Source optimization for anamorphic magnification high-numerical aperture extreme ultraviolet lithography based on thick mask model

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ABSTRACT

Source optimization (SO) is one of the important resolution enhancement techniques (RETs) in computational lithography. The anamorphic magnification high-numerical aperture (NA) extreme ultraviolet (EUV) lithography can achieve a higher resolution by increasing the NA. However, the increase in NA leads to a significant mask three-dimensional (M3D) effects in the partial direction on the mask, and traditional Kirchhoff model no longer works. In this paper, we propose a SO method for 0.55 NA EUV lithography based on thick mask model. The results demonstrate that thick mask model aware SO can effectively mitigate the M3D effects, achieve high fidelity patterns, and enlarge the process window (PW). PW consists of exposure latitude (EL) and depth of focus (DOF).The DOF (EL=10%) of thick mask model aware SO at two types of target patterns is 52nm and 67nm, which is 116.7% and 48.9% larger than that of thin mask model aware SO.

MODELS AND METHODS

Based on our previous work, we establish a vectorial imaging model for anamorphic magnification high-NA EUV lithography, the aerial image of the lithography system can be expressed as

$$\mathbf{I}=\frac{1}{J_{sum}}\sum_{x_s}\sum_{y_s}\mathbf{J}\left(x_s,y_s\right)\times \sum_{p=x,y,z}\left|\mathcal{F}^{-1}\left\{\begin{bmatrix}\mathbf{V}'\left(x_s,y_s\right)\odot e^{j2\pi\mathbf{W}}\odot \\ \mathcal{F}\left\{\mathbf{M}\left(x_s,y_s\right)\right\}\odot\mathbf{E}_i\left(x_s,y_s\right)\end{bmatrix}_p\right\}\right|^2,$$

where matrix $\mathbf{J}\in\mathbb{R}^{N_S\times N_S}$ represents the intensity distribution of the source pattern. The $\mathbf{J}\left(x_s,y_s\right)$ represents the intensity of the source point $\left(x_s,y_s\right)$ .The $J_{sum}=\sum_{x_s}\sum_{y_s}\mathbf{J}\left(x_s,y_s\right)$ is an illumination intensity normalization factor. Where $\mathbf{M}\in\mathbb{R}^{N\times N}$ denotes the mask pattern, and $\mathbb{R}^{N\times N}$ is the real number set with the size $N\times N$ and $\mathcal{F}\left\{\mathbf{M}\left(x_s,y_s\right)\right\}$ represents the diffraction spectrum of the mask. The notation $\mathcal{F}$ and $\mathcal{F}^{-1}$ represent the Fourier transform and inverse Fourier transform, respectively. The $\odot$ represent entry-by-entry multiplication operation. $\mathbf{E}_i$ is the polarization of the illumination. W is the pupil wavefront.

In this paper, the derivative sigmoid function is used to approximate the CTR model. Sigmoid function is referred as

$$\mathbf{Z}=sig\left(\mathbf{I}\right)=\frac{1}{1+\exp\left[-a\left(\mathbf{I}-t_r\right)\right]}.$$

The Euclidean distance between target pattern and resist image is usually selected as a cost function:

$$F_{SO}=\left\|\tilde{\mathbf{Z}}-\mathbf{Z}\right\|_2^2,$$

where the notation $\left\|\ \right\|_2^2$ represents the square of L2-norm. The problem of optimizing the distribution of the source pattern can be expressed as

$$\vec{J}=\underset{\vec{J}}{\arg\min}\,F_{SO}.$$

Table1.Pseudo-code of the SO method based on Gradient Descent algorithm.

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Input: Set the simulation parameters, initialize $k=0$, the initial source parameter $\Omega_J$, the source step size $\eta$,
    the maximum of iteration number $l_{SO}$.
Update the source pattern:
while    $k\le l_{SO}$
        $k\leftarrow k+1$;
    Calculate the initial PAE
    Calculate the gradients $\nabla F_{SO}\left(\Omega_J^k\right)$
    Update the source parameters: $\Omega_J^{k+1}=\Omega_J^k-\eta\nabla F_{SO}\left(\Omega_J^k\right)$;
end
Output the optimized source parameters.
```

SIMULATION RESULTS

Test pattern

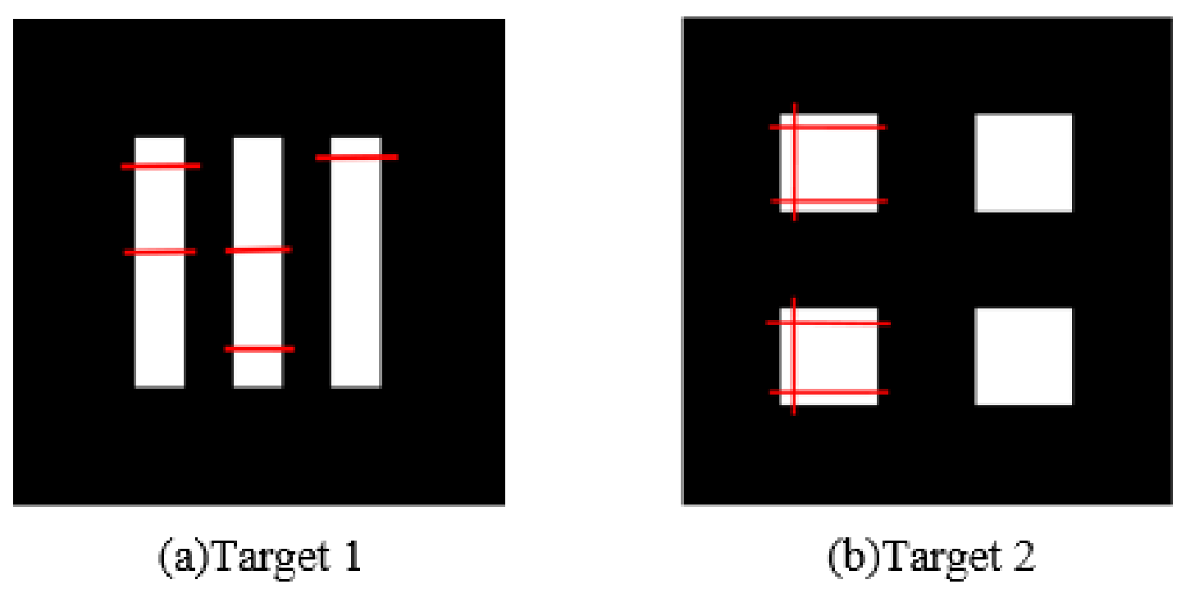
(a)Target 1 (b)Target 2

Fig.1. Target patterns used in the simulation. The red lines mark the locations for PW calculation (a) Target 1. (b) Target 2

Target 1 has a CD of 18nm with a pixel size of 0.9 nm × 0.9 nm on the wafer scale. Target 2 has a CD of 21 nm with a pixel size of 0.525 nm × 0.525 nm on the wafer scale.

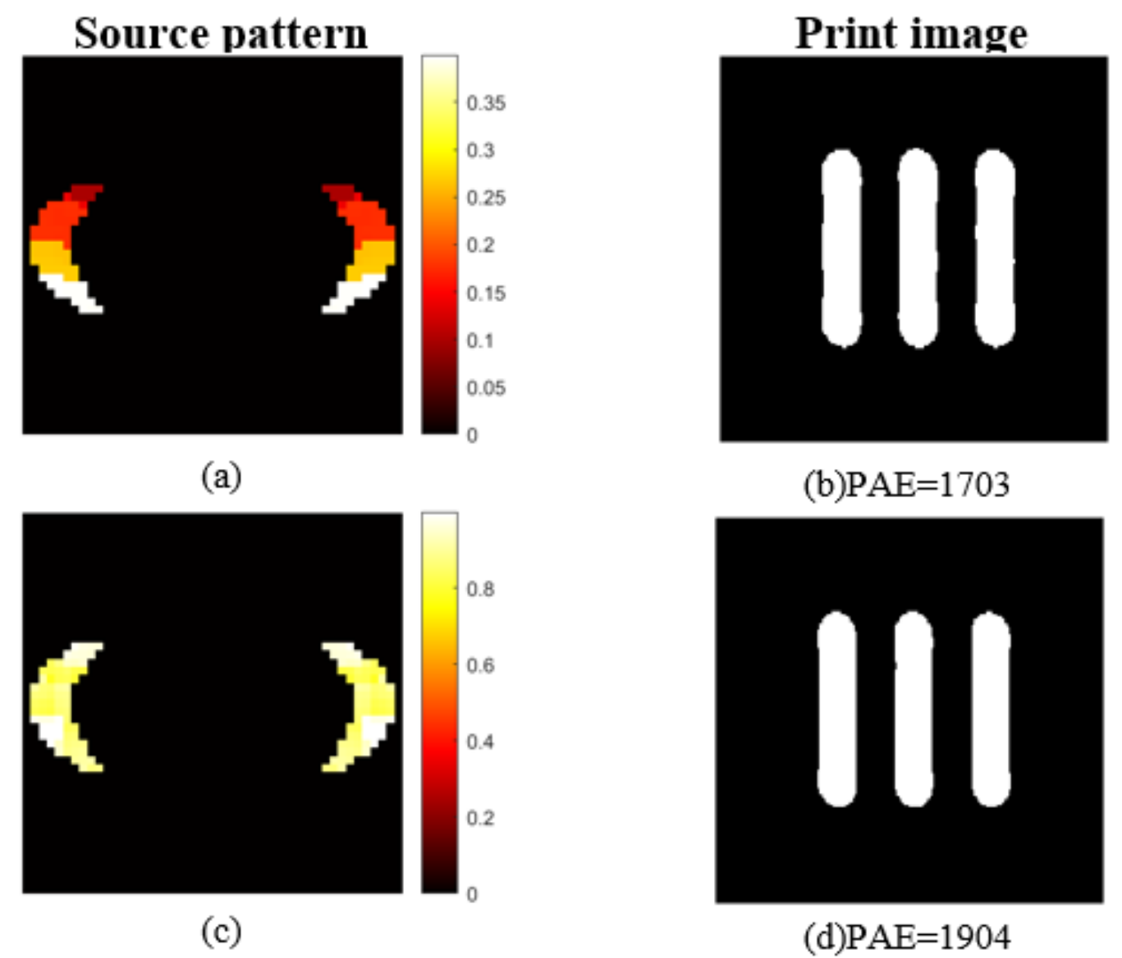

Fig.2. Simulation results of Target 1: (a)Optimized source pattern based on thick mask model, (b) print image of (a) based on thick mask model, (c) optimized source pattern based on thin mask model; (d)print image of (c) based on thick mask model.

Fig. 2 shows the simulation results of Target 1.The PAE of print image shown in Fig.2(b) is 1703, which is about 200 less than Fig. 2(d). This shows that the thick mask model aware SO has a higher fidelity pattern. In order to further measure the stability of lithography imaging performance, the PW is also used as an evaluation index. As shown in Fig. 3, the DOF(EL=10%) of the optimized source pattern shown in Fig.2(a) imaging based on the thick mask model is 52 nm. However, the DOF(EL=10%) of the optimized source pattern shown in Fig. 2(c) imaging based on thick mask model is only 24 nm.

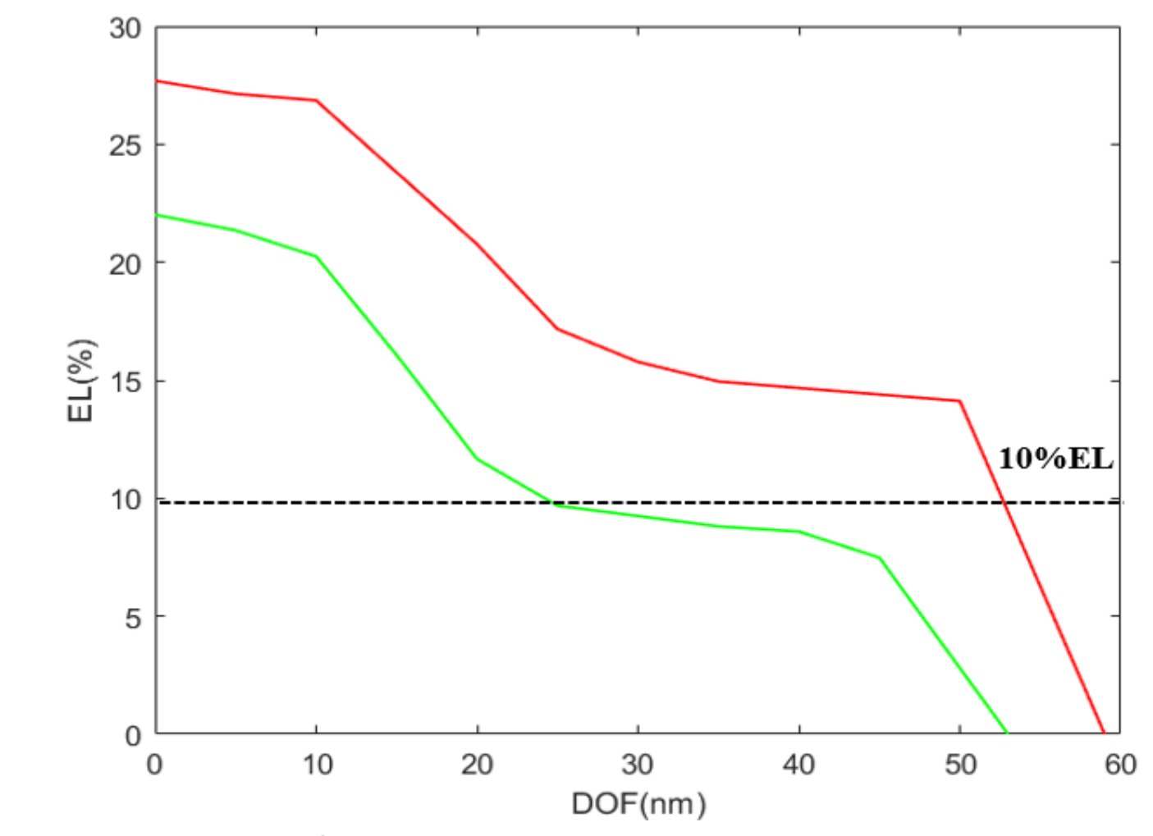

Fig.3. PW result of optimized source pattern shown in Fig.3(a) based on thick mask model (red curve), PW result of optimized source shown in Fig.3(c) based on thick mask model (green curve).

In order to verify the universality of our study, we also simulate the contact hole pattern at 5nm technology node. We can observe a similar situation, that the thick mask model aware SO achieves a smaller PAE and a larger PW.

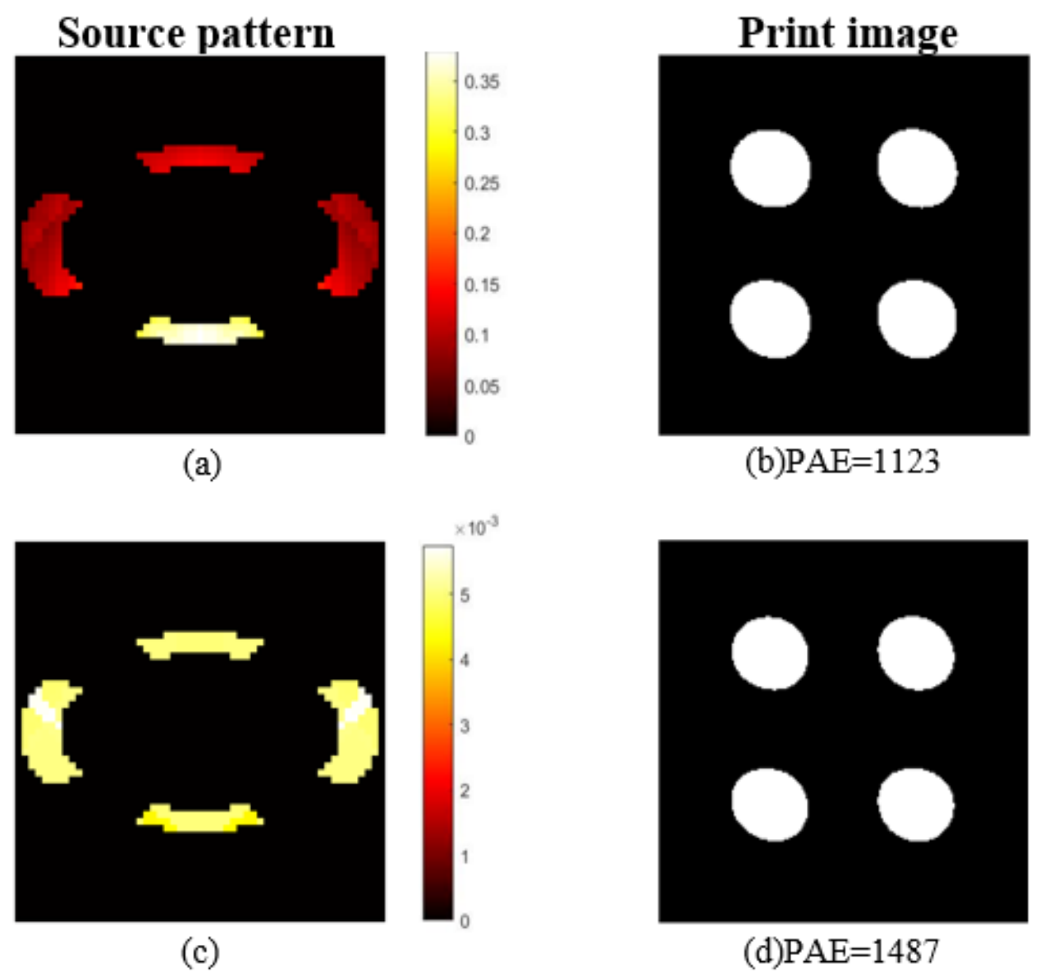

Fig.4. Simulation results of Target 2: (a) Optimized source pattern based on thick mask model, (b) print image of (a) based on thick mask model, (c) optimized source pattern based on thin mask model; (d) print image of (c) based on thick mask model.

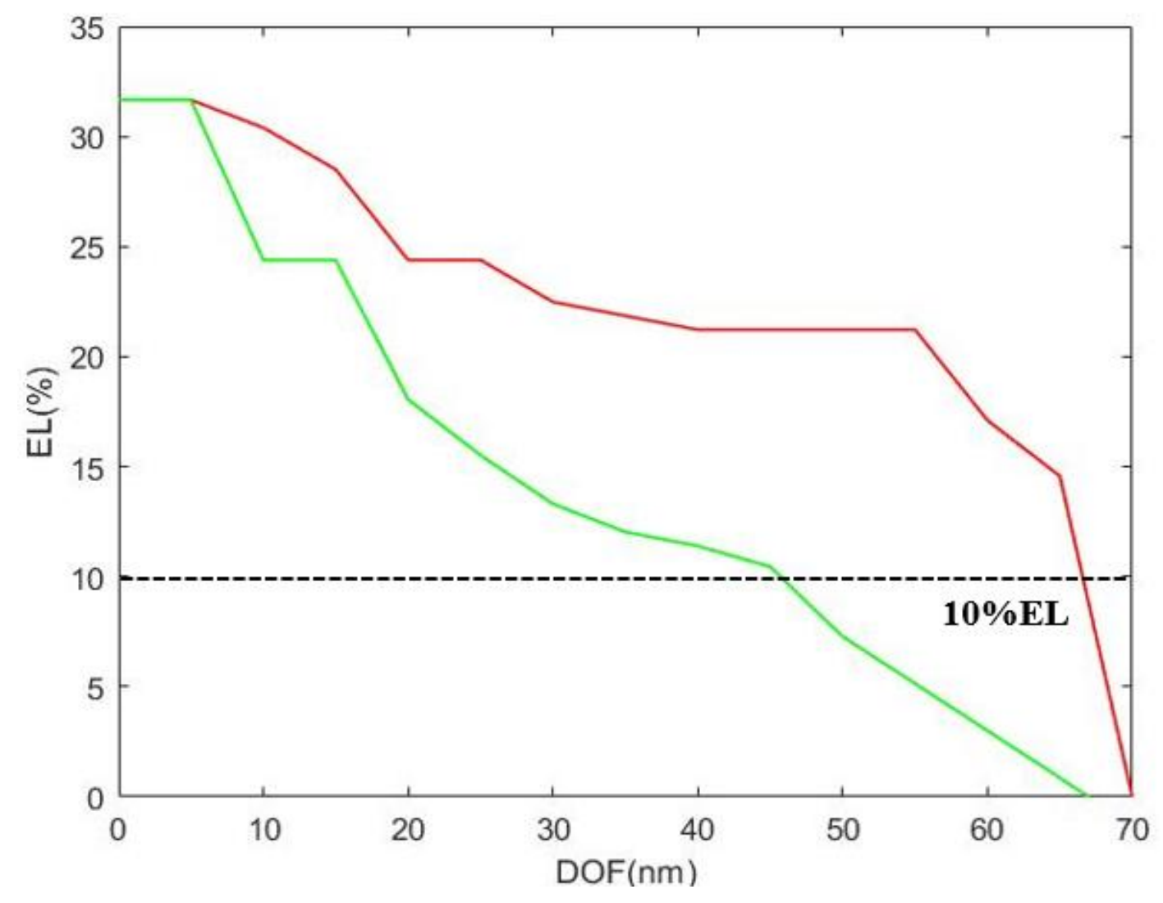

Fig.5. PW result of optimized source pattern shown in Fig.5 (a) based on thick mask model (red curve), PW result of optimized source pattern shown in Fig.5 (c) based on thick mask model (green curve).

CONCLUSIONS

In this paper, we propose a SO method for 0.55NA EUV lithography based on thick mask model. Based on the vectorial imaging model for anamorphic magnification high-NA EUV lithography, the steepest gradient descent algorithm is used to optimize the pixelated source pattern at two types of target patterns.The results demonstrate that thick mask model aware SO can effectively mitigate the M3D effects, achieve high fidelity patterns, and enlarge the PW. The DOF (EL =10%) of the thick mask model aware SO at two types of target patterns is 52nm and 67nm, which is 116.7% and 48.9% larger than that of the thin mask model aware SO.