In-Situ Aberration Metrology using Phase Wheel Targets

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Abstract— Aberration metrology and monitoring of lithography projection systems in the semiconductor industry are becoming more important as today's ICs are printed at sub-100 nm resolution. All lenses suffer from lens aberrations and it is important that the lithographer knows which aberration and the magnitude of the aberration in order to understand its impact on the process window and resolution limitations. A technique and process to recognize and measure lens aberrations in-situ has been developed using a phase wheel target at 157nm and 193nm lithography. This project will use the phase wheel target technique to extend aberration monitoring into i-line lithography using RIT's Canon exposure tool. Test reticle design, layout and fabrication, as well as the exposure process optimization will be carried out for the technique to work at 365nm. First order aberrations from the Canon exposure tool will be identified using this system.

***Index Terms*— Aberration, Phase Wheel Aberration Target, Phase Shift Reticle**

I. Introduction

THE process design begins with simulation of the phase target feature using KLA Tencor's lithography simulator Prolith. The phase wheel target consists of eight dots that are phase shifted 180°, each azimuthally placed at 45° intervals beginning at 0°. Centered in the eight phase shifted target is one more phase dot also phase shifted 180°. Phase wheel target dimensions are dependent on the wavelength of lithography. The feature design is divided into three components (Fig. 1). L1 is the first component and is the width of the outer or radially positioned phase dots. The second dimension L2, is the spacing between the radially positioned phase shifted dots and the phase dot centered in the phase wheel feature. The third dimension is the diameter of the central phase dot. The correct ratio of L1:L2:L3 must be found through simulation to minimize the number of iterations needed to develop a working process for aberration detection at i-line lithography. L4 is the distance from the outer edge of the phase shifted to the "shield." The use of the shield eliminates stray light preventing shadowing of phase dot features. Geometry dimensions to be simulated are limited by two relations $\frac{0.5\lambda}{NA} \le L1 \le \frac{1.5\lambda}{NA}$ and $\frac{2.5\lambda}{NA} \le L3 \le \frac{5\lambda}{NA}$. L2 is experimentally determined so that L1 and L3 are spaced far enough that aberrations do not cause the phase dots to interfere but rather do allow them to come in contact each other when heavily aberrated or severely defocused. The phase wheels also are not to be placed at a dimension where they are completely isolated from each other. Simulations have been done based upon the above geometrical considerations to test these targets under a wide range of conditions. Once simulations demonstrated the desired sensitivity results from an aberrated wavefront, the mask layout is then created. The phase wheel target has been used to detect higher order aberrations but for this project will be demonstrated to detect mainly low order aberrations. Past attempts at developing correct geometries have demonstrated that simulations do not always correspond to actual results; to help ensure a working target design multiple simulated geometries have been placed on the designed reticle. The completed reticle design was submitted to the SMFL Mask House. The mask was then etched using the Drytek Quad to give a 180° phase shift in the phase dots, and the chrome shields were then patterned over the etch phase dots on the mask. Using the SSI track, the 6" wafers were coated with ~3000Å of photoresist and exposed through focus and dose. The phase wheel targets were then inspected under a scanning electron microscope and compared with simulated results. Using this technique, aberrations the Cannon stepper suffers from were revealed.

The phase wheel target is being implemented as an aberration monitoring tool because lines created at phase transition regions demonstrate a high sensitivity to aberrations [1]. This target increases the sampling of the pupil, detecting aberrations at multiple orientations. The feature on wafer results in dark lines along phase transitions in the shape of a doughnut.

This work is part of the senior design project requirement for a B.S. degree in Microelectronic Engineering at the Rochester Institute of Technology (RIT). The results of this project were presented at the 23rd Annual Microelectronic Engineering Conference on May 10, 2005 at RIT in Rochester, NY.

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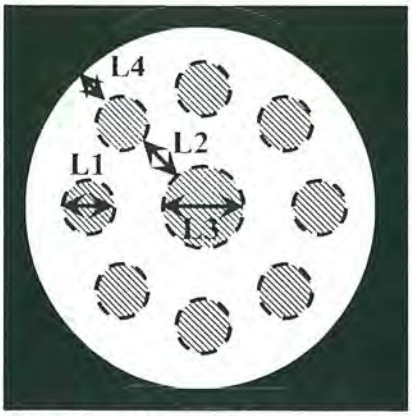

Figure 1. Phase Wheel Target feature mask layout. The white area is quartz. The grey circle areas are π phase shifted dots. The dimensions of the phase wheel target are also labeled.

In an ideal exposure tool aberrations would be close to zero or nonexistent. In this case all of the phase dots printed would appear to be concentric and show no apparent deviation from a circular shape as seen in Figure 2.

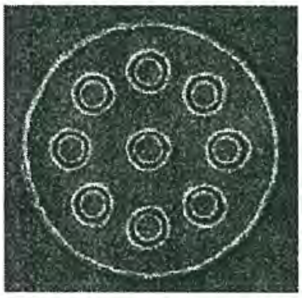

Figure 2. Ideal pattern printed on wafer phase wheel target. All phase dots appear concentric suffering from very little aberration.

When aberrations are introduced or can not be eliminated from a lithography system, the appearance of the phase dots changes dependent on the severity and type of the aberration.

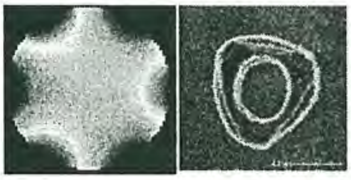

Figure 3. Demonstration of three-foil aberration and the resulting phase dot image in resist. The phase dot is no longer a perfect circle but appears almost triangular.

II. Mask Processing

A. Layout

The mask for the phase wheel target is a two-layer mask. The first layer of the mask is the "dots." These dots become the phase dots once the quartz is etched using the remaining chrome as the etch mask. Once the phase dots are etched the chrome around the phase dots needs to be cleared. This is completed by writing a large circle around all of the other phase dots. Also included in the first layout of the mask are 100μm x 100μm boxes used to measure the etch depth of the smaller phase dots because of the possibility of loading effects. The etch depth is very important because the phase shift is dependent upon the etch depth. However the phase dots themselves are too small to be measured using the profilometer because the tip of the profilomter is larger than the phase dots themselves.

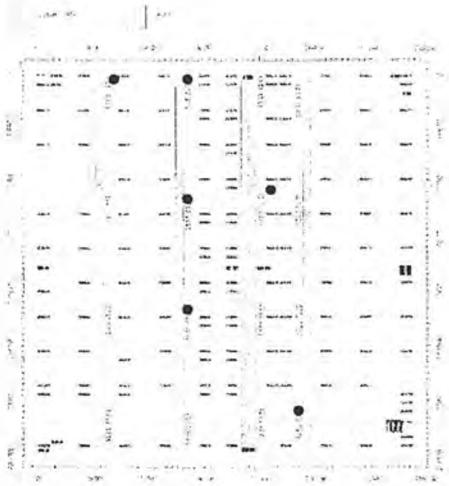

Figure 4. Mask layout of phase wheel targets. The phase dots can not actually be seen because of their sub-micron size. The red dots indicate where etch rates and depths were obtained for different areas of the mask

Using the KLA/Tencor's lithography simulation software nine phase wheel targets were designed for i-line lithography. The feature dimensions are given in Table 1.

TABLE I
PHASE WHEEL TARGET DIMENSIONS ON WAFER

	Ratio				Diameter [nm]		
	L1	L2	L3		L1	L2	L3
Feature "A"	1.5	2.5	2		600	1000	800
Feature "B"	1.5	2.5	2		525	875	700
Feature "C"	1	1	1		540	540	540
Feature "D"	1.5	2	2		600	800	800
Feature "E"	1.5	2.5	2		900	1500	1200
Feature "F"	1.5	2.5	2		500	833	667
Feature "G"	1	1	1		450	450	450
Feature "H"	1	1	1		700	700	700
Feature "I"	1	1	1		600	600	600

Green highlighted features are the features that were analyzed from the mask.

B. Mask Etch

To obtain a π phase shift, equation 1 must be used. Equation 1 is dependent on λ, the illumination source in this case i-line illumination (365nm). Lastly n_i is the refractive index of the quartz. With these variables the required etch depth for a π phase shift can be calculated, about 3720Å.

$$\Delta\Phi=\frac{2\pi}{\lambda}(n_i-1)t \qquad (1)$$

An in house etch recipe was developed. This recipe was developed to be very conservative to ensure the correct etch depth would be achieved. This recipe can be seen in Table II

and has an etch rate of about 7 Å/second.

TABLE II
DRYTEK QUAD REACTIVE ION ETCH RECIPE FOR QUARTZ

CHF_3	100 sccm
O_2	5 sccm
Ar	50 sccm
Power	375 W
Pressure	100mTorr

The total etch was divided into four etches to ensure an etch depth close to the target etch depth. This allows the etch rate to be controlled throughout the etch process and reduce the risk of an over etch. The etch depth was achieved by ½ etch, ¼ etch, and two 1/8 etch final etches. The final etch depth was in the range of 3612-3705Å, just a few degrees short of the desired 180° phase shift but well with in the required phase shift to get quality results.

III. EXPOSURE/RESIST PROCESSING

A. Resist Processing

Olin620 photoresist was used in this experiment. To clear the center of the phase dots, a thin high-contrast resist is needed. However original viscosity of this resist, when spun at high RPM's, produced a ~7000Å film. Resist was thinned (as to increase the solvent/decrease the solids) to allow the thinner coats. The Olin 620 resist was thinned using BTS 280-Ethyl Lactate in a 1:1 ratio. The new thinned resist coated uniformly (±100 Å) at 2700 Å, at a spin speed of 2000RPM using a manual coating technique.

B. Exposure Tool Setup

The exposure tool evaluated was RIT's Cannon i-line exposure tool. The tool settings can be seen in Table III.

TABLE III
RIT'S CANNON I-LINE EXPOSURE TOOL SETTINGS

- NA = 0.52
- Sigma = 0.6
- Dose = 80mJ/cm2
- Focus = -1.5 – 1.5 µm, steps 0.6µm
- Reduction Ratio = 5:1

The correct exposure dose for the phase wheel targets was determined by running a dose matrix on a wafer and locating the dose required to clear all exposed photoresist.

IV. RESULTS

Phase Wheel Target images were collected through focus after exposure. The images were collected using a LEO scanning electron microscope (SEM). Phase wheels were analyzed using knowledge of phase wheels shape dependence on lower order aberrations by completion Prolith simulations of aberrations through focus. Using iterative technique, combining previous knowledge from Prolith simulations and resimulating obvious aberrations to match on-wafer results. Results of feature "A" from the RIT Canon exposure tool through focus can be seen in Table III. The simulation demonstrates that the RIT i-line Canon exposure tool suffers from ~0.1λ 45°-astigmatism and ~-0.1λ x-coma third-order aberrations.

TABLE III
RIT CANON EXPOSURE TOOL RESULTS OF "A" FEATURE AND PROLITH SIMULATIONS

	Focus(µm)			
	-.90	-.30	.30	.90
SEM Results				
Simulation Results				

V. CONCLUSION

The ground work for i-line phase wheel targets has begun at RIT. Mask design, feature dimensions through simulation, fabrication of mask, and demonstration of working phase wheels has been completed. Using this technology the RIT Canon exposure tool suffers from ~0.1λ 45°-astigmatism and ~-0.1λ x-coma third-order aberrations.

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