Absorber height effects on SWA restrictions and ‘Shadow’ LER

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Absorber Height Effects

As extreme-ultraviolet lithography (EUVL) approaches introduction at the 22-nm half-pitch node, several key aspects of absorber height effects remain unexplored. In particular, sidewall angle (SWA) restrictions based on the height of the mask absorber has not yet been clearly defined. In addition, the effects of absorber height on line-edge roughness (LER) from shadowing has not been examined. We make an initial investigation into how tight SWA constraints are and the extent to which ‘shadow’ LER alters basic LER.

Our approach to SWA aims to find SWA restrictions based on 10% of the total CD error budget (10% of CD). Thus, we allot the SWA budget a 0.2nm tolerance for 22nm half-pitch.

Absorber Height Restrictions on SWA

We do rigorous aerial image modeling of mask features with a nominal SWA of 80 degrees and correctly sized to target 22nm features measured at the top, 70nm TaN absorber on a 40 bilayer ML mirror with a 2.5nm Ru cap. Simulations were on a 4X system with an ideal pupil of NA = 0.32, illumination wavelength 13.4nm at 6° off-axis, and disk source shape with partial coherence factor of σ = 0.50. We first implement a defocus offset to the aerial image so that best focus lies at a nominal zero defocus value. We then calculate the depth of focus (DOF) for which the image-log-slope (ILS) delivers a contrast greater than 50%, an arbitrary standard for a good quality photoresist to print.

In examining ‘shadow’ LER, we use FDTD simulations to obtain a rigorous solution for the source intensity immediately after the patterned TaN mask absorber pattern on a 2.5nm Ru capped 40 bilayer ML mirror. The optical system was comprised of an ideal pupil map, NA = 0.32, 13.4nm light at 4° off-axis, and annular source shape with partial coherence factor of σ = 0.35 – 0.55. We assumed a 90° SWA.

‘Shadow’ LER

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Results

In the course of our investigation of SWA, we found that the nominal angle has no effect on process window size, and neither does sensitivity on changing angle alter as a function of nominal angle. For nominal 80°, 85°, 88° SWA, the amount of angle tolerance for 0.2nm change in CD was in total 0.5°. For ‘shadow’ LER, we found minimal difference between left and right LER when illuminated perpendicularly to the pattern, to at most 0.1nm LER at best focus. CTFs confirm the uniqueness and linearity of an LER transfer function as opposed to the traditional MTF, as shown in a previous study.

New with EUVL is the off-axis illumination system. One potential pitfall that must be carefully monitored is the effect of mask absorber height blocking light from reaching, and therefore, correctly detecting, the base edge position of a feature.

While mask features can correctly compensate sizing to target at the wafer, the effects of this shadowing on LER have not yet been investigated. Specifically, ‘shadow’ LER may exacerbate or mitigate the inherent LER on the mask. Shadowing may also cause a difference in the observed LER on the right and left side of the features. We carefully probe this issue for a range of spatial frequencies.

In the future we wish to expand our work on ‘shadow’ LER into the regime where the k1-factor of the optic is stressed. In particular, 16nm lines and spaces on an NA = 0.32 optic with off-axis illumination.

For SWA of 80 degrees, we found the nominal SWA is tightly constrained by 0.5 degrees.

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<tr>
<th>SWA 80 degrees:</th>
<th>79.8 – 80.3 degrees</th>
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<tr>
<td>SWA 85 degrees:</td>
<td>84.85 – 85.35 degrees</td>
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<tr>
<td>SWA 88 degrees:</td>
<td>87.8 – 88.25 degrees</td>
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We repeated these calculations for other nominal values of SWA 85 and 88 degrees, and found that CD sensitivity to nominal SWA is relatively independent.

Results show that even off-axis illumination perpendicular to the lines and spaces gives minimal difference between the left and right LER to at most 0.1nm difference at best focus.

We followed up this study by repeating the data for a mask designed with 2mm LER with similar results. A plot of the transfer functions for LER of both 2nm and 4nm compared to the contrast of simple 50% duty cycle lines and spaces shows that LER has a unique transfer function as well as a linear response to LER amplitude.
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