THE IMPACT OF SUBMICRON 10X RETICLE DEFECTS ON IMAGES PRINTED WITH A 0.28 NA G-LINE STEPPER

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ABSTRACT

A 10X reticle was produced with programmed defects of both polarities varying size, proximity to adjacent features, and feature sizes. The defects were imaged in various resist materials over silicon, silicon dioxide, silicon nitride, polysilicon, aluminum, and a 1X chrome mask using a GCA/Mann 4800 stepper. Results obtained using optical and scanning electron microscopy demonstrated that reticle defects as small as 1.0 micron, when in proximity to a feature, will cause linewidth variation in the printed image. The resist film and underlying substrate did affect the linewidth variation. Defocus and over/under exposure also influenced the severity of damage created by reticle defects. A two-dimensional aerial image simulator SPLAT, which is a version of SAMPLE, was used to simulate the optical interactions of defects with adjacent features.

INTRODUCTION

An optical tool will produce an aerial image of a reticle defect which will interact with the aerial images of adjacent features. The formation of the aerial image is dependant upon the resolution capabilities of the optical tool. The resolution capabilities of an optical tool can be described by the tool's Modulation Transfer Function (MTF), which is dependant upon the wavelength (L), numerical aperture (NA), and the coherency (S) of the tool.

Figure 1 shows the MTF of a 0.28 NA g-line stepper with a partial coherency of 0.7. Photoresist requires a critical percent modulation in order to resolve an image. Most organic photoresists require a MTF > 0.4 [1], which according to this curve would resolve a spacial frequency of 800 line-pairs/mm, or 0.6 micron features. A realistic minimum sized feature would follow the equation,

$$R(min)=.6L/NA \qquad (1)$$

which corresponds to a dimension of approximately 1 micron.

FIGURE 1:
MODULATION TRANSFER FUNCTION [1]

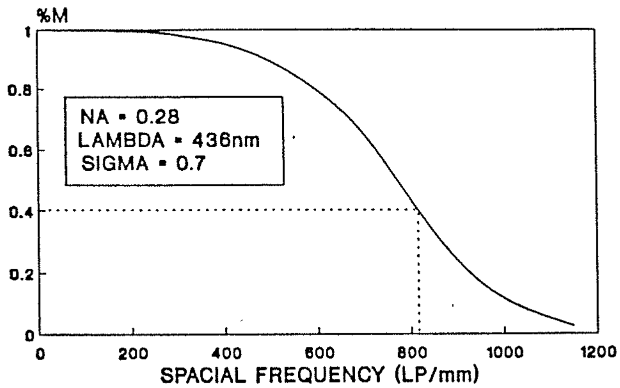
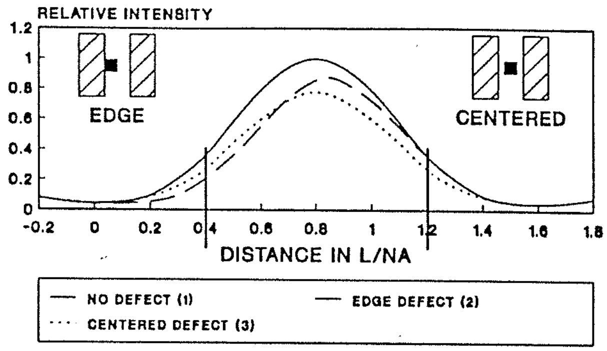


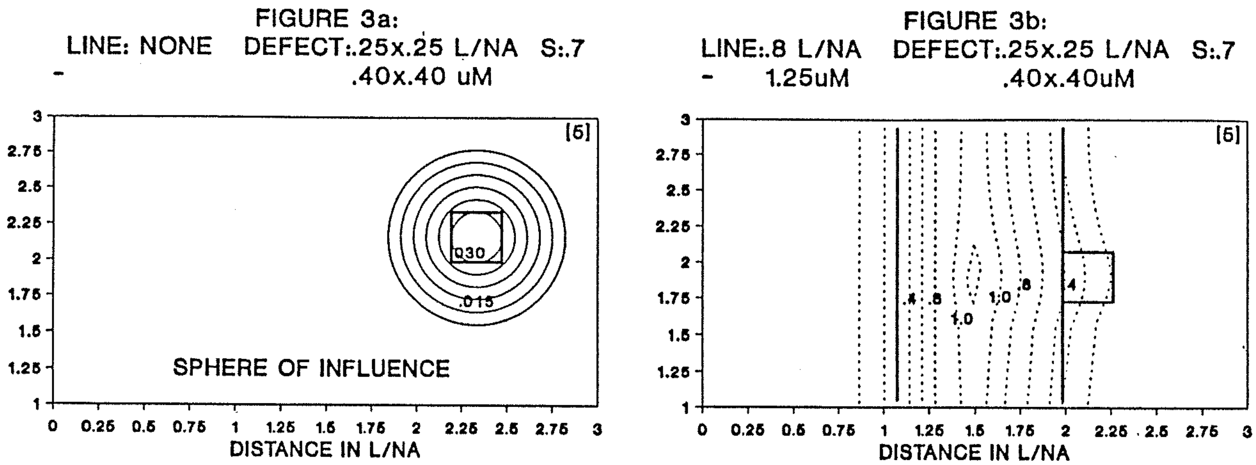
FIGURE 2: INTENSITY PROFILES [2]
.2L/NA DEFECT - 3.1uM ON 10X RETICLE
1.25uM LINEWIDTH



An isolated defect on a reticle which has a final printed size of .25L/NA will not resolve in a partially coherent system. This would correspond to a 4.0 micron reticle defect on the GCA/Mann 4800 10X stepper, and 0.4 micron is well below the resolution capabilities of this system. However, when the defect is placed in proximity to neighboring features, aerial image interaction will take place. The aerial image interaction is dependant upon the defect size, polarity, and proximity to adjacent features.

Figure 2 shows the aerial image intensity profiles of a line/space pair with different defect conditions. Curve #1 shows the intensity profile with no defect in between the two opaque features. The vertical lines show the printed images with no defect. Curve #2 shows the intensity profile with an opaque edge defect on the left feature. This defect lowers the intensity at the left feature edge, possibly resulting in a bump on the resist image. Curve #3 shows the intensity profile with an opaque defect centered in between two opaque features. This defect lowers the intensity at both feature edges, possibly resulting in bumps on the resist images of both features and/or resist bridging [2]. Defects which are neither edge nor centered will form an intensity profile in between curves 2 and 3.

Figures 3a and 3b are intensity contour plots of defects from SPLAT, a two dimensional aerial image simulator. Figure 3a shows the intensity contour plot for a 0.4 X 0.4 micron pinhole reticle defect. This defect will not print because the dimension is well below the resolution limit of a 0.28 NA g-line stepper. The contour plot shows the "sphere of influence" which the reticle defect has on the substrate. Figure 3b shows the intensity contour plot of a 1.25um space with an edge pinhole defect of the same magnitude as the isolated defect. This plot shows the interaction between the defect and the feature. The defect may cause linewidth variation in the final printed image, but there are several factors which influence how the aerial image is transferred into the resist.



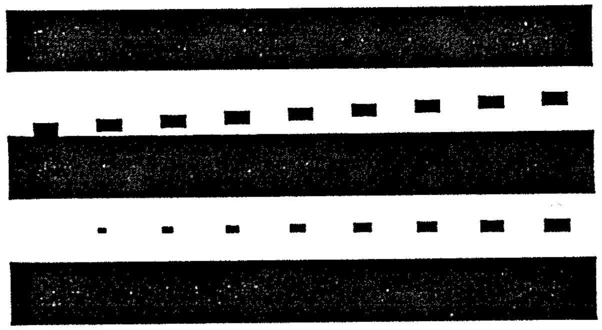
The exposure throughout the thickness of the resist, particularly at the bottom of the resist profile, will determine the impact of the reticle defects on the final printed image. This depends upon resist thickness, exposure/development parameters, processing capabilities and underlying substrates. As the thickness of a resist film decreases, the resolution capabilities of the film improve. However, the photoresist profile will not replicate the aerial image produced by the exposure tool. Standing waves are formed in the resist as a result of coherent interference from reflecting substrates [1]. The standing wave effect can influence the impact of reticle defects. Changes in process bias, resist sensitivity, and substrate reflectivity such as over-development, high temperature postbakes, dyed resist processes, and anti-reflective layers, can be used to reduce the effects of standing waves.

Changes in the focus and exposure values also affect the impact of reticle defects. Depending upon the polarity of the defect, changes in exposure will alter the linewidth variation introduced by the defect. Focus changes will also alter the impact of reticle defects by changing the aerial image contribution of the defect and its interaction with the aerial image of the feature [3].

This project studied the printability of defects using a GCA/Mann 10X 0.28 NA g-line stepper. The reticle was designed with programmed defects of varying size, polarity, proximity to neighboring features, and feature sizes following a layout used by KLA [4]. Figure 4 demonstrates examples of the reticle design. This example shows a feature linewidth of 10um on the 10X reticle. The bottom section of this figure shows the varying defect sizes from 0.6 to 2.0 microns measured perpendicular to the feature on the 10X reticle. The dimension of the defect parallel to the geometry edge is designed to be twice the perpendicular dimension to provide a more realistic defect. The top section of this diagram shows the varying defect proximities from zero to 5.0 microns on the 10X reticle, or zero to 0.5 microns on the printed substrate. The reticle linewidths varied from 10 to 20 microns. Both polarities of this design are included in the reticle. The complete 10X reticle provides over 1000 combinations of defect size, polarity, proximity, and feature size.

FIGURE 4: RETICLE DESIGN

DEFECT PROXIMITY
0 TO 0.5 MICRONS ON WAFER



DEFECT SIZE
0.6 TO 2.0 MICRONS ON 10X RETICLE

This reticle was printed in various resist materials over substrates of varying reflectivity. Analysis was performed using optical and scanning electron microscopy.

EXPERIMENT

The reticle was designed on ICE, an in-house CAD tool at RIT. A 1000X design was used to obtain the desired defect size and proximity distances on the final 10X reticle. Several 1000X emulsion reticles were manufactured on a GCA/Mann 3000 Pattern Generator. Two 10X reductions were performed on the GCA/Mann 4800 Stepper to obtain a final 10X chrome reticle on an EMC chrome blank pre-coated with 0.5um of AZ1350-J resist.

The substrates investigated included a 1.25 micron coating of KTI820 positive photoresist over bare silicon, polysilicon, silicon dioxide, silicon nitride, and aluminum; a 1.3 micron coating of AZ1512-SFD dyed resist over aluminum; and a 0.5 micron coating of AZ1350-J resist on a 1X chrome mask. The reflectivity of each of these substrates was measured on a Nanometrics Nanospec/AFT film thickness measurement system at 436nm, using aluminum as the reference. Each of the substrates was exposed on the GCA/Mann 4800 Stepper with the designed defect reticle using a focus/exposure matrix. The substrates were then developed appropriately. See appendix A for a detailed exposure/process description of the reticle and substrates.

Optical microscopes and a Cambridge Stereoscan 600 SEM was used to analyze the substrates. From the observations, some conclusions were made concerning the impact of reticle defects on this type of optical lithography system.

RESULTS/DISCUSSION

Defects that were much smaller than the resolution limits of an optical tool did affect the linewidths of adjacent features. The micrographs in Figure 5 show the effect of 2.0um chromespot and pinhole reticle defects on printed 1.0um line/space pairs (minimum geometry) on a 1X chrome mask. The bottom lines show the effects of 2.0 micron edge defects on the reticle. Further observations taken on this sample demonstrated that a reticle edge defects of both polarities as small as 1.0 micron, or 0.64L/NA, would vary printed linewidths. Edge defects on larger features showed the same results with negligible differences. Centered defects as small as 1.4 microns caused linewidth variation in both nearby resist lines. However, defects as large as 2.0 microns, or 1.3L/NA, centered in between minimum geometries did not cause resist bridging or opens when nominal values of focus and exposure were used.

FIGURE 5a: CHROMESPOT DEFECTS

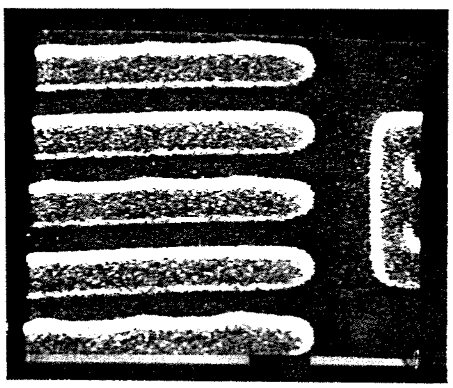
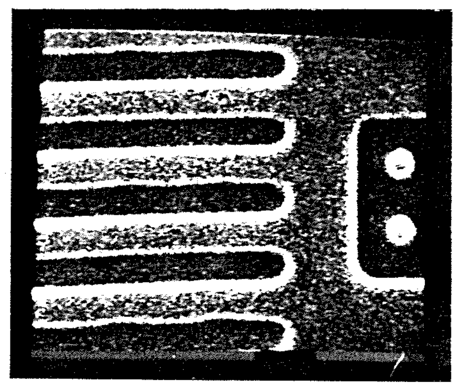


FIGURE 5b: PINHOLE DEFECTS



Defocus significantly affected the impact of reticle defects. Although the depth of focus of a 0.28NA g-line stepper is approximately 3uM, a deviation from nominal focus of only 1uM showed considerable influence in the imaging of the defects. The severity of the damage created by a reticle defects of both polarities increased when the image deviated from nominal focus. This becomes particularly important when imaging over topography.

Deviations from the nominal exposure value had an influence on the damage caused by reticle defects. Results showed that underexposure significantly increased the linewidth variation caused by opaque defects, while decreasing the linewidth variation caused by pinhole defects. Overexposure showed opposite results, but to a lesser degree. The effects of exposure, however, correspond directly with the development time, or process bias being used. Adjustments in both the exposure dose and the process bias will alter the printability of defects.

The thickness of the resist material showed differences in resolving the defects on the printed image. The 0.5 micron resist coating on the 1X chrome mask resolved smaller defects compared to the 1.25 micron resist coatings on the wafer substrates. In addition to resist thickness, the resist profile has an effect on the printability of defects. The underlying substrate materials alter the standing wave pattern throughout the resist by changing the magnitude and phase of reflected waves. Reflectivity measurements at g-line showed that the reflectivity of the aluminum substrate was approximately twice that of the other wafer substrates. Although there were differences in substrate reflectivity, the differences in defect imaging on the substrates were minimal. This is most likely due to the postbake used after development, which eliminated the standing wave profile by allowing the resist to flow. The results of the dyed resist also showed minimal differences in defect imaging. The dyed resist should lower the effects of standing waves due to its decreased sensitivity. However, since a postbake was used for the standard resist process, the comparison is not appropriate.

CONCLUSION

This study has provided information on defect imaging in a 0.28NA g-line 10X optical projection system. Reticle defects in proximity to features caused variations in linewidths, while isolated defects of the same size would not resolve. In order for 1.0 micron minimum size geometries to be free from printable defects, it was determined that 10X reticle defects can not be larger than 1.0 micron, or 0.64L/NA. An optimized lithographic processes would show that defects even smaller than this would cause linewidth variation, as determined by references [3] and [4]. It was also determined that focus and exposure values significantly affect the damage caused by reticle defects; with nominal values showing the best results. Recommendations for further investigation would include a resist profile comparison without the use of a postbake after development. This would maintain the standing wave profiles which could be observed using scanning electron microscopy. Actual profiles of imaged defects could then be compared among the different substrates and resist coatings.

ACKNOWLEDGMENTS

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APPENDIX A

EXPOSURE/PROCESS DESCRIPTION

10X Reticle
- EMC Chrome Blank
- Pre-coated 0.5 micron AZ1350-J photoresist
- Pre-bake 90 degrees C for 30min
- GCA/Mann 4800 10X 0.28 NA g-line stepper
- 117mJ/cm2 to process chromespot defects
- 225mJ/cm2 to process pinhole defects
- 35sec immersion Shipley 351 diluted 5:1

KTI820 RESIST
- Various substrates
- 1.25 micron resist coated on GCA wafertrac
- GCA/Mann 4800 10X 0.28 NA g-line stepper
- 12 X 12 Focus/Exposure matrix
  Focus: +/- 2.5 microns
  Exposure: 75% to 200%
- 30sec KTI934 diluted 1:1 puddle develop on GCA wafertrac
- 140 degree hotplate postbake for 160sec

AZ1512-SFD DYED RESIST
- aluminum substrate
- 1.3 micron resist spin coated
- Focus/Exposure matrix
- 60 sec immersion AZ312MIF pre-diluted 1:1.2

1X CHROME MASK
- 0.5 micron pre coated AZ1350-J
- Prebake 90 degrees C for 30min
- Focus/Exposure matrix
- 35sec immersion Shipley 351 diluted 5:1