Resolution Enhancement Techinques for Optical Lithography

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Abstract:

The increasing demands for smaller device structures have pushed Optical Lithography (OL) to its resolution limit. Several techniques have been developed to extend the use of optical lithography. Phase Shifting Lithography (PSL) and Immersion Lithography (IM) are two of these techniques.

The focus of this paper is to report the results of using PSL with a broadband UV light exposure and then coupling it with IM. This was done to produce features with a high aspect ratio and high resolution.

Introduction:

PSL has extended optical lithography by allowing the fabrication of sub-wavelength features without much modification of the OL process. The phase shifting is done by taking a regular chrome-on-quartz mask and reactive ion etching it to a pre-determined depth in certain regions. Next, the chrome is striped off, leaving a chromeless phase shifting mask. Then, the mask is exposed to broadband irradiation. Due to the fact that these adjacent regions have different depths, the transmitted light will undergo a phase shift. Normally, for monochromatic light, the relationship between the phase and etch depth is given by the Equation 1 [1].

$$\Theta = \frac{2\pi d(n-1)}{\lambda}$$

Equation 1: Determines the resultant phase shift

In this equation Θ is the phase, λ is the wavelength of the exposing light, *d* is the etch depth, and *n* is the index of refraction at this wavelength. Ideally it is desired to have a phase shift of 180º. This will allow the transmitted light from the etched and non-etched regions to form a dark field on the photoresist due to destructive interference.

Due to the fact that a broadband exposure was used, the exact shifter depth to produce the phase shift was not known. Therefore, four phase shifting masks, with different shifter depth gradients across each mask were used to determine which shifter depth produced the higher resolution features.

Recently IM has been accepted by the integrated circuit industry as a new technique that will extend the use of OL. The resolution (minimum feature size) is determined by the Raleigh equation listed in Equation 2 [2].

$$R = k_1 \frac{\lambda}{NA}$$

Equation 2: Determines resolution (min. feature size).

In this equation *R* is the resolution, λ represents the wavelength of the exposing light, k_1 is the resolution factor, and *NA* is the numerical aperture. IM focuses on increasing NA, which is proportional to the index of refraction of the medium between the wafer and the lens of the contact aligner. Traditionally the medium was air, which has an index of refraction of 1. In IM, the air is replaced with water, which has an index of refraction of 1.33. This allows for a higher NA and leads to a higher resolution.

The focus of this project was to use broadband irradiation with PSL to fabricate high aspect ratio sub 200 nm features. Then IM would be used to produce even higher resolution features. This project used bare silicon wafers, MF-CD-26 developer, four pre-fabricated phase shifting masks, and SPR 3012 photoresist. The exposure tool used was a Karl Suss MA-6 Contact Aligner with a broadband UV light exposure.

Experimental Procedure:

The experimental procedure can be divided into three parts: First, a lithography process was developed. This was done using a chrome-on-quartz mask. This process consisted of learning how to optimize different parameters using OL. The steps included application, exposure, and development of the photoresist. Figure 1 illustrates this process.

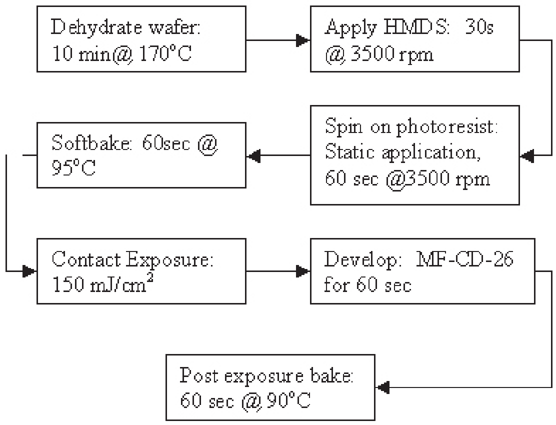

Figure 1: Optical lithography process.

The second part involved using four pre-fabricated chromeless phase-shifting-masks to produce sub-wavelength features. Each mask had a different shifter depth gradient. This gradient allowed for an investigation of which shifter depth produced the highest resolution features, while keeping all other parameters constant.

In the final step, the phase shifting process was coupled with immersion lithography to decrease the minimum feature size even further. This was done using the same phase shifting mask that produced the highest resolution feature, and placing a drop of water between the mask and the wafer.

Results and Conclusion:

After optimizing the parameters in the PSL process, a sub-200 nm feature was fabricated. Mask 3 produced the 193 nm feature at a shifter depth of 3820 Å. This is shown in Figure 2. The image was taken using a LEO 1530 Field-Emission Scanning Electron Microscope. This shows that a PSL can produce sub-wavelength features when broadband exposure is used.

The result of coupling IM with the PSL was not as successful. The first experiment was done with the same 150 mJ/cm^2 exposure dose used in the PSL, but that was too strong. As soon as the wafer was placed in the developer, all the features were developed away. The dose was then decreased to 72 mJ/cm^2. This produced features that had a lower resolution than the features produced using PSL. The result was not consistent with what was conjectured to be the outcome. Unfortunately, due to time constraints the goal to produce higher resolution features was not reached.

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References:

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[2] Y.Fan, N. Lafferty, A. Bourov, L. Zavyalova, B.W. Smith, "Study of Air Bubble Induced Light Scattering Effect On Image Quality in 193 nm Immersion Lithography", Proc. SPIE 5377, (2004).

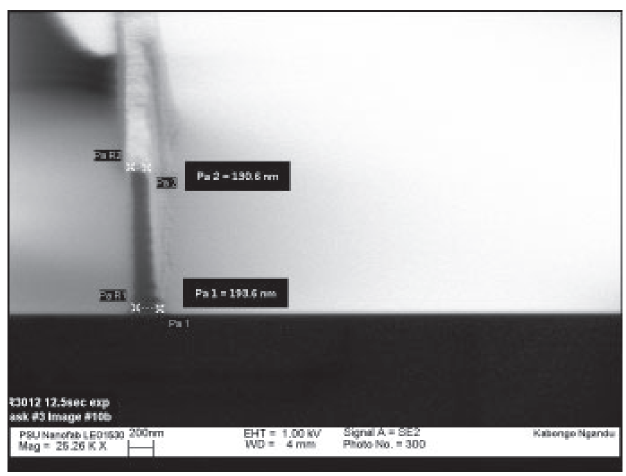

Figure 2: Resultant 193 nm feature using a broadband exposure and Phase Shifting Lithography.