

FABRICATION OF CHROMELESS PHASE-SHIFTING MASK USING SPIN ON GLASS

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ABSTRACT

This project investigated the concept of a chromeless phase-shifting mask. An optical simulator, SPLAT, was used to predict the aerial image formed for various chromeless phase-shifting patterns. Allied Signal 311 spin on glass was patterned on a quartz plate and imaged using a GCA MANN4800, 10X, NA=0.28, G-line stepper to demonstrate the concept. Simulations showed and experimental results confirmed that a dark field could be produced with checkerboard patterns below $0.4\lambda/NA$. Using 25% solid KT1820 resist coated at a thickness of 5000Å, 0.6µm lines and spaces were resolved.

INTRODUCTION

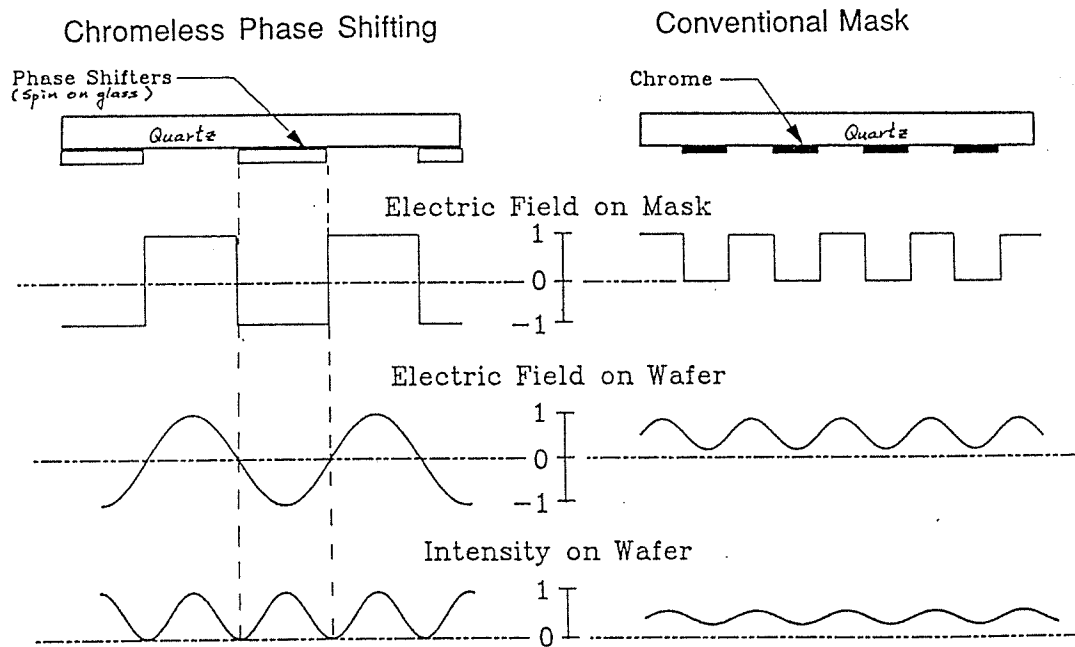
With the ever increasing demands for smaller feature sizes in the microelectronic industry, it has become necessary to employ either complicated multilayer resist schemes and/or utilize costly exposure tools to extend the limits of practical resolution in optical pattern transfer. Traditionally, the resolution of an imaging system can be improved either by moving to a higher numerical aperture lens, using exposure source with shorter wavelength, or switching to a high contrast or multi-layer resist system. All of these methods have their own inherent problems such as loss of depth of focus or increase of processing complexity. An alternative to these techniques is the use of a phase shifting mask.

Over the past few years, several different phase-shifting mask techniques have been proposed for improving resolution in optical lithography [1-5]. Studies have shown that the image projected by an optical stepper can be improved by incorporating transparent phase-shifting patterns on a conventional chrome mask. The light passing through the phase-shift layer will be delayed so that it is 180° out of phase with

the light through the clear area on the mask. Consequently, the resultant destructive interference of the light reduces light diffraction effects, thus increasing the contrast of the projected image. This in turn improves the resolution of the optical projection tool. However, this phase shifting technique requires aligning the phase-shift layer to the chrome layer on the mask. This creates engineering difficulties as the present commercially available mask-patterning tools are not able to align layers on masks. An alternative is to make a chromeless phase-shifting mask which only involves patterning the 180 degree phase shifter on a clear quartz mask plate. This project was an investigation of using spin on glass to fabricate a chromeless phase-shifting mask.

Pattern imaging using chromeless phase-shifting masks is slightly different from conventional chrome mask techniques. For the chromeless phase-shifting mask, aerial images are defined by the destructive interference of light passing through the clear quartz areas and the phase-shifting areas. This destructive interference occurs at the edge of the phase shifter. As a result, the null electric field region, and therefore, the null intensity region are created at the phase shifter edge as shown in Figure 1. Additionally, enhanced optical contrast of the projected image is achieved with a chromeless phase-shifting mask when compared to the conventional chrome mask. Also note the frequency of lines and spaces formed on the wafer will be double that on the mask. Small gratings, like

Figure 1: Comparison of Chromeless Phase-shifting Mask and Conventional Mask [6].



checkerboards and/or line/space pairs, can be used to form opaque areas on the wafer, since small enough gratings can cause sufficient destructive interference to completely inhibit the transmission of light.

In order to optimize the performance of a chromeless phase-shifting mask, it is essential to control the thickness of the phase-shifters and their slope profiles so that destructive interference occurs at the phase-shifter edges. The thickness d of the phase-shifter that results in a 180° phase shift is given by Equation (1):

$$d = \text{Lambda}/[2(n-1)] \dots\dots\dots(1)$$

where n is the index of refraction of the phase-shifter, and Lambda is the wavelength of the exposure tool.

EXPERIMENT

The mask was designed using ICE, an in-house circuit design tool. The design consisted of line/space patterns from 0.5um to 2.0um, dark field grating checkerboard patterns, and contact cut patterns from $0.2\text{Lambda}/\text{NA}$ to $1.8\text{Lambda}/\text{NA}$. Large isolated phase-shifter lines from $1.0\text{Lambda}/\text{NA}$ to $6.5\text{Lambda}/\text{NA}$ were also designed to compare the resulting line/space/line pattern with respect to the design.

A MANN 3000 Pattern Generator was used to expose a 5" x 5" emulsion reticle which was later used to pattern the phase shifter. Two coatings of Allied Signal 311 spin on glass were applied to a clear quartz plate to obtain a thickness of 5600A. The spin on glass was applied and cured by the following procedures:

- i) Spin on glass was spin coated on a quartz plate at 3000rpm for 20 seconds.
- ii) The quartz plate was then baked on a hot plate at 250°C for 1 minute.
- iii) A second coating of spin on glass was applied at 3000rpm for 20 seconds.
- iv) The film was stabilized in a convection oven at 140°C for 10 minutes.
- v) The final cure of the film was done on a hot plate at 350°C for 10 minutes in nitrogen.

The mask was coated with approximately 1.2um KT1820 positive photoresist, followed by a 20min / 90°C convection oven prebake. It was then exposed at $62 \text{ mJ}/\text{cm}^2$ on a GCA MANN4800 10x $\text{NA}=0.28$ G-line stepper. The focus was optimized at 235. Following exposure, the mask received a 80 second development in KT1934 developer diluted 1:1 with D.I. water. The quartz plate was then hard baked in a convection oven at 140°C for 20 minutes. The spin on glass was etched in buffered HF diluted

10:1 with D.I. water for 7 minutes. The resist was then stripped by soaking the plate in acetone.

Five silicon wafers were spin coated at 5000rpm for 30 seconds with KT1820 positive photoresist (25% solid, diluted with KT1920 thinner) to obtain a thickness of approximately 5000Å. The wafers were baked for 100 seconds at 90°C on a hot plate prior to exposure. The wafers were exposed on a GCA MANN4800 10x NA=0.28 G-line stepper, using an exposure dose of 34mJ/cm² and a focus setting of 250. The wafers were developed in KT1934 developer diluted 3:2 with D.I. water until clear.

RESULTS/DISCUSSION

The wafers were evaluated using scanning electron microscopy (SEM). Dark field was achieved by using checkerboard or lines and spaces gratings below 0.4 λ /NA (0.6 μ m) on the mask as shown in Figure 2. When the checkerboard size was increased from 0.4 λ /NA (0.6 μ m) to 0.6 λ /NA (0.9 μ m), the dark field started to degrade. These agree well with the predictions made by the optical simulator, SPLAT.

Images of 0.6 μ m lines and spaces were resolved by using the chromeless phase-shifting mask as shown in Figure 3. These images corresponded to 12 μ m lines and spaces on the mask (10X stepper). Therefore, line/space periodic arrays on the mask formed double-frequency line/space images on the wafer. Narrow lines were printed at locations corresponding to the edge of the phase shifter as indicated by the arrows in Figure 3.

One of the problems observed was for line and space patterns on the mask. The resolved images were line pairs joined together at the end of the lines as indicated by the arrow in Figure 4. In order to eliminate this undesirable effect, 90° phase shifters should be placed at the end of each line on the mask. Another problem concerned with using chromeless phase-shifting mask was the fact that checkerboard or line/space gratings were used as substitutes for the chrome regions on a conventional chrome mask. This would tax even the most sophisticated mask-making tools as a large number of boxes would be required to generate dark field regions on the mask.

Figure 2: Comparison of SPLAT Simulations with Experimental Results for Checkerboard Patterns.

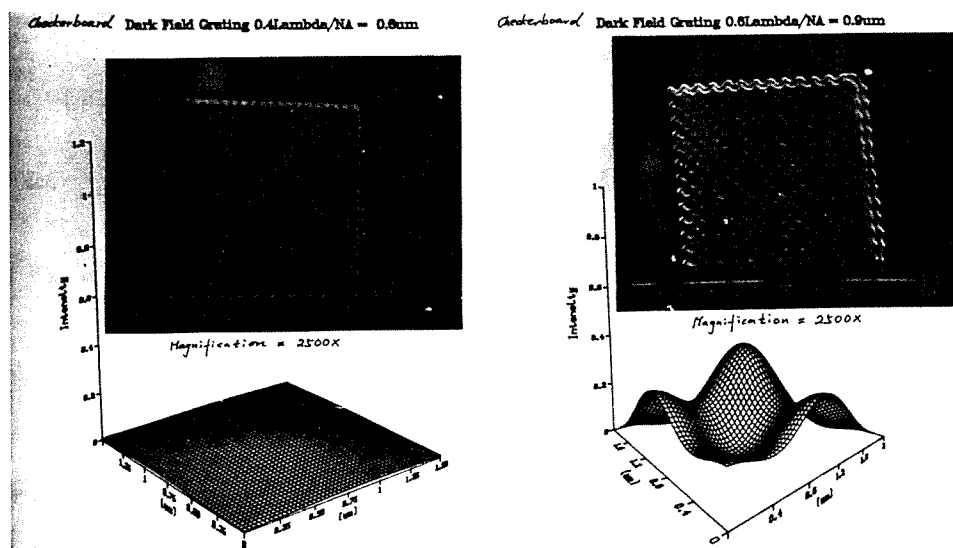


Figure 3: Wafer SEM: 1.2um Phase-shifter Lines and Spaces.

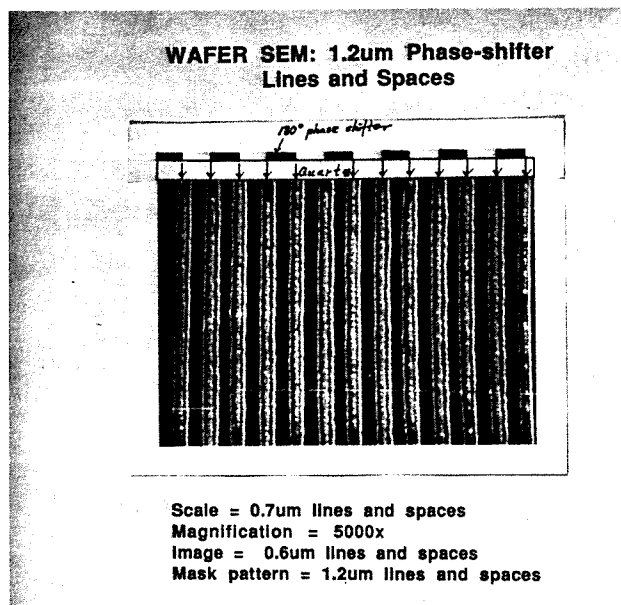
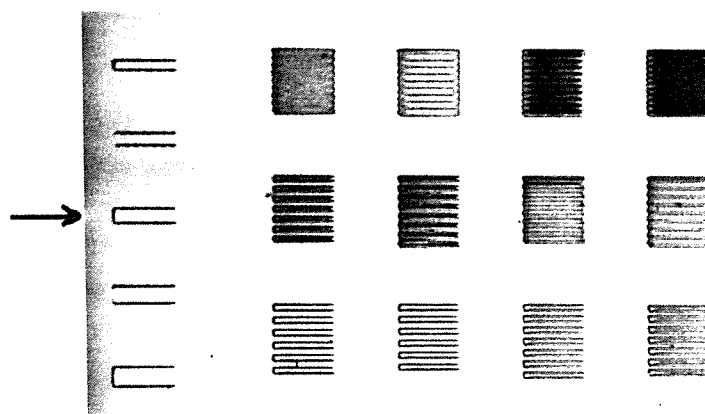


Figure 4: Images of Lines and Spaces Test Patterns from 0.3Lambda/NA to 1.3Lambda/NA.



CONCLUSIONS

The chromeless phase-shifting mask was successfully demonstrated as a method for improving resolution in projection optical lithography. From the SEM images, it was observed that $(0.4\lambda/NA)$ 0.6 μ m lines and spaces were resolved. Grating sizes required to create dark field regions were determined. Evidence is given that the creation of line/space pairs will require the addition of 90° phase-shifters to the mask. In general, this scheme does seem promising as it simplified the fabrication process of a phase-shifting mask.

Improvements in this process will be necessary prior to it being practically implemented into today's production technology. Further research should be focused on improving the uniformity of spin on glass coating and establishing a dry etching process of spin on glass to improve the slope of the phase-shifters. The use of a chromeless phase-shifting mask is a relatively inexpensive method to extend the lifetime of current exposure tools into tomorrow's technology. It improves the resolution of an optical projection tool without sacrificing the depth of focus associated with using a higher numerical aperture lens and/or using shorter exposure wavelength.

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REFERENCES

- [1] M.D. Levenson, N.S. Viswanathan, R.A. Simpson, IEEE Trans. on Elec. Dev., ED-29, (12), 1812-1846 (1982).
- [2] I. Hanyu, S. Asai, K. Kosemura, H. Ito, M. Nunokawa, M. Abe, Proceedings of SPIE: Optical/Laser Microlitho. III, 1264, 167-177 (March 1990).
- [3] T. Terawawa, N. Hasegawa, T. Kurosaki, T. Tanaka, Proceedings of SPIE: Optical/Laser Microlitho. II, 1088, 25-33 (March 1989).
- [4] A. Nitayama, T. Sato, K. Hashimoto, F. Shigemitsu, M. Nakase, Proceedings of IEDM, 57-60 (December 1989).
- [5] K.K.H. Toh, K.G. Dao, R. Singh, H. Gaw, Chromeless Phase-Shifted Masks: A New Approach to Phase-Shifting Masks. Presented at the BACUS 10th Ann. Sym. on Microlitho. (September 1990).
- [6] Burn J. Lin, IBM Corp., Proceedings of SPIE: Short Course 11, 108A (April, 1991).