BOE-ziSIM: A Design-Technology-Manufacturing Co-optimization Platform

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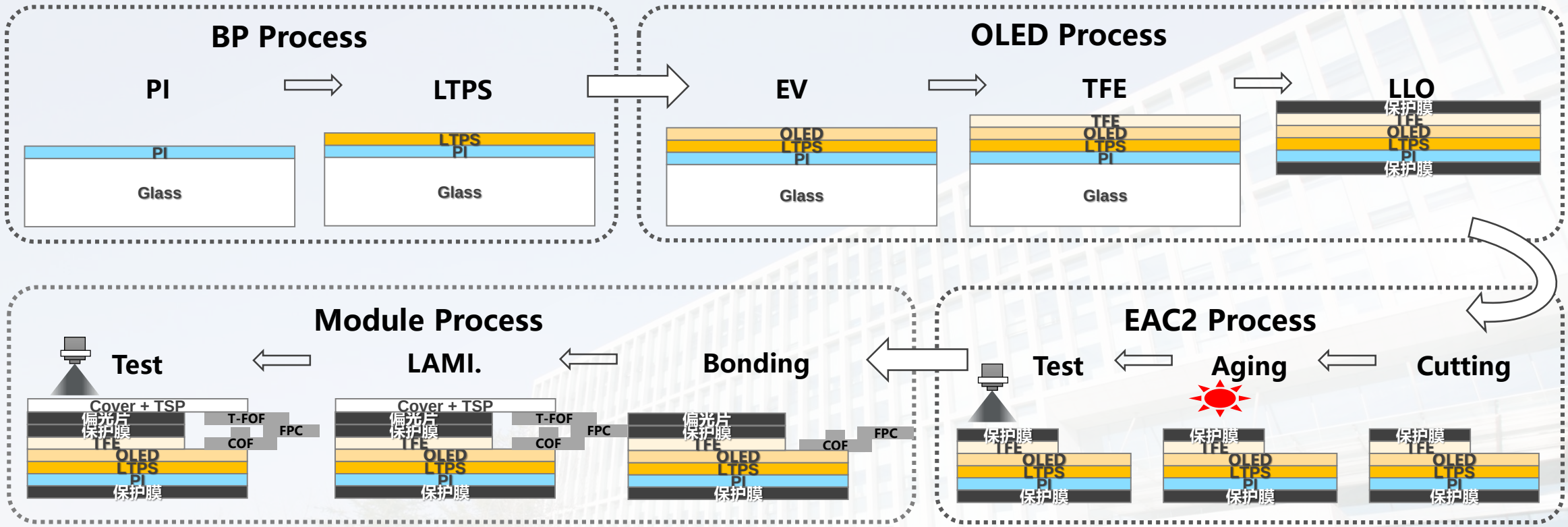
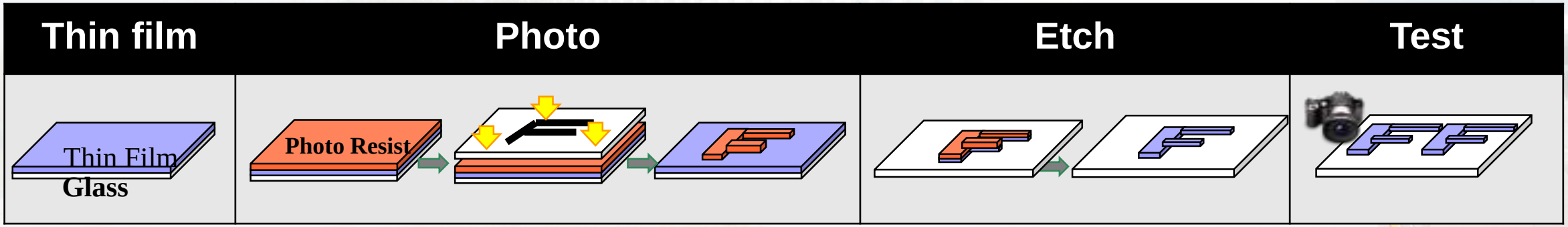
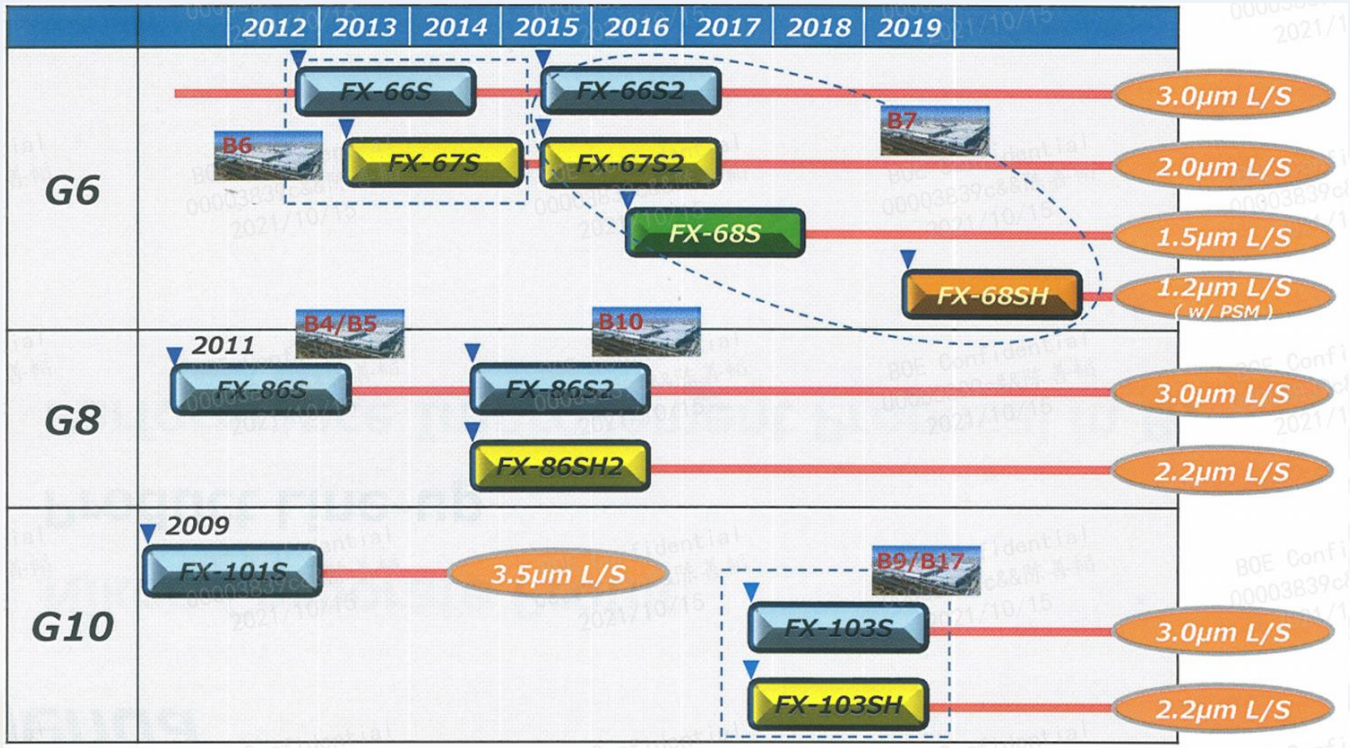
1. Introduction

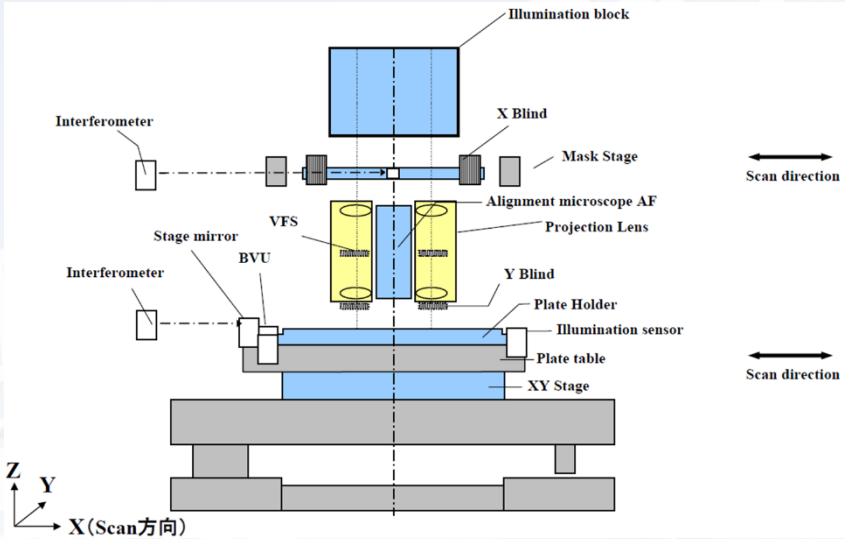
OLED Fabrication Process

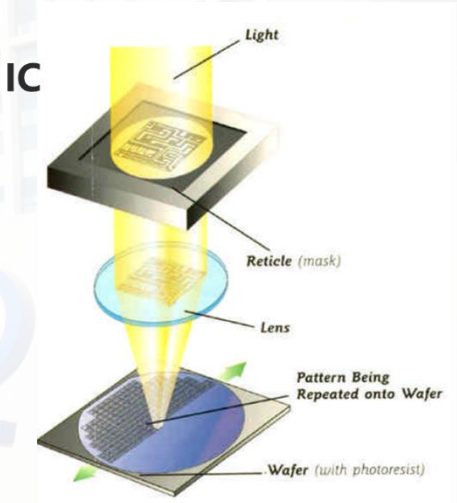


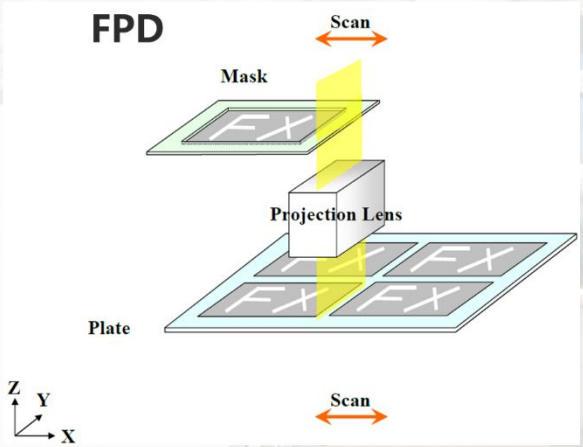


OLED Photo Process & IC Photo Process









Why OLED Simulation is Necessary

More Cost

More Development Time

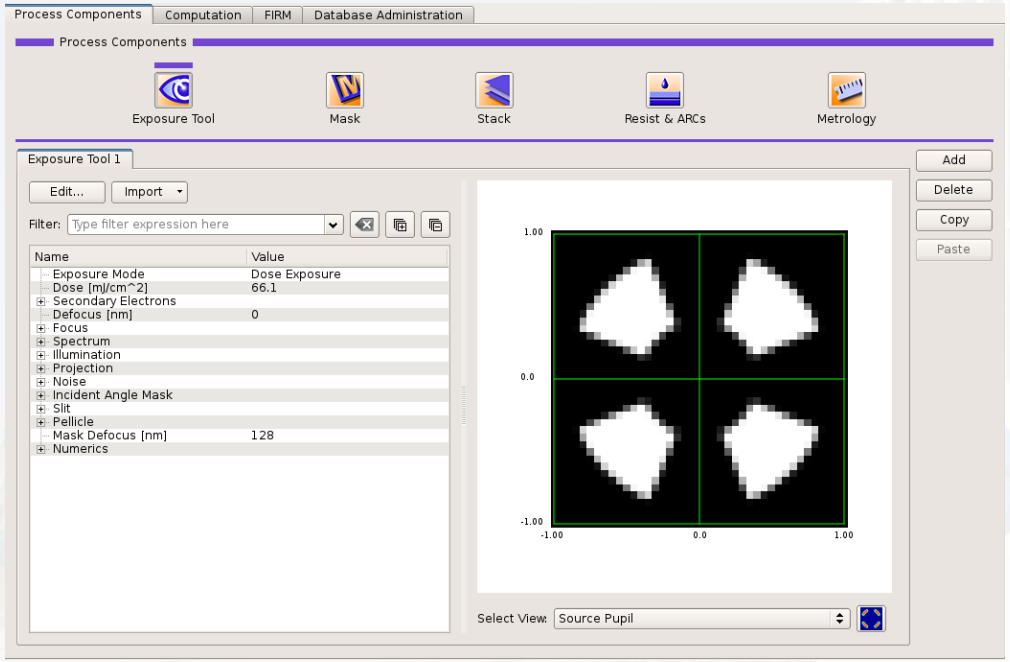
More Time to Market

Shorten Product Life Time

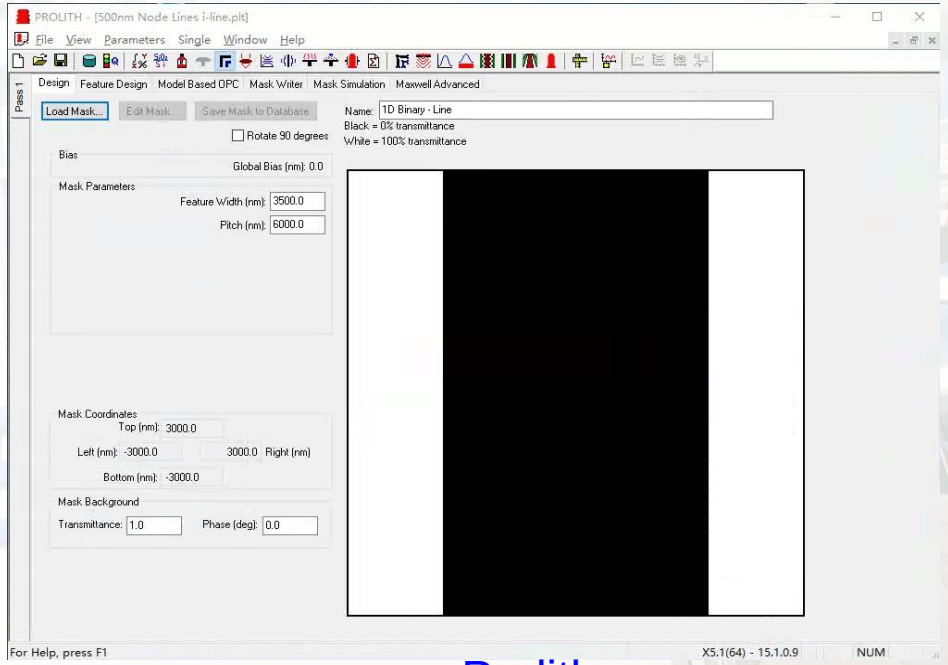
2. Litho Simulation

Background of Litho Simulation

- In 1975, F. H. Dill from IBM gave the first attempt to describe lithography with mathematical equations.
- In 1979, Andy Neureuther from UC Berkeley released the lithography simulation program SAMPLE，which was made available to the lithography community.
- In 1985, Chris Mack introduced the model PROLITH (Positive Resist Optical LITHography model).
- In 2006, Synopsys acquired Sigma-C and released Sentaurus Litho (S-Litho).

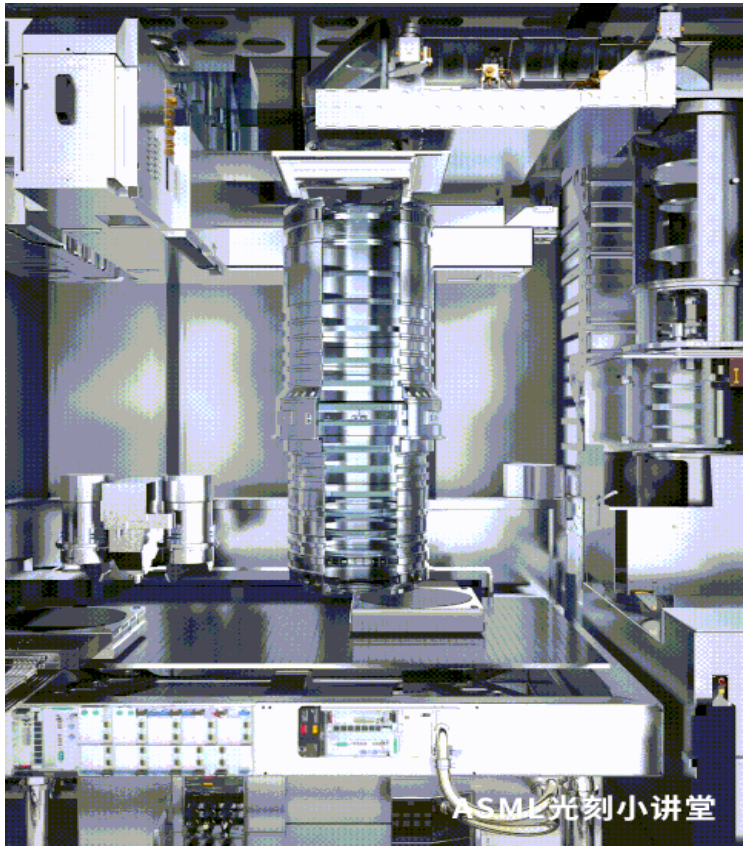


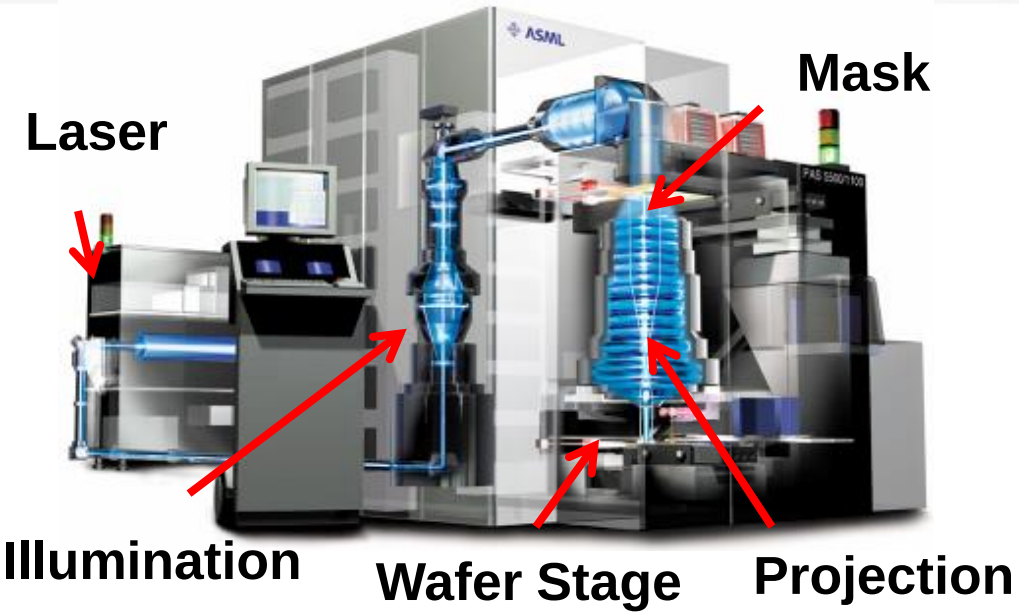
S-litho

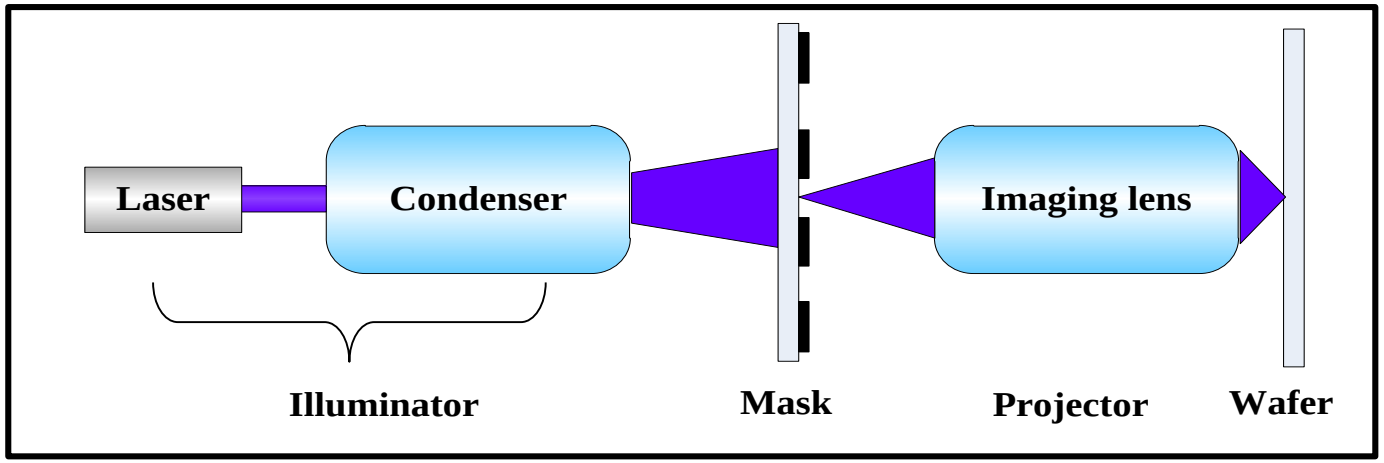


Prolith

Detail of Litho Simulation



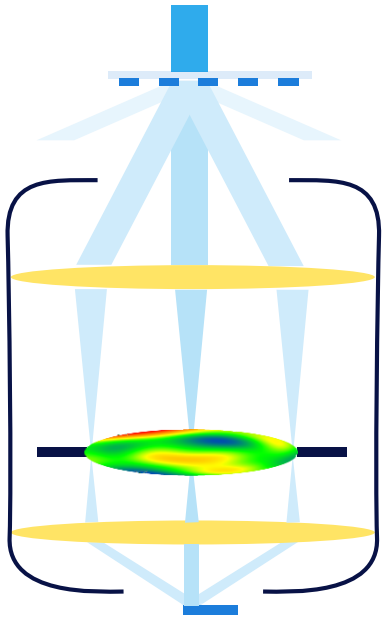




Detail of Litho Simulation

Optical Image

Three Main part:



- Decomposition
  - ✓ Diffraction efficiency
  - ✓ Diffraction angle

$$E_i^{obj}(f)\Big|_{f=\frac{\sin\theta}{\lambda}} = \mathcal{F}[E_i^{obj}(x)]$$

$$d\sin\theta = m\lambda$$

- Transformation
  - ✓ Phase
  - ✓ Amplitude

$$E_i^{img}(f) = E_i^{obj}(f) \times P(f) = E_i^{obj}(f) \times A(f) \times e^{i\,2\pi\,w(f)}$$

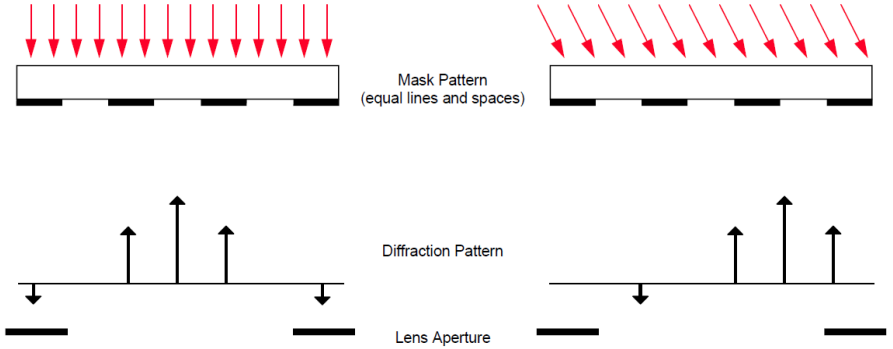
- Synthesis
  - ✓ Defocus

$$E_i^{img}(x) = \mathcal{F}^{-1}[E_i^{img}(f)] \qquad I_i(x) = E_i^{img}(x)E_i^{img\,*}(x)$$

$$I_i(x) = Q(f_s)\left(\mathcal{F}^{-1}\left[\mathcal{F}[Mask(x)e^{\cdots}]P(f)\right]\right)^2$$

Illumination

Source Intensity | Mask | Projector



Shift invariance of mask diffraction spectrum

$$I(x) = \iiint Q(f_s)L(f'+f_s)L^*(f''+f_s)\left[E^{obj}(f')E^{obj*}(f'')\right]e^{-i2\pi(f'-f'')x}df'df''\,df_s$$

Source + Projector | Mask

$$I(x) = \iint TCC(f',f'')\left[E^{obj}(f')E^{obj*}(f'')\right]e^{-i2\pi(f'-f'')x}df'df''$$

where, $$TCC(f',f'') = \int Q(f_s)L(f'+f_s)L^*(f''+f_s)\,df_s$$

Hopkins Model

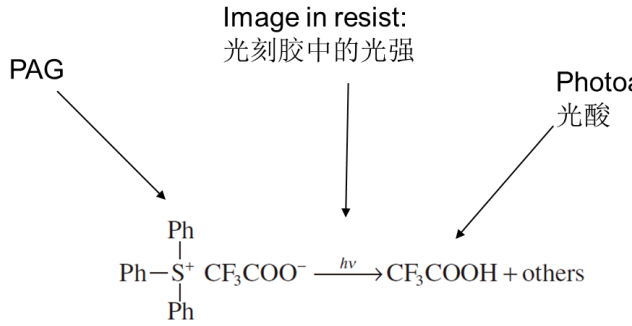
Detail of Litho Simulation

Resist Profile

Exposure
- Optical intensity →
- Acid distribution

Bake
- Acid distribution→
- Blocked Polymer distribution

Develop
- Blocked Polymer distribution→
- Resist Profile



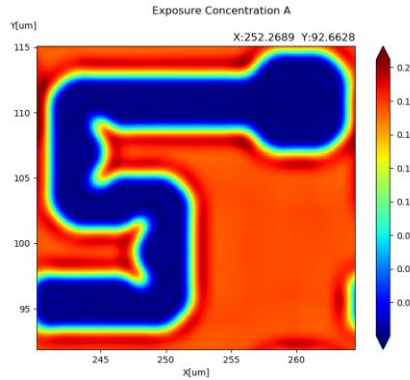
$$H = G_0\left(1 - e^{-CIt}\right)$$

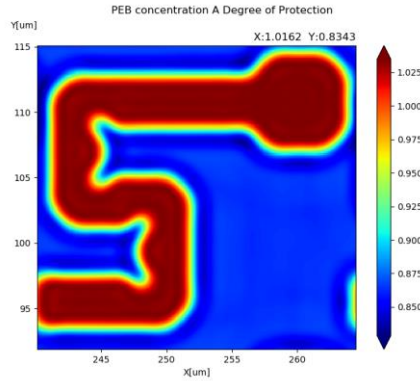
$$e^{-CIt} = e^{-C \cdot Dose_{\text{inc}} I_r(x,y,z)}$$

$$\frac{dh}{dt} = -K_{quench} hq + D_H \nabla^2 h$$

$$\frac{dq}{dt} = -K_{quench} hq + D_Q \nabla^2 q$$

$$r = r_{max} \frac{(a+1)(1-m)^n}{a + (1-m)^n} + r_{min}$$





Litho Simulation in OLED

Development with Prof. Dong Lisong of IMECAS and Nanjing Chengxin IC research co.,Ltd;

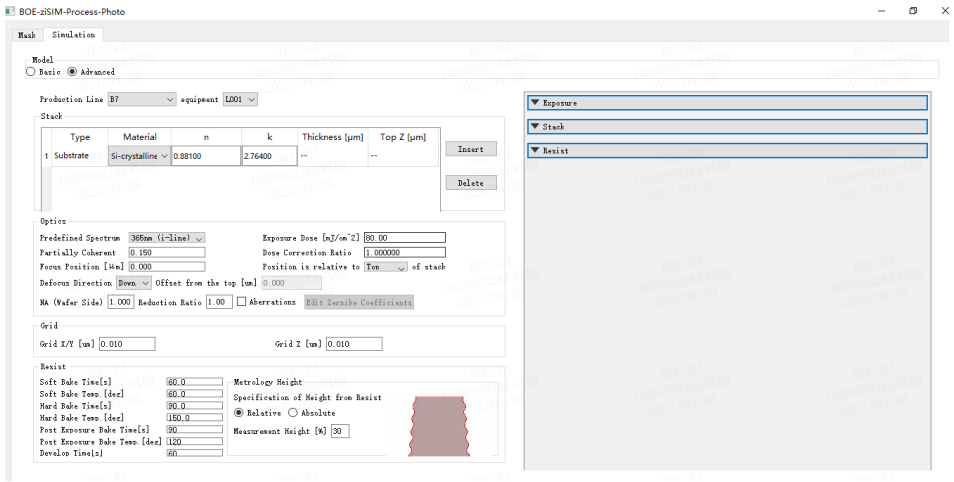


Photo Process UI

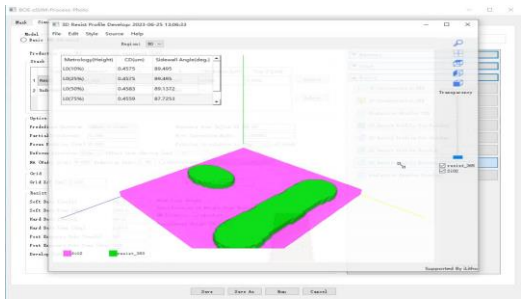
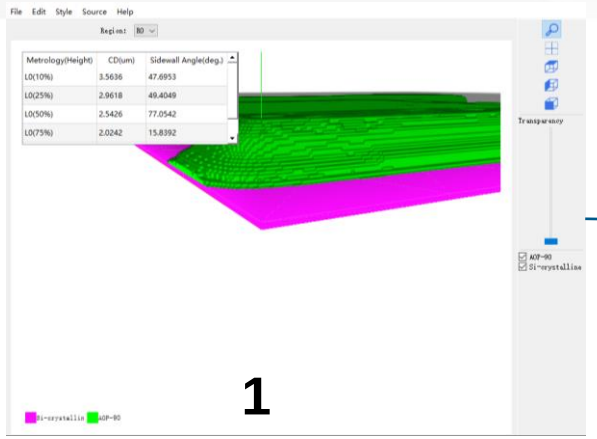
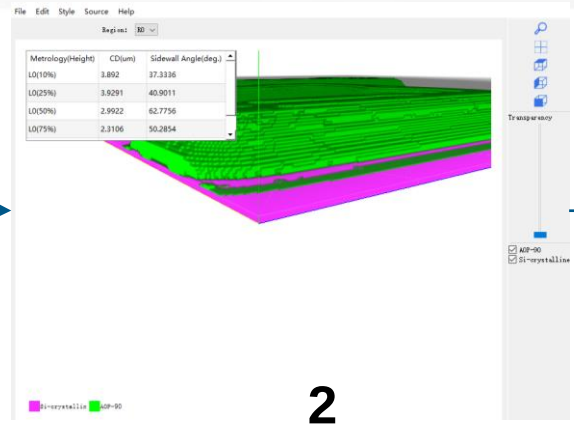


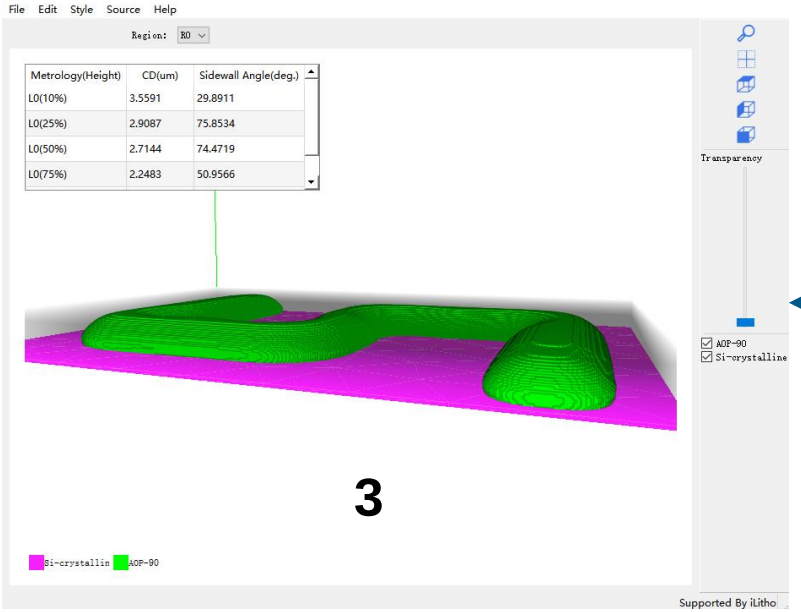
Photo Process





Initial without Post-bake Model

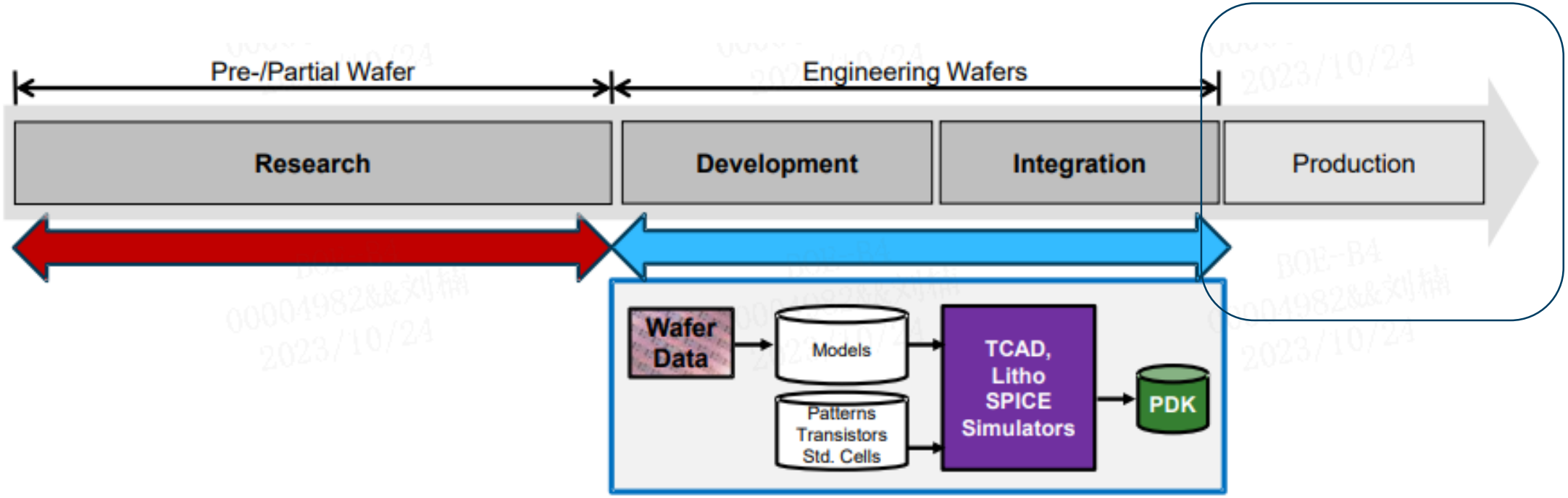
Post-bake Model



Post-bake Model Optimization

3. Design-Technology-Fabrication Co-optimization

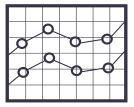
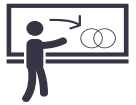
No Volume Production Optimization



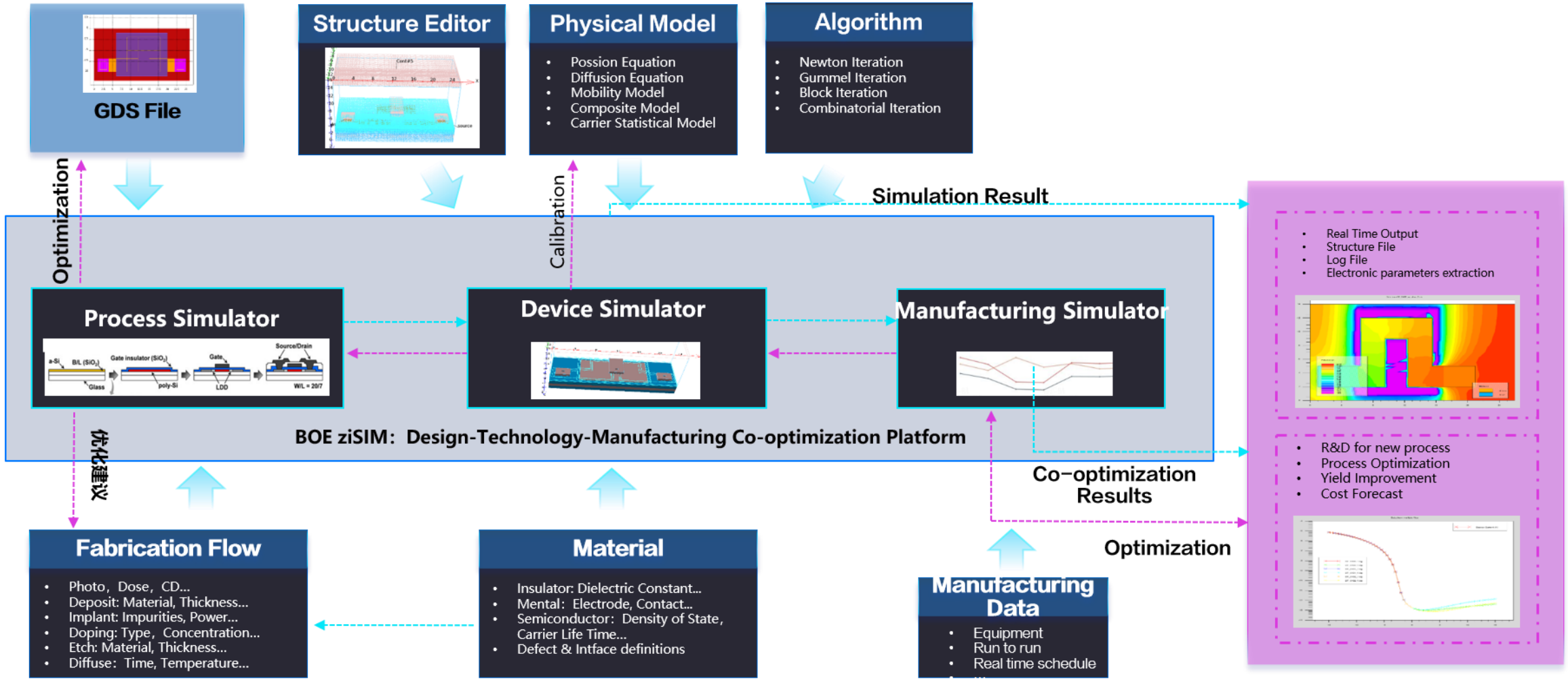
DTCO: Picture from Synopsys

OLED Fabrication RCA

Yield is the most important thing for fabrication, and RCA is the most useful method to improve.

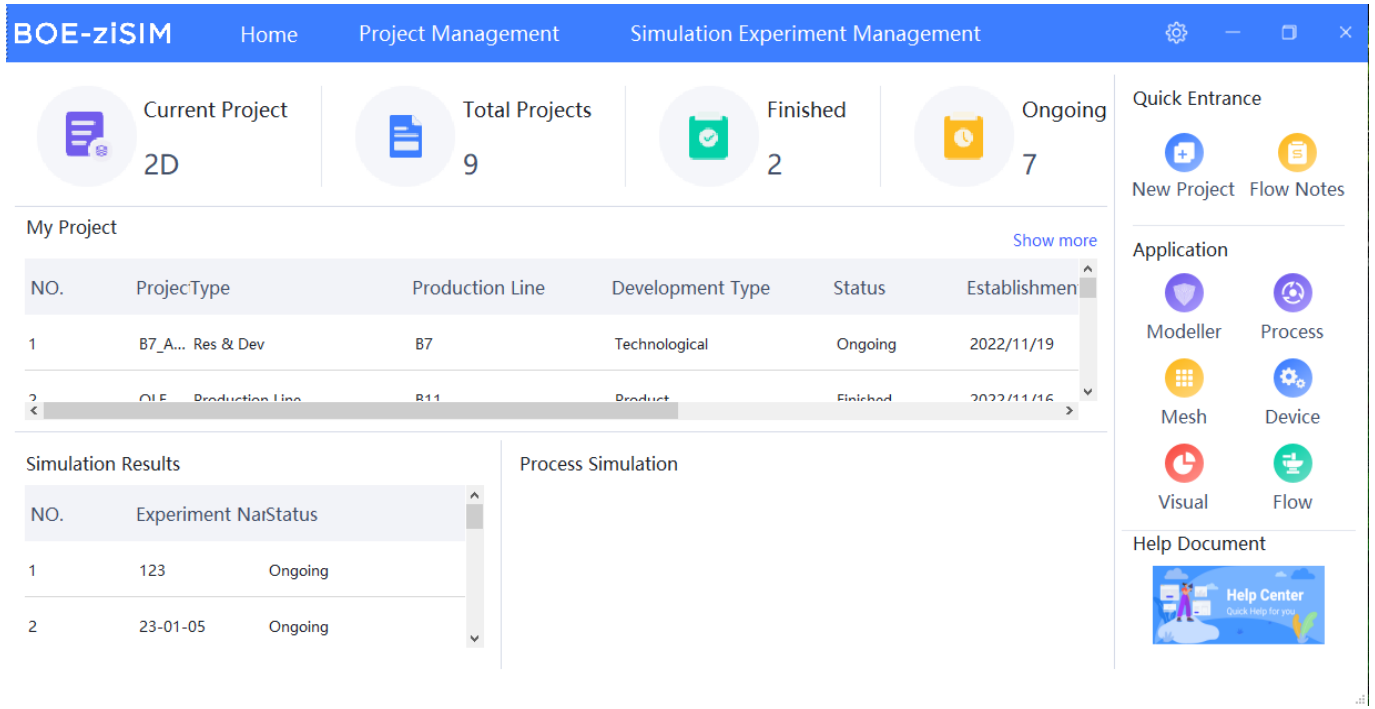
Work Flow	 Monitor	 Data	 Decide	 Demo Analysis	 Improve
Work Content	➢ Monitor Defective	➢ Data Integrated	➢ Find Out Reason	➢ Mechanism Confirm	➢ Improvement
Method	➢ Manual	➢ Manual + System	➢ Tool + Experience	➢ Manual	➢ Manual
System	➢ BO/YMS	➢ MDW/YMS/DFS	➢ Minitab/JMP	➢ No	➢ Np
Percentage	➢ Daily	➢ **33%**	➢ **21%**	➢ **30%**	➢ **16%**
Dis-advantage	➢ Time Delay	➢ Inefficiency ➢ No relative	➢ Experience	➢ Repeat Data Reduction	➢ No Know-how Reuse

Design-Technology-Manufacturing Co-optimization



Design-Technology-Manufacturing Co-optimization Structure

BOE-ziSIM Platform

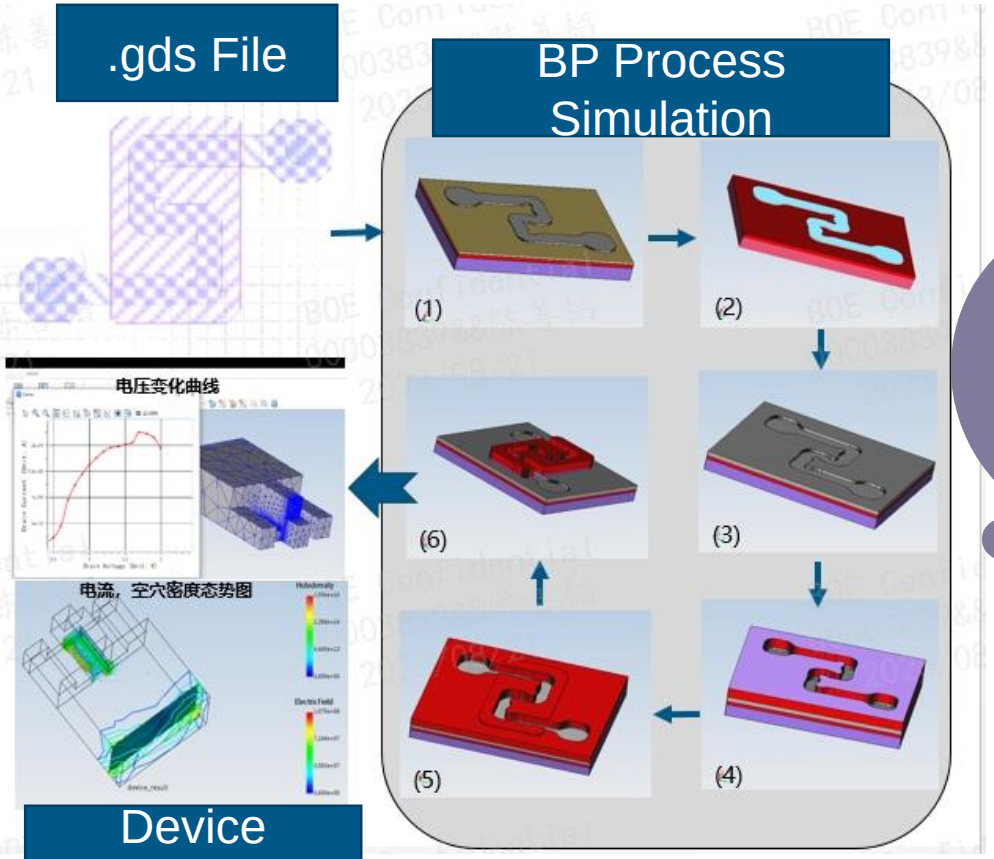


BOE-ziSIM: A Design-Technology-Fabrication Co-optimization Platform

Process-Device-Yield

.gds File

BP Process Simulation

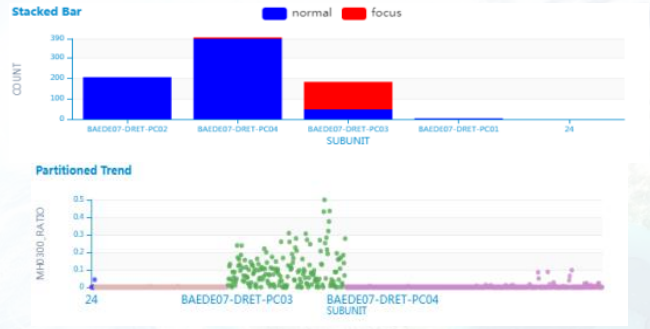


Device Simulation

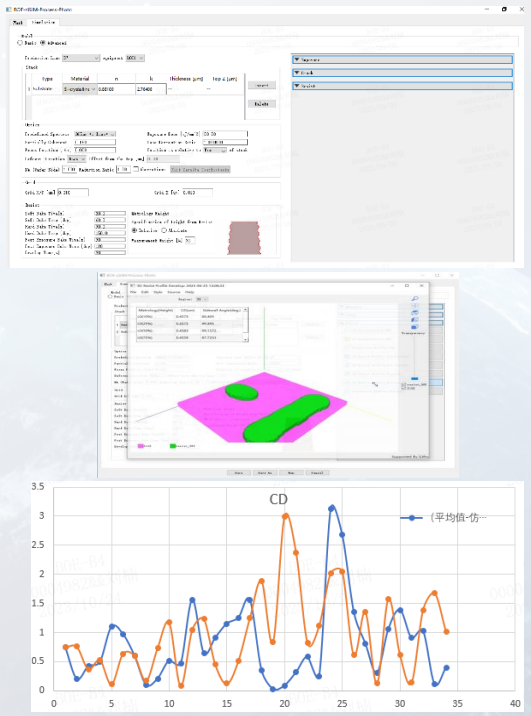
Defective: Process Data Tracing

4. Experiment

Experiment

Defect	Mura
Background	➢ Product: BOEXXX ➢ ACT From X.23 to X.27 Defective ➢ Measurement Data after X.23
Method	➢ Choose 3% as negative sample
Data	➢ 1250 Tracking Parameter
Time	➢ 5min
RCA Results	➢ Chance Difference Rank No.1 is Equipment XXX 
Relative	➢ Relative to Dose Value of Photo Equipment XX

Process Simulation



Process Parameter Turing

Yield Improvement time reduce from **Day to Minutes!**

Future Work

- Design-Technology-Manufacturing Co-optimization is a new way to improve yield, as well as process and device.
- Process simulation is more important for fabrication.
- More partners are welcome to join this work to complete the relative theory, algorithm, software, and …

Thanks very much!