Machine Learning SRAF Improves OPC Performance at 1X Node and Below
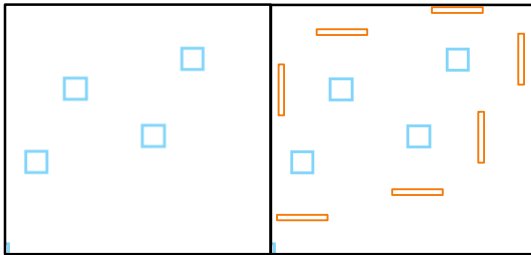
Yuanwei
ICRD/ASML
Oct.2019

- ✓ Patterning Technology Roadmap

- ✓ Machine Learning SRAF Training

- ✓ Machine Learning SRAF Application

- ✓ Wafer Data Verification and Comparison

- ✓ Challenges and Future Plan

- ✓ Summary

Patterning Technology Roadmap

ICRD

Mask
Illumination
OPC
Resist
Integration

Complexity

High-T PSM
MPT
Machine learning?
FinFET
ILT
NTD
SMO
SADP DPT
OMOG
Resist 3D
LELE DPT
Wafer 3D
SAV/SAC
Dipole
Mask 3D
LEC
MBAF
C-Quad
Tri-Layer
6% PSM
Annular
RBAF
APF
MBOPC
PTD
Binary
Conventional
RBOPC

10/7nm
ArF-i/EUV

16/14nm
ArF-i

22/20nm
ArF-i

32/28nm
ArF-i

≧ 45nm
ArF/ArF-i
DUV/I-line

✓ Sub-Resolution Assist Feature (SRAF) has become a normal used resolution enhancement technique.
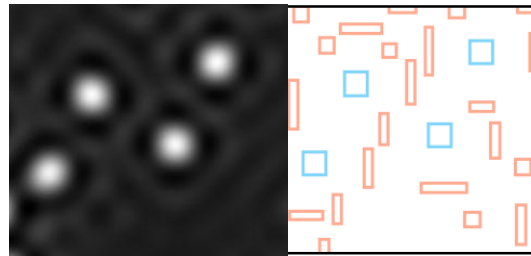
Rule-based

Advantage and Drawbacks:

- Fast run time, works well with simple design or regular repeated patterns.

- Difficult to optimal for complex design patterns. Cost litho and OPC engineer long time and big loading for SRAF rule developing.

Application：
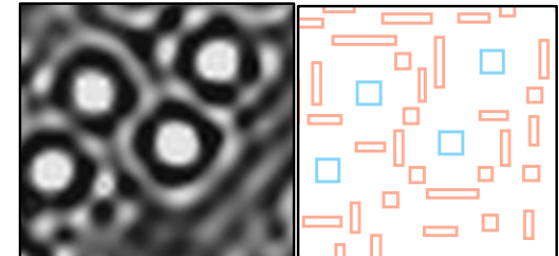
Full chip application

Model-based (SGM)

Advantage and Drawbacks:

- **SRAF Guidance Map (SGM)** makes use of computational lithography model to guide assist feature placement.

- Uses gradient-based map calculation method.

- Shorter development cycle time.

Application：

Full chip application.

Model-based (CTM)
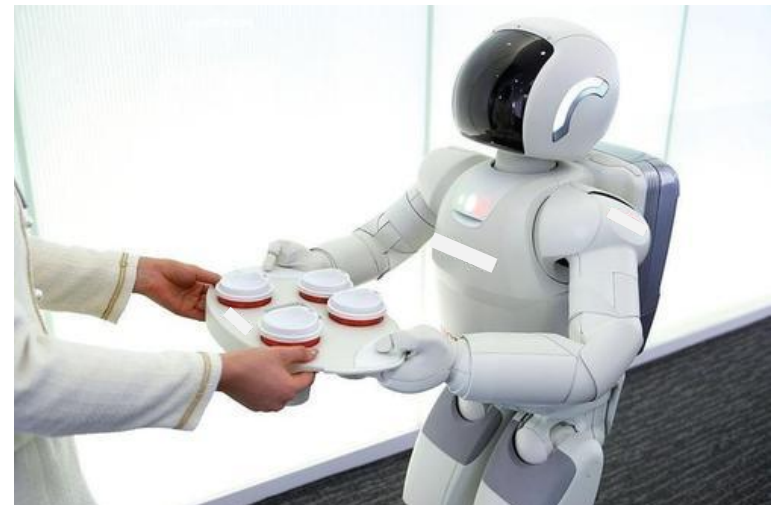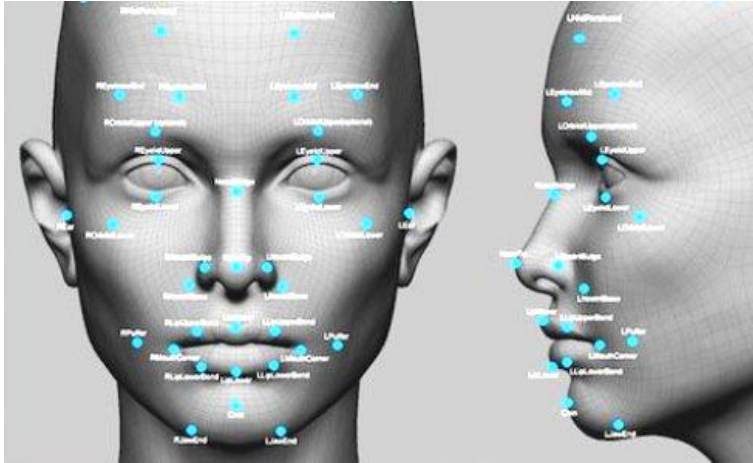

Advantage and Drawbacks:

- **Continuous Transmission Mask (CTM)** is an ILT technology. It models the electric field transmission after the mask plane as CTM image. Many iterations to optimize for SRAF extraction.

- Much longer runtime.

Application：

Clip based or local hotspot repair,

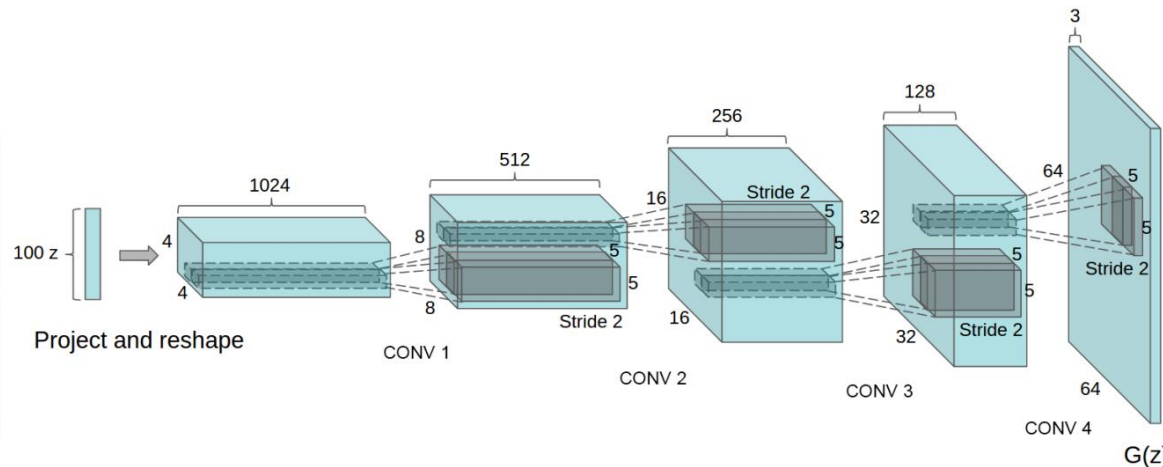key engine for ASML's inverse lithography solution (Tachyon SMO/iOPC)

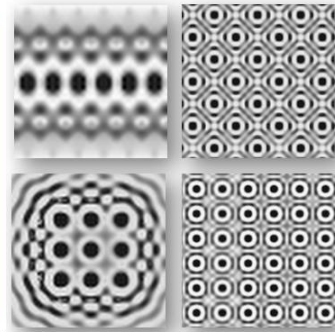✓ Machine learning is changing our lives and it is widely applied in more and more industries.

- ✓ How to apply machine learning technology in OPC for smart SRAF generation and placement to balance the performance and runtime?
- ✓ Newron SRAF is a Deep Convolutional Neural Network (DCNN) based SRAF solution developed by ASML for fast and accurate CTM images extraction and SRAF placement;
- ✓ Newron SRAF method utilizes supervised machine learning technique under Tensor flow framework.
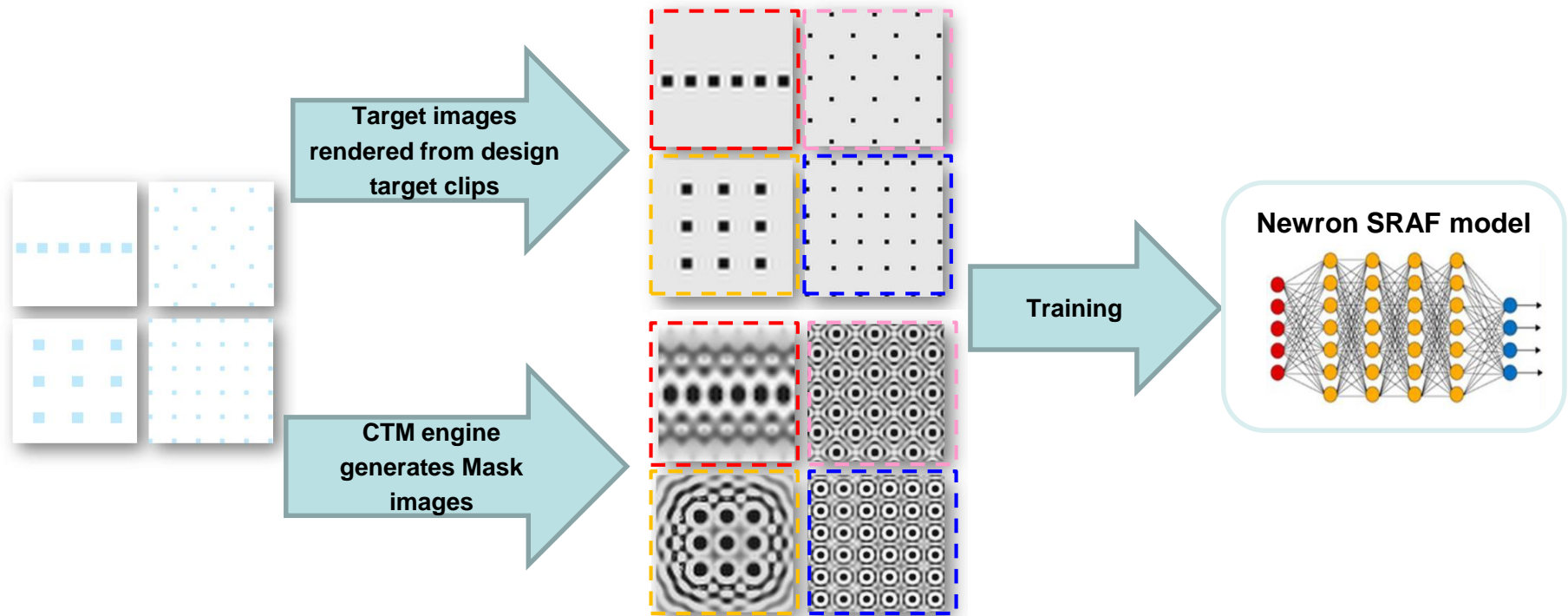
- **Input**
- **Output**

- • Tensor flow: An open source machine learning library for research and production by Google.

✓ Stage1: Data preparation；

✓ Stage2: Newron SRAF model training；

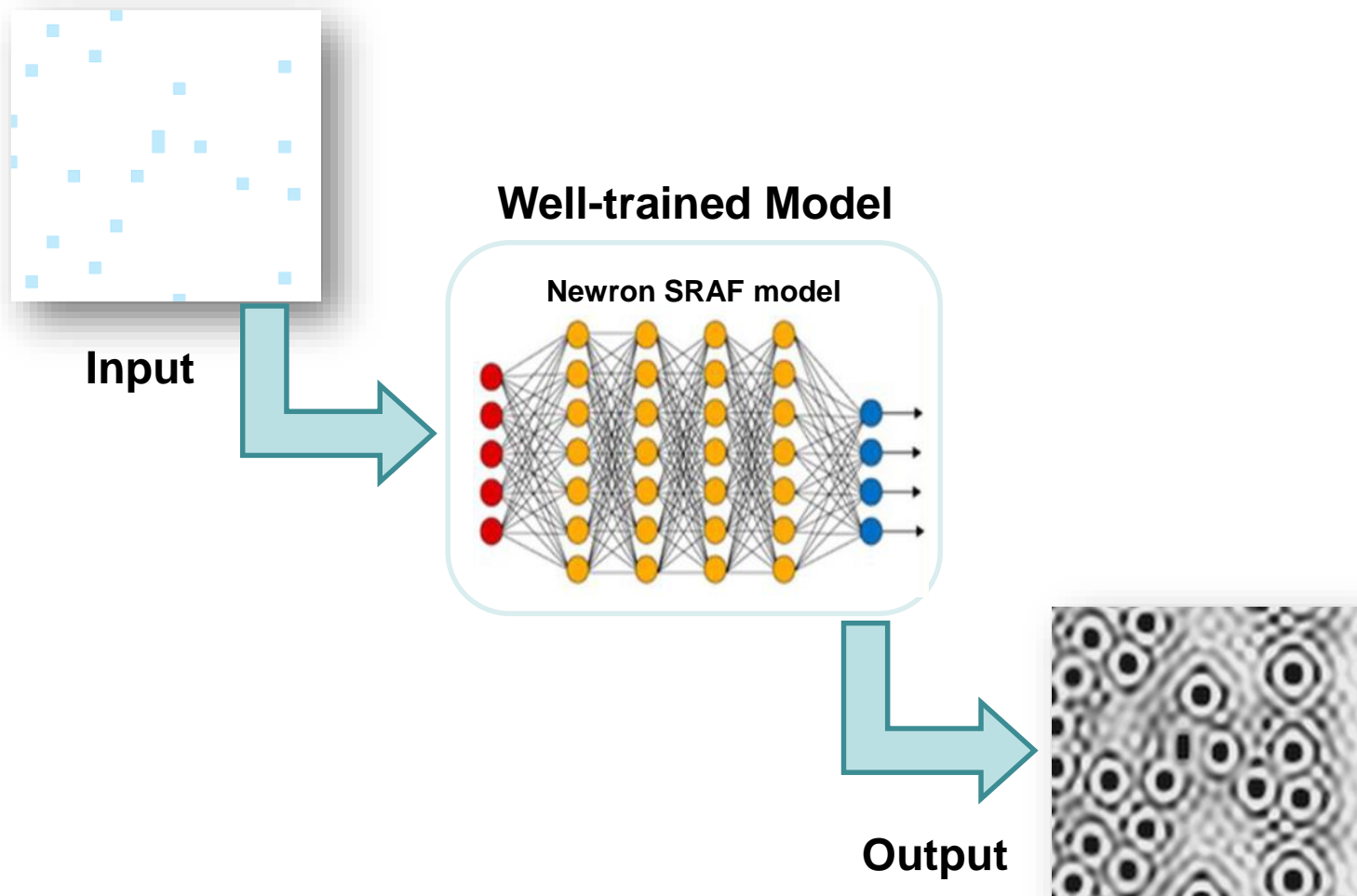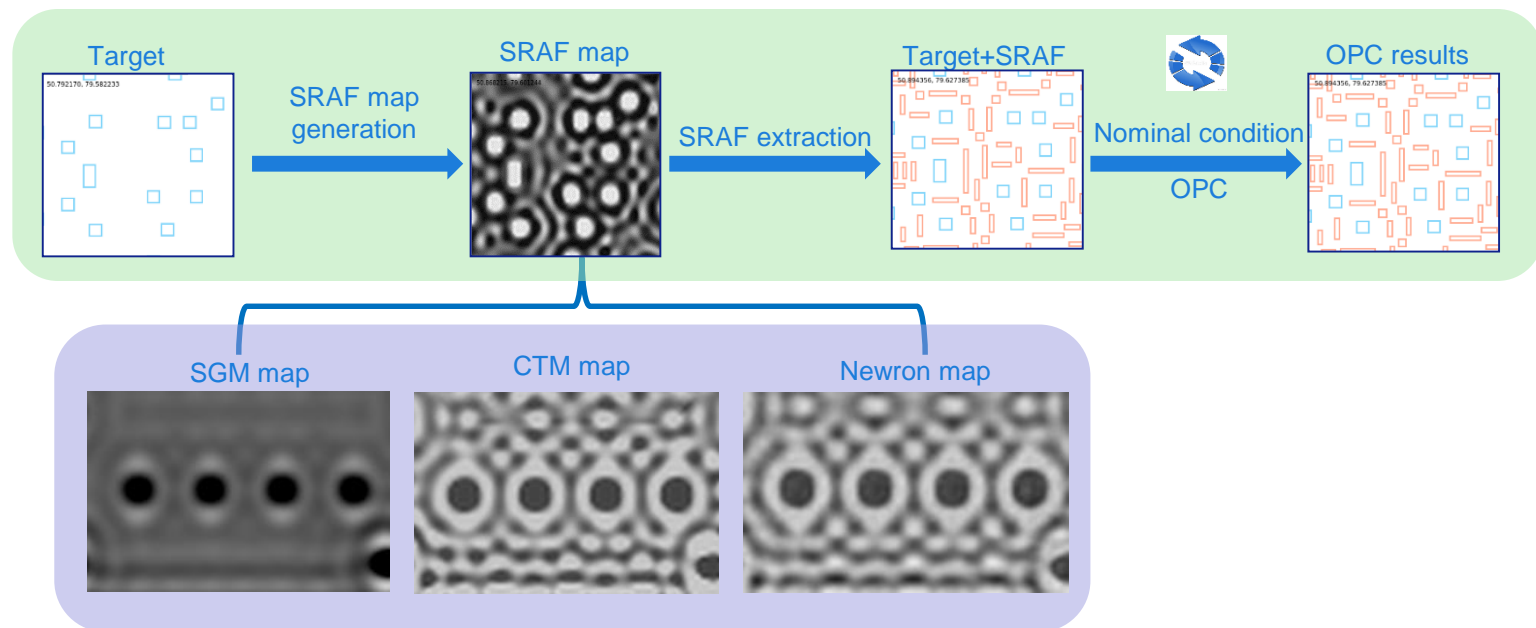Pair images are fed into tensor flow network for Newron SRAF model training.

Target images rendered from design target clips

CTM engine generates Mask images

Training

Newron SRAF model

✓ Stage3, Newron SRAF application.

Apply well trained model on target images.
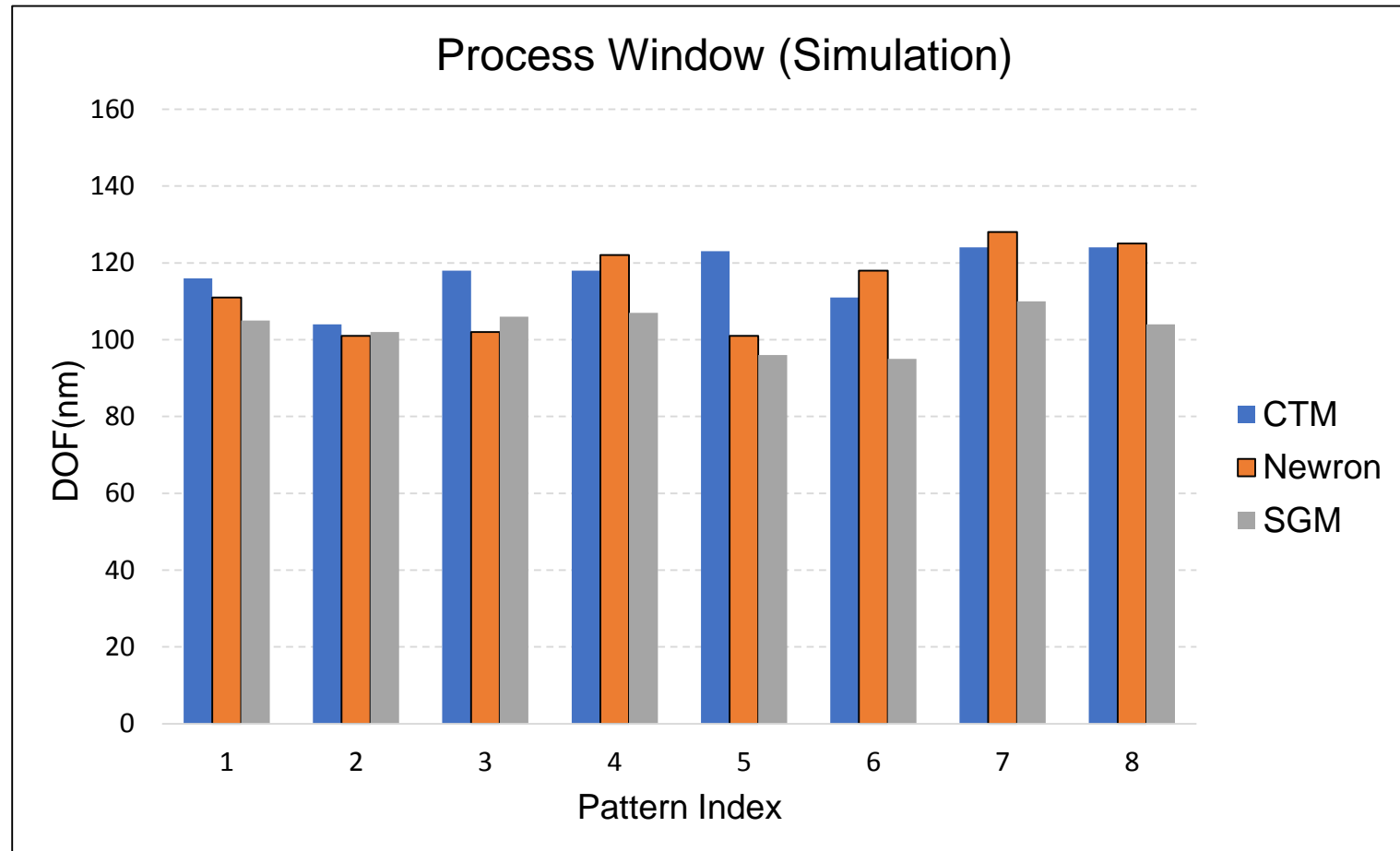
Newron engine output the predicted CTM images.

Input

Well-trained Model

Newron SRAF model

Output

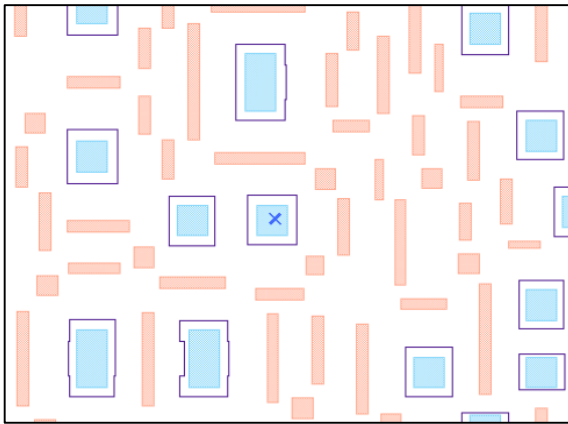✓ Apply three different SRAF solutions on the same design to compare the performances of SGM SRAF, CTM SRAF and Newron SRAF.

✓ Test chip: L14 Via layer gds; chip size 1mm*1mm;
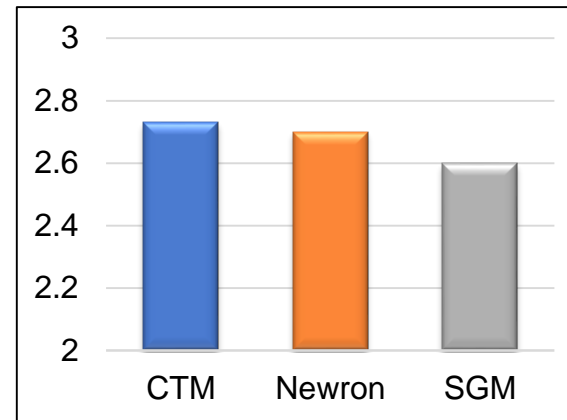✓ OPC model test patterns and a few logic and SRAM patterns are selected for Newron SRAF model training.

ICRD

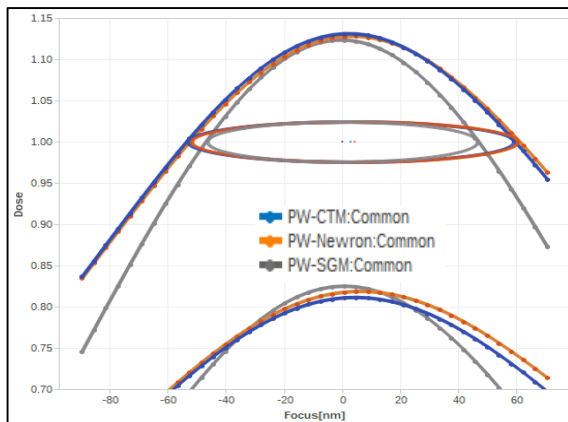✓ Newron SRAF shows comparable process window as CTM SRAF and both of them are better than SGM SRAF.

Process Window (Simulation)

✓ Both of Newron SRAF and CTM SRAF are better than SGM SRAF in terms of process window, NILS and EL.
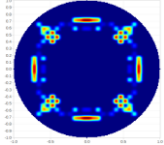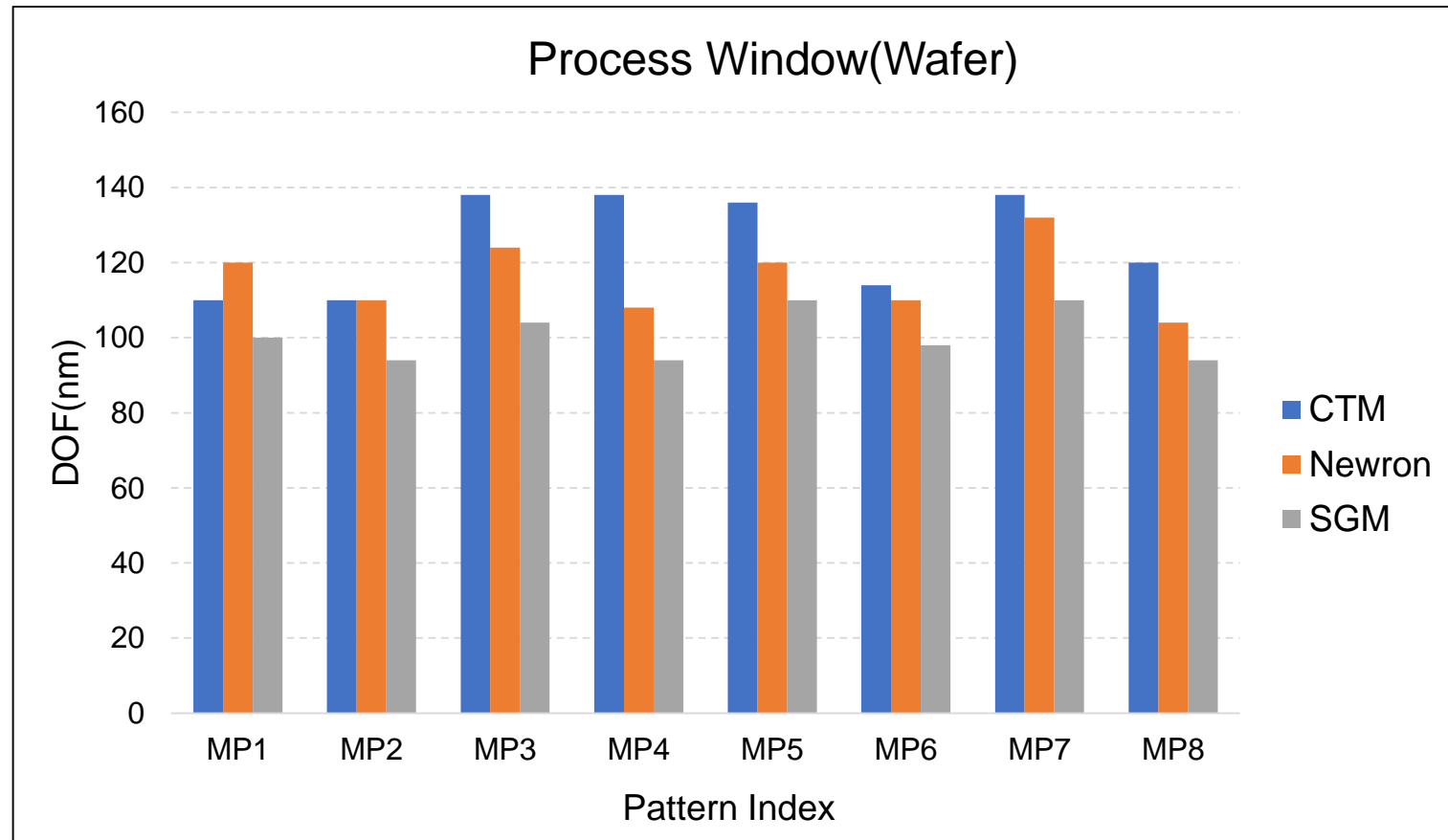

Pattern Layout

NILS

DOF

EL

ADI Spec:53nm +/-10%

Wafer Processing Condition

Item	Condition
Substrate	Si+ ILD Oxide+ NDC+ TEOS+ Low K+ NDC+ NF DARC
Litho Film Stack	SOC 2000A+ Si-ARC 370A+ NTD Resist 850A
Illuminate Source	Freeform Source for 14nm Via0
Mask	6% att-PSM
OPC	ASML Tachyon platform
Scanner	ASML XT1900-Gi with flexray
Track	TEL LITHIUS Pro-Zi with NTD nozzle
CDSEM	Hitachi CG6300

Wafer Processing Result

- ✓ Newron process window is between CTM and SGM's, which shows consistent trend with the simulation results.
- ✓ CTM SRAF brings 24.9% PW improvement and Newron SRAF brings 15.4% PW improvement compare with SGM SRAF method.
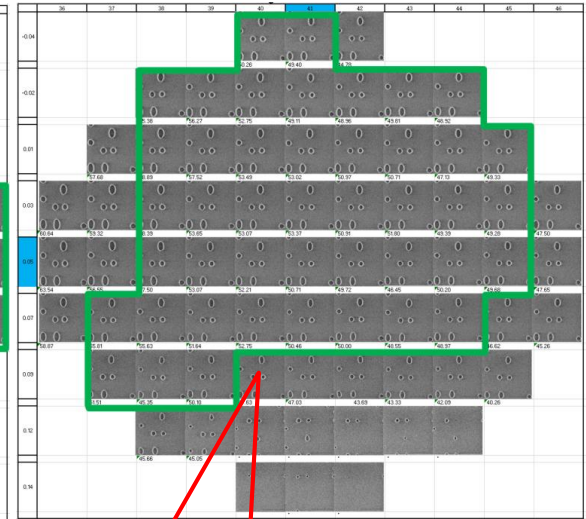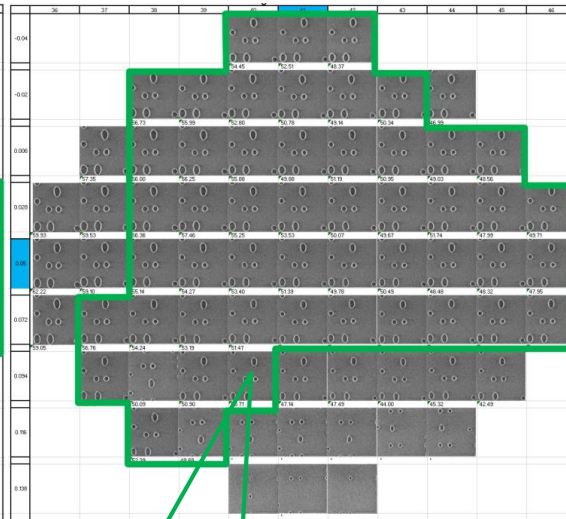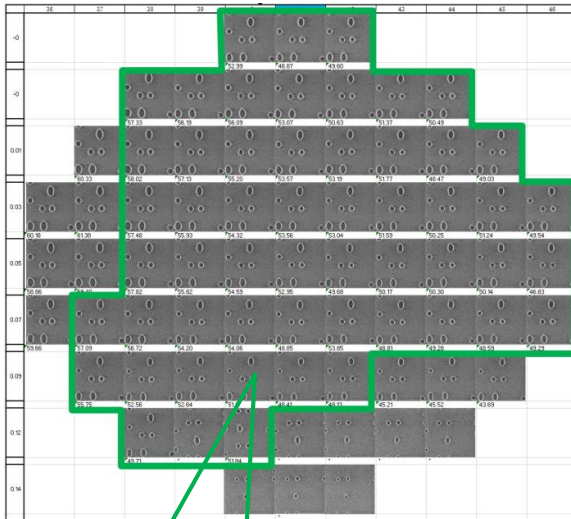
SEM PW Comparison

✓ FEM images show the overall PW improvement of CTM and Newron.
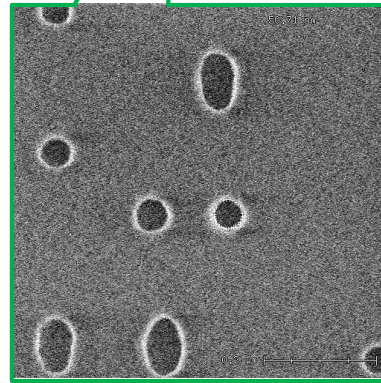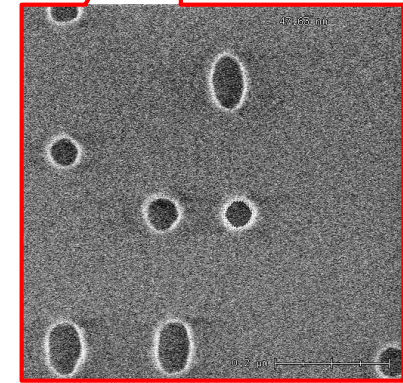
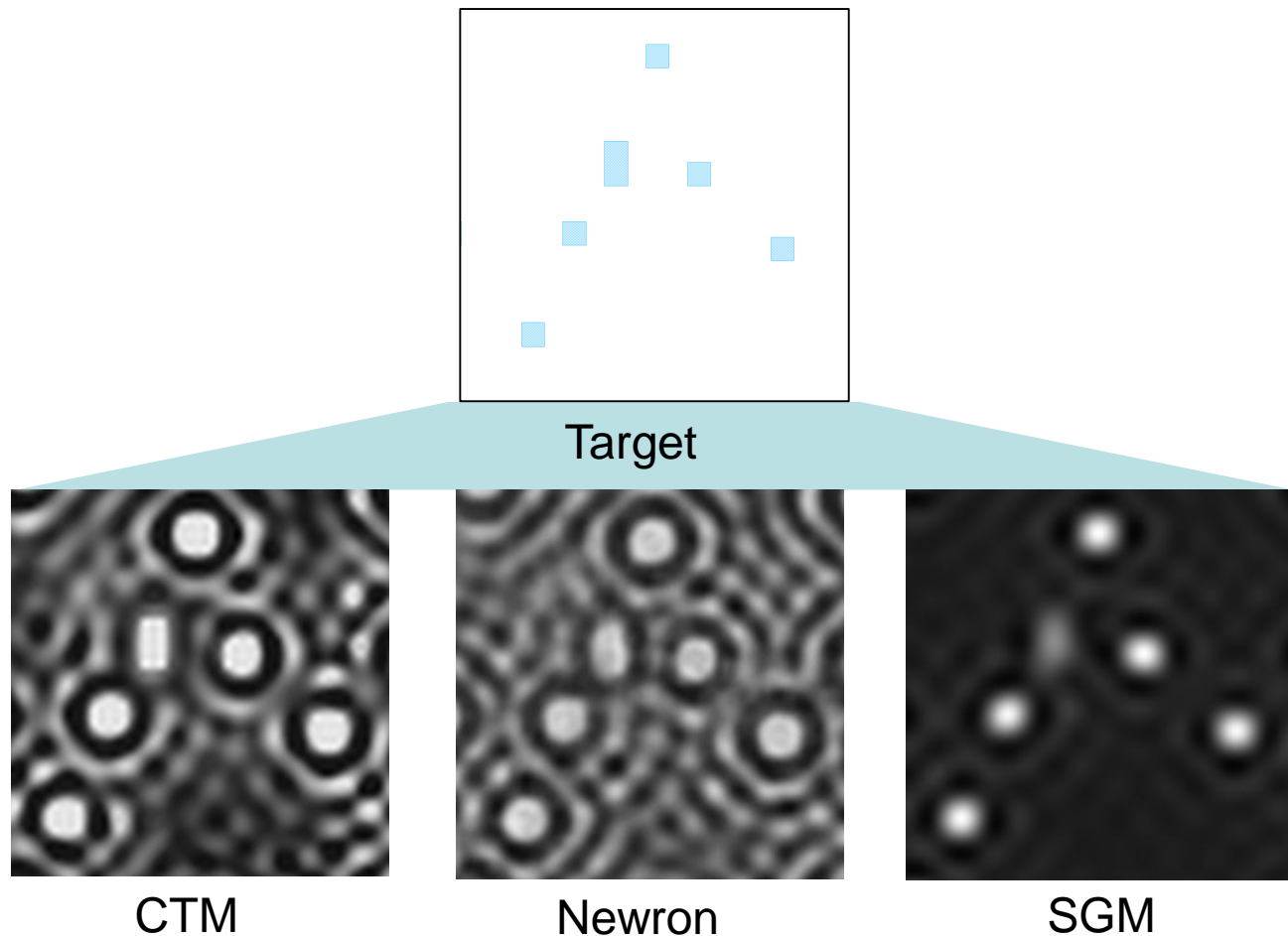| CTM	Newron	SGM

ADI CD:51.17nm ✓

ADI CD: 50.71nm ✓

ADI CD:47.63nm ☐

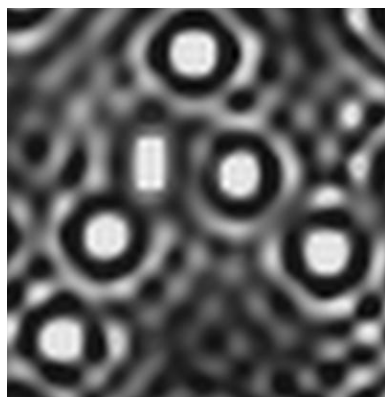*ADI Spec:53nm +/-10%

✓ The mask images extracted from target to guide SRAF placement.

✓ CTM image shows the best image contrast.

✓ Newron image is quite similar as CTM image in shape but with lower contrast.
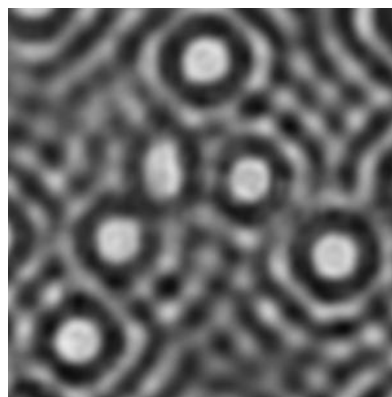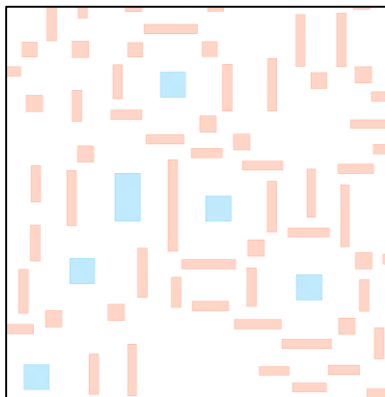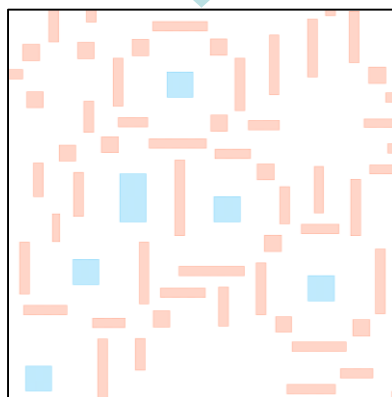

Target

| CTM | Newron | SGM |

✓ CTM method extracts the densest SRAF, and Newron method gets the similar SRAF as CTM; SRAF of SGM is much sparser and isolated.

CTM

Newron
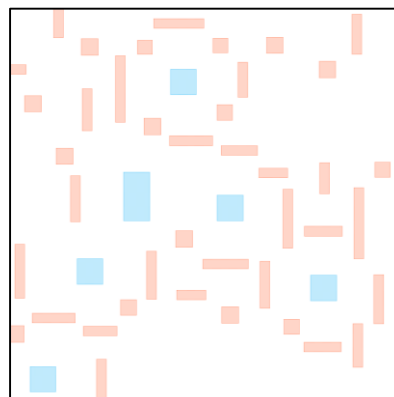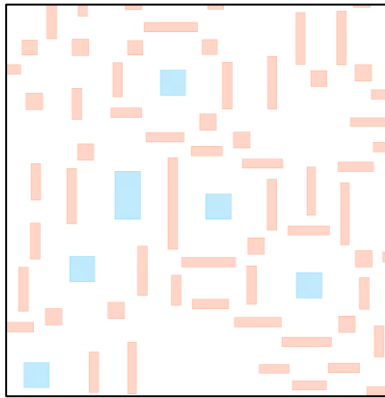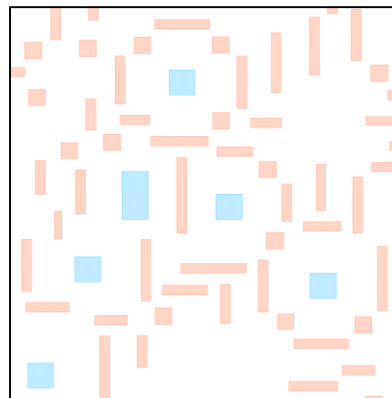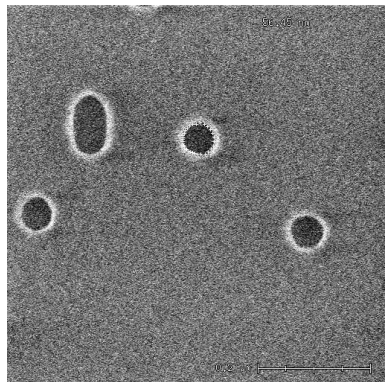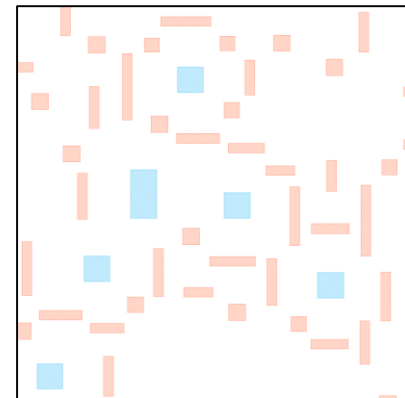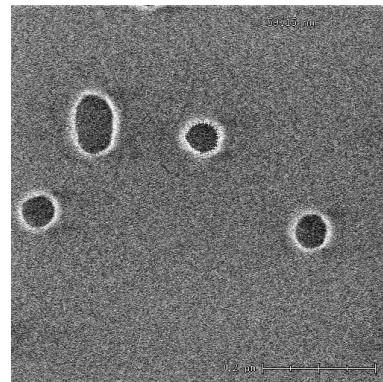
SGM

✓ The SEM images at nominal condition clearly show that CTM SRAF has the best performance and Newron SRAF is pretty close to it.
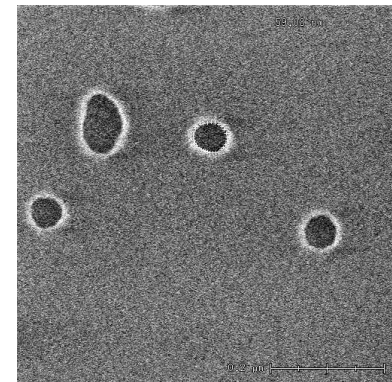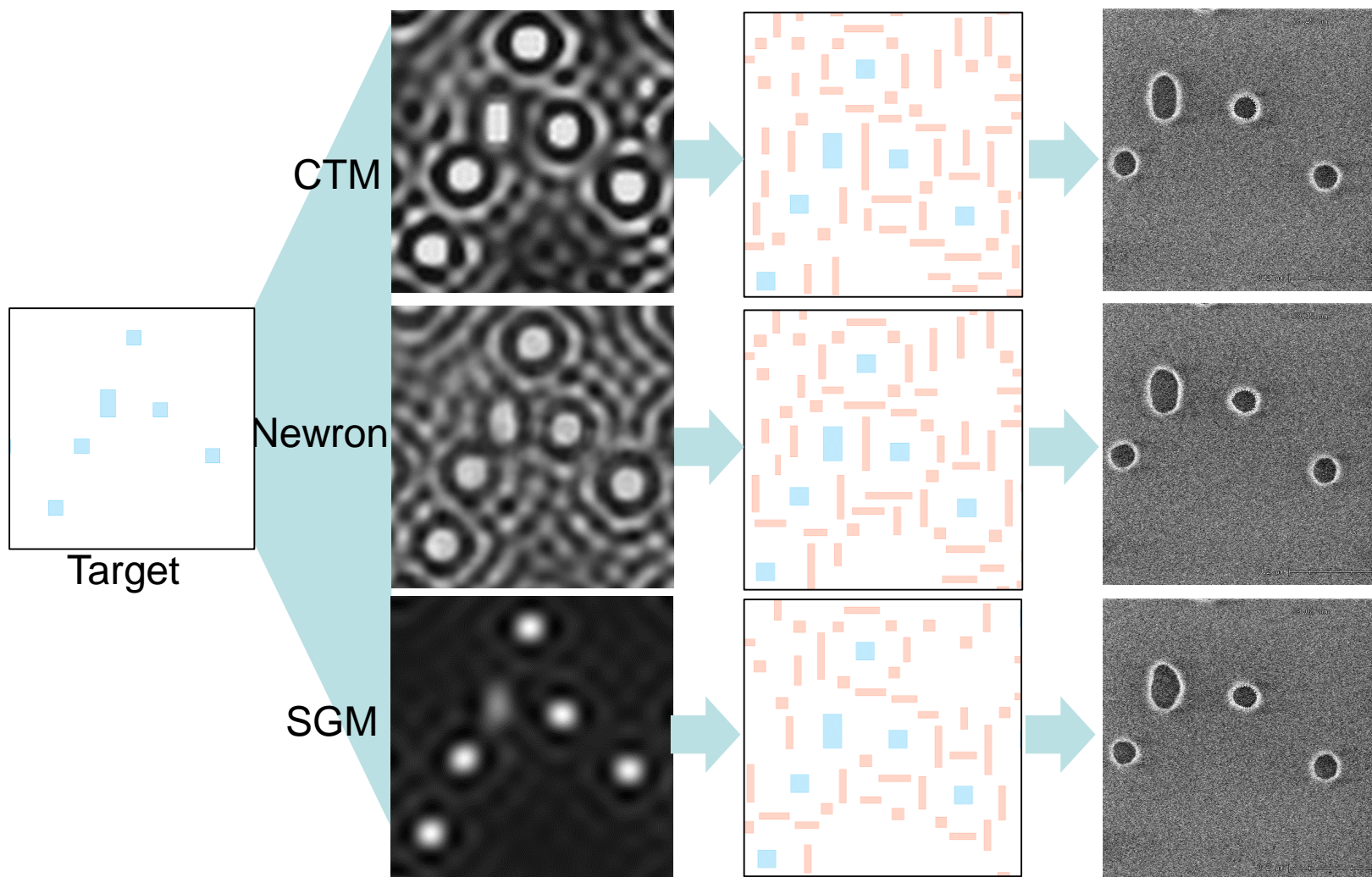

CTM

Newron
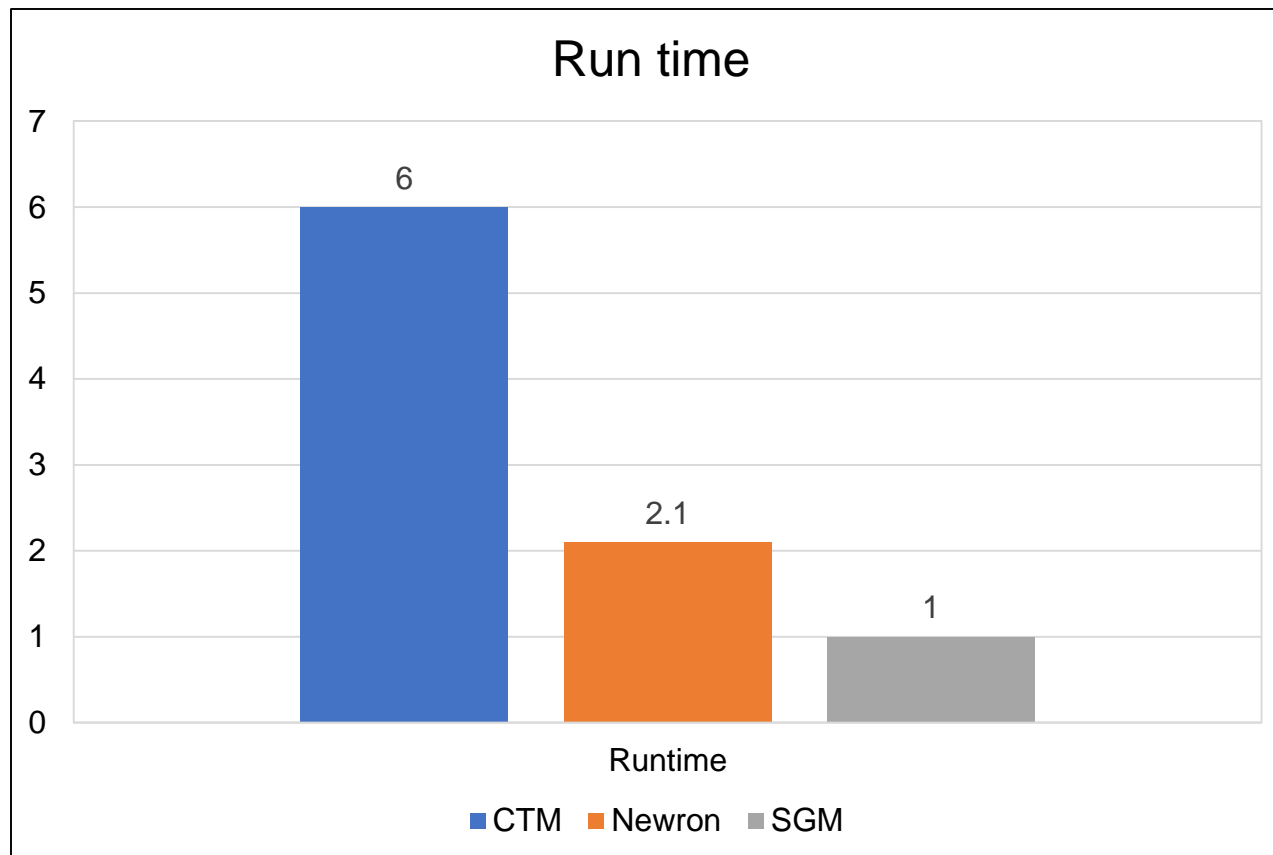

SGM

✓ Newron image is quite similar as CTM image in shape but with lower contrast.

✓ Newron method gets the similar SRAF as CTM.

✓ The SEM images of Newron SRAF is pretty close to that of CTM SRAF.

Target

CTM

Newron

SGM

✓ The run time of Newron SRAF is about 30% of CTM SRAF, only nearly 2X of SGM SRAF.

Challenges and Future Plan

- ✓ Smart pattern selection to ensure pattern coverage for Newron SRAF model training.

- ✓ Further runtime reduction for Newron SRAF model application.

- ✓ Better integration of Newron SRAF model training flow and full-chip Newron SRAF model application flow.

- ✓ Expansion of Machine learning technology from SRAF insertion to holistic lithography(OPC and Verification)

Summary

- ✓ ICRD and ASML-Brion co-worked to test and apply an innovative machine learning SRAF insertion method on 14nm logic Via layer process.

- ✓ The Newron SRAF flow has been optimized and the performance was verified successfully on both logic and SRAM patterns.

- ✓ A Tachyon integrated flow, including Newron SRAF insertion, OPC correction and LMC verification, successfully enables the inversed lithography mask optimization on full chip layout to achieve good imaging performance with affordable run time.

✓ Thank ICRD and ASML-Brion OPC team's great support and co-work to finish this study.

Thank you 谢谢

Q&A 请您提问