Horizontal-Vertical (H-V) Bias, part 2

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In the last edition of this column we looked at H-V bias, the systematic difference in linewidth between closely located horizontally and vertically oriented resist features that, other than orientation, should be identical. We saw that one potentially significant contributor to H-V bias was astigmatism, which causes a shift in best focus between vertical and horizontal lines. This results in a nearly linear variation of H-V bias with focus, which is the classic signature of objective lens astigmatism.

The second major cause of H-V bias is illumination aberrations (that is, source shape asymmetries). Consider conventional illumination where the center of the disk-shaped source is not perfectly aligned with the center of the optical path (called an illumination telecentricity error). The impact of such a source telecentricity error is dependent on the partial coherence, the pitch, and of course on the amount of telecentricity error. Figure 1 shows that, in general, an x-shift of the center of the illumination source shape affects vertically oriented (y-oriented) lines significantly, but horizontal (x-oriented) lines very little.

Figure 2 explores the pitch dependence of H-V bias for a given amount of telecentricity error using PROLITH simulations. Several important conclusions can be drawn from these results. First, the smaller partial coherence cases show a larger maximum H-V bias. With the source center shifted by 0.1 sigma, the worst case H-V bias goes from 6.3nm for the $\sigma = 0.4$ case to 4nm for $\sigma = 0.6$ and down to 1.6nm for $\sigma = 0.8$. Second, there is a weak feature size dependence, but this is small compared to the pitch dependence, which provides the most interesting trend. For each sigma value there is a pitch which gives the maximum H-V bias for a given illumination telecentricity error. For $\sigma = 0.4$ the worst case H-V bias occurs at a K_{pitch} (= pitch*NA/λ) of 1.65. For $\sigma = 0.6$ the maximum H-V bias occurs at $K_{pitch} = 2.5$. And for $\sigma = 0.8$ the maximum H-V bias occurs at about $K_{pitch} = 4.8$. Other simulations show that the value of the most sensitive pitch is essentially independent of the magnitude of the telecentricity error.

What causes one pitch to have a more sensitive H-V bias response to source telecentricity errors than all the others? For the simple case of dense line/space patterns where only the zero and the two first diffraction orders are used in the imaging, the image will be made up of combinations of one, two and/or three beam interference. The change in CD for the vertical features for an x-shift in the source center is caused by a change in the ratio of two beam to three beam imaging. Figure 3 shows an example case where the total three-beam imaging area (in yellow) and the total two beam imaging area (red + blue) does not appreciably change as the center of the source is shifted by about 0.1 sigma. Thus, for this pitch and sigma one would not expect to see much change in the vertical feature CD. Consider a different pitch, as shown below in Figure 4a. At this particular pitch, all of the first order is inside the lens, so that all of the imaging is three beam (note that the second diffracted order is not shown in the diagram for clarity's sake). However, when the source is shifted in x by 0.1 sigma (Figure 4b), the amount of three beam imaging for the vertical lines is reduced and two beam imaging is introduced. By contrast, the horizontal lines (which spread the diffraction pattern vertically in the pupil) have only an imperceptible change in the amount of three beam imaging for the same x-shift of the source position (Figures 4c and 4d). Thus, at this pitch one would expect to see a large amount of H-V bias with source shift.

The pitch that just allows only three beam imaging for a given partial coherence is the pitch that is most sensitive to a shift in the source center position. Thus, the worst case pitch from an H-V bias telecentricity error sensitivity perspective is given by

$$\textit{worst case } K_{pitch} = \frac{pNA}{\lambda} \approx \frac{1}{1-\sigma} \tag{1}$$

For σ = 0.4, 0.6, and 0.8 this corresponds to worst case K_{pitch} equal to 1.67, 2.5, and 5, respectively, corresponding almost exactly with the simulation results seen in Figure 2.

As the simulations and analysis above have shown, source shape errors can cause a change in the ratio of two beam to three beam imaging, affecting vertical and horizontal lines differently. The most sensitive pitch for a given value of partial coherence will be the pitch that puts all of the first order just inside the lens. For well designed and maintained illumination systems, the amount of H-V bias should be small. However, small is a relative term. For the σ = 0.6 case presented here, 1nm of H-V bias can result from less than 0.04 sigma shift in the center of the source when at the worst case pitch. Are source shapes and alignments controlled to this level? That is a question that requires more characterization and measurement of illumination source shapes in real world lithographic systems.

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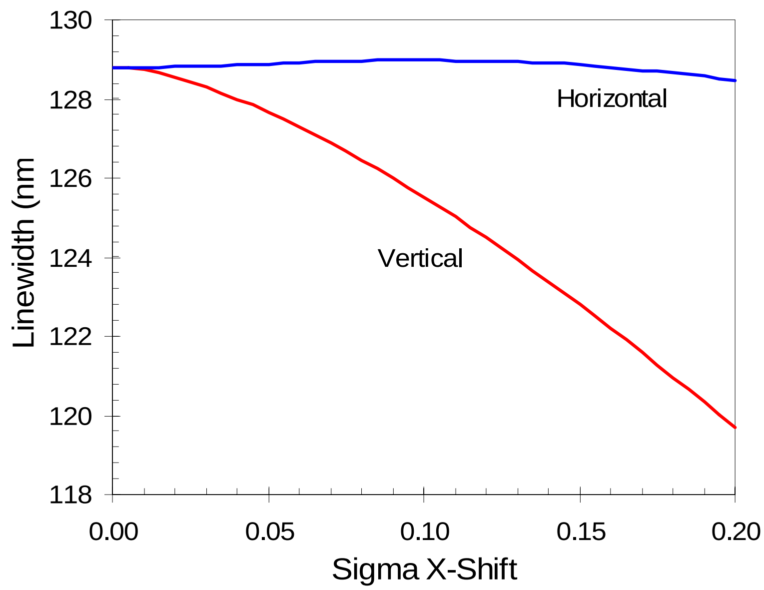

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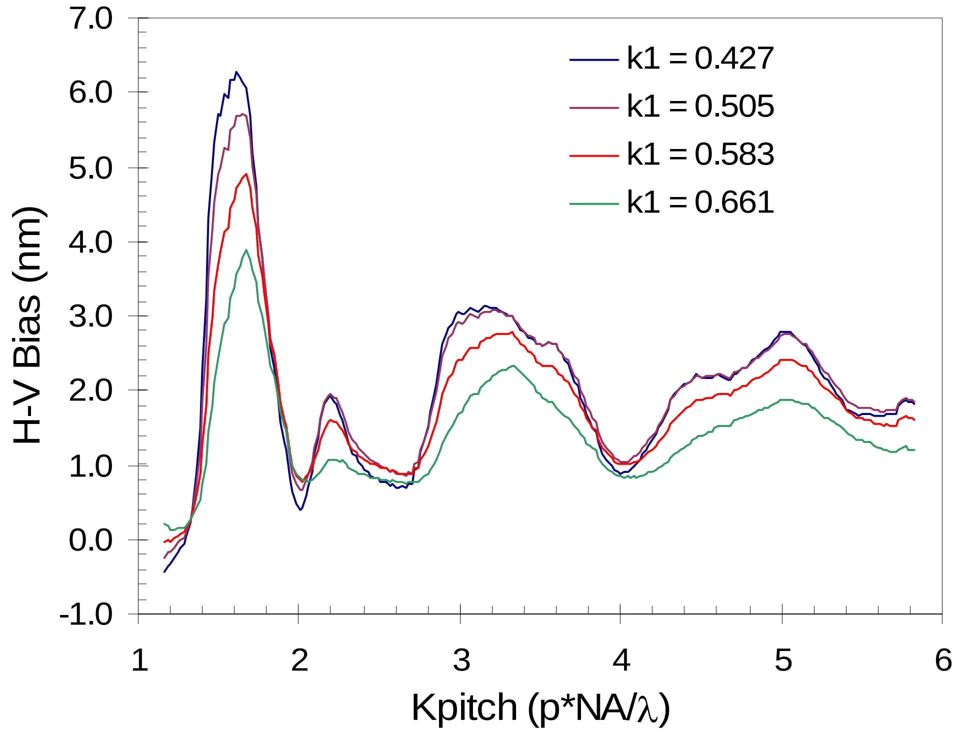
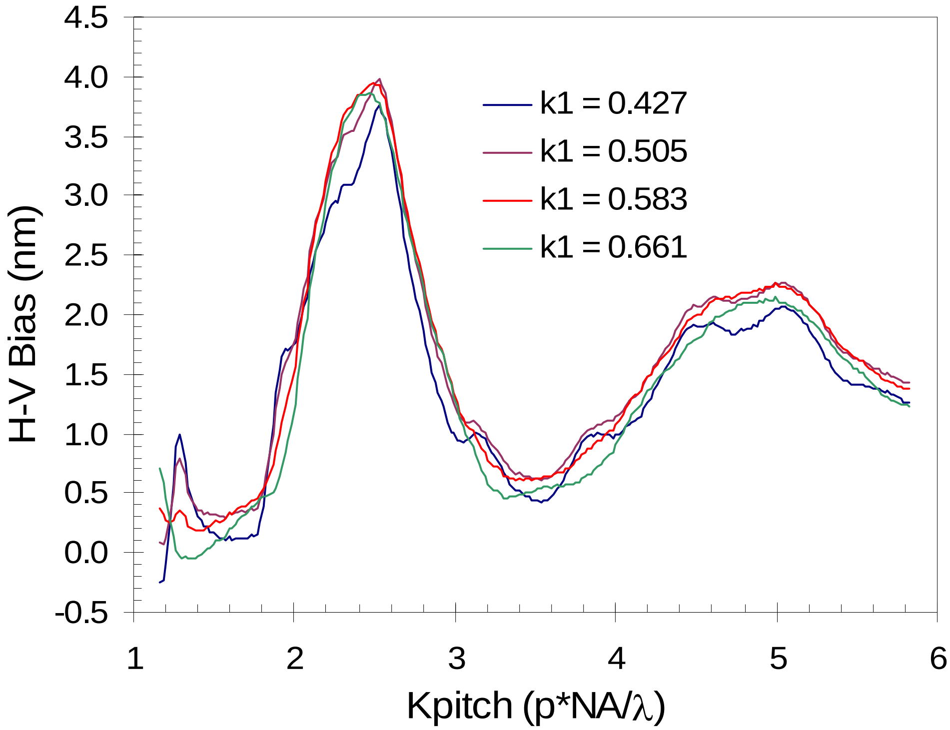


(a)



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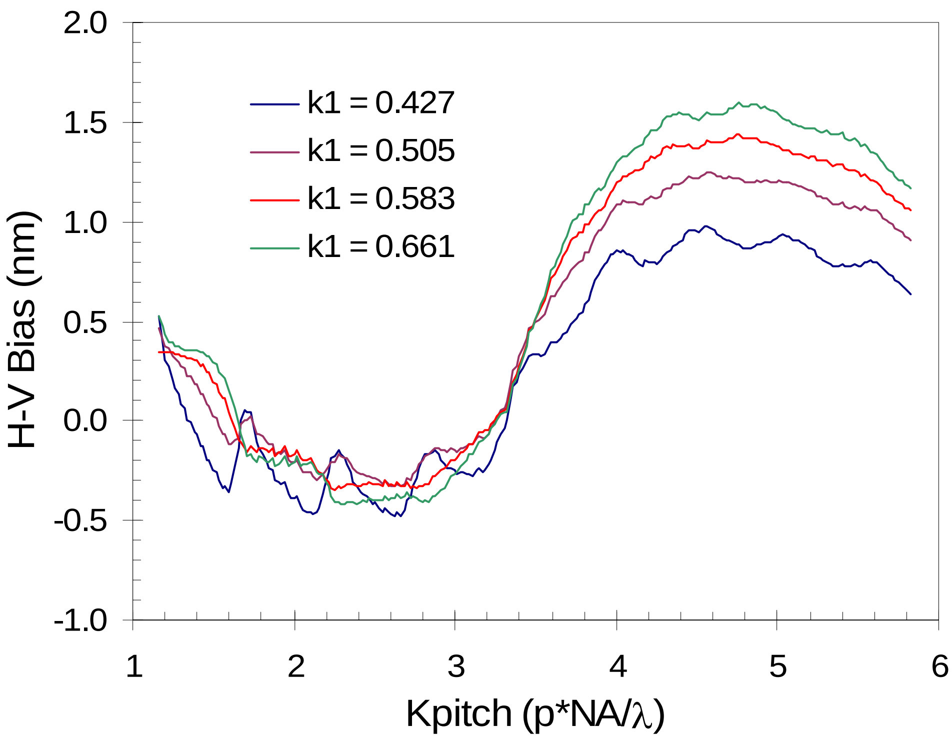

(c)

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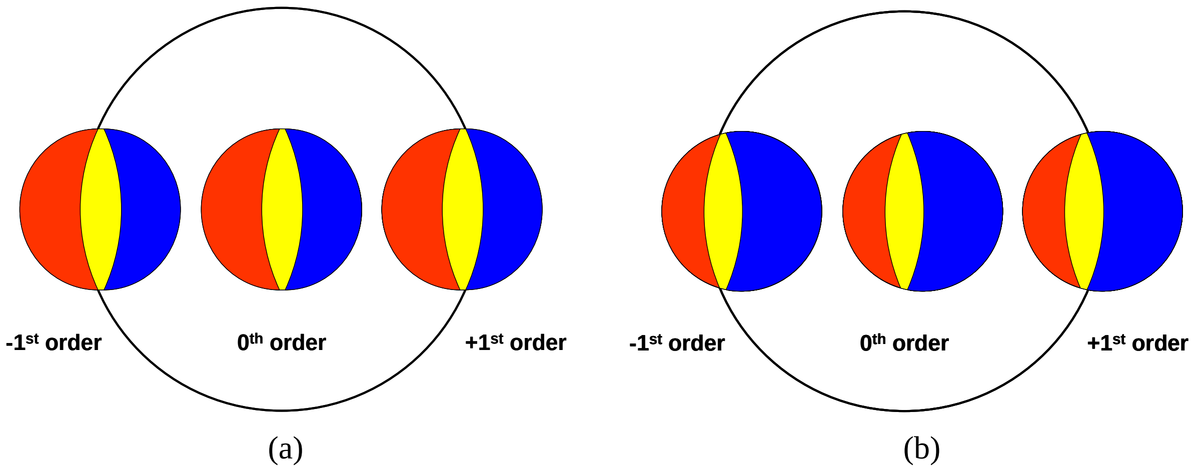

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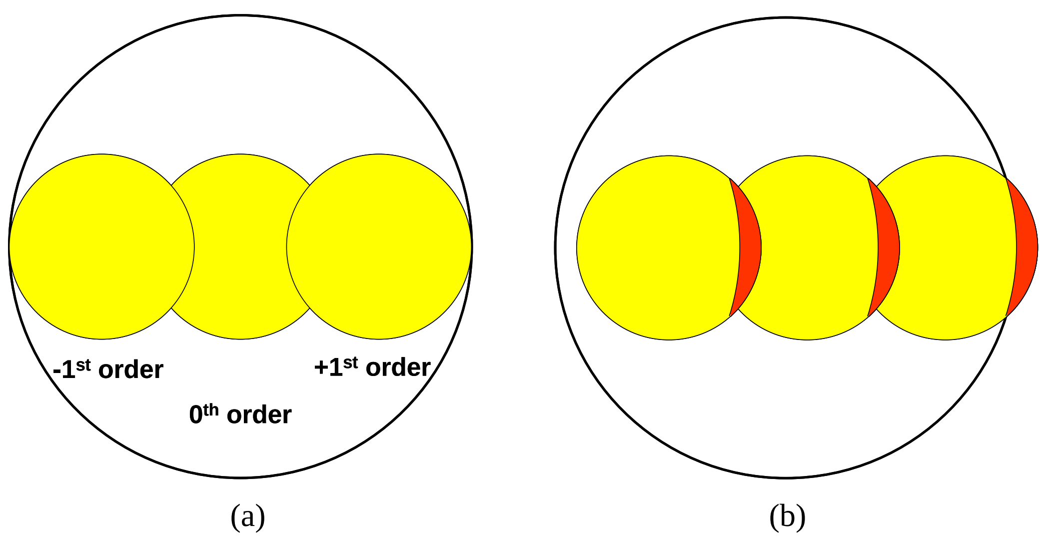

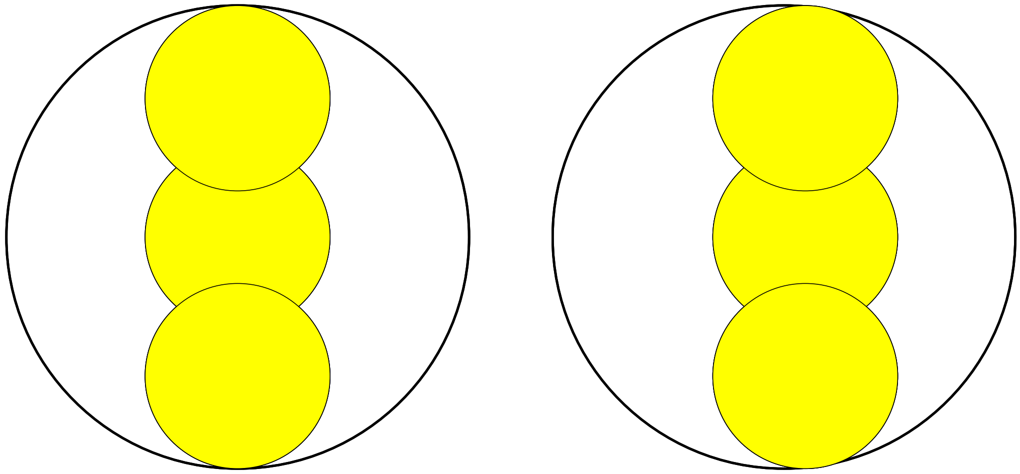

(c) (d)

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