A Hybrid Curvilinear Mask Process Correction Method Integrating Shape and Dose Modifications

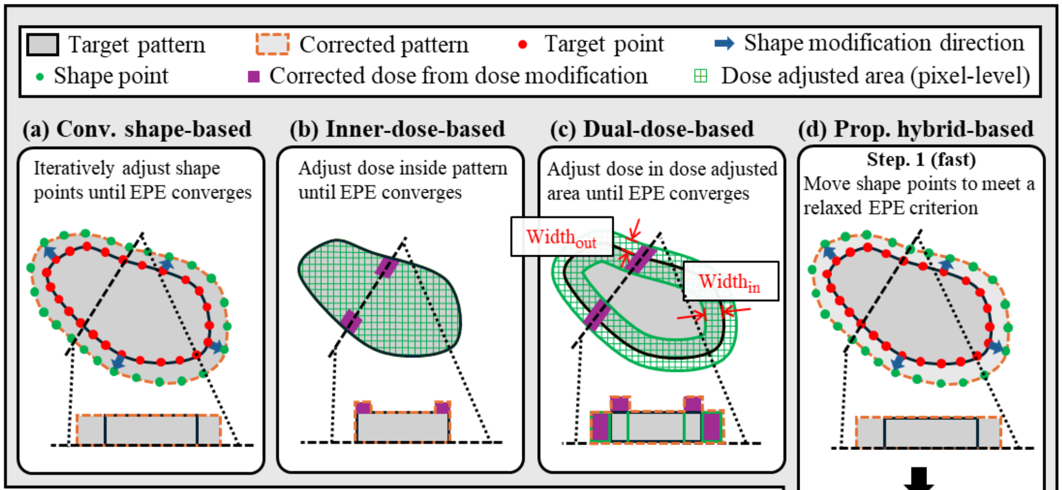
*C.H. Liu, N.T. Wu, Y.L. Chung, S.K. Wong, Z.A. Ding, Y.H. Tu, T.C. Huang, Y.T. Sun, M.G. Tsai and Y.J. Zhong
Dept. of Electrical Engineering, National Taipei University, New Taipei City, Taiwan
**E-mail: chliuzzh@mail.ntpu.edu.tw*

Curvilinear Mask Process Correction (CL-MPC) has become a critical technique for maintaining high-Numerical Aperture (NA) Extreme Ultraviolet (EUV) mask fidelity, ensuring the precise imaging of complex curvilinear patterns generated by Inverse Lithography Technology. Existing CL-MPC methods are generally categorized into shape-based[1] and dose-based modification[2] methods. The former is efficient but with lower fidelity, while the latter is higher fidelity but costly. To overcome this trade-off, we propose a hybrid-based modification method that integrates the strengths of both to improve accuracy and efficiency at the same time, validating our proposed method through the following steps: (1) We established a parametric point spread function model under a 50 keV acceleration voltage to simulate the absorbed-energy distribution within a 64 nm HSQ resist layer for high-NA EUV mask pattern prediction; (2) applied a shape-based, two dose-based and our proposed hybrid modification method to modify corrected pattern; (3) compared the fidelity of the corrected exposure contours and the computational efficiency of these four modification methods upon achieving EPE convergence. Figure 1 illustrates the adjusting strategies of the four modification methods used to modify the corrected pattern, aiming to best align the corrected exposure contour with the target pattern. Conventional shape-based modification method (Fig. 1(a)) modifies corrected pattern by dissecting edges at fixed intervals and adjusts the shape points. Inner-dose-based modification method (Fig. 1(b)) adjusts the pixel-level dose within the corrected pattern based on energy-intensity error (IE) relative to the nearest edge. Dual-dose-based modification method (Fig. 1(c)) adjusts pixel-level dose both inside and outside the corrected pattern, and the dose adjusted area is determined according to empirical rules. Our proposed hybrid-based modification method (Fig. 1(d)) starts with shape-based modification method. Once the EPE reaches a predefined relaxed criterion, we transition to the dual-dose-based modification method to achieve higher precision.. Figure 2 illustrates the simulation results after applying four modification methods. Conventional shape-based modification method (Fig. 2(a)) only moves boundary segments during each iteration, resulting in faster convergence but lower fidelity due to the lack of fine adjustments for precise details. Inner-dose-based modification method (Fig. 2(b)) limits pixel-level dose adjustment within the pattern. Although pixel-level dose adjusting provides precise adjustments, the limited dose adjustment range results in overexposure (4 times compared to machine limit) in certain areas, making it impractical for real-world applications. Dual-dose-based modification method (Fig. 2(c)) allows for more flexible pixel-level dose adjustments while keeping the maximum dose within machine limit; however, pixel-level dose adjustments still need longer computational time. Hybrid-based modification method (Fig. 2(d)) integrates shape-based and dual-dose-based modification method. By applying the shape-based modification, it achieves efficient convergence; also, by utilizing dual-dose-based modification, it ensures precise pixel-level control and higher fidelity. Thus, the method integrates both the high efficiency of shape-based modification and the high fidelity of pixel-level dose-based modification. Table I summarizes the performance metrics: the hybrid method reduces total runtime by over 80% compared with inner-dose-based modification, lowers the average NMSE by 17.7% relative to shape-based modification, and reduces correction iterations by at least 13%. In conclusion, the proposed hybrid CL-MPC method—starting with shape-based modification followed by localized dose adjustment—successfully combines speed and accuracy, providing an efficient and accurate correction solution for advanced curvilinear EUV mask fabrication.

---

[1] C.-H. Liu et al., *Appl. Phys. Exp.*, vol. 16, no. 1, Art. no. 11001 (2023).

[2] M. Matsumoto et al., *Proceeding of SPIE*, vol. 13216, pp. 132160H (2006)



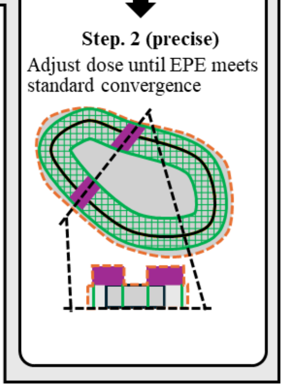
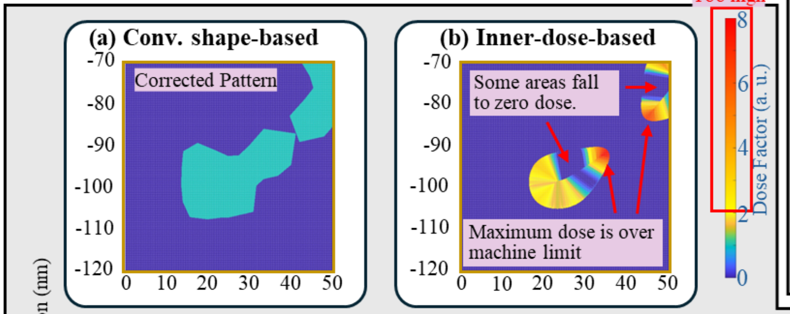


Fig. 1. Illustration of adjusting strategies (a) conventional shape-based, (b) inner-dose-based, (c) dual-dose-based, and (d) proposed hybrid-based modification methods.



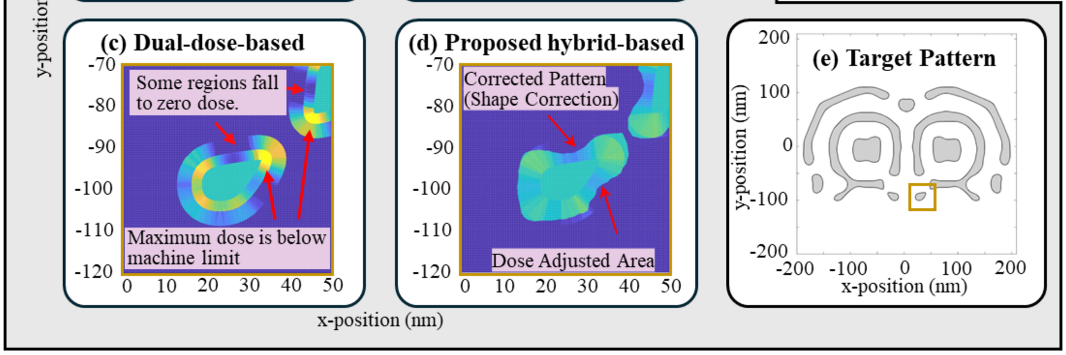


Fig. 2. Simulation result of corrected results after applying four modification methods: (a) conventional shape-based modification method, (b) inner-dose-based modification method, (c) dual-dose-based modification method, and (d) proposed hybrid-based modification method. (e) Full target pattern. The area shown in (a) – (d) corresponds to the brown box in (e).

Table I Comparison of performance indices in terms of fidelity and efficiency among four modification methods. Both absolute values and relative improvements are shown.

Performance index	Modification Methods				Improvement		
	Conv. Shape-based	Inner-dose-based	Dual-dose-based	Prop. Hybrid-based	vs. Conv. Shape-based	vs. Inner-dose-based	vs. Dual-dose-based
EPE_{MAX} (nm)	0.42	0.45	0.42	0.50	-19%	-11.1%	-19%
EPE_{MEAN} (nm)	0.07	0.09	0.04	0.04	42.9%	55.6%	0%
EPE_{SIG} (nm)	0.07	0.05	0.05	0.06	14.3%	-20%	-20%
NMSE (%)	1.08	1.43	0.66	0.73	32.4%	49%	-10.6%
Iteration (times)	16	119	14	13	18.6%	89.1%	13.3%
$Runtime_{Single}$ (s)	0.27	2.17	1.74	0.40	-48.1%	81.6%	77%
$Runtime_{Total}$ (s)	4.39	257.72	26.14	25.23	-19.1%	90.2%	80%

Fidelity improvement

Computational efficiency improvement

Runtime improvement