INCREASING THE PRACTICAL RESOLUTION OF PROJECTION LITHOGRAPHY USING A PHASE-SHIFTING MASK.

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ABSTRACT

A phase shifting mask, to be used for the purpose of improving the resolution of a projection lithography system, was fabricated. This type of mask consists of line-space pairs in which every other aperture induces a 180 degree phase shift in the transmitted radiation. In order to obtain this phase shift there must be a thickness difference between the apertures. Etching of the glass mask plate in 3:100 HF to DI water was used to obtain the required etch depth.

INTRODUCTION

Improving the practical resolution of optical projection lithography has been a consistent goal of the semiconductor industry. Practical resolution is defined as the minimum feature size obtainable with a depth of focus (DOF) required for VLSI fabrication processes [1]. Typical techniques used for achieving this goal consist of increasing the numerical aperture of lenses, decreasing the exposure wavelength, and advanced resist process schemes (such as multi-layer structures, silylation, and portable conformable masks). However, these approaches require additional modifications of the projection system or wafer processes.

One approach for improving the resolution which does not require these modifications is through the use of a phase-shifting mask. This type of mask reduces the diffraction effects associated with a standard transmission mask which ultimately determine the practical resolution of a projection system. The phase-shifting technique essentially overcomes these limitations by creating destructive interference between the fields diffracted by adjacent apertures with opposite optical phases [2],[3]. Thus, this technique is very effective in printing line-space pair patterns. Holes and isolated lines can also be printed as described in reference [4].

An optical phase difference between two rays of light is achieved by having an optical path difference. Thus, in order to achieve an optical phase difference between two apertures on a mask, material must either be deposited or removed from one of the apertures. The techniques used in industrial research typically consists of selectively depositing an SiO2 material at a specific thickness onto the mask [3]. However, for this project it was decided to take an etching approach mainly because of the difficulties which would have been encountered with applying and curing a phase-shifter material, such as spin on glass, (SOG) on a 5" X 5" chrome plate.

In order to obtain destructive interference between the adjacent apertures, a 180 phase shift is required. The required etch depth to produce this difference was found using Equation (1) [2],[3];

$$\text{Etch Depth} = \text{Lambda} / 2 \times (n-1) \qquad (1)$$

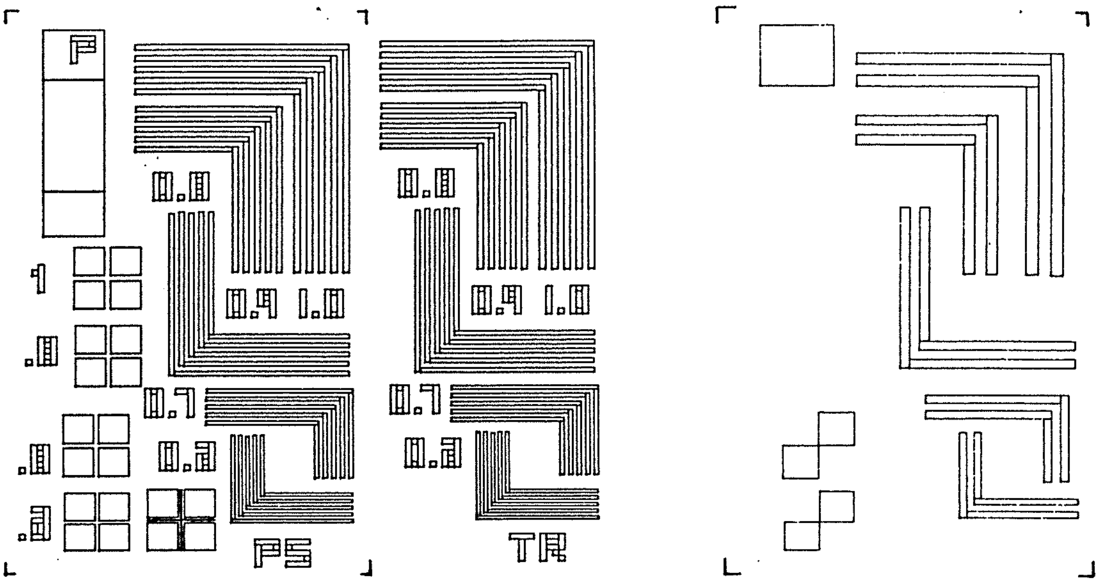
where lambda is the wavelength of the exposure radiation and n is the refractive index of the material being etched. Thus, using 436 nm(g-line) for the wavelength and 1.528 (White Crown glass) for the refractive index, an etch depth of 4126 Angstroms is required for a 180 degree phase shift.

EXPERIMENT

Since the phase shifting technique is ideal for improving the resolution of fine periodic patterns, the mask design consisted mainly of line-space pairs. An illustration of this mask design is given in Figure 1. These patterns ranged from 10.0 microns down to 6.0 microns in increments of 1.0 microns on the mask. Thus, when patterns are imaged onto a resist coated wafer they will range from 1.0 microns to 0.6 microns since the GCA MANN 4800 stepper is a 10X reduction tool (Note: Keep this point in mind during the following description of the mask feature sizes). These dimensions were considered adequate enough to test the improvement capabilities of the technique since the resolution limit of a standard transmission mask being used on the GCA MANN 4800 stepper is approximately 0.95 microns (using Rayliegh's Equation and assuming a k factor of 0.6).

The affect of phase shifting on isolated lines as well as line-space pairs was also considered during the design of the mask. This was accomplished by having a 100um x 100um box split into quarters and then spacing each section a specific distance apart. These distances, which corresponded to the width of the isolated line, ranged from 10.0 microns down to 6.0 microns.

In order to ensure that any improvement in resolution was induced by the phase shifting technique and not to variations in the resist application process or oxide thicknesses, the transmission and phase shifting patterns were placed on the same mask rather than having two separate ones. As can be seen from Figure 1, the line-space pair patterns of the transmission level (first level) are identical.



(a) Transmission Level (b) Phase-Shift Level

Figure 1: Mask levels

The phase shifting regions were defined on the second masking level. As described in the Introduction, every other aperture has a 180 degree shift. This level was designed to have an alignment tolerance with the first level equal to one half of the smallest geometry. Since the smallest geometry was equal to 6.0 microns, the alignment tolerance equal to 3.0 microns.

The two additional structures on the mask are used for alignment and measurement purposes. The alignment structure had to be designed so that it would be compatible with with the GCA alignment target. Note that an alignment structure was not placed on the second level. This is because the GCA aligns all subsequent levels to the first one. The measurement structure was designed so that it could be used to measure the etch depth on the Alpha Step Profilometer. Thus, it had to be approximately 100.0 microns wide and 400.0 microns long.

The first step in fabricating the mask consisted of laying the design out on ICE, an in-house circuit design editor,0 in a 1000um x 1000um area. Once this was complete MANN files were made so that 5" X 5" emulsion reticle could be exposed on the MANN 2000 Pattern Generator. Note that when a MANN file is created, it compensates for the 10X reduction of the emulsion reticle by making the pattern dimensions ten times bigger than the ICE dimensions. Thus, the ICE design and the final chrome mask will have the same dimensions. After the emulsion reticles were exposed, their images were developed using the RIT image reversal process so that the patterns which were exposed on the emulsion reticle would be transparent.

The EMC 5" X 5" chrome masks were patterned with the emulsion reticles using the GCA stepper as a photorepeater. In order to use the stepper for this purpose, the mask plate holder built by Scott M. Bruck [5] was utilized. The stepper exposure program which was written for this project was ERIC PSM with a pass name of PS1. Note that before the actual mask was exposed, a standard focus exposure test was performed to determine the best exposure and focus settings.

The EMC chrome masks which were utilized were pre-coated with AZ-1350J positive photoresist, thus only a 30 minute pre-bake at 85 degrees (convection oven) was required before they were exposed. After they were exposed, they were developed in AZ Developer diluted 1:1 with DI water for 35 seconds, rinsed, and blown dry with N2. After the resist coated mask was exposed and developed, the chrome was etched in CYANTEK CR-4 Chromium Photomask Etchant until clear. The resist was then stripped by flood exposing and then developing until clear. Note, ashing was not used to strip the resist because it tended to remove the antireflective coating on the chrome.

A second photoresist coat was applied for imaging the second level. This process consisted of using the ERICHSEN large mask spinner to first apply HMDS and then Kodak KTI-820 positive photoresist. Both materials were applied with a dynamic dispense at 100 RPM and then ramped up to 1800 RPM for 40 seconds. Following the application the plate was pre-baked at 85 degrees C for 30 minutes in the convection oven.

Alignment of the second level required some modifications of the mask plate holder. The problem which was encountered during the alignment was that the alignment target was not in focus through the GCA alignment microscope. In order to correct for this problem, tape had to be applied to the bottom of the holder to shim the height of the mask plane.

Once the alignment focus problem was corrected, baseline correction and focus exposure procedures had to be executed to ensure that the pattern would be adequately imaged and aligned. Following the exposure of the second level the masks were developed in ZX-934 developer for one minute, rinsed, and blown dry with N2.

Before the glass was etched, resist was coated on the backside of the mask to prevent etching from occurring on both sides of the mask. The procedure for applying this protective coat was identical to that described earlier. It was decided that HF was to be used as the glass etchant, however, several etch rate tests had to be conducted in order to determine which dilution gave the best etch rate and uniformity. Upon completion of these tests it was determined that etching the plate in 3:100 HF to DI water for 4 minutes and 6 seconds would provide the necessary etch depth of 4126 Angstroms. Note, the etch depth was measured using the Alpha Step Profilometer. After the phase shifting regions were etched, the resist was removed using the flood expose technique described earlier.

RESULTS/DISCUSSION

Due to initial errors in the mask design (the first mask was ten times larger than it should have been) and difficulties encountered during the alignment of the second level, a mask was not completed. However, the critical etching step has been characterized. In 3:100 HF to DI Water the etch rate was experimentally determined to be 1005 Ang/min. Thus, a 4 minute and 6 second etch time is required to obtain the desired etch depth of 4126 Ang. This etch time provided a % nonuniformity of 7.6% over a 75mm x 75mm area on the mask.

CONCLUSIONS

Future realization of this project will require several improvements in the fabrication process. For instance, in order to achieve adequate alignment of the second level, the mask plate holder will have to be redesigned so that the alignment target is within the focal plane of the GCA alignment optics. The measurement structure can also be redesigned so that an in-situ determination of the etch depth can be made without the need for removing the photoresist mask first.

The approach of selectively depositing phase-shifting materials, such as spin on glass, onto the mask should also be investigated. This will require the use of a quartz mask plate rather than a glass mask plate in order to match the refractive index's of the two materials. By doing this, reflections at the interface will be reduced.

REFERENCES

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