HNU-EBL: A Software Toolkit for Electron Beam Lithography Simulation and Optimization

Jie Liu

Professor, PhD

Hunan University

December, 2021
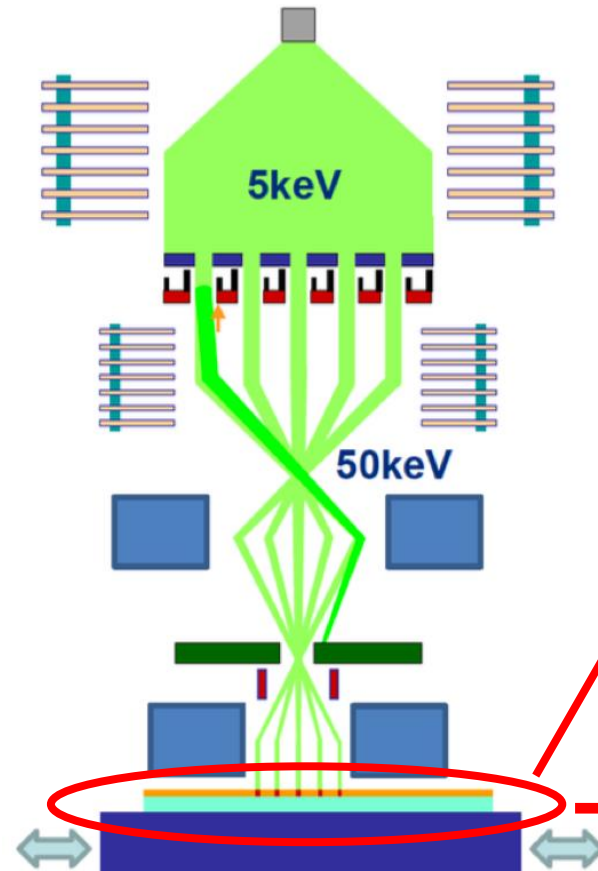
Contents

➢ Background

➢ Software Toolkit

➢ Demonstration

➢ Verification

➢ IP & License
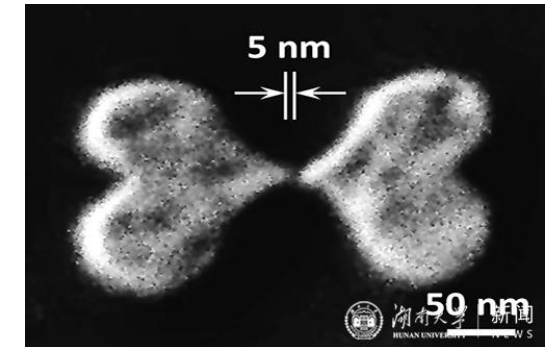
➢ Conclusion

Background

Electron Beam Lithography
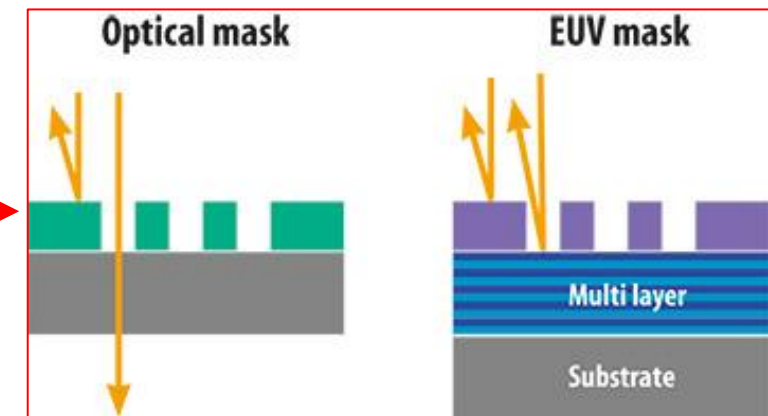
direct-write patterning

EUV mask fabrication

Raith GmbH
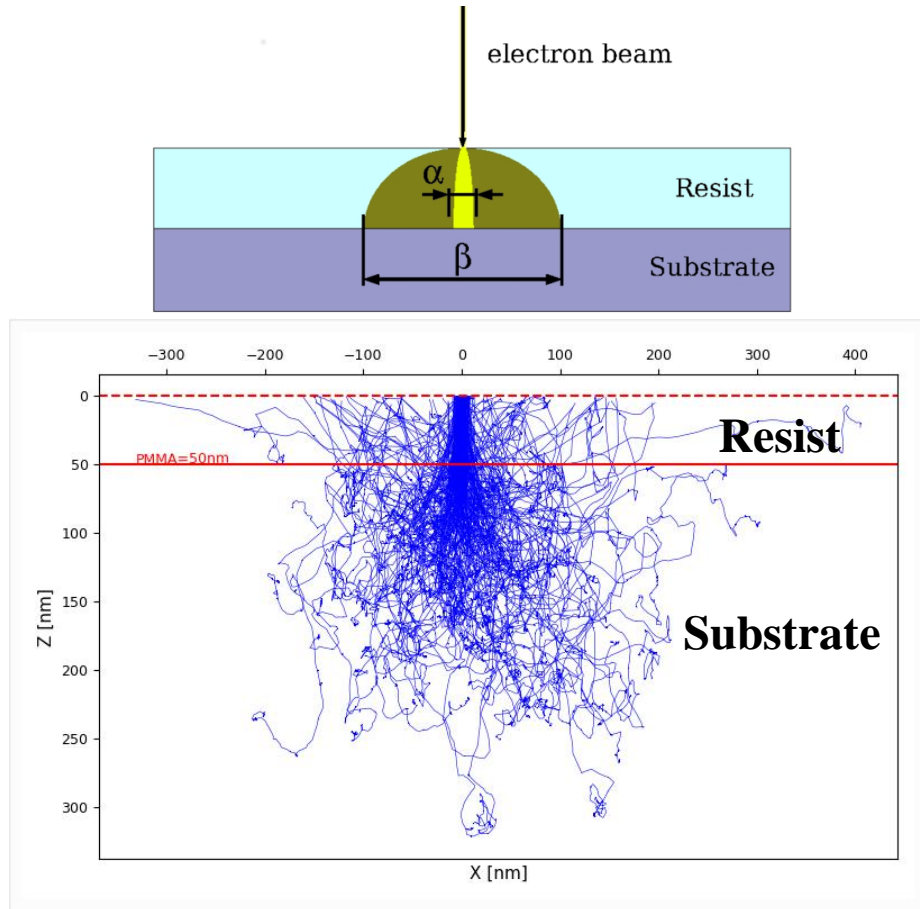
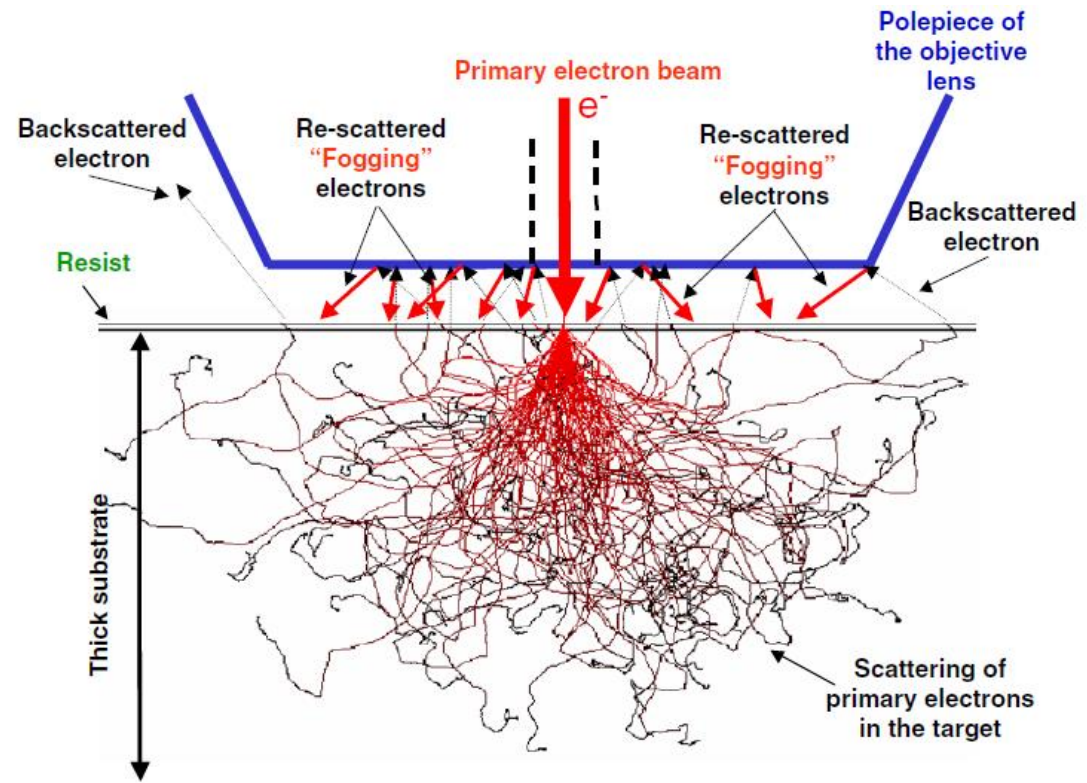IMS Nanofabrication GmbH

© 湖南大学-电气与信息工程学院-刘杰 jie_liu@hnu.edu.cn

Background

(1) proximity effect, (2) fogging effect, (3) loading effect, (4) charging effect, …

PE: Proximity Effect

FE: Fogging Effect

https://doi.org/10.1016/j.mee.2007.01.025

Background

Energy deposition w/o PEC

Layout

Energy deposition with PEC

τ : Development threshold
D: energy density absorbed
H: development results

EBL pattern w/o PEC

EBL pattern with PEC

Background

"Export Control" to P. R. China
by 《Wassenaar Arrangement》:

https://www.wassenaar.org/control-lists/

3. D. 2. "Software" specially designed for the "use" of equipment specified by 3.B.1.a. to f. or 3.B.2.

3. D. 3. 'Computational lithography' "software" specially designed for the "development" of patterns on EUV-lithography masks or reticles.

3. B. 1. f. 3. Equipment specially designed for mask making having all of the following:

a. A deflected focused electron beam, ion beam or "laser" beam; and

b. Having any of the following:

   1. A full-width half-maximum (FWHM) spot size smaller than 65 nm and an image placement less than 17 nm (mean +3sigma); or

   2. Not used since 2015

   3. A second-layer overlay error of less than 23 nm (mean + 3 sigma) on the mask;

"Export Control" to P. R. China
by U.S. federal government:

https://www.govinfo.gov/content/pkg/FR-2020-10-05/pdf/2020-18334.pdf

Destination Control Statement

The technology used in Sentaurus Lithography is strictly controlled for export (under **Export Classification Number 3D003**).
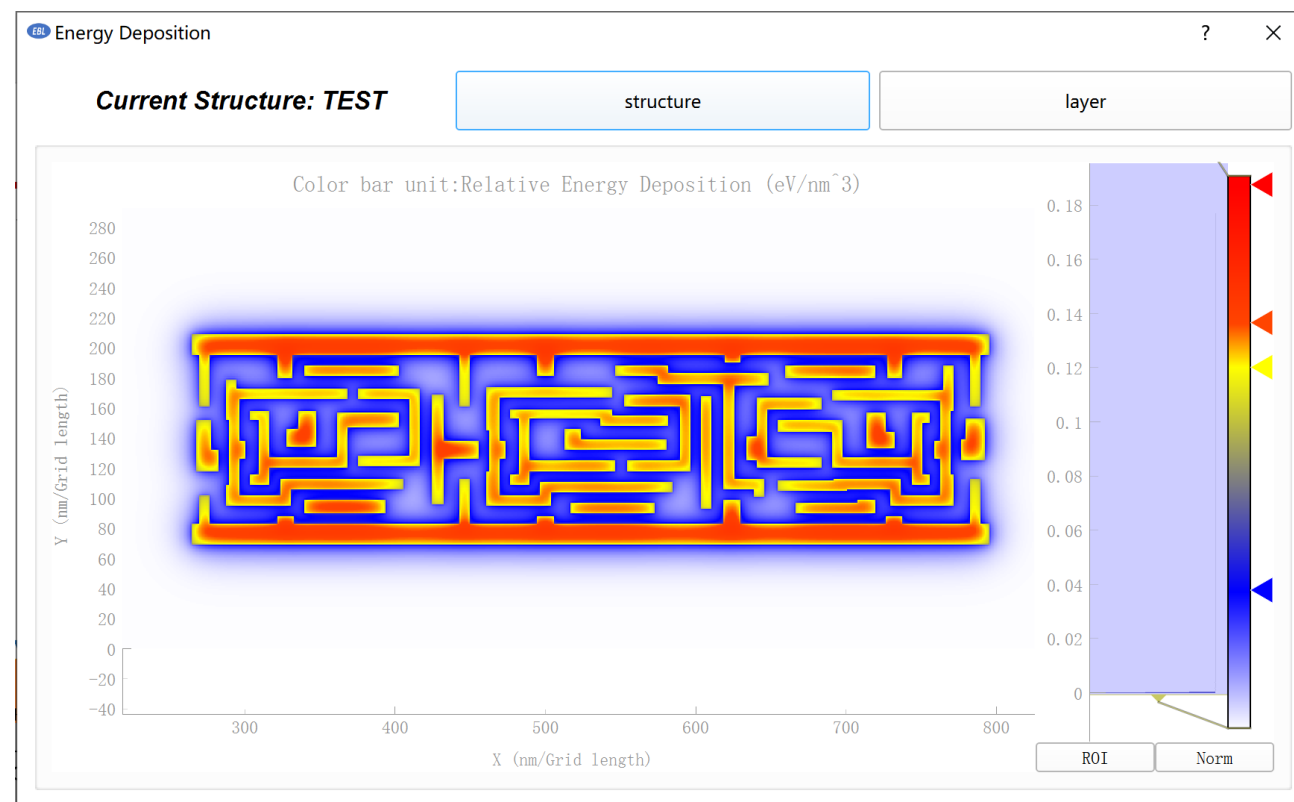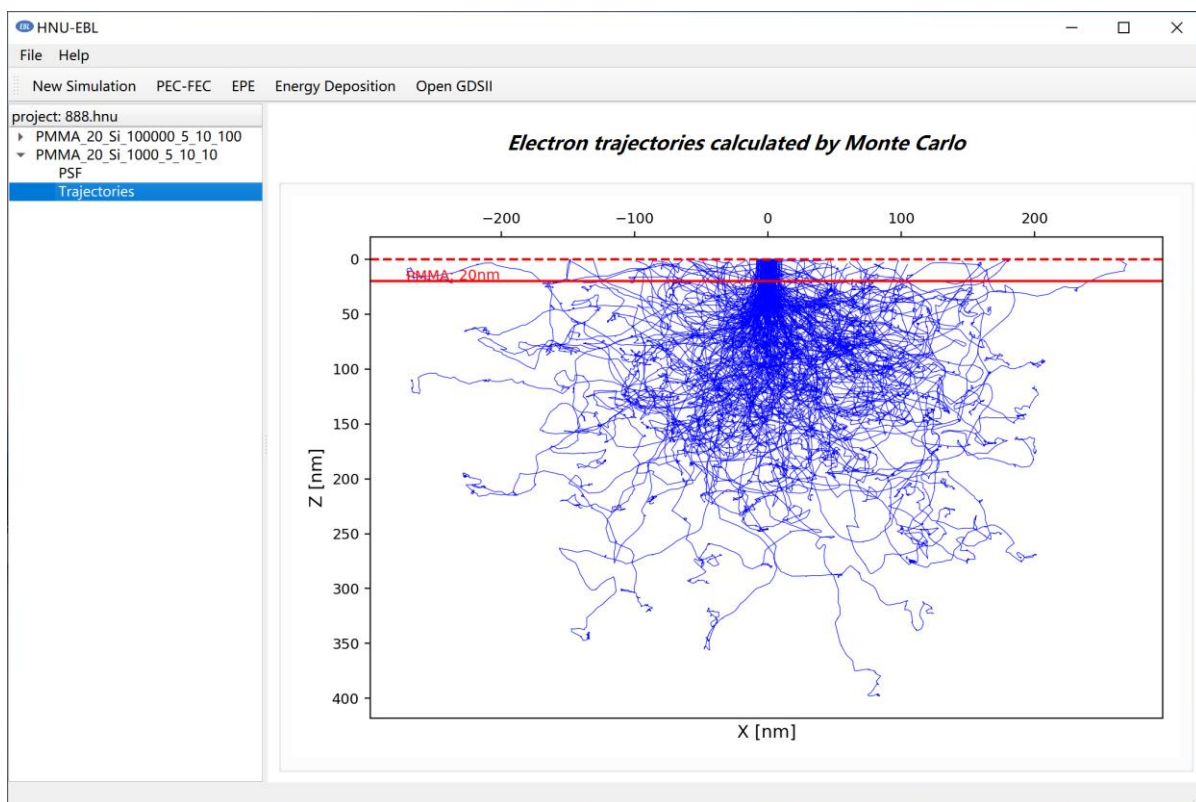
You may not transfer the product or any technical information about the product, or make it available to anyone else, unless you have verified that it is permitted by export laws.
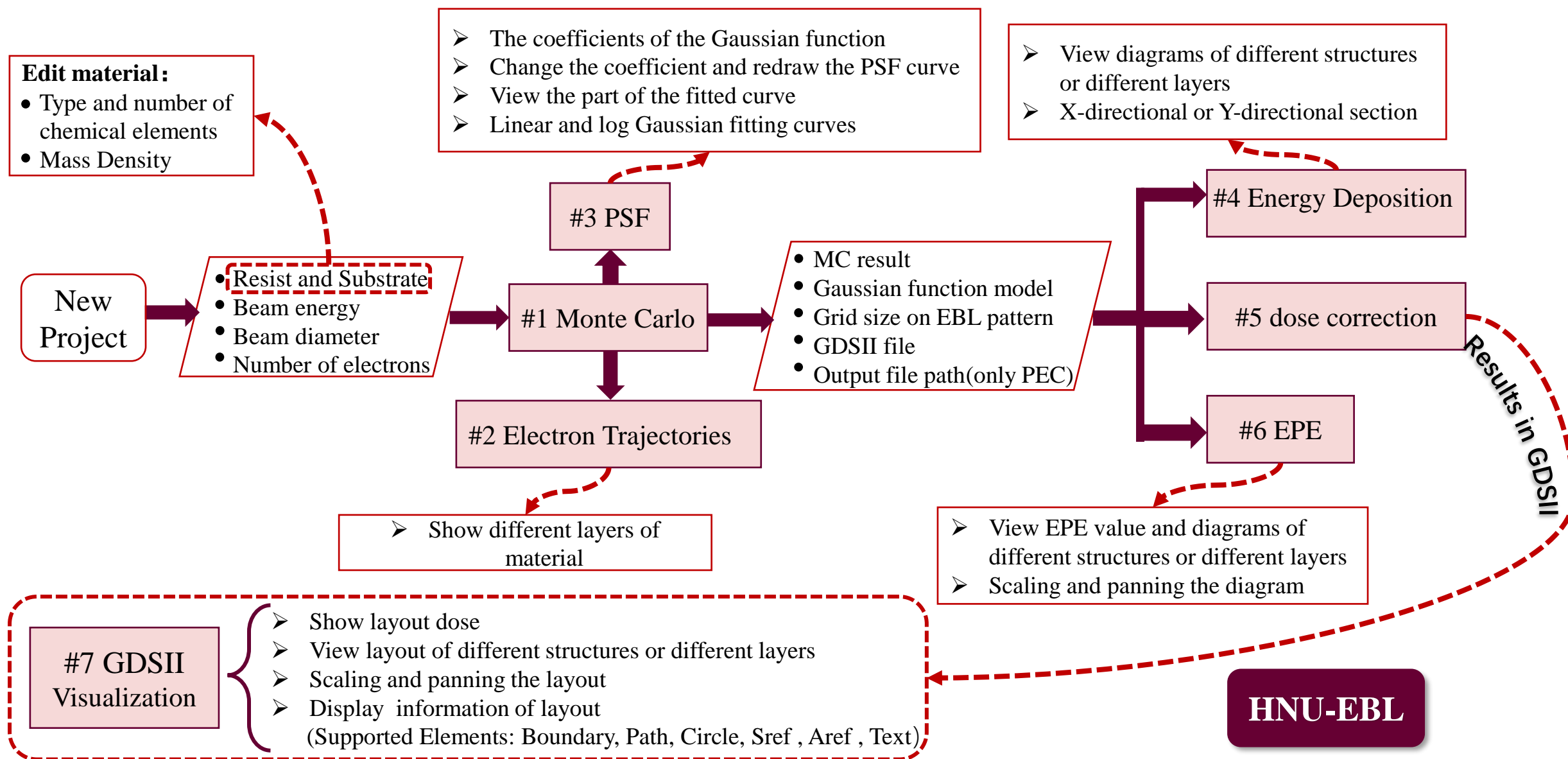
The product may not be exported or re-exported to China, Russia, Armenia, or Vietnam, as well as many other countries, without a valid export license issued by a government agency. Foreign nationals of these and other countries are restricted from receiving this technology unless they are documentedpermanent residents of countries where export is permitted.

Software Toolkit – HNU-EBL

Developed from scratch at Hunan University in China
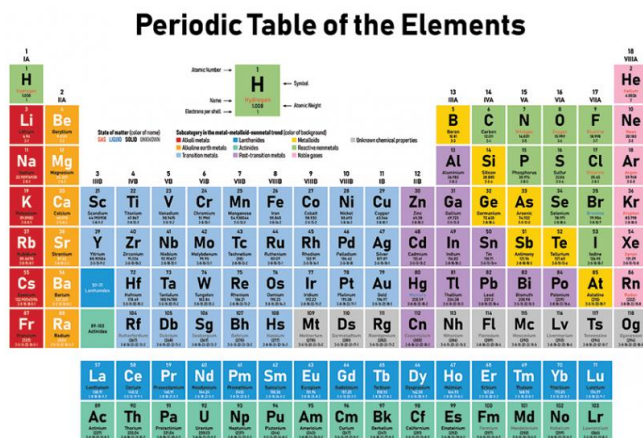
≈45,000 lines of C++/Python codes

© 湖南大学-电气与信息工程学院-刘杰 jie_liu@hnu.edu.cn

Edit material：
- Type and number of chemical elements
- Mass Density

➢ The coefficients of the Gaussian function
➢ Change the coefficient and redraw the PSF curve
➢ View the part of the fitted curve
➢ Linear and log Gaussian fitting curves

➢ View diagrams of different structures or different layers
➢ X-directional or Y-directional section

#3 PSF

New Project

- Resist and Substrate
- Beam energy
- Beam diameter
- Number of electrons

#1 Monte Carlo

- MC result
- Gaussian function model
- Grid size on EBL pattern
- GDSII file
- Output file path(only PEC)

#4 Energy Deposition

#5 dose correction

#2 Electron Trajectories

#6 EPE

➢ Show different layers of material

➢ View EPE value and diagrams of different structures or different layers
➢ Scaling and panning the diagram

Results in GDSII

#7 GDSII Visualization

➢ Show layout dose
➢ View layout of different structures or different layers
➢ Scaling and panning the layout
➢ Display information of layout
(Supported Elements: Boundary, Path, Circle, Sref , Aref , Text)

HNU-EBL

Demonstration

Step 1. electron scattering & trajectories

Features:
- Arbitrary # of layers
- Arbitrary chemical elements & composition

© 湖南大学-电气与信息工程学院-刘杰 jie_liu@hnu.edu.cn

Demonstration

Step 1. electron scattering & trajectories

Features:

➢ Monte Carlo based on Rutherford, Mott, etc.

➢ Point Spread Function curve fitting

Demonstration

Step 2. dose correction & EPE evaluation

$$E(\boldsymbol{r}) = K \iint P(\boldsymbol{r}, \boldsymbol{r'}) d(\boldsymbol{r'}) d^2 \boldsymbol{r'}$$

$$P(\boldsymbol{r}, \boldsymbol{r'}) = \frac{1}{\pi(1+\eta)} \left[\frac{1}{\alpha^2} exp\left(-\frac{r^2}{\alpha^2}\right) + \frac{\eta}{\beta^2} exp\left(-\frac{r^2}{\beta^2}\right) \right]$$

Features:

➢ CD down to 1.0 nm
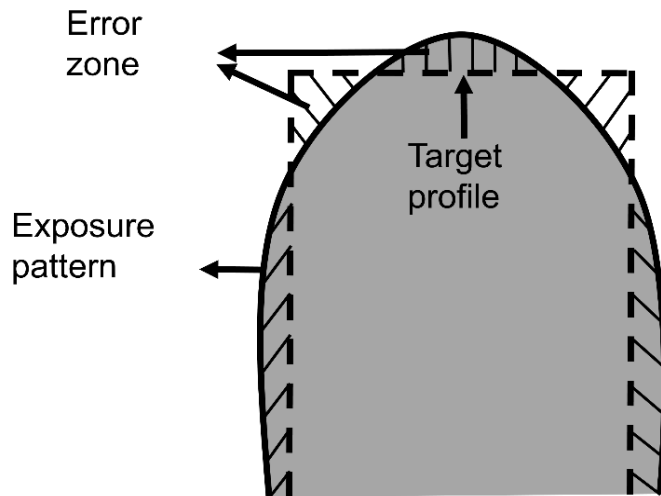
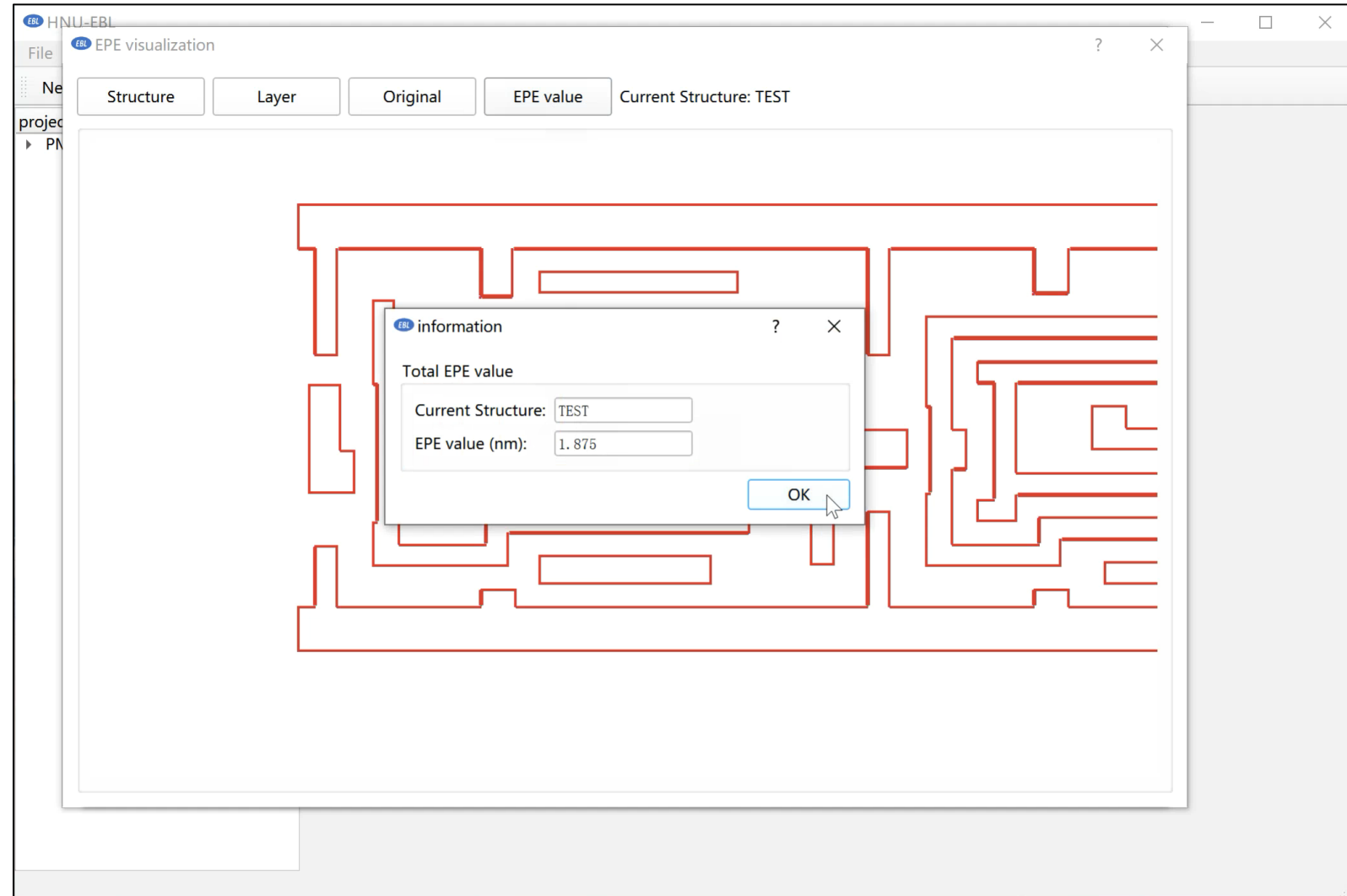➢ Efficient codes (FFT, FMM, parallelization)

Demonstration

Step 2. dose correction & EPE evaluation

Edge Placement Error (EPE)

Banerjee et.al, "Electrically driven optical proximity correction,"
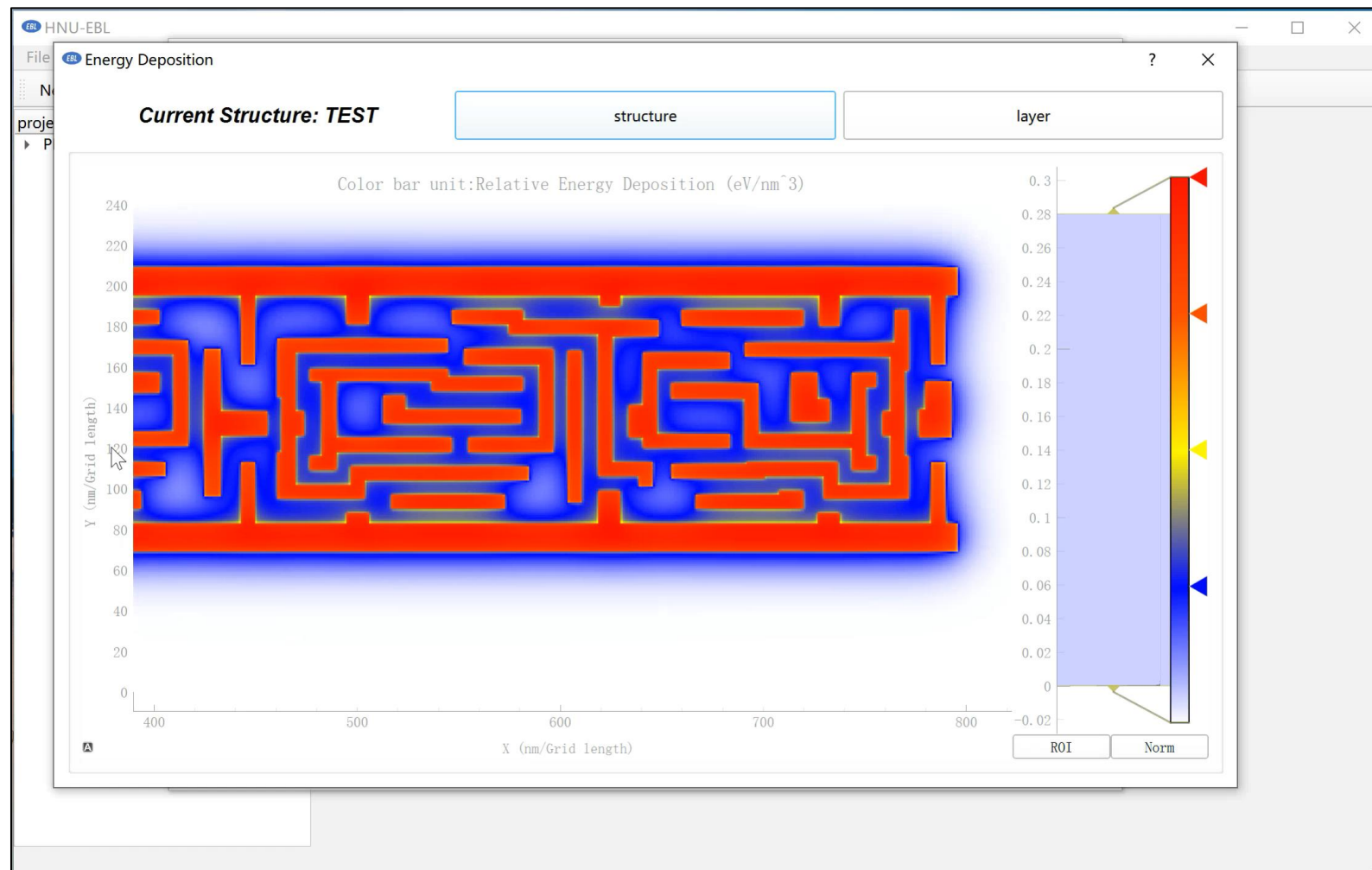Proc of SPIE, 2008.

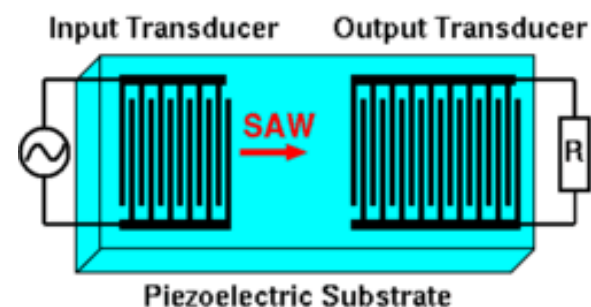# Demonstration   Step 3. visualization & inspection (GDSII)

Features:

➢ GUI-based visualization

➢ Interfaces to standard formats GDSII files
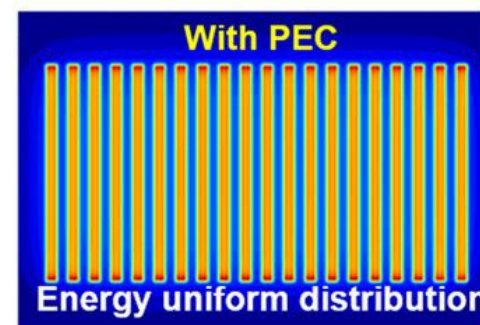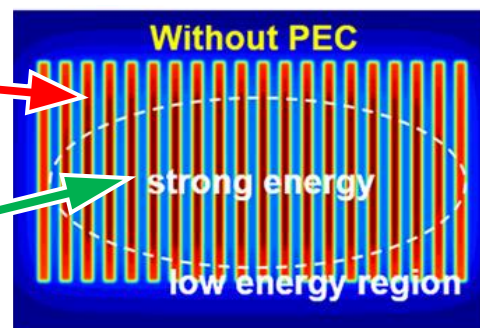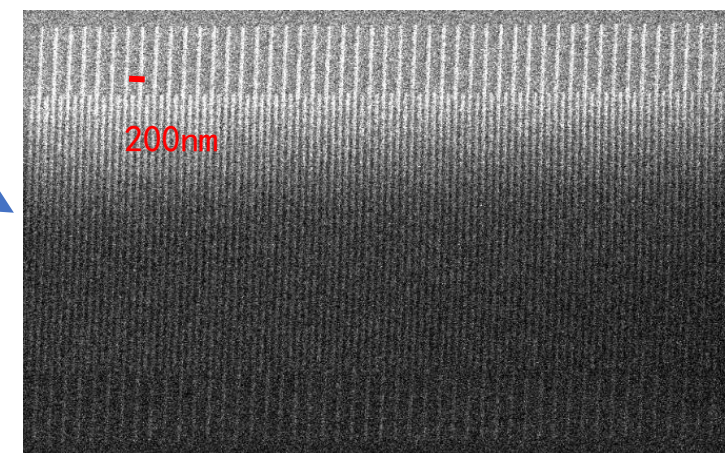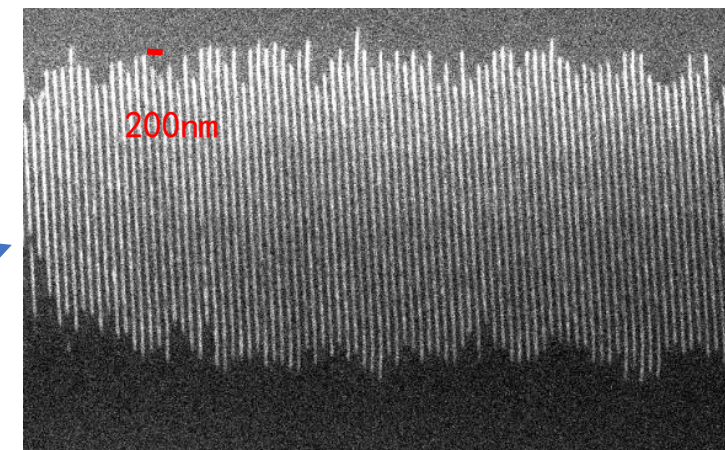
Verification – Accuracy

Surface acoustic wave (**SAW**) device

5G high-freq filter
Surface Acoustic Wave

Input Transducer   Output Transducer

SAW

R

Piezoelectric Substrate

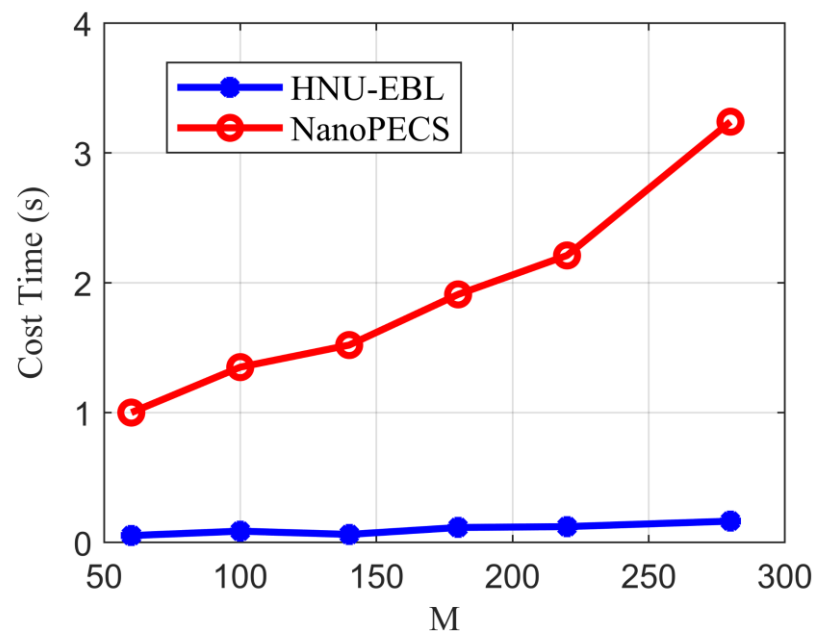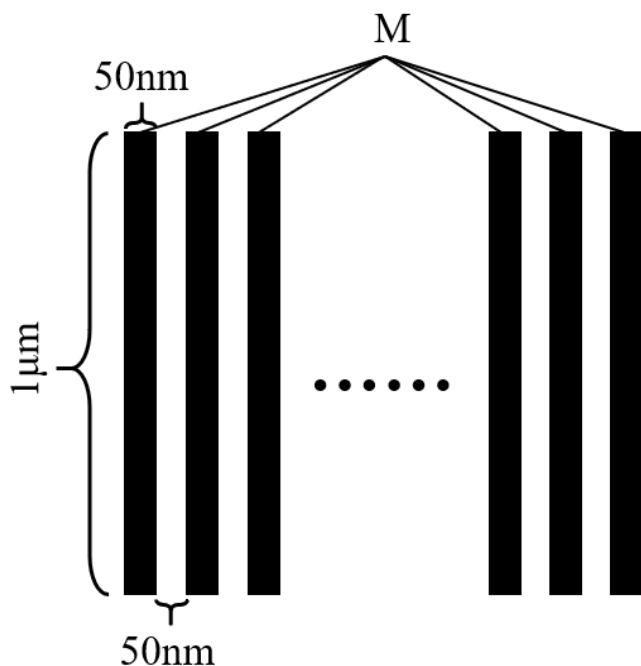under exposure

proper exposure

proper exposure

PEC: Proximity Effect Correction

Raith 150 Two EBL machine

Verification – Efficiency

- Same computer – Intel(R) Core (TM) i5 CPU (2.40 GHz) , 16GB RAM

- Same calculation layout – M gratings with a size of 1μm×50nm

- Same calculation grid – max calculation with $N=10^8$ pixels

Comparison of PEC calculation time between **HNU-EBL** & **NanoPECS**

R&D Team of HNU-EBL

EBL

Role:

Software Development

Experimental Verification

Jie Liu

Huigao Duan

Yiqin Chen

Wei Liu

Wenze Yao

Chengyang Hou

Hongcheng Xu

Haojie Zhao

Conclusion

➢ GUI-based EDA with 45,000 lines of C++, Python codes for EBL (EUV/optical mask)

➢ IP by Hunan University (4 patents + 4 software copyrights)

➢ **Free license to academia/industry users in any country**

Limitations:

➢ **Version**: first-release (under improvement)

➢ **Functionalities**: dose-based, 2D correction

➢ **Verification**: limited experimental verification

➢ ……

IWAPS
2021

湖南大学
HUNAN UNIVERSITY

http://www.ebeam.com.cn

Free of Charge!

License to all EBL Users
from Academia/Industry

> IP: 4 patents + 4 software copyrights
> "setup.exe" of GUI-based software
> 70+ pages of software user guide

jie_liu@hnu.edu.cn