Phase Edge Contact Immersion Lithography at 193nm

Bryan P. Watson

Abstract— **A phase-edge contact immersion optical lithography system utilizing a 193nm Argon Fluoride (ArF) excimer laser was designed. The ArF laser was passed through a 600nm quartz diffraction grating. The diffraction grating was placed in contact with the substrate. The gap between the mask and substrate was varied by the use of transparency sheets to study the effects of linewidth control and resolution as a function of this distance. This was done for both air and water as the indexing medium between the mask and substrate. Images were acquired from scanning electron micrographs (SEM's) for each of the cases analyzed.**

Index Terms— **Immersion lithography, Phase edge contrast**

I. Introduction

OPTICAL lithography has been approaching hard limits over the last few years. As smaller and smaller linewidths are needed for next generation IC's, the question of reaching such small features with optical lithography comes into question. Advancements in optical lithography have kept it as the favorable choice in reducing line widths to produce high-density devices because of the costs, knowledge, and ease of processing. To further overcome the limits of optical lithography, various methods of lithography at 193nm are being researched more and more. Some methods being explored are interferometric lithography, contact lithography, and immersion lithography. Each technique has it's own advantages and disadvantages. Much research is currently being done to implement such methods, and much more still needs to be done in order to further push the limits of optical lithography.

One method that is being used is phase shifting techniques. Using a simple quartz diffraction grating accomplishes this. This grating is essentially a chromeless phase-shifting mask. This mask has the characteristic in which some transparent areas of the mask are given 180° shift in optical phase relative to other nearby transparent areas. The interaction of the aerial images between two features with a relative phase difference of 180° creates interference regions that can be used to print images much closer together and with an increased depth of focus. This is the general idea of interference or interferometric lithography, which can be seen in Figure 1.

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Interferometric lithography has the ability to produce highly coherent repeating patterns. These patterns maintain a high contrast over a large depth of focus and resolution is constrained only by diffraction and the coherency of the source. Another benefit of interferometric lithography is its ability to be implemented inexpensively and with minimum complexity since there is limited use of masks and refractive components.

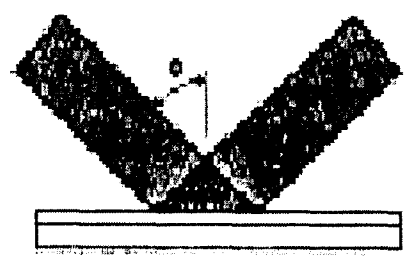

Figure 1: Two mutually coherent light beams interfering on a substrate at angle ϕ.

The simplest method of implementing an interferometric lithography system centers on the interference of two mutually coherent light beams of wavelength λ. The beams interfere at the surface of a substrate coated with photosensitive material at an angle θ with respect to the substrate normal. The interference of the light beams produces a sinusoidal intensity distribution with period P (line/space) specified by $\lambda/2\sin\theta$. The minimum resolvable line width decreases as the angle of incidence θ increases, therefore the minimum period that can be imaged with wavelength λ is $\lambda/2$ as θ approaches 90°. While this sort of perfect interference is not likely to occur in this experiment, it is worth mentioning due to the desire to make this assumption when imaging in the Fraunhofer region.

By placing such a mask in contact with the substrate, the image created will resemble that of the geometric shadow provided that it is in the Fresnel or near-field

region. This brings about the name phase-edge lithography, since the image is produce from the edge of the phase shift portion of the mask. As the contact gap is increased slightly, imaging moves into the Fraunhofer region of diffraction, which is the conventional projection type of lithography. The intensity profile of the wave will further be reduced on the principal of Fourier optics. This principle can be seen in Figure 2.

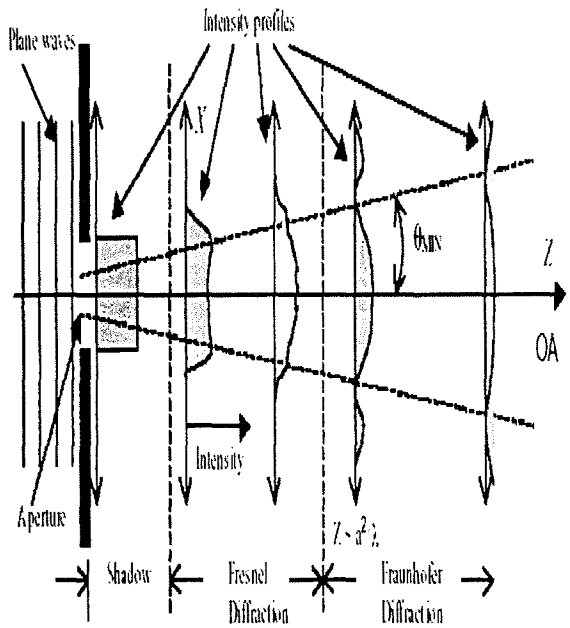

Figure 2: Fresnel and Fraunhofer region intensity modeling.

To further increase resolution for smaller features comes the idea of immersion lithography. Immersion lithography focuses on the idea of using a liquid as an indexing medium instead of air. This is attractive because of liquids having a higher index of refraction, n, than that of air (for air n=1.0). By using water as an indexing medium, an optical system can be improved greatly. Water has a higher index of refraction than air (~1.33 at 193nm). Other benefits of water is that it is highly transparent at 193nm, it is easy to obtain, and does not have an adverse reaction to photoresist. These properties make water very attractive for immersion lithography. The higher index of refraction will increase the Numerical Aperture (NA) of the system since NA=n $\sin\theta$. By adding the water the effective wavelength, given by λ_o/n, will also decrease. The combination of these two factors will lead to increased resolution, which is given by $k_1 * \lambda_{eff} / NA$.

There are some obstacles that still need to be overcome in immersion lithography. One of the major problems is that of microbubbles. Microbubbles are small bubbles that are inherent in water. Bubbles as small as 1micron can alter the intensity of the beam. This altered intensity pattern can lead to incorrect patterning and imperfections in resist features. One way to combat microbubbles is by the use of an outgassing system, which is the removal of dissolved air from water. This problem will not be explored in this experiment, as this is just the first stage of using this immersion technique. There is currently an outgassing process being developed by the Thermal Analysis Lab at RIT.

By further increasing the contact gap and moving further into the Fraunhofer region, the intensity drop off will become greater. This can be seen by Figure 3.

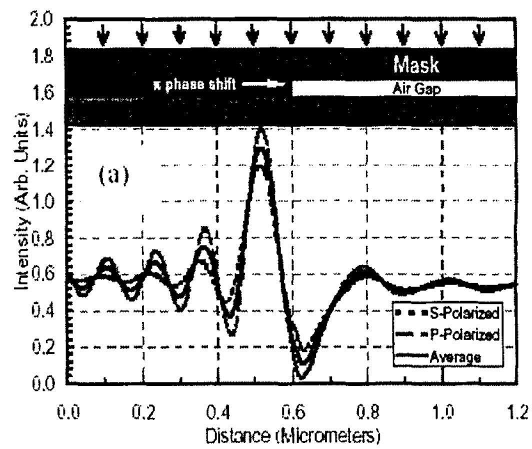

Figure 3: Intensity profile drop off for a given gap.

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II. EXPERIMENTATION AND RESULTS

A. Optical System Design

A 193nm ArF Excimer laser was used to provide illumination for the lithography system. The laser is controlled by the EX10/200 Excimer Laser Control Software on the computer hooked up to the system. The software allows for the control of the repetition rate, which is given in Hz. This value was set to a constant 200Hz for all exposures. To create different exposure doses, the number of pulses of the laser has to be varied. This was set to anywhere from 1000 to 30000 pulses. The laser source was passed through a 600nm pitch quartz diffraction grating that generated a coherent diffraction pattern (see appendix – Phase-Shift Diffraction Grating). The diffraction grating was placed in direct contact with the substrate, or was separated only by a distance of a sheet of transparency film. See Figure 4. Imaging was done with both air and water as the indexing medium in the gap between the mask and substrate.

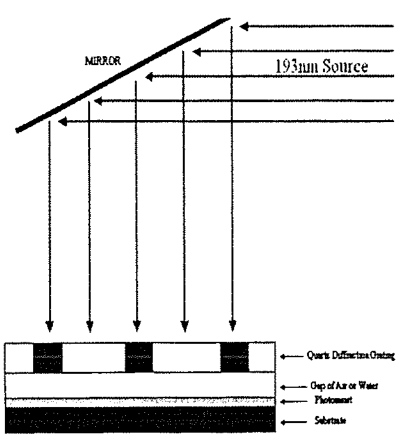

Figure 4. : Interferometric optical system design

B. Photoresist Characterization

A TOK TL307 photoresist, which is a 193nm type of photoresist, was used for this experiment (see appendix – Substrate Preparation and Processing). Before any imaging could be done, the exposure dose had to be found in order to know at what number of pulses to image at.

An exposure series was run for exposure in air and in water to generate a characteristic curve for the photoresist. This was found to be at around 8000 pulses for exposure in air, and about 8500 pulses for exposure in water. The characteristic curve can be seen in Figure 5.

`This experimentation in finding the dose-to-clear gave a rough estimate of what pulse number to image around for imaging with the mask. It is important to note that this curve may not be beneficial for future use. Over the last half of the quarter, the excimer laser has been steadily losing power. It's consistency in power and functioning was not ideal for this experiment. After the laser is fixed, more experiments will have to be run in order verify the characterization of this TOK resist.

C. Contact Lithography with variable gap spacing

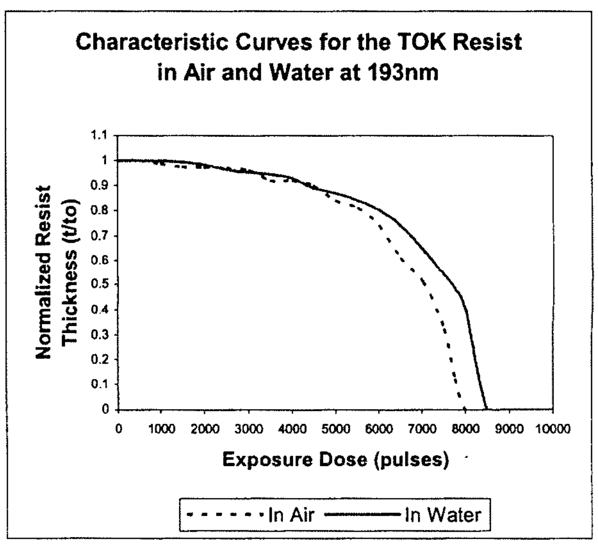

Figure 5: Characteristic curve for the TOK photoresist in air and in water.

It was desired to image line/space patterns for various gaps between the mask and substrate for both air and water. This was to study the effect of linewidth control and resolution as a function of this distance, and to see the effects of moving from the Fresnel diffraction region into the fraunhofer diffraction region. The goal was to

image first with the mask in direct contact with the substrate to try and achieve imaging in the Fresnel region. This was to be done both with and without water in between the mask and substrate. To then move into the fraunhofer region, this gap was varied by the use of transparency sheets (~50um thick). It was desired to do imaging for 1,2, and 3 transparency sheets gap spacing for both air and water as the indexing medium. However, as mentioned earlier, due to the lack of a consistently stable laser source, this was not able to be completed.

Only one SEM picture was able to be attained from the various attempts at imaging with the diffraction grating. A line/space pattern was generated with the quartz diffraction grating from exposure through water with a gap spacing of one transparency sheet. The lines produced are around 124 microns. This can be seen in Figure 6.

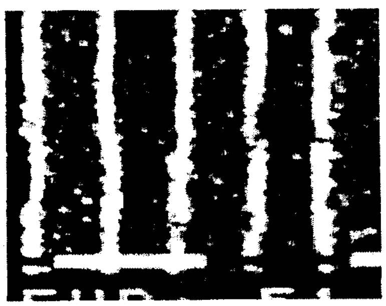

Figure 6: SEM picture of 124-micron lines

The poor resolution could be attributed to a number of things. First of all, this is a very crude optical setup. More imaging and tweaking of the system needs to be done in order to try and maximize resolution. Second, the light beams that were interfered at the resist surface may not have been mutually coherent. Coherent beams at the correct angle of interference are needed to produce images of the expected size and resolution. Theoretically, the lines should be on the order of $\lambda/4$, or about 50nm. However, if there isn't the correct interference, then the line size can change from the expected, as it did here. One other possibility for the poor resolution could have to with microbubbles as mentioned in the introduction.

III. DISCUSSION AND CONCLUSIONS

An optical system utilizing a 193nm ArF laser source has been developed and researched to produce small line/space features using a combination of various lithography techniques. By using a phase-shift mask (600nm pitch quartz diffraction grating), contact lithography, and immersion lithography together in one system, the ability to produce very small features with good resolution becomes available.

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IV. APPENDIX

A. Substrate Preparation and Processing

The substrates used were bare 4" silicon wafers. Resist processing was conducted on the SVG88 wafertrac in photolithography I of the SMFL cleanroom. The wafers were vapor primed with HMDS, to promote adhesion, at 140°C for 60 seconds and then cooled to 25°C. A TOK TL307 193nm photoresist was dispensed and coated at 4500RPM to a thickness of about 1600 Angstroms. The wafers were then soft baked at 90°C for 60 seconds. After exposure, the wafers were developed in CD26 for 30 seconds and then rinsed in the bath for three minutes. After develop, a post-exposure bake, PEB, was done at 115°C for 90 seconds. The wafers were then coated and gold for image retrieval in the scanning electron microscope (Philips 525 SEM).

B. Phase-Shift Diffraction Grating

A diffraction grating is a repetitive array of diffracting elements that have the effect of producing periodic alterations in phase and amplitude. When the diffraction grating is illuminated with the laser source a series of intensity spots are generated called diffraction orders. The intensity of each successive diffraction order is dependent upon the level of interference between individual wave fronts that pass through each of the diffraction grating slits.

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III. ACKNOWLEDGMENTS

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Bryan P. Watson, originally from Sarasota, FL, received a B.S. in Microelectronic Engineering from the Rochester Institute of Technology in 2003. He has obtained co-op experience at the University of Rochester Laboratory for Laser Energetics doing research for NASA. Upon graduation, he will be commissioned as an Ensign in the United States Navy and will report to Nuclear Power School in Charleston, SC this summer.