LithoBench: Benchmarking AI Computational Lithography for Semiconductor Manufacturing

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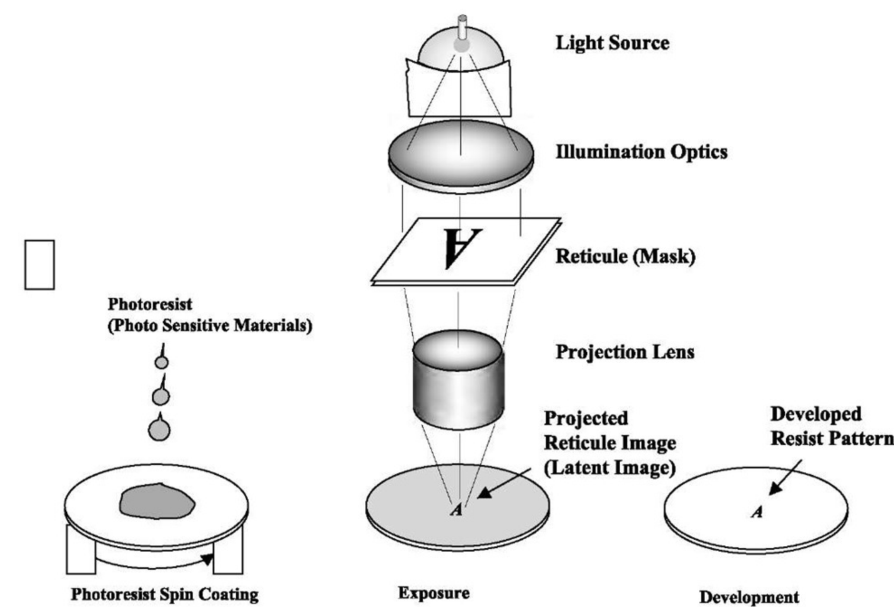
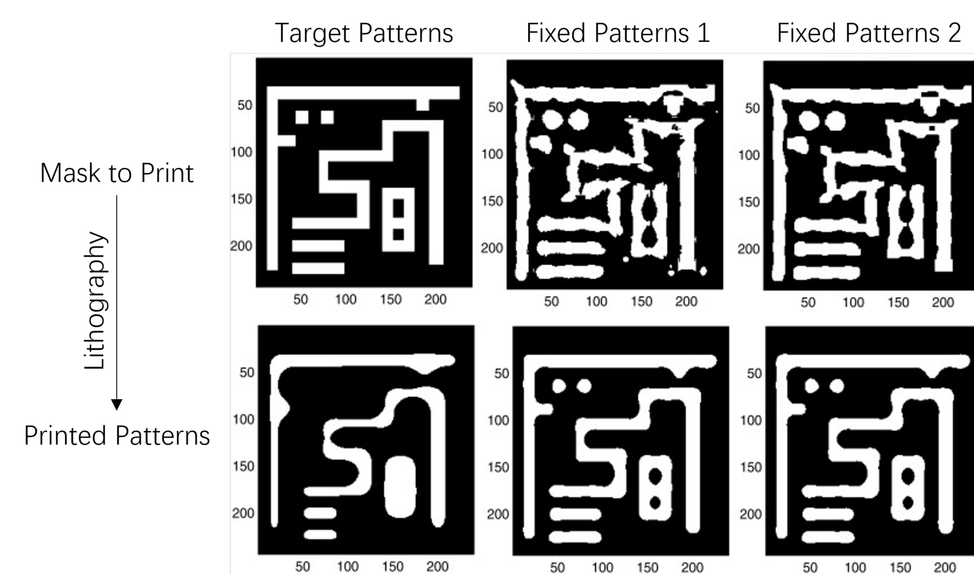
Introduction

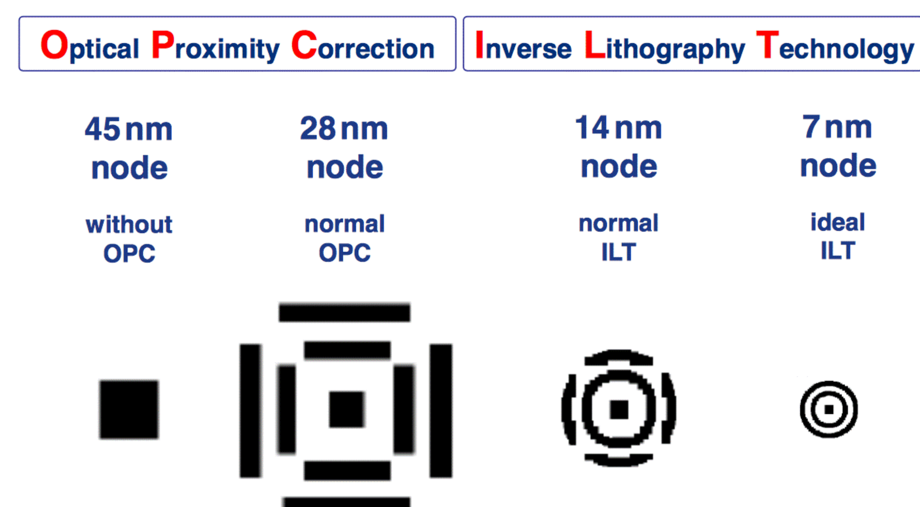
- Semiconductor lithography



- Fail to get target patterns due to the distortion brought by lithography
  → Fix it by distoring the mask!

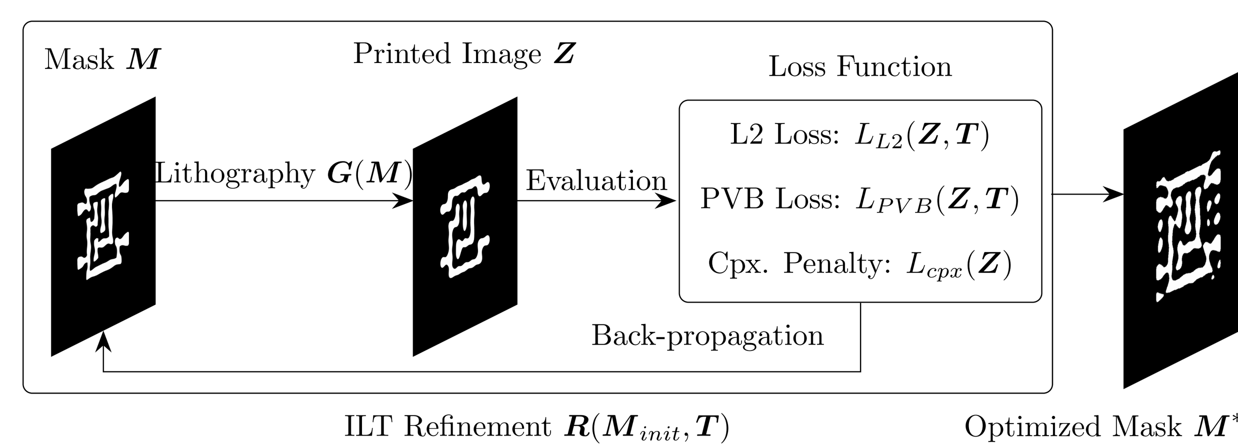


- Mask optimization: OPC vs. ILT

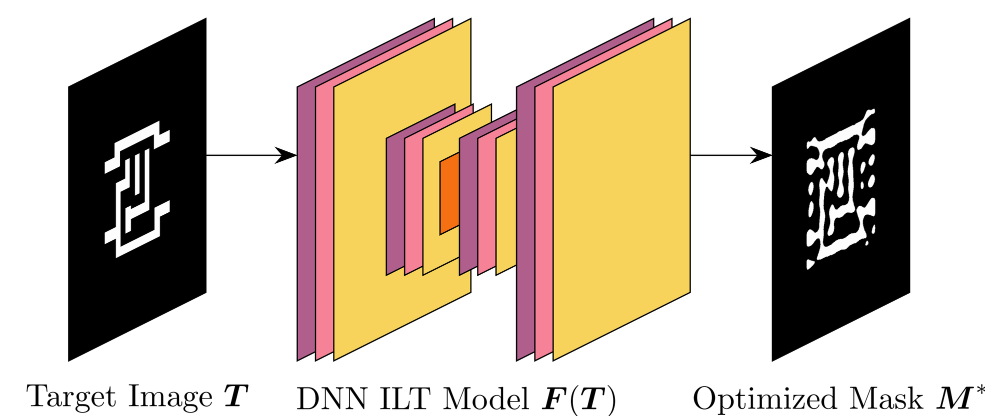


Tasks

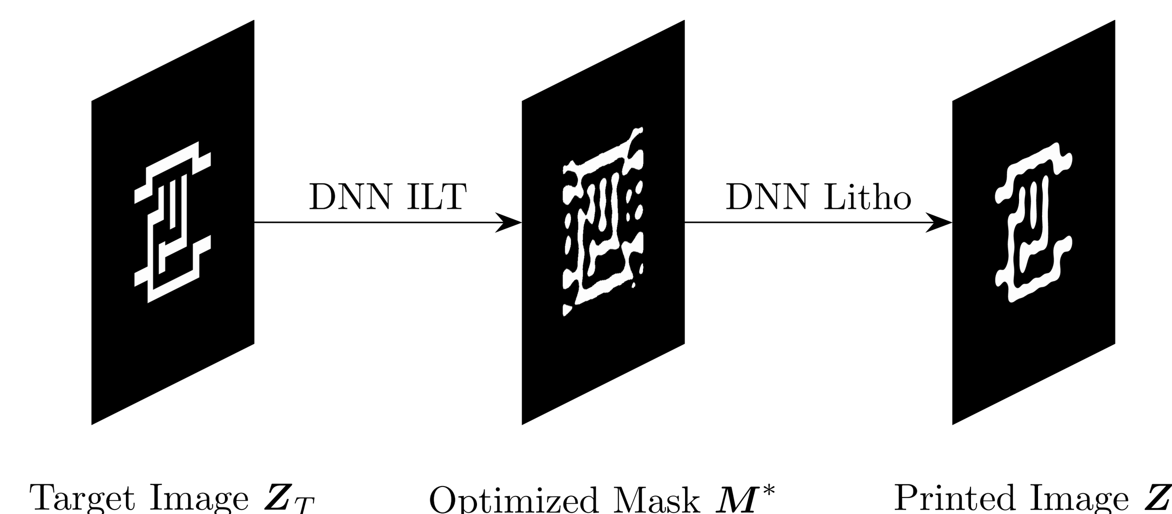
- ILT → iterative optimization



- DNN-based ILT → end-to-end, faster



- LithoBench Tasks
  - **Lithography simulation**
    - Mask → printed image (DNN ILT)
  - **Mask optimization**
    - Target image → optimized mask (DNN Litho)



Dataset

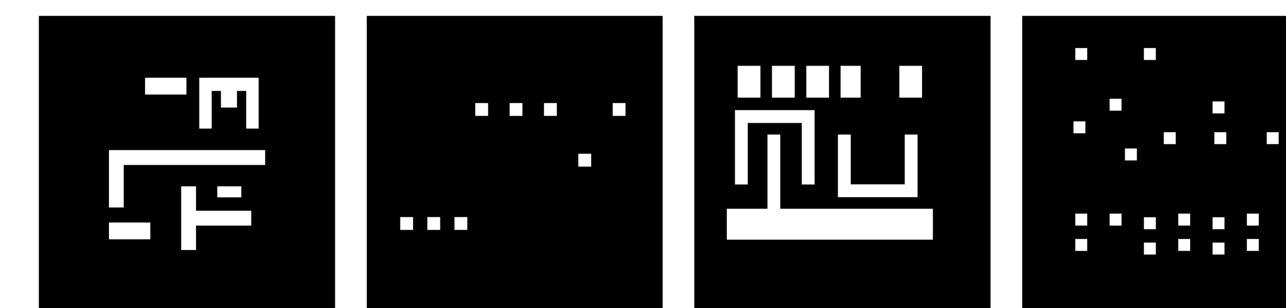
- Targets of the subsets

Subset	Target
MetalSet	for metal layers, compatible with ICCAD-13 benchmark
ViaSet	for via layers, compatible with related works
StdMetal	generalization test of the model trained on MetalSet
StdContact	generalization test of the model trained on ViaSet

- Data collection

Subset	Target	Tiles
MetalSet	generated following the design rules of ICCAD-13	16,472
ViaSet	cropped from the layouts generated by OpenROAD	116,415
StdMetal	cropped from the metal layer of 45nm circuit cells	271
StdContact	cropped from the contact layer of 45nm circuit cells	328

- Examples

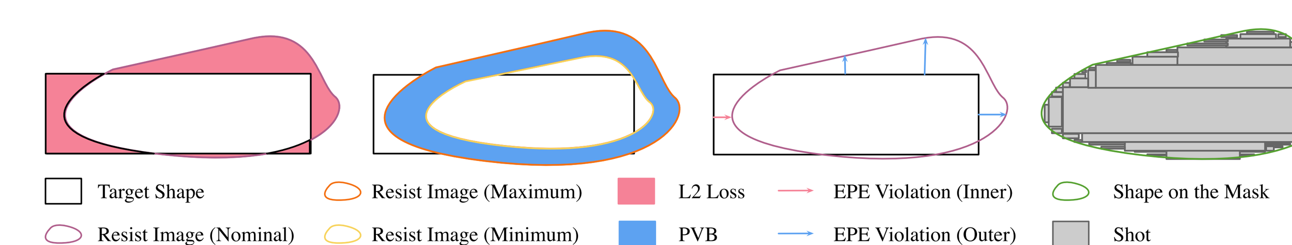


- Lithography simulation metrics ($Z_1 = \{Z = 1\}$)

$$\text{IOU}(Z, T) = \frac{Z_1 \cap T_1}{Z_1 \cup T_1} \quad (1)$$

$$\text{PA}(Z, T) = \frac{Z_1 \cap T_1}{T_1} \quad (2)$$

- Mask optimization metrics
  (a) *L2*; (b) *PVB*; (c) *EPE*; (d) *#Shots*



Results

- Lithography simulation models

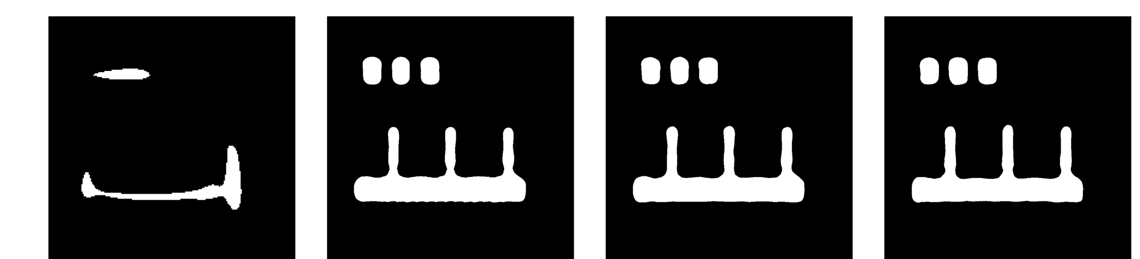
Model	Architecture	Resolution
LithoGAN	CGAN with FCN generator and CNN discriminator	256×256
DAMO	CGAN with UNet++ generator and CNN discriminator	1024×1024
DOINN	Reduced Fourier neural operator architecture	1024×1024
CFNO	Vision transformer + Fourier neural operator	1024×1024

- Mask optimization models

Model	Architecture	Resolution
GAN-OPC	CGAN with- the novel ILT-guided pretraining	256×256
Neural-ILT	UNet generator with complexity reduction loss	512×512
DAMO	CGAN with UNet++ generator and CNN discriminator	1024×1024
CFNO	Vision transformer + Fourier neural operator	1024×1024

- Comparison on lithography simulation

	LithoGAN				DAMO				DOINN				CFNO			
Subtask	MSE_A	MSE_P	IOU	PA	MSE_A	MSE_P	IOU	PA	MSE_A	MSE_P	IOU	PA	MSE_A	MSE_P	IOU	PA
1	$9.8 \cdot 10^{-4}$	$1.7 \cdot 10^{-2}$	0.38	0.43	$\mathbf{8.4 \cdot 10^{-6}}$	$7.5 \cdot 10^{-4}$	**0.97**	**0.98**	$8.5 \cdot 10^{-6}$	$\mathbf{6.6 \cdot 10^{-4}}$	**0.97**	**0.98**	$1.9 \cdot 10^{-5}$	$1.5 \cdot 10^{-3}$	0.94	0.97
2	$2.6 \cdot 10^{-4}$	$1.4 \cdot 10^{-3}$	0.47	0.53	$3.0 \cdot 10^{-6}$	$1.5 \cdot 10^{-4}$	0.94	0.96	$\mathbf{1.9 \cdot 10^{-6}}$	$\mathbf{1.0 \cdot 10^{-4}}$	**0.96**	**0.98**	$3.8 \cdot 10^{-6}$	$2.1 \cdot 10^{-4}$	0.92	0.96
3	$1.4 \cdot 10^{-3}$	$2.6 \cdot 10^{-2}$	0.30	0.34	$2.5 \cdot 10^{-5}$	$1.5 \cdot 10^{-3}$	0.95	0.97	$\mathbf{1.8 \cdot 10^{-5}}$	$\mathbf{1.2 \cdot 10^{-3}}$	**0.96**	**0.98**	$2.6 \cdot 10^{-5}$	$2.3 \cdot 10^{-3}$	0.93	0.96
4	$2.7 \cdot 10^{-3}$	$1.2 \cdot 10^{-2}$	0.01	0.01	$4.6 \cdot 10^{-5}$	$1.6 \cdot 10^{-3}$	0.87	0.93	$2.4 \cdot 10^{-5}$	$\mathbf{1.3 \cdot 10^{-3}}$	**0.90**	**0.94**	$\mathbf{2.1 \cdot 10^{-5}}$	$2.2 \cdot 10^{-3}$	0.83	0.90
Average	$1.3 \cdot 10^{-3}$	$1.4 \cdot 10^{-2}$	0.29	0.33	$2.1 \cdot 10^{-5}$	$1.0 \cdot 10^{-3}$	0.93	0.96	$\mathbf{1.3 \cdot 10^{-5}}$	$\mathbf{8.2 \cdot 10^{-4}}$	**0.95**	**0.97**	$1.7 \cdot 10^{-5}$	$1.5 \cdot 10^{-3}$	0.91	0.95
Runtime	**0.013** s / image				0.030 s / image				0.017 s / image				0.035 s / image			



- Comparison on mask optimization

	GAN-OPC				Neural-ILT				DAMOILT				CFNO			
Subtask	L_2	PVB	EPE	Shots	L_2	PVB	EPE	Shots	L_2	PVB	EPE	Shots	L_2	PVB	EPE	Shots
1	43414	41290	8.7	574	36670	42666	7.3	476	**32579**	**41173**	**5.4**	523	47814	46131	12.5	**302**
2	14767	**6686**	8.3	**166**	12723	8537	6.2	263	**5081**	9962	**0.0**	176	8949	9890	0.1	184
3	25929	23715	4.6	457	20045	**23548**	2.4	373	**16120**	23796	**0.2**	418	26809	26814	4.2	**232**
4	81378	**4931**	73.2	276	**25422**	41537	**3.2**	**265**	50445	35673	26.7	458	70740	17950	55.1	396
Average	41372	**19156**	23.7	368	**23715**	29072	**4.8**	344	26056	27651	8.0	394	38578	25196	18.0	**279**
Runtime	**0.010** s / image				0.025 s / image				0.028 s / image				0.040 s / image			

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