# Near-Field EUV Imaging for Spatial Frequency Multiplication

Yijian Chen

*Peking University, Shenzhen Graduate School, Shenzhen, China*

*chenyj@pkusz.edu.cn*

Yashesh Shroff

*Intel Corp., 2200 Mission College Blvd., M/S: SC1-01, Santa Clara, CA 94054*

As a potential solution to break the diffraction limit of conventional optical systems, near-field imaging has gained extensive research interest recently. However, applying this novel technique for current 193nm lithographic process is not possible due to its long wavelength. For example, the 193nm exposure wavelength with a manageable propagation depth Z (e.g., about 10nm or larger) will result in a Fresnel number $W^2/\lambda Z$ (W: half width of an aperture, λ: wavelength [1]) small than one. This corresponds to a far-field diffraction mode that does not provide any resolution benefit to break the diffraction limit. As 13.5nm EUV lithography starts to mature for high-volume application, the possibility of near-field EUV imaging also emerges due to its much shorter wavelength which can bring Fresnel number into the near-field range (larger than one). Once the imaging system operates in the near field, there exist several wave peaks and valleys in the near-field region immediately underneath the opening aperture where the light propagates through. This will enable spatial frequency multiplication by a simple open-field exposure of an imaging material with patterned line/space absorbers sitting on top (to absorb EUV light), as shown in Fig. 1. Moreover, recent research progress made in CVD and inorganic EUV resist [2, 3] brings this technique close to production worthy as the proposed near-field imaging film stack can become a routine practice in a future fab environment. In this paper, we present a simulation study of such a near-field EUV imaging technique.

The following results are generated using un-polarized light with results presented as TE/TM waves. The material stack is composed of a patterned layer, photosensitive thin-film, and a hard-mask layer. Keeping the patterned layer material constant (50nm thick TaN), we modify the photosensitive thin-film thickness (5nm and 7.5nm) as well as choice of the underlying hard-mask (substrate) layer. The aerial image is observed through various depths in the photosensitive thin-film. For this study, we chose halfnium-oxide's (n,k) parameters to approximate the complex refractive index of a polymer based on a HfO2 core. HfO2 based polymer resist has been used for negative direct writing in e-beam lithography [2] and its core particles are used to build stable metal inorganic resists for EUV and DUV lithography [3]. The choice of underlying substrate is TaN, amorphous carbon (a typical hard mask material for pattern transfer), and silicon dioxide.

In Figure 1, we show a typical film stack on top of wafer that already has a coarse 1st layer patterned by standard EUV lithography and a following etching step (in this case TaN, pitch 60nm, overexposed/trimmed line CD of 10nm). After this, the wafer is exposed with open-field EUV light. According to the near-field optics, a series of line/space patterns (with a density higher than that of TaN absorber) can be generated (and captured) in the underlying HfO2 based photosensitive thin-film. Two cases of TE/TM intensities are shown in Figure 2 for amorphous carbon and TaN underlying hard-masks. Even though the second layer is self-aligned to the TaN pattern, our simulation shows that varying HfO2 thicknesses can shift the near-field line/space patterns. Impact of focus and process variations will be discussed in the paper. The near-field patterns are not just limited to 1-D structure. We shall also discuss the generation of robust 2D contacts through this process. Finally, we shall present practical implications and limitations of using an embedded near-field patterning in the context of EUV lithography.

References:

1. J. Goodman, *Introduction to Fourier Optics*, McGraw-Hill, 1996.
2. M. S. M. Saifullah, M. Z. R. Khan, David G. Hasko, et. al., "Spin-coatable HfO2 resist for optical and electron beam lithographies", JVST-B, vol. 28, no. 1, pp 90, 2010.
3. Markos Trikeriotis, Woo Jin Bae, Evan Schwartz, et. al., "Development of an inorganic photoresist for DUV, EUV, and electron beam imaging", Advances in Resist Materials and Processing Technology XXVII. Proceedings of the SPIE, Vol 7639, 2010.

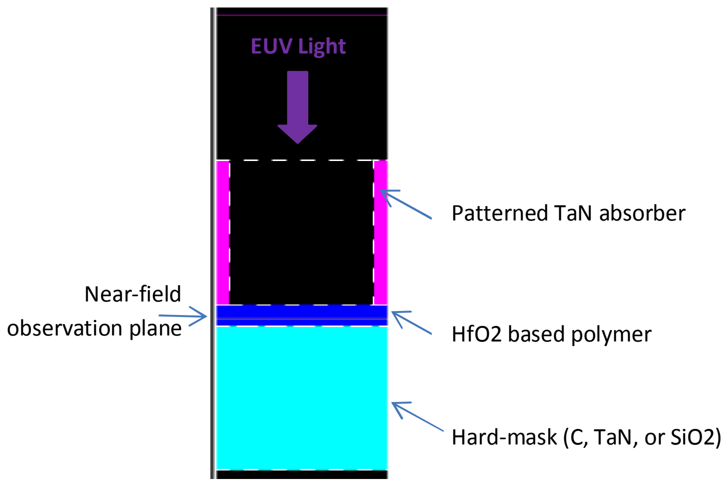
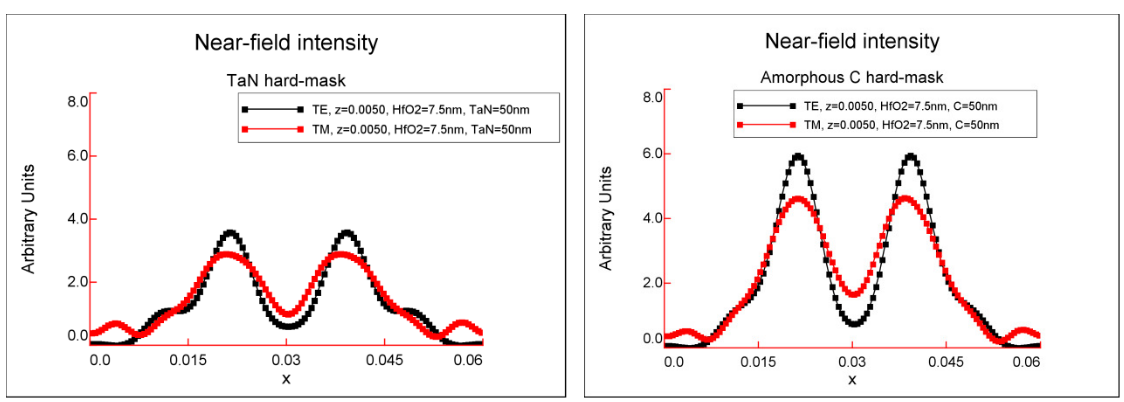



Figure 1. *Film-stack to capture near-field image from EUV exposure of patterned 1st absorber layer into photosensitive HfO2 based thin film(polymer) on top of a hard-mask .The pitch of patterned absorber (line/space) is 60nm.The formed near-field pattern in the HfO2 layer will eventually be transferred into the hard mask layer for further processing.*




*(a) Near-field with TaN hard-mask* *(b) Near-field with $\alpha$-C hard-mask*

Figure 2. *Examples of image profiles in the HfO2 layer (near field)right underneath the opening aperture (50nm wide as shown in Fig.1). Multiple image peaks and valleys will make pitch division possible.*