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# Accurate Resist Profile Simulation for Large Area OPC

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**Abstract**

In this paper, we discuss the method of computing an accurate optical kernel for large area optical proximity correction (OPC). The kernel can be calculated fast in the Fourier domain, where the higher Fourier terms are cut by a finite pupil. We apply this method to the image simulation of the fine pattern exposed by the optical system with various coherence factors and various defocuses. It is good agreement with the rigorous result within 5 % error. And also, we present the photoresist profile computation method by using the kernel for chemically amplified resist.

## 1 Introduction

The methods of the fast aerial image simulation have been presented for an optical proximity correction (OPC) [1],[2]. Pati *et al.* approximated the optical imaging system with the sum of kernel functions (Optimal Coherent Approximations: OCA)[1]. This method can compute aerial images fairy fast compared with the rigorous solution of the Hopkins equation. Especially it is effective for large area calculation. However, this method is not suitable for a fine photomask pattern and for an optical system with aberration because the kernel accuracy is not sufficient in those cases.

In this work, we developed a new method to compute the accurate kernel by using the transmission cross coefficient (TCC) for the purpose of predicting an accurate photoresist profile.

## 2 Model

### 2.1 TCC Kernel Method

In the Hopkins model, the image intensity $I(\mathbf{x})$ can be written as

$$I(\mathbf{x}) = \iint t(\xi)t^*(\boldsymbol{\eta})W(\mathbf{x}-\xi, \mathbf{x}-\boldsymbol{\eta})d\xi d\boldsymbol{\eta}, \tag{1}$$

where $t$ is the mask transmission function and $W$ is defined by

$$W(\xi, \boldsymbol{\eta}) = J(\boldsymbol{\eta}-\xi)K(\xi)K(\boldsymbol{\eta})^*. \tag{2}$$

Here, $J$ is the mutal intensity function (Fourier transform of the source intensity $S$) and $K$ is the coherent transfer function (Fourier transform of the pupil $P$).
In the OCA model [1], Eq.(1) is approximated as

$$I(\mathbf{x}) \approx \sum_{k=1}^{m} \alpha_k \,|\, (t * \phi_k)(x) \,|^2 . \tag{3}$$

Here, $\alpha_k$ and $\phi_k$ (kernel function) are obtained as the result of decomposing $W$ in Eq.(2) by solving the eigen value problem. In this method, the pupil function is assumed as a periodic functin to calculate the coherent transfer function $K$ in Eq.(2). It needs a fine sampling interval of the pupil function for the optical system with aberration. It means the matrix size of the

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eigen value problem is large.

In this work we calculated the kernel function with the TCC formula of the Hopkins equation expressed by

$$I(\mathbf{x}) = \iint \hat{t}(\xi)\hat{t}^*(\boldsymbol{\eta})TCC(\xi,\boldsymbol{\eta})\exp[-2\pi i(\xi-\boldsymbol{\eta})\mathbf{x}]d\xi d\boldsymbol{\eta}, \tag{4}$$

where $\hat{t}$ is the Fourier transform of $t$, and the transmission cross coefficient $TCC$ is defined by

$$TCC(\xi,\boldsymbol{\eta}) = \int S(\mathbf{r})P(\xi+\mathbf{r})P(\boldsymbol{\eta}+\mathbf{r})d\mathbf{r}. \tag{5}$$

The TCC is approximated by

$$TCC(\xi,\boldsymbol{\eta}) \approx \sum_{k=1}^{m} \alpha'_k \Phi_k(\xi)\Phi_k(\boldsymbol{\eta})^*. \tag{6}$$

The obtained kernels $\Phi_k$ by decomposing the TCC are the Fourier transform of thoes of the OCA model. In this method the size of the TCC is determined with the cut off order of the pupil in Eq.(5) [3]. It can reduce the size of the matrix and compute the pupil shape accurately.

The sparse kernels in the Fourier domain can be calculated in a short time by the above method. The fine grid kernels in the spatial domain can be also calculated without interpolation as follows. The kernels in Fourier domain are extended to the higher Fourier region and these regions are padded with the null data. Then the fine grid kernels in the spatial domain can be calculated as the Fourier transform of these extended kernels by the Fast Fourier transform (FFT) as shown in Figure 1.

### 2.2 Convoluted Kernel Method

In the previous work [4], we proposed a threshold model that the photoresist profile is determined by the contour of the profile function. The profile function is described by the convolution formula of image intensity $I$ and the gaussian $G$. The defocus and the diffusion length are adjusted to experimental data for the diffusion reaction of a chemically amplified resist. This method needs the accurate aerial images with defocus, and the fine interval of aerial images compared with the diffusion length. As it means that the fine interval of aerial images must be always calculated, its cost is very high.

In this work the diffusion reaction in a chemically amplified resist is incorporated with the kernel function in advance as follows:

$$I_p(\mathbf{x}) = \sum_{k=1}^{m} \alpha_k \,|(t * \psi_k)(\mathbf{x})|^2 \tag{7}$$

Here $I_p$ is the profile function, $\psi_k$ are convoluted kernels with $G$, and * denotes the convolution operator. The lookup tables of $\psi_k$ are prepared for fast computation.

## 3 Result and Discussion

The kernels calculated by the above method (TCC kernels) are compared with those of the OCA model (OCA kernels) in Figure 2. The OCA kernel (Fig.2 (a)) is more complicated and broader function than the TCC kernel (Fig.2 (b)). It is caused by the aliasing. The computation time is 5 seconds for the TCC kernels and 120 seconds for the OCA kernels on a workstation (SPECfp95=8). In the TCC kernels the aliasing can be eliminated and the eigen,value problem can be solved in a short time because the matrix is small and sparse.

Aerial images of the TCC kernels are compared with those of the OCA kernels to estimate the accuracy of this method quantitatively. Figure 3 shows the image intensity of the 0.18μm line and space patterns by the KrF stepper with the defocus aberration. For both the TCC kernels and the OCA kernels, the diameters of kernels are 2μm, the grid intervals of kernels are 10nm and 6 kernels are summed up. The dot lines in Figure 3 are the rigorous simulation results that are calculated by Eq.(4) and Eq.(5). The peak intensity error between the TCC kernels and the rigorous results is within 5% (Fig.3(b)), and it is smaller than the OCA model

(Fig.3(a)). It shows the TCC kernels have a sufficient precision for an optical system with aberration and for a fine pattern.

Figure 4 shows the simulated photoresist profile with a 0.24μm-design-rule that is calculated by the convoluted kernels. The diffusion length and the defocus are extracted from the experimental results. The time for the pre-calculation of kernels is 45 seconds and for a profile of a $10 \times 10 \mu m^2$ area with the grid interval of 40nm is 18 seconds on the above workstation. This method makes it possible to compute a phtoresist profile for a large area in a practical time.

## 4 Conclusion

We have presented a method to compute an accurate kernel of an optical imaging system. Compared with the rigorous simulation, the error of this method is within 5% and it is effective for an optical system with aberration and for a fine pattern. Integrating the diffusion reaction of a chemically amplified resist into the kernel, it is possible for a model-based OPC to compute a phtoresist profile of a large area in a practical time.


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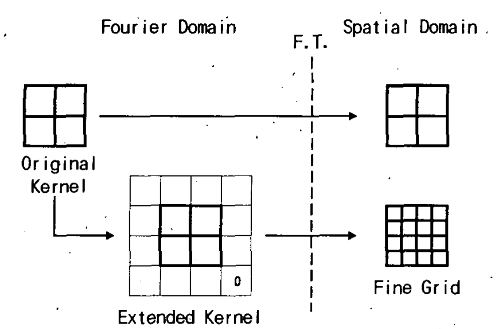


Figure 1: Schematic view of the principle to compute the fine grid kernel from the kernel in the Fourier domain without interpolation.

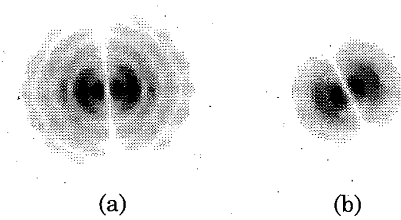


Figure 2: Powers of the second kernels for a KrF ($\lambda$=248nm) stepper with NA=0.6, $\sigma$=0.6 and defocus=0.5μm. (a) is the OCA kernel and (b) is the TCC kernel. The diameter of these kernels is 2μm.

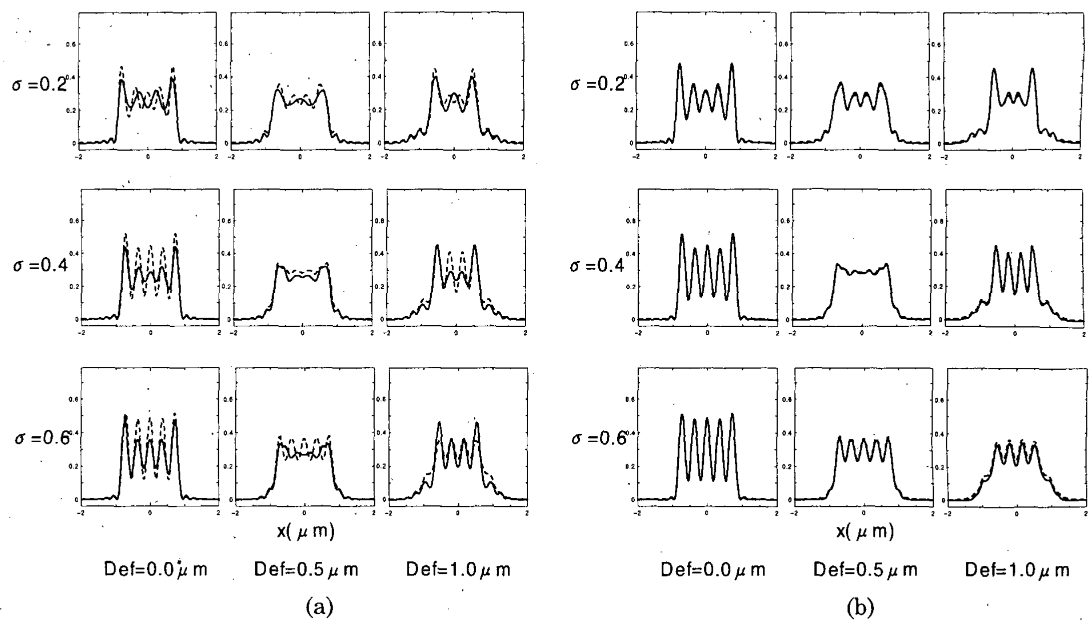


Figure 3: Image intensity of 0.18 μm line and space patterns by a KrF stepper (λ=248nm) with NA = 0.6. Parameters of a defocus in optics and a coherence factor σ are given in figures. (a) is the results of the OCA model, and (b) is those of the TCC kernels. These are shown as solid lines. Dot lines show rigorous results.

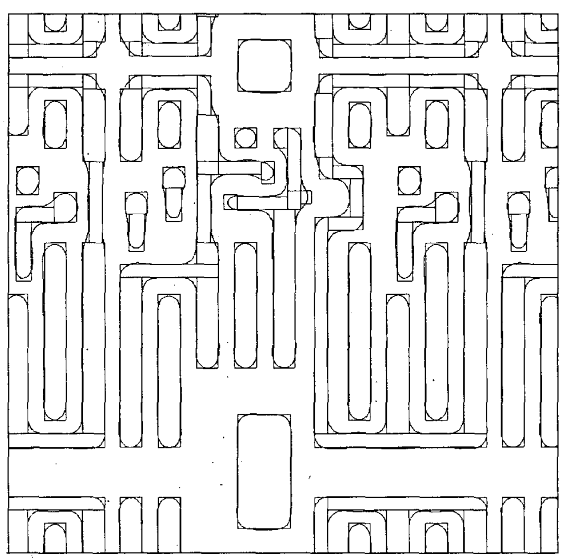

Figure 4: A 0.24μm-design-rule pattern layout and its simulated profile by convoluted kernels. A diffusion length is 0.07 μm and a defocus in optics is 0.4 μm. The computation time is 18 seconds for a 10×10 $\mu m^2$ area with the grid interval of 40nm.