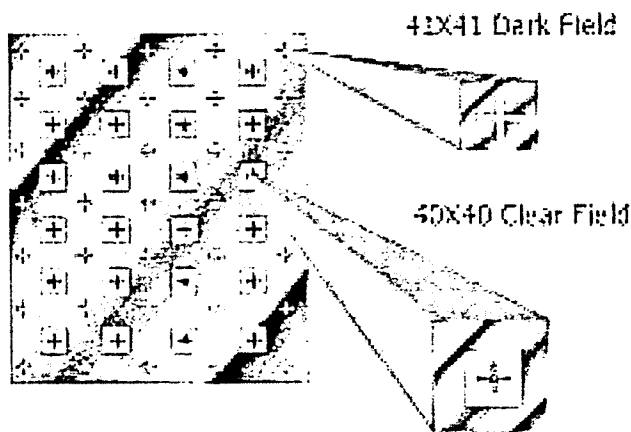


Fig. 2. Reticle Layout

Upon creation of the test reticle, its error file was then generated. The reticle underwent a MEBES market analysis to record displacement errors of the crosshairs. Crosshair migration data was stored in a database, which in turn plotted its error vector map. The vector key is shown in fig. 3.

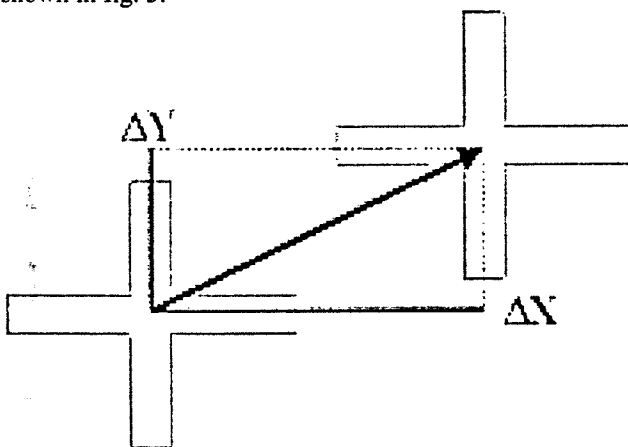
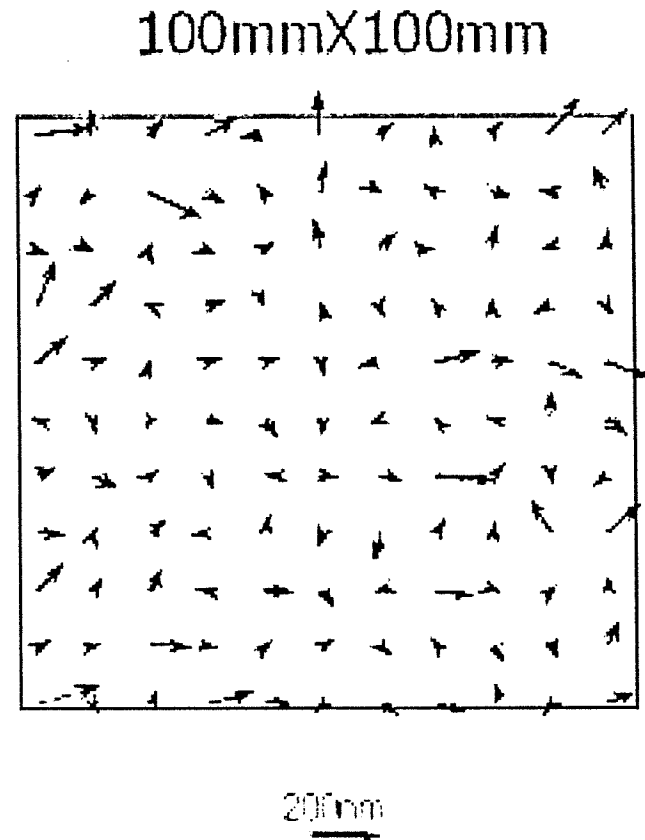


Fig. 3. Vector Key

The vector map shown in fig. 4 reveals a vivid picture of the amount of error contained within the reticle.

Fig. 4. Reticle Error (every 4th mark)

The MEBES market analysis was limited to measuring a maximum array of 11X11. Tool time limitations also prevented measuring of all 1681 points. Fig. 4 shows an 11X11 array of every 4th crosshair measured. An additional 11X11 array at the center of the reticle was also measured, shown in fig. 5. The stepper used for this investigation mostly prints chips on this field size versus the maximum field size of fig. 4.

With the necessary reticle errors obtained, the next step was to expose this pattern into photoresist on silicon wafers. The exposure tool used for this project was SMFL's GCA 6700 g-line Stepper. The patterned wafers then underwent the same measurement procedure as the test reticle. Another market analysis was then performed measuring the same points that correspond to the points in figures 4 & 5. The results from those tests follow in the next section.

25mmX25mm

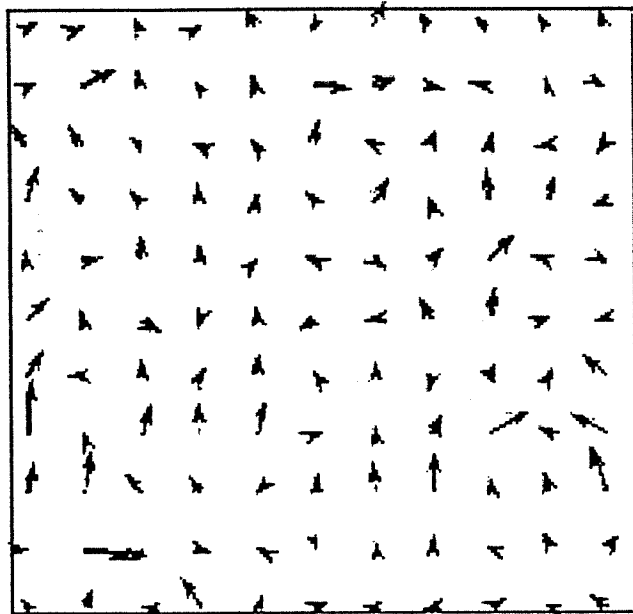


Fig. 5 Reticle Error (center field)

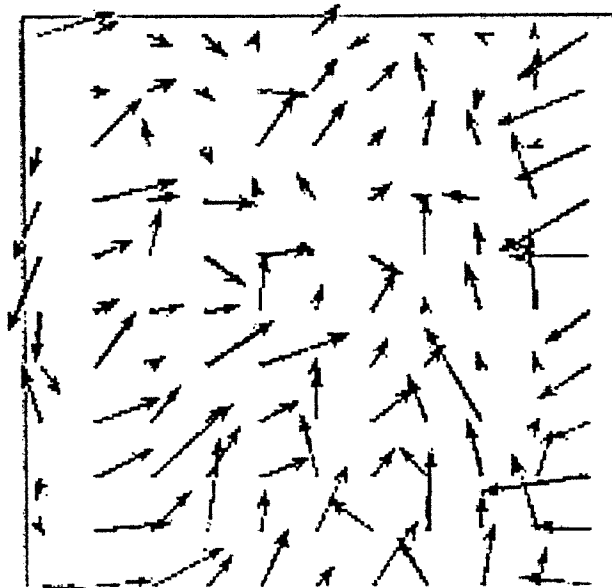
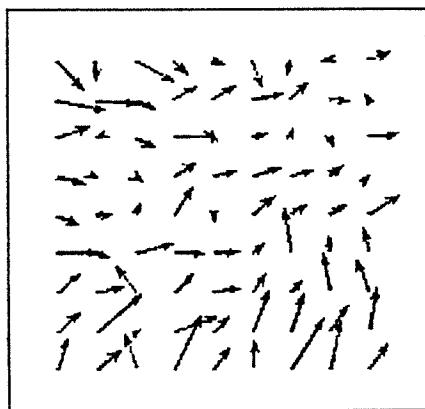
5000 μ mX5000 μ m

Fig. 7. Raw Data (center field)

3. RESULTS

Using the MEBES market analysis, crosshair pattern displacement was measured within the photoresist pattern. The raw data was collected, entered into a database and plotted. This raw data can be seen in figures 6 & 7.

16mmX16mm

9X9
ArrayFig. 6. Raw Data (every 4th)

The wafer level 9X9 array in fig. 6 was due to pattern degradation at the edge of the field. The 11X11 array of fig. 4 was reduced by one column on each side, as well as one row at the top and bottom. Fig. 7 shows the 11X11 array of the center field at the wafer level. Figures 6 and 7 only represent the raw measurements as they come off the MEBES. They are not the final residual maps of non-correctable errors. The data had to be modeled to correct for any additional machine errors.

The raw measurement results were modeled to correct for additional shift, rotation, and magnification. Shift was modeled by an average change in both x and y directions. Rotation and magnification averages x any y errors along center axes with respect to field size. This can be seen in fig. 8. Figure 9 shows examples of these errors and their signatures when intentionally added to the exposure. The patterns represents what the raw data would look like with the intentional magnification and rotation errors.

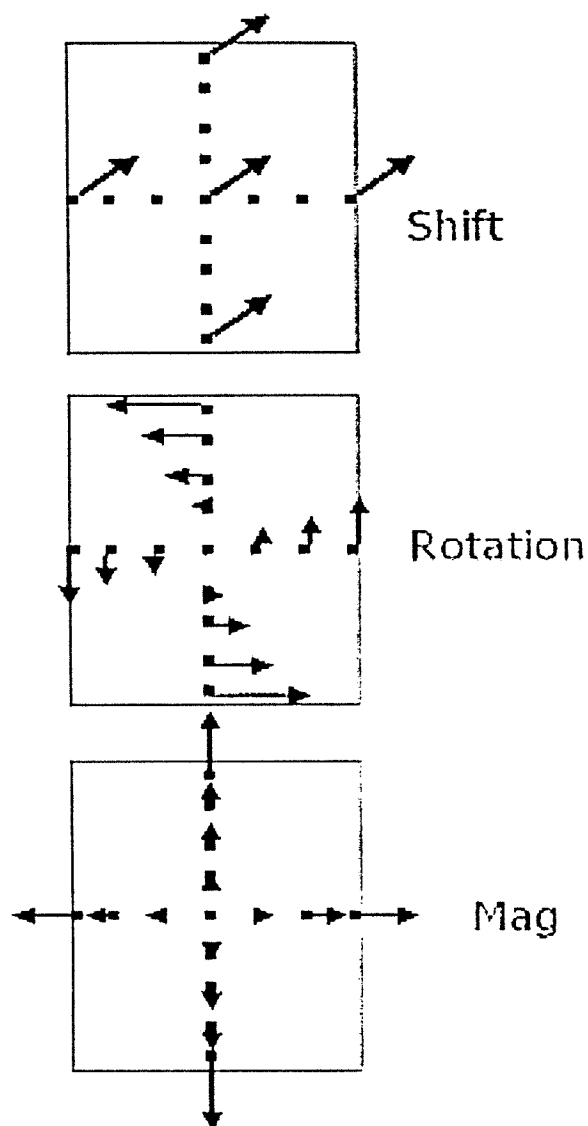


Fig. 8. Additional Machine Correctables

The raw data was entered into a custom database, which models, and generates coefficients for the errors in fig. 9. Those correctables are removed as well as reticle errors from figures 4 & 5. The resulting residual vector maps can be seen in figures 10 & 11.

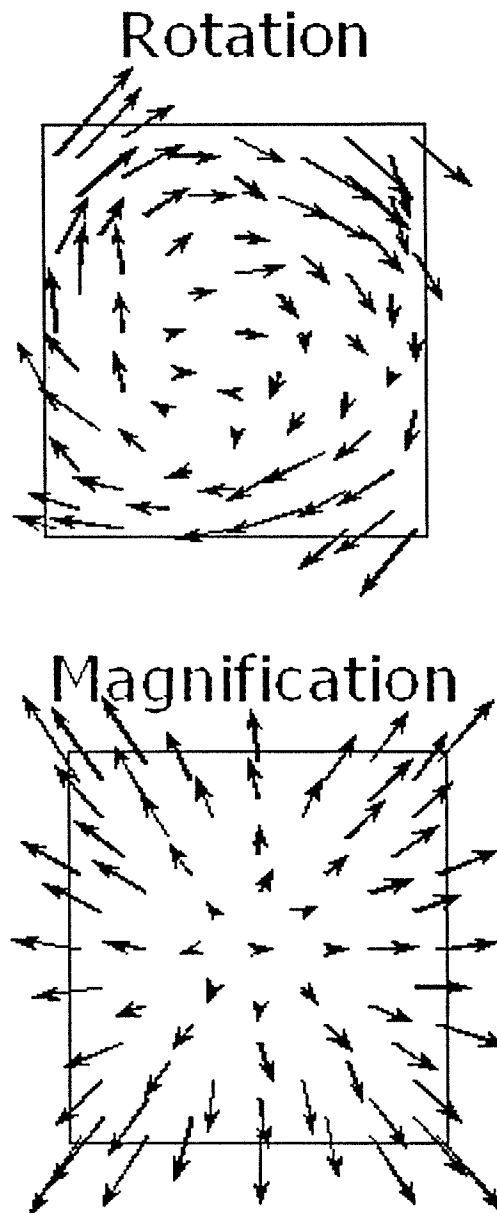
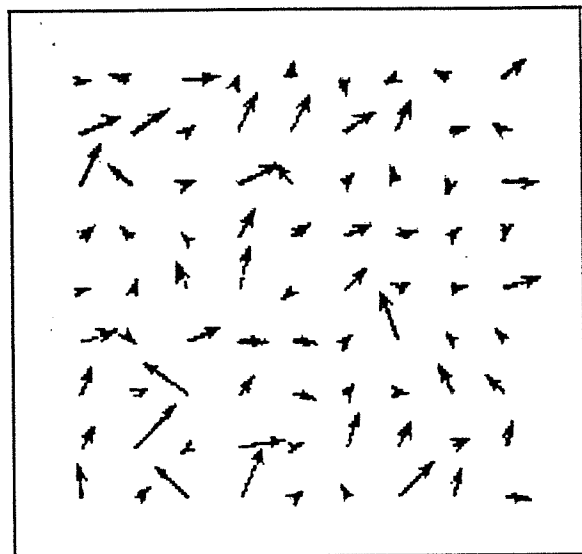


Fig. 9. Modeled Errors

16mmX16mm

9X9
Array200nm
→

X shift 580nm

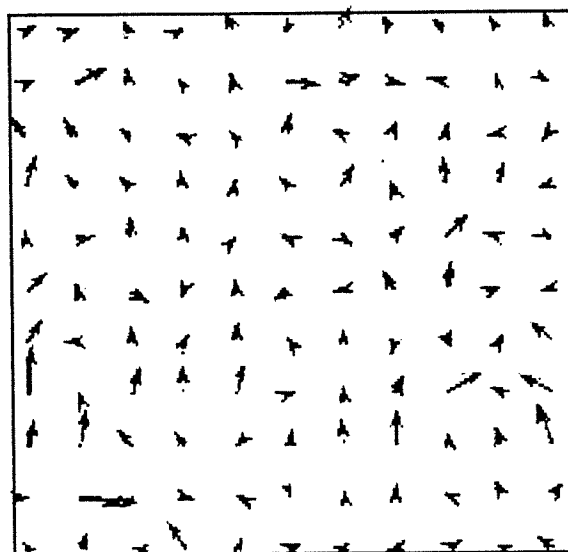
Y shift 241nm

Rotation -0.416 μ rads

Magnification 1.096 ppm

Fig. 10 Residuals (every 4th)

25mmX25mm

11X11
Array200nm
→5000 μ mX5000 μ m

X shift 321nm

Y shift 198nm

Rotation -0.402 μ rads

Magnification 1.037 ppm

Fig. 11. Residuals (center field)

4. SUMMARY

Test Reticle was Designed and Created
 Reticle Error Measured
 Reticle Error File Generated
 Silicon Wafers were Exposed
 Wafer Errors Measured
 Wafer Errors Modeled
 Residuals Generated

5. CONCLUSION

The intrafield distortion project was successful. Non-correctable errors were made known. Data modeling provided coefficients for correction. SMFL process developed for measuring distortion in photolithographic tools.

REFERENCES

- [1] **Deciphering and encoding product overlay: hidden errors**
Gould, Christopher J.; Roberts, William R.; Goodwin, Francis G.;
Proc. SPIE Vol. 4181, p. 68-79, Challenges in Process Integration and Device Technology, David Burnett;
Shin'ichiro Kimura; Bhanwar Singh; Eds
- [2] **Scanner and stepper intrafield distortion characterization: a comparison and correlation of current techniques**
Martinick, Brian N.; Roberts, William R.;
Proc. SPIE Vol. 4344, p. 623-630, Metrology, Inspection, and Process Control for Microlithography XV, Neal T. Sullivan; Ed.