Three Dimensional Nanochannel Formation by Reflective Interference Lithography

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Abstract—**An imaging technique using TM polarized illumination at 45 degree incidence to a highly reflective surface has been demonstrated possible. The imaging technique was able to produce a single row of over exposed nanochannels. Further experimentation will be required to develop a stable process where multiple rows of channels can be formed. Once the optimal process is determine, experimentation can be designed to create either or both photonic crystal structures and a pitch doubling technique.**

Index Terms— **lithography, immersion, interferometry, transverse-electric, transverse-magnetic**

I. Introduction

In an effort to enhance lithography as hyper-NA with oblique angle imaging is approached, a novel method of imaging is investigated and tested. The imaging technique employs two -beam interferometry immersion lithography. The imaging makes use of a frequency doubling phenomena when transverse-magnetic (TM) polarized 193nm wavelength irradiation illuminates a photo-sensitive polymer (photoresist) over a highly reflective substrate at a specific interference angle. As the two beams of the interferoetry system interfere at 45 degree incidence or 90 degrees to each other the intensity of the interference drops to zero. Although no intensity remains from the interference, the beams are able to reflect off the substrate. The reflected beam leaves the surface on a parallel trajectory to the other incoming beam. This causes an interference pattern with the reflected beam along the 45 degree trajectory. The resulting reflected interference creates a standing wave pattern along the 45 degree diagonal, where the node and anti-nodes are both intensity maximums, resulting in a frequency doubled pattern of channels transverse to the substrates surface.

II. Theory

Highly temporal coherent illumination source, as used in 193nm lithography, create a standing wave effect from interference between incoming and reflected beams. Most lithography applications require the suppression of reflected beams to reduce this standing wave effect. As will be seen in later sections, imaging conditions will be chosen such that the standing wave pattern created will be along a 45 degree diagonal, which will result in a frequency doubling of intensity maximums.

Lithography use interference from a diffracted pattern of irradiation to create an image in photoresist. As incident angles of interference increases the intensity of the interfering beams begins to decrease. This decrease of intensity is a result of the interference of the magnetic field component of irradiation. The intensity of illumination for polarized illumination is defined as;

$$I_{TE} \propto 2|E|^2[1+\cos(2kx\sin\theta)] \tag{1}$$

For transverse electric (TE) polarization

$$I_{TM} \propto 2|E|^2[1+\cos(2kx\sin\theta)\cos(2\theta)] \tag{2}$$

For transverse magnetic (TM) polarization

The contrast of the formed image is defined as;

$$C = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \tag{3}$$

For TE polarization the image contrast is always 1, which is why it is often used to enhance contrast in hyper-NA lithography.

$$C_{TE} = 1 \tag{4}$$

While for TM polarization the contrast has an incident angle dependence define as

$$C_{TM} = \cos(2\theta) \tag{5}$$

As the angle of incident light approaches 45 degrees, the contrast is decreasing until it falls to zero at 45 degrees and then becomes negative at angles above 45 degrees. At 45 degrees there can be no interference of TM polarized

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illumination.

Using TM polarized illumination at 45 degree incident angles should result in no imaging. If this illumination is combined with a highly reflective substrate, the reflected illumination leaves the surface parallel to the incoming illumination as seen in Figure 1. This creates a standing wave pattern. Since the incoming and outgoing waves are at 45 degree incident angles, the standing wave pattern created is on the 45 degree diagonal. Combined with the two beam fringe effect across the substrate's surface, the resulting intensity pattern in the vertical direction is an alternating stack of intensity maximums and minimums. The simulation tool ILSim[4] was employed to create this intensity simulation in Figure 2. The simulation uses 193nm illumination, water immersion lithography at 1.2NA, JSR ARX2829 JN-09 photoresist on a silicon substrate.

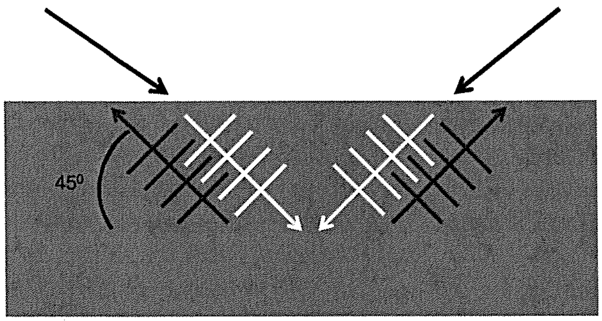


Figure 1. An illustration of the required illumination. The incoming beams are TM polarized

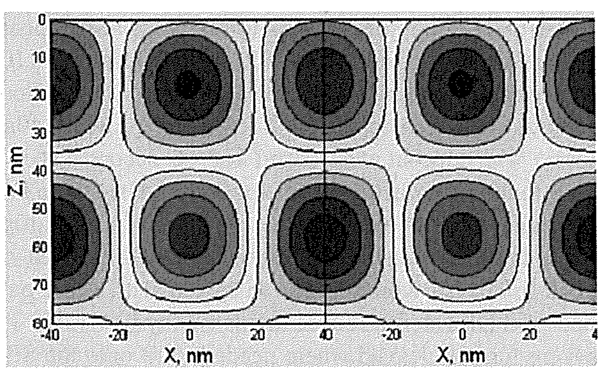


Figure 2. An exposure intensity simulation using ILSim.

Figure 3 is the intensity simulation of figure 2 with a threshold filter applied. The threshold filter would be equitant to the photoresist detector. This is the ideal illustration of the resulting nanochannels that should be created. In order to produce a frequency doubling, 20nm channels need to be created in the resist.

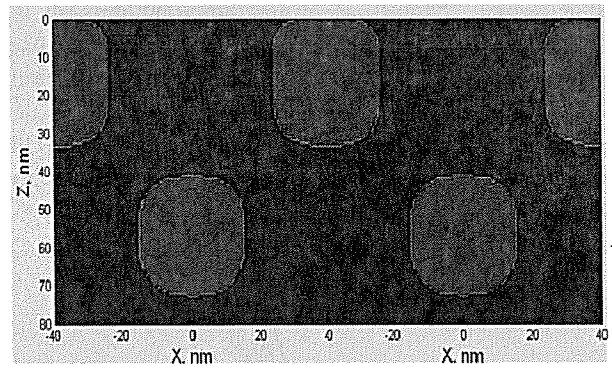


Figure 3. The intensity simulation with a threshold filter applied to show the resulting channels in resist.

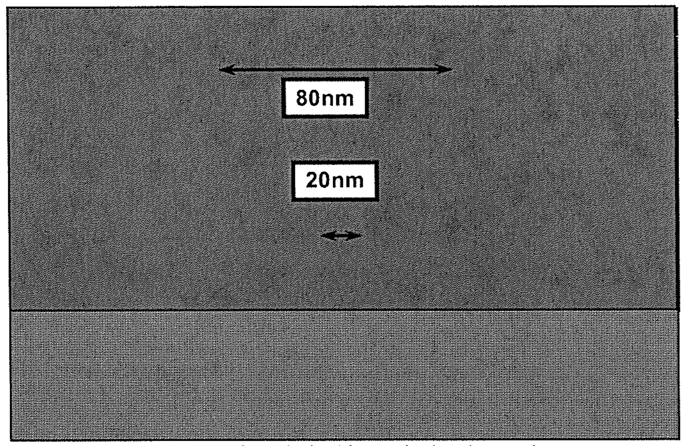


Figure 4. An illustration of the desired image in the photoresist.

III. PROCEDURE

To create the nanochannels, a 193nm immersion lithography microstepper research tool by Amphibian Technologies [3] is used. The tool employs a 193nm coherent ArF eximer laser, chromeless phase-shift mask and a Smith Talbot prism setup to allow for NA up to 1.65 with advanced immersion fluids. For this experiment the incident angle of the beams must be at 45 degrees in the resist. The NA is defined as;

$$NA = n \sin(\theta) \tag{6}$$

Where n is the index of refraction of the media. In this case there need to be a 45 degree angle of incidence in the photoresist. The JSR ARX2928 JN-09 has a complex index of refraction of 1.6895-0.041i. The required NA for this experiment can be calculated as

$$NA = 1.6895 \sin(45^0) \tag{7}$$
$$NA = 1.1947$$

With the prisms available a 1.2NA prism was chosen to carry out the experiments.

The Amphibian XIS uses a chromeless phase-shift mask to act as a beam splitter, creating ideal only a +1st and -1st

diffraction orders. These orders are then sent through the Smith Talbot prism. The Smith Talbot prism's design uses total internal reflection (TIR) off angled faces to recombine the diffraction orders. The unique design of the prism is such that translation alignment need not be perfect, as the diffraction order always travel the same distance before recombining.

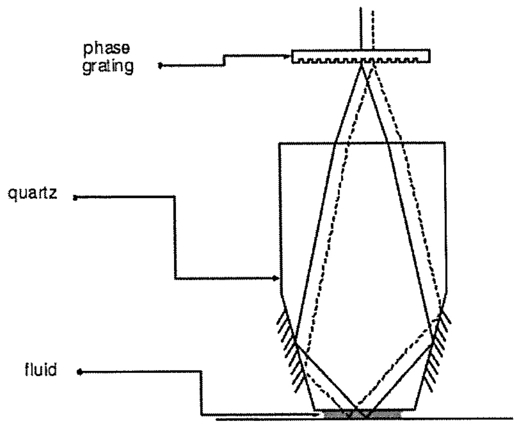


Figure 5.The smith Talbot prism from the Amphibian XIS [3]

From the simulations, it was desired to create two layers of channel in the photoresist. The photoresist needed to be 80nm to accomplish this. At 193nm the silicon substrate had sufficiently large reflectivity to use it as the reflective surface beneath the photoresist, eliminating the need for additional processing.

Most immersion systems also employ a topcoat for protecting the lens from contamination caused by resist leaching. This experiment would also use a topcoat for protecting the prism. The topcoat should also be able to provide additional advantages. Photoresist is easily contaminated be amines and bases in the air. This neutralizes the top of the exposed regions and creates a condition called t-topping. A topcoat will eliminate the possibility of t-topping. Topcoats come in a multitude of varieties. For this experiment a developer insoluble topcoat was chosen to help maintain the top surface from collapsing. TOK TSP-3A was selected for the topcoat.

The substrate with photoresist and topcoat are then exposed on the Amphibian system. A post exposure bake is required to chemically amplify the photoresist. Since the channels in the photoresist are completely contained, the substrates need to be cleaved prior to development to expose the channels from the side. A standard Tetramethylammonium Hydroxide (TMAH) developer is used. Rohm and Haas CD-26 developer was selected.

After development the substrates can be baked if desired to harden the photoresist by causing cross-linking of the polymer chains. Hardbakes are often desirable in preventing samples from charging in scanning electron microscopes (SEM).

The samples are then prepared for mounting and SEM imaging. Cross-sections which have been coated with gold are investigated to see the formation of the channels.

IV. Results and Discussion

Prior to beginning any experimentation on the proposed imaging technique, the Amphibian XIS had just been upgraded to provide better vibration isolation. Baseline wafers were run to prove the tool could operate at 1.2NA in a TE polarized state, with substrates prepared to suppress all standing waves. The upgrade to the tool performed exceptionally well.

Initial experiments were performed to create a reliable process for uniformly coating the photoresist. Using spin-speed curves from previous experiments on this photoresist, 2000RPM spin speeds were used as the starting point. 5 wafers were coated from 1900-2100RPM in steps of 50RPM to determine a process window for coating. The substrates were measured on a variable angle spectroscopic ellipsometer (VASE, by J. A. Woollam Co., Inc. U.S.A). The VASE revealed previous experiments were still accurate and 2000RPM was the optimal spin-speed. To measure across-wafer uniformity, the Cauchy coefficients of the photoresist were determined to be used in the Tencor SpectraMap. Two SpectraMap tools were available, so both tools were setup with identical recipes to determine which was best calibrated to the VASE. After many attempts to tweak the recipes on the SpectraMap, the tool was not able to accurately measure the thin layer of photoresist. The VASE measurements were used for the remainder of the experiment.

The first run of experiments consisted of two wafers with 80nm of ARX2928 photoresist and 40nm of TSP-3A topcoat. The photoresist was coated at 2000RPM and baked at 110C for 90 seconds according to the manufacturer's instructions. The topcoat was coated at 4000RPM to provide 40nm thickness. The topcoat was baked for 60 seconds at 90C according to the manufacturer's instructions. They were both exposed using a dose meander recipe to provide multiple doses on a single exposure pass. The wafers were cleaved and developed in CD-26 which had been mixed with equal parts developer and DI water to reduce the normality to 0.13N. The pieces were further cleaved where needed to fit onto the SEM mounts, and then coated for 6 seconds in a gold desktop sputter system.

The samples were loaded into the ARAY 1830 SEM. The SEM images for all the samples (6 fields) all showed signs of edge cleave problems. The samples clearly showed what appeared to be a tearing of the topcoat, rather than a clean break. This tearing left the entire edge of the photoresist with defects many microns in size. This completely covered and/or destroyed any channels that would have formed.

A second set of experiment were design to eliminate the topcoat problem. It was decided to run the experiment without the topcoat. The problems with running without a topcoat is the possibility of the developer creating pattern collapse if any of the top most portion of the resist is

developed away. To prevent pattern collapse it was necessary to take advantage of the t-topping phenomena of the resist to neutralize some of the top of the resist creating a capping layer on the top of the photoresist. The other concern was the possibility of photoresist leaching contaminating the lens. The risk was acceptable, and the prism would be monitored after every exposure. All other parameters were held constant as the first experiment. There was a fluctuation in the gold sputter tool, it was left at a high current setting, which may have caused an over deposition of gold

Upon inspection in the AMRAY SEM there was no longer a significant amount of debris and damage to the edge of the samples. A bigger issue however unfolded. THE AMRAY 1830 was not designed to image 20nm features and was at the time using a tungsten filament. The University of Rochester Optics and Biomedical program was kind enough to donate some time on their field emission Carl Zeiss. There SEM was able to produce great high resolution images of the samples. With the Zeiss SEM it quickly became apparent that the samples had too much gold deposited on them. One good sample was discovered. Figure 6 is the first and only image that showed signs of nanochannels. The image shows channels which are approximately 30nm in width, which is overexposed for the intended dimension. Only one layer of channels is seen. The photoresist may have been left to t-top too long.

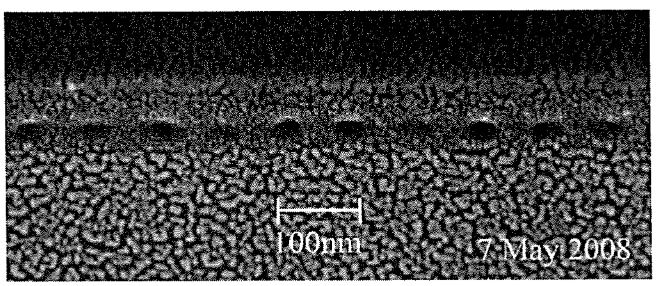


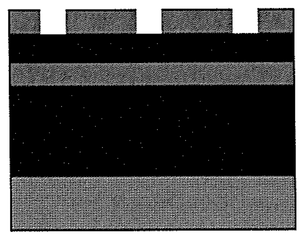
Figure 6. Results from the second experimental run

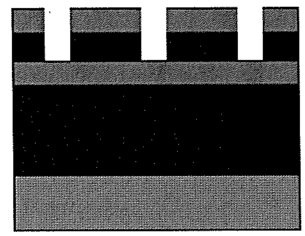
In order to reproduce these result, a third set of identically processed wafers were run to attempt to get better images with a properly applied gold coating. In order to get a finer gain size, the samples were coated with a gold alloy at the University of Rochester. None of the samples for the third experiment showed any signs of channels forming. All the samples appeared unexposed. Due to time constraints another set of samples could not be processed.

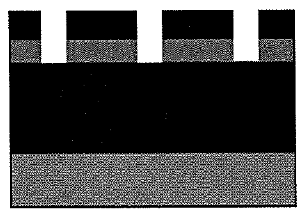
V. Future Work

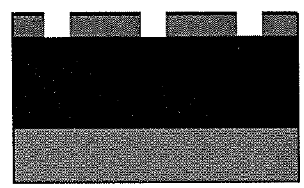
There are two potential applications for this imaging technique. The first application is in the production of interference bandgap photonic crystals. Photonic crystals are used to alter the path of light. They contain repetitive patterns of two different dielectrics with high and low dielectric constants, where certain wavelengths are able to pass through the dielectrics. The application of this imaging technique would require a photosensitive dielectric capable of changing dielectric constant upon exposure. This method of photonic crystal creation is much simpler than the method of beam splitting and recombining currently practiced.

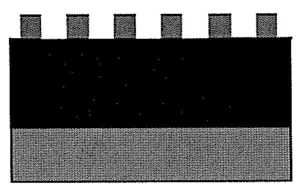
The second application of this imaging technique is as a single lithography method for pitch doubling. A novel method of pattern transfer has already been theorized. The process adapted from Dr. Bruce Smith of Rochester Institute of Technology is shown below. Two photoresist layers are alternately layered with a dielectric that has a matched complex index of refraction with the photoresist to minimize reflection between the layers. The process results in a single pass lithography pitched doubled image. At the parameters used in modern lithography and this experiment, 193nm water immersion lithography with 1.2 NA can produce 20nm half-pitch features.

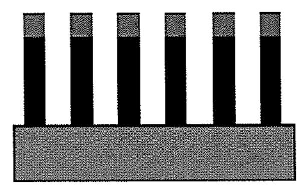

1) Develop Image in photoresist layer #1


2) Fluorine based reactive ion etch (RIE) into dielectric layer #1


3) O2 based RIE into photoresist layer #2, Stripping photoresist layer #1


4) Strip dielectric layer #2


5) Develop image in photoresist layer #2


6) Transfer pattern into dielectric layer #2

VI. Conclusions

An imaging technique using TM polarized illumination at 45 degree incidence to a highly reflective surface has been demonstrated possible at the Rochester Institute of Technology. The imaging technique was able to produce a single row of nanochannels. Further experimentation will require the development of a stable process where multiple rows of channels can be formed. Once the optimal process is determined, experimentation can be designed to create either or both photonic crystal structure and a pitch doubling technique as described.

Experimentation into developing a process for creating a pitch doubling technique would have major benefits to the semiconductor industry. The current generation of immersion lithography systems can be extended down to 20nm half-pitch.

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