Frequency doubling and resolution enhancement technique exploration for chrome-less phase shift mask

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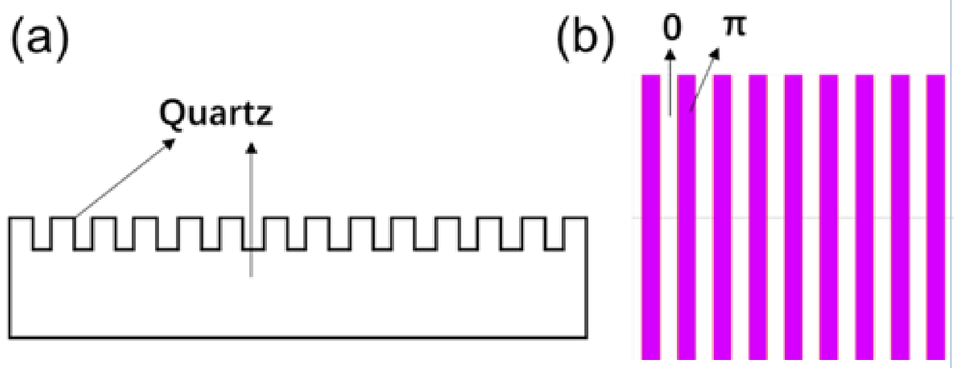
INTRODUCTION

Chrome-less PSM is a 100% transmission low k1 technique. The shifter edge causes dark intensity and the bright intensity at the shifter center due to interference between adjacent shifters, resulting in halved period of aerial images. This is so-called frequency doubling or pitch halfling. The studies of frequency doubling for chrome-less PSM are few, but the fundamental theory is till worthwhile to be studied. In addition, the frequency doubling may have special application scenarios. In this paper, we have investigated the resolution limit of the frequency doubling from chrome-less PSM, based on aerial image simulations. We've also studied the frequency doubling generation conditions. Finally, we would draw conclusions.

SIMULATIONS STRUCTURE, CONDITIONS

In this paper, chrome-less PSM that only has quartz is simulated. The simulation is based on 2D 1:1 line/space structure. The line and spaces are arranged in alternating 0 and π phases.



The resolution limit and generation conditions of the frequency doubling from chrome-less PSM, based on aerial image simulations and resist model. Both simulations have used immersion scanner parameters. The simulation has used various conventional illuminations which favors alternating PSM masks, at max NA 1.35, various TE-polarization; 1:1 line/space with CD/pitch (at mask level) ranging from 70/140nm to 72/144nm and unequal line space with CD/pitch (mask level) 36/300nm. FEM analysis has also been performed with 1:1 line/space at CD/pitch (mask level) from 120/240nm to 168/336nm with step of 24nm.

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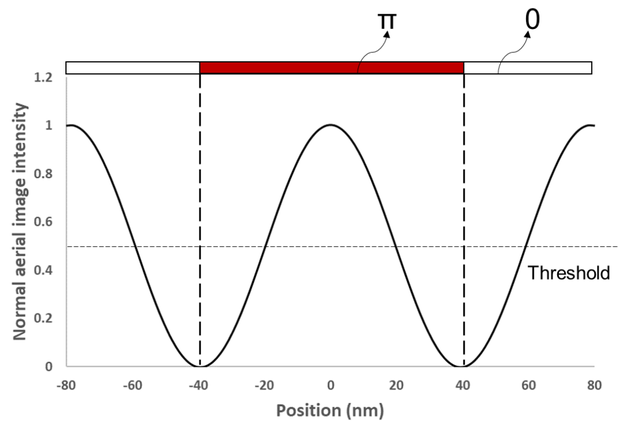
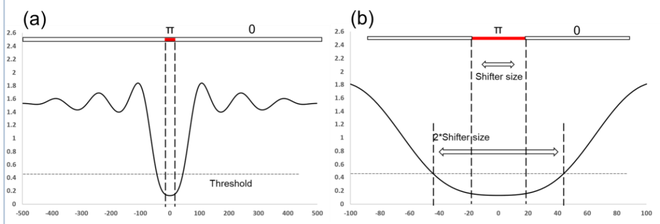
RESULTS

The frequency for aerial image intensity is doubled comparing to simulated structure. The aerial image intensity threshold is set based on target CD value with optical model and best focus.

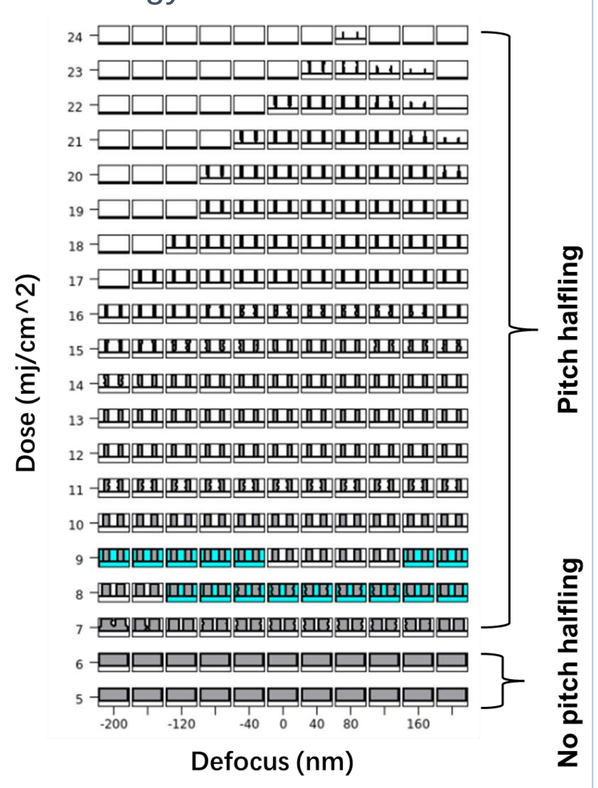


When line and space are unequal, shifter width is close to the optical limit and far less than pitch, final width printed on wafer is about 2 times mask shifter width.

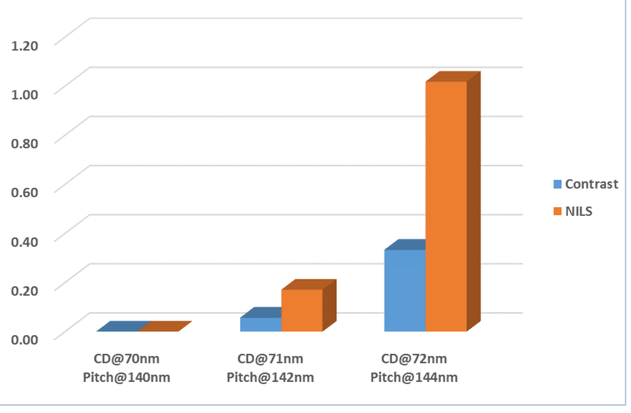


At most energy and focus steps, the pitch halfling happens, the final pitch printed on wafer is 144nm. At very low and very high energy steps, the pitch halfling does not happen since there is no patterns. While the line/space ratio at best energy and best focus is 1:1, and no long 1:1 at other energy and focus steps.

So, if we use chrome-less PSM to reduce pitch and print equal line and space, the energy and focus need to be controlled well at best focus and best energy



The minimal CD/pitch that can make it is 72/144nm at mask level, and 36/72nm at wafer level. If further reducing the 1:1 line/space patterns to less than 72/144nm CD/pitch (mask level), the contrast disappears.



CONCLUSIONS

1. The frequency doubling can be achieved for equal line and space with chrome-less PSM, where the final wafer CD is halved comparing reticle design target.

2. For unequal line and space, when shifter width is close to optical limit and far less than pitch, the final CD printed on wafer is about two times to shifter width at reticle design.

3. If we use chrome-less PSM to print complex pattern, the energy with respect to CD target is necessary to be well chosen, or extensive OPC to be made.

4. The minimal CD/pitch printed on wafer is 36/72nm from chrome-less PSM, which agrees with the Rayleigh formula of optical limit for immersion.