The Relationship of Line Edge Roughness and Contrast by Deep UV Immersion Interferometric Lithography

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Abstract:

In today's microchip industry, focus has been shifted to immersion lithography due to water's 44% higher refractive index than air for deep UV, which allows for lens NA values greater than 1. This new technology has been allowing for the printing of smaller and smaller structures on silicon wafers. However, the problem of the roughness of these features is gaining importance at such small sizes. This experiment attempts to ascertain the relationship between the severity of line edge roughness (LER) and the reduction of contrast.

To accomplish this task, 150 mm silicon wafers were coated with a dual layer of ARC and an 80 nm layer of IRC1500 positive photoresist. These wafers, behind a film of de-ionized water, were exposed to varying amounts of two-beam interferometric light and one beam light generated by a 193 nm Excimer Laser (this variance produces differing contrast), which produced a 71 nm half-pitch. The exposed areas were cleaved from the wafers, gold plated to ~ 40Å, and viewed under a scanning electron microscope at 100 kX and 150 kX. The pictures taken from the SEM undergo a Fourier Transform which is analyzed to produce a value for the LER which can be plotted against the percent contrast used in the sample.

Introduction:

In order to allow for the proliferation of faster, cheaper and smaller microchips, the immerging problem of LER (line edge roughness) must be fully understood. Since the primary and insurmountable problem causing LER is a loss of contrast, this paper investigates the direct mathematical relationship between contrast and LER.

Procedure:

In order to create variable contrast, an interferometric setup was utilized (see Figure 1). This was achieved by splitting and recombining a 193 nm laser beam generated by an ArF Excimer Laser. The beam was split 50/50 with a fused silica beam splitter and then recombined through a window and a thin layer of water

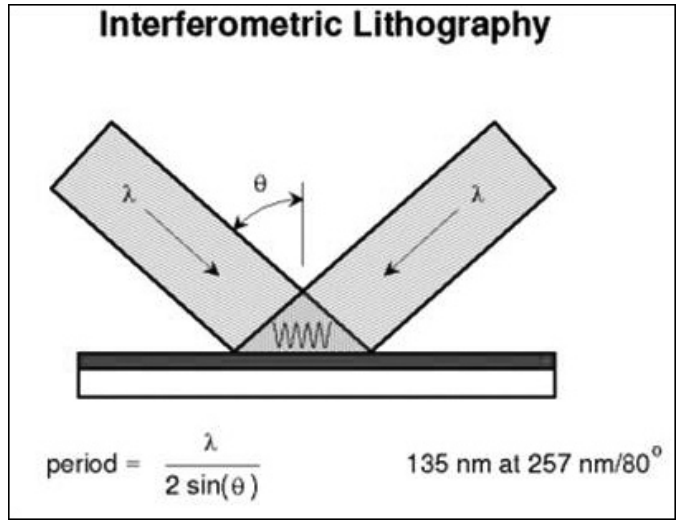

Figure 1: Diagram of interferometric lithography.

onto a silicon wafer coated with an 80 nm layer of IRC 1500 photoresist. Immersion was used to emulate immersion lithography conditions so that the effects of the interaction of water with the photoresist could be observed. Activating this set up with 120 laser pulses generated uniform lines approximately 65 nm thick and 65 nm apart with 100% contrast. To vary the contrast, a shutter was installed to block one of the split beams.

The one beam exposure had the effect of lowering the contrast of the two beam exposure by a factor of one fourth of the double beam pulses due to it having one fourth the intensity of an interferometric, two beam exposure. Since the power was kept constant in order to preserve a 1:1 ratio of line thickness to line spacing, the number of pulses was calculated according to [2-beam: (120-n) 1-beam: (4n)] and contrast calculated as [(total 2-beam pulses)/120] x 100.

Once exposures were generated with varying levels of contrast, the degree of roughness had to be quantitatively analyzed. To do this, exposures were first plated with approximately 40Å of gold and viewed under a scanning electron microscope at 100,000x and 150,000x (see Figure 2). At least eight pictures were taken of each exposure so that LER values could be averaged. In order to assign a quantitative value to

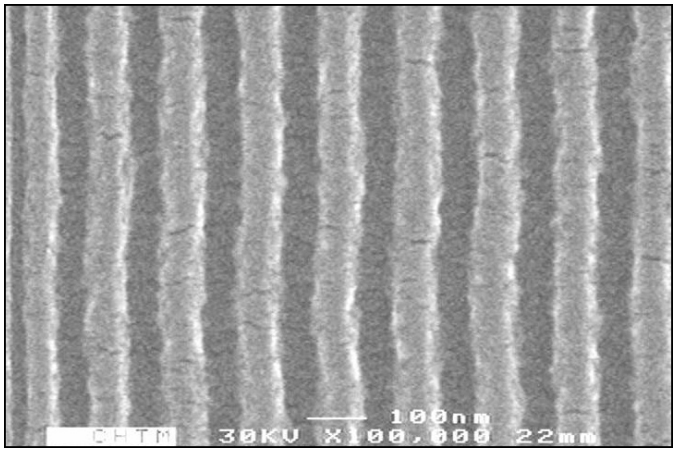

Figure 2: 100,000x SEM image of 70% contrast. Note horizontal gold cracks.

LER, Fourier Transforms were performed on the SEM pictures. Since the lines in the pictures were vertical, frequencies in the y-direction were averaged and full-width-half-maximum points were derived and recorded with respect to the number of pixels away from the center. This was necessary because the amplitude of the average frequencies in the y-direction was highly sensitive to the brightness of the images; a factor that could not be controlled.

Results and Conclusions:

Data was compiled for both 150,000x and 100,000x in graphs plotting LER versus percent contrast. The resulting graphs showed a strong power and exponential relationship with the 150,000x data resulting in an R^2 value of 0.8055 for a power regression and 0.7101 for exponential, and the 100,000x data displaying R^2 values of 0.8787 and 0.8209 for the power and exponential regressions respectively. Combining the data results in Figure 3. It was also observed, through side-view SEM images, that the "roughness" found on the lines was actually uniform across the breadth of the lines and their spaces instead of being confined to the edges (see Figure 4).

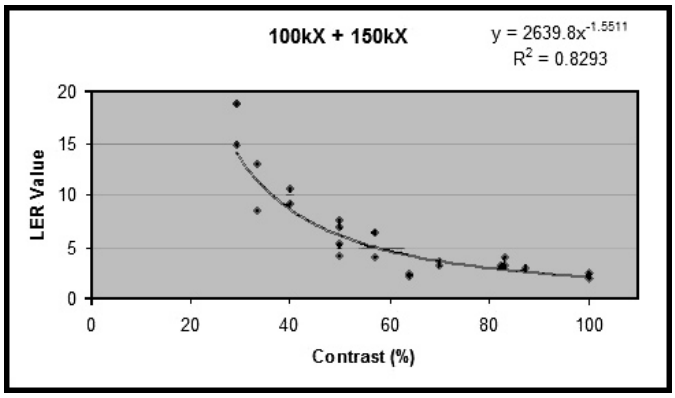

Figure 3: Power regression for 100,000x and 150,000x combined data.

Further Research:

Further research could be conducted on a few different related matters. First, and probably of greatest interest, would be to perform the same experiment in air and observe any differences. To possibly improve the accuracy of the data, one could repeat the same experiment but use more laser pulses at a lower energy so as to do a better job of averaging out the variations in the laser, use higher resolution images, and/or plate with chromium instead of gold to prevent gold cracks from creating artificial roughness or simply use a more powerful SEM that does not require metal plating.

Acknowledgements:

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References:

[1] Brueck, S. R. J. "Directions in Nanoscale Lithography and Pattern Transfer" PowerPoint (2005).

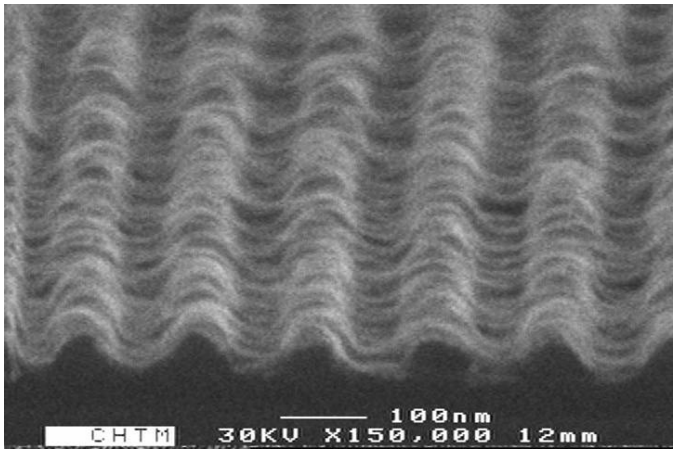

Figure 4: 150,000x side view of 50% contrast.