Evaluation of Source Geometry Using a Pinhole Camera

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Abstract -- **A pinhole camera was used to evaluate source geometry of the GCA6700 g-line stepper. To create the camera, a photomask with various pinhole sizes was placed in the stepper, in close proximity to a wafer to generate an image. The images were evaluated to determine the shape and observe the radial intensity of the source. The variation across the source was evaluated because varying intensity across the wafer results and contributes to changes in critical dimension. Dose was varied in order to show how an illumination source might be characterized. As dose increased, the pinhole image became larger. Stacking the images could be used to create a three dimensional image of the source. Additionally, source images were used to verify the numerical aperture of the condenser lens of the illumination system.**

1. INTRODUCTION

Knowledge of illuminator geometry is important in achieving optimum performance from optical tools. Illumination source geometry is used to measure telecentricity error effects, effective source shift, and resulting changes in intensity across the wafer.

Telecentricity is when the chief rays of an optical system are collimated, meaning the chief rays are parallel to the optical axis [1].

An illumination source can shift so that it is not in direct alignment with the pupil of our lens system. The illuminator system is designed to align with the lens system, when it may have actually shifted to one side. Some intensity will be lost when the energy falls outside the lens pupil [2].

Changes in intensity across the source are important because this results in changes in intensity across the wafer. This in turn changes linewidths on the wafer, and can be detrimental when printing small gate sizes.

Source imaging with a pinhole camera is a convenient way to observe source geometry using an easily repeated, simple setup. Since the illumination source cannot be inspected by the naked eye, a pinhole camera projects an image of the illuminator onto the wafer surface.

A. What is a pinhole camera?

The setup for a pinhole camera is shown in Figure 1. A mask with small pinhole causes an image of the source to appear in resist on the wafer. The pinhole in a pinhole camera acts as the lens. The pinhole forces every point emitting light from the source to form a smaller point on the wafer, so the image is crisp. This method requires longer exposure time than imaging with a lens. Conventional camera lenses allow a much larger hole to admit light, and therefore have faster exposure time. [3]

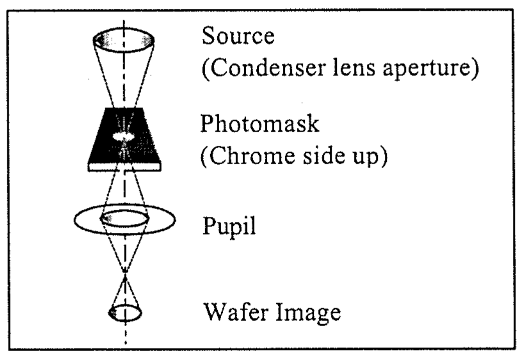

Figure 1: General Pinhole Camera Setup

2. EXPERIMENT

In this experiment, source geometry of the GCA 6700 436 nm G-line stepper was evaluated using a pinhole camera. A dark field mask was designed with pinholes varying in size from 50 – 600 μm. The mask was created using the MEBES III electron beam mask making system. The illumination source was imaged in one μm thick Shipley 812 photoresist on p-type wafers. HMDS (hexamethyl-disilazane) adhesion promoter was used before the resist coat. Small pellicle rings were used to attach the wafer in close proximity to the photomask. Table 1 shows the source imaging process steps. CD-26 developer was used in the develop step.

Table 1: Process Steps for Pinhole Imaging

Step	Time (sec)	Temp (°C)
Dehydration Bake	120	200
Coat (4500 RPM)	60	
Prebake	120	90
Expose	30	
Post-Exposure Bake	45	115
Develop	50	
Hardbake	160	120

A. Setup

Normally, a stepper setup from top to bottom begins with the source, then condenser lens, photomask, objective lens, and finally, the wafer. Figure 1 illustrated the standard setup. In this experiment, imaging was done at the mask plane, above the objective lens. This way, there were no aberrations from the objective lens to deal with.

The wafer was attached to mask using a small pellicle ring. When illumination travels through the objective lens, the area exposed at the wafer plane is 5x5 times smaller than the area at the mask stage, so the intensity is 25 times higher at the wafer stage. Since all imaging was done at the mask plane, wafers were exposed 25 times longer than in standard processing. The wafers were exposed manually using the 436nm source of the GCA 6700 G-line stepper. Figures 2a and 2b show the experimental setup.

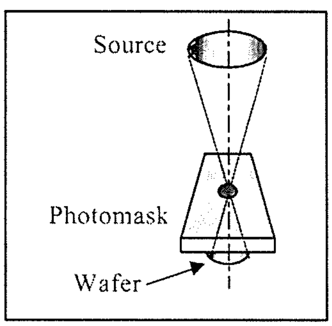

Figure 2a: Experiment Setup

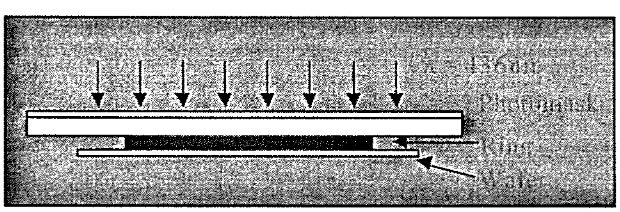

Figure 2b: Setup at Mask Plane

B. Exposure Dose Variations

The source was imaged at various exposure doses to observe the possibility of three-dimensional source imaging. The intensity measured at the mask was 7.0 mW/cm^2. The dose, D, was found by multiplying the intensity, I, by the time, t, in seconds, as shown in the following equation. Table 2 shows resulting dose for each wafer.

$$D = I * t \tag{1}$$

Table 2: Varied Exposure Dose Values

Wafer	Intensity (mW/cm^2)	Exposure Time (sec)	Dose (mJ/cm^2)
M1	7.0	30	210
M2	7.0	25	175
M3	7.0	20	140
M4	7.0	15	105
M5	7.0	10	70
M6	7.0	5	35

C. Beam3 Simulations

Beam3 software was used to determine the theoretical numerical aperture of the condenser lens. The mask was placed 2700 μm from the source in the simulation. The mask thickness was 3000 μm. A ray was placed 460 μm above the optical axis, creating a half angle of 9.67? with the pinhole center. The ray reached the wafer at 1300 μm below the optical axis. As the pinhole size increased, the distance from the incident ray on the wafer from the axis was 1300 μm added to the radius of the pinhole. This accounts for some variation in experimental calculation of the numerical aperture of the condenser lens.

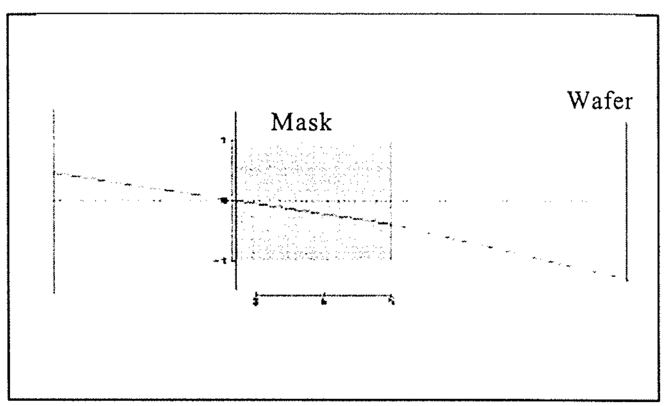

Figure 3: Beam3 Simulation

3. Results and Analysis

A. Source Images

Images of the source are shown in Figure 4. It is evident that intensity drops off radially for each image. The source shapes in Figure 4 were projected through a 300um pinhole to form resist images. To create each image, the exposure dose was increased. The varied exposure dose from Table 2 was used to get an idea of what a three-dimensional source image would look like. Variations in radial intensity, though less of a threat than asymmetry, could have an effect on printable critical dimension. Figure 5 shows negligible asymmetry in the images, and any questionable effects were the result of standing waves in the resist.

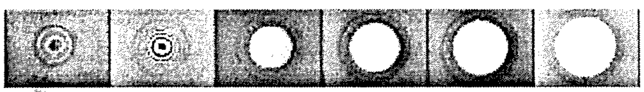

Figure 4: Images of 300μm Pinhole with Varied Exposure Dose

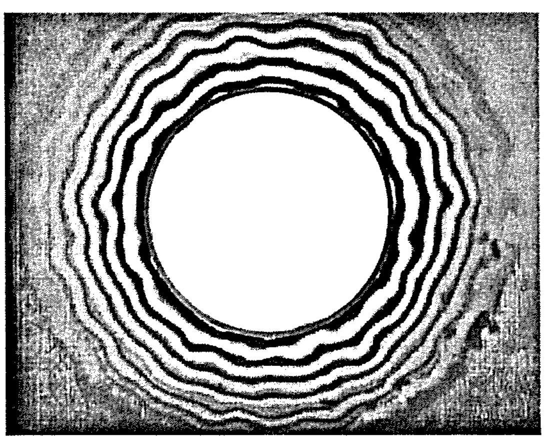

Figure 5: Symmetrical Pinhole Shape

B. Three-dimensional Source Images

Dose was varied from $35 mJ/cm^2$ to $210 mJ/cm^2$, effectively changing the image of a 300μm pinhole, as seen in Figure 4. Stacking the images on top of one another can be used to produce a three-dimensional effect, as seen in Prolith source images. Software is available to create the three-dimensional images to help in characterizing sources. Just as lenses are characterized, source characterization is an important way to evaluate tool capabilities.

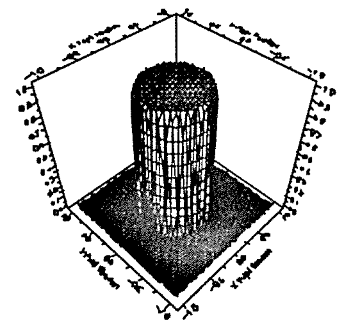

Figure 6: Prolith 3-dimensional Source Image

C. NAc Measurement

The pinhole images were used to verify the Numerical Aperture of the condenser lens. Figure 7 demonstrates the angles and measurements used in the calculations. The angle at the mask is equal to the angle formed by the condenser lens. The numerical aperture is the sine of the half angle the incident light makes as it reaches the quartz through the pinhole. Theoretically, the numerical aperture should be 0.16. Experimental measurements gave a numerical aperture of 0.14, about 12.5% error. This error is due to the threshold of the resist, exposure time, and size of the pinhole.

Theoretical:

$$NA_c = NA_o * \text{partial coherence} \quad (2)$$

$$NA_c = \sin\alpha = 0.16$$

Experimental

$$a^2 + b^2 = c^2 \quad (3)$$

$$NA_c = \sin\alpha = a / c \quad (4)$$

$$NA_c = 0.14$$

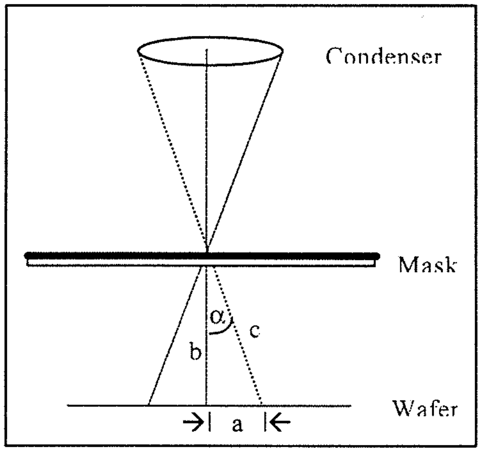

Figure 7: Prolith 3-dimensional Source Image

4. CONCLUSION

Evaluation of source geometry has a definite benefit to industry. Using a pinhole camera, source geometry can be determined easily and conveniently. The projected image shows any irregularities in intensity distribution. As previously mentioned, imperfect source geometry accounts for across chip linewidth variations, and partial coherence variations. Another type of pinhole that may be used is a diffraction grating pinhole, often used in experiments to determine effective source shift [4].

Future work may include many quantitative experiments, such as source shift measurement, telecentricity error measurement, and Fourier Transform evaluation of images. A BARC should be used to eliminate standing waves in the resist. It would also be beneficial to perform the experiment with I-line, Deep UV, and off-axis illumination sources.

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