Fast Aerial Image Simulation for Partially Coherent Systems by TCC Decomposition with Analytical Kernels

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Aerial image simulation is one of the most critical components in the model-based optical proximity correction (OPC) for optical lithography. In Hopkins' theory for partially coherent systems [1], the aerial image is formulated by introduction of the transmission cross coefficient (TCC), which can be decomposed into many eigenvectors with their eigenvalues based on matrix treatment such as singular value decomposition (SVD). It is then possible to use a fewer eigenvectors to accelerate the aerial image calculation. However, since TCC is a four-dimensional matrix, its decomposition by SVD method is quite time-consuming, and the eigenvectors of TCC are usually unknown and need to be re-decomposed if the TCC size changes.

In this paper we propose a TCC decomposition method with pre-defined analytical kernels, which can be circle sampling functions, Zernike polynomials, Fourier series, or any other orthogonal functions. The matrix combining the kernels' respective coefficients can be treated as the projection matrix of TCC on the selected function space, and can be fixed for a given system and pre-defined kernels. Then the aerial image for a given mask can be quickly calculated by the lookup table algorithm using one basis mask pattern [2].

We performed simulations of TCC decomposition and aerial image calculation for a partially coherent system. As an example, Figure 1(a) and 1(b) present some typical kernels and the TCC reconstruction error, respectively. Table 1 shows the calculation runtime by the proposed method compared with that by the SVD method. It is noted that the runtime remains almost the same for different TCC size, as the calculation is performed in an analytical way. Therefore, it is expected to achieve a high aerial image resolution with a small TCC size, which is an important advantage over the SVD method. Figure 2 depicts the aerial image simulation results for a five-bar mask pattern compared with that by PROLITH. It demonstrates that the proposed method is not only fast but also accurate enough for aerial image calculation, thus it will have applications in practical OPC systems.

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[1] H. H. Hopkins, Proc. R. Soc. A 217, 408-432 (1953).
[2] S. Y. Liu, X. F. Wu, W. Liu, C. W. Zhang, J. Vac. Sci. Technol. B **29**, 6 (2011).

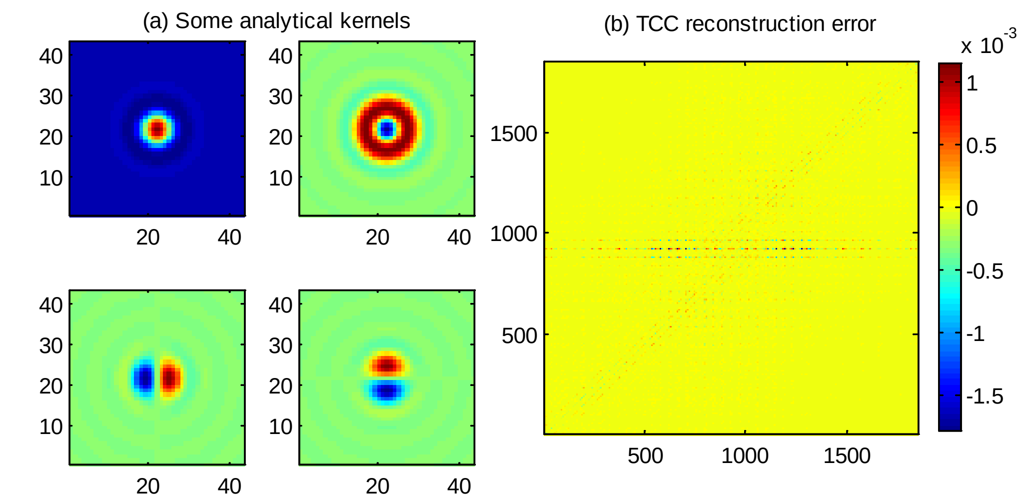

Figure 1: Some typical TCC kernels and its reconstruction error. The partially coherent system is with a conventional source of σ=0.6, λ=193nm, and NA=0.75. The size of TCC matrix is 43^4.

Table 1: The runtime for different TCC matrix size by the proposed method and the SVD method. The calculations are performed with Matlab (version 2010a) on a 3.47GHz Xeon CPU and 16G RAM.

TCC Matrix Size	12^4	24^4	36^4	48^4
SVD Method (sec)	0.02272	2.01705	30.78883	191.50563
Proposed Method (sec)	0.00091	0.00630	0.03012	0.091813

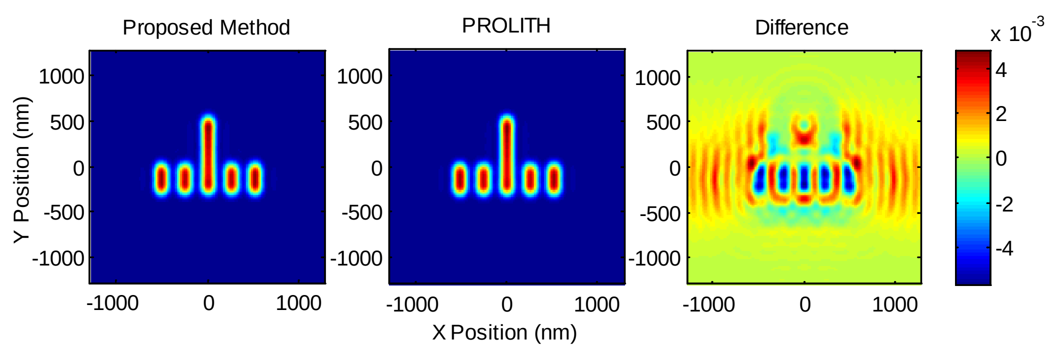

Figure 2: The aerial image simulation by the proposed method and by PROLITH for a five-bar mask pattern with CD=128.67nm and simulation range=2573nm. The partially coherent system is with a conventional source of σ=0.60, λ=193nm, and NA=0.75. The calculations are performed with Matlab (version 2010a) on a 3.47GHz Xeon CPU and 16G RAM, and the runtime for each point is about 2.45×10^{-5} seconds.