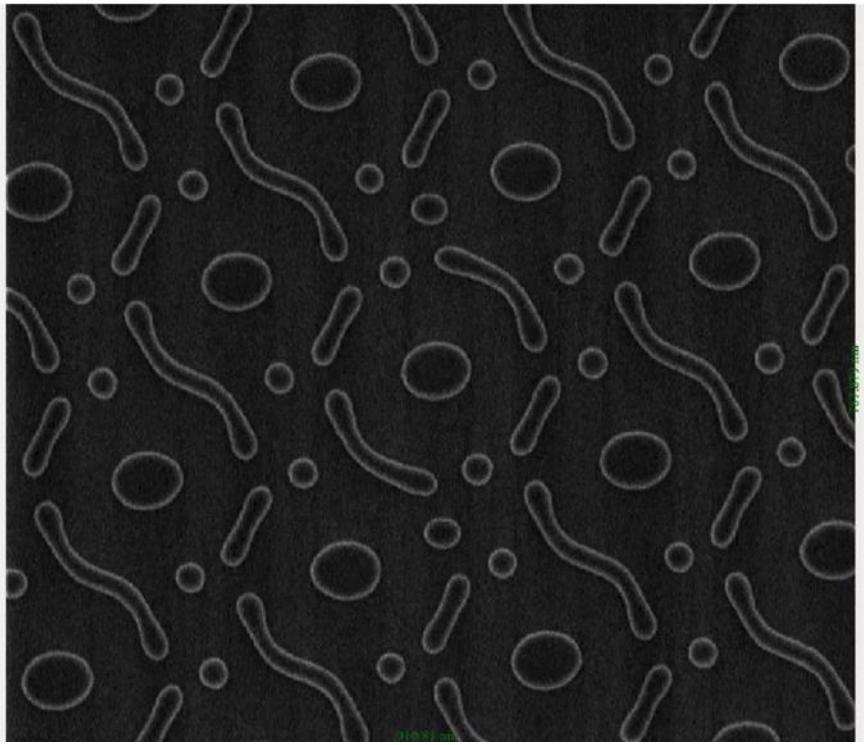
SEPTEMBER 17, 2019| LEO PANG, PHD

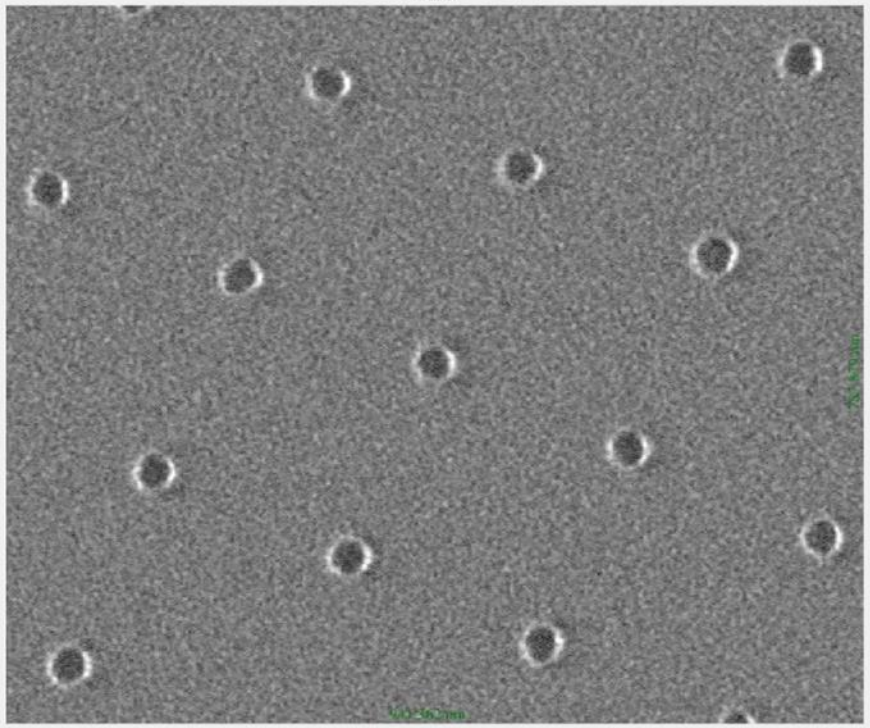
Digital Twins for Curvilinear World

- Everyone Here Needs a Curvilinear ILT Digital Twin

Curvilinear Data is Here Today and Just Going to Increase



D2S TrueMask® ILT curvilinear mask SEM for different pitches & orientations



Corresponding wafer print SEM

Mask printed on NuFlare MBM-1000, mask & wafer SEM courtesy of Micron, wafer data collected by ASML eP5

Ecosystem Needs Curvilinear Data for Testing

MDP

Mask Writer

Mask CD SEM

Mask Inspection

Mask Review

Mask Repair

eBeam Wafer Inspection

Wafer CD SEM

Wafer Review SEM

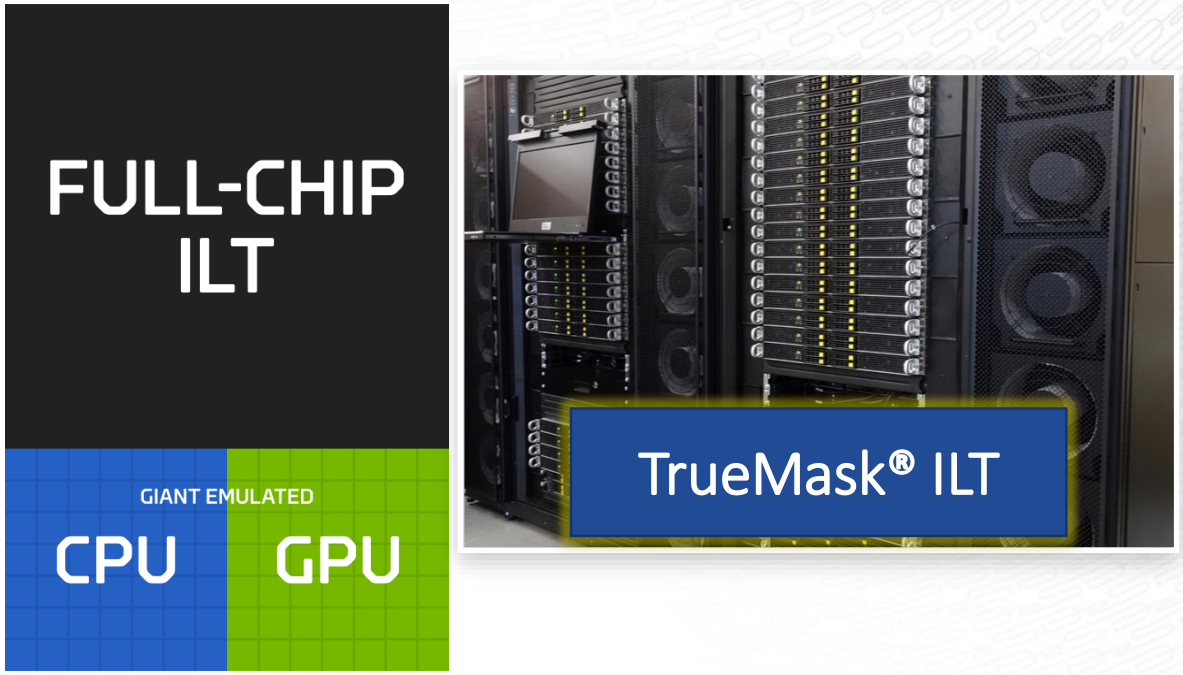
How Do You Get Access to Curvilinear Data?

Conventional ILT

- Split full chip into partitions
- Ideal ILT generation
- Clean mask with mask rules
- Manhattanization
- Re-optimization of Manhattan Pattern
- Re-do stitching boundaries

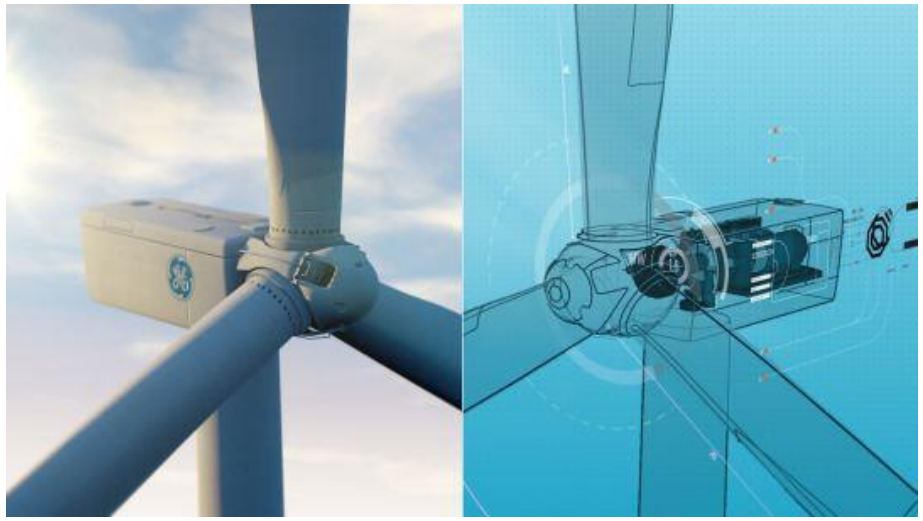
TrueMask ILT

Curvilinear ILT generation with Mask Rule Compliance (MRC)



You Need a Digital Twin of ILT

What is a Digital Twin?

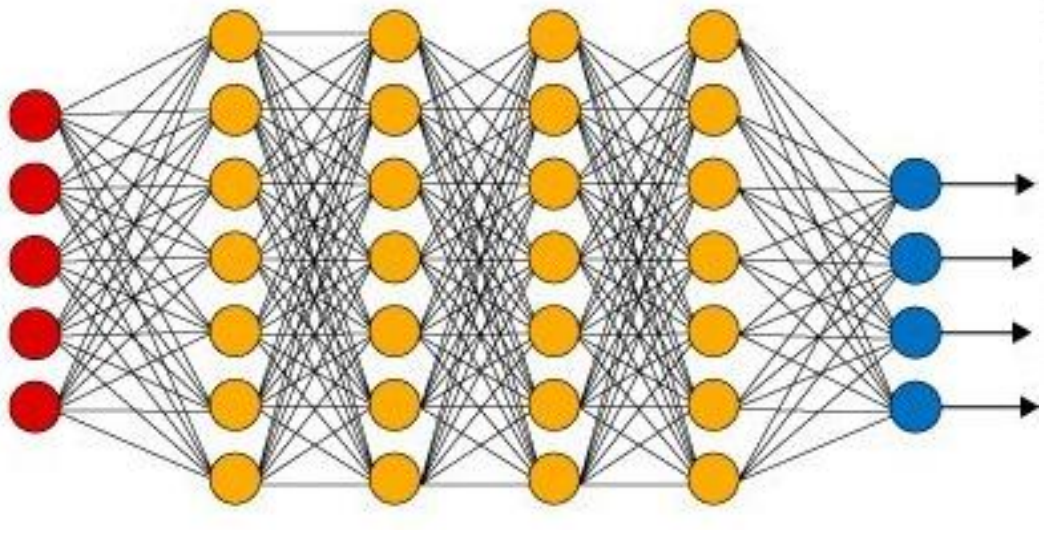


Real System and Its Digital Twin

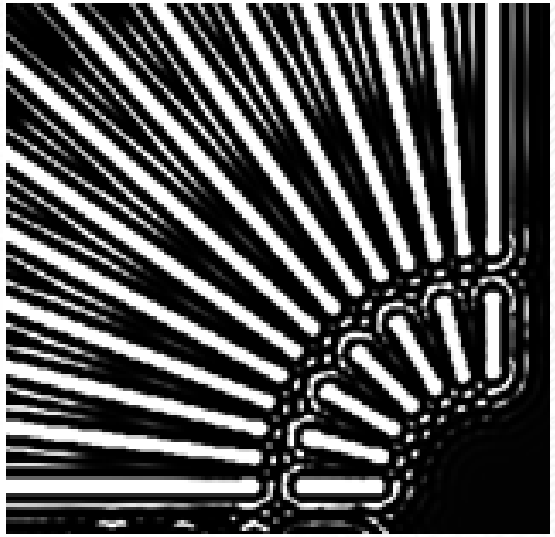
- Dynamic, virtual representation of a physical asset, product, process, or system
- Digitally models the properties, condition, and attributes of the real-world counterpart
- Used for
  - Training
  - Prediction
  - Generate input

Deep Learning Generates Curvilinear ILT Digital Twin: Fast & Cost Effective Way to Create Curvilinear ILT

Wafer Target Pattern



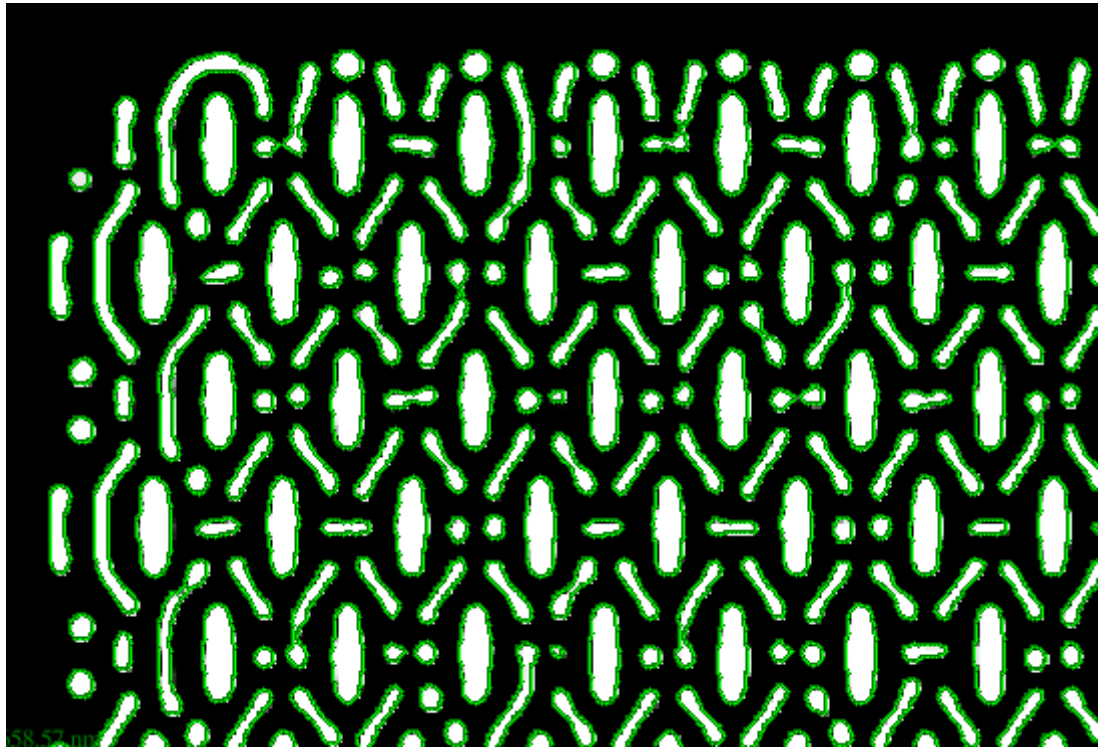
Deep Learning Neural Network Trained with TrueMask ILT



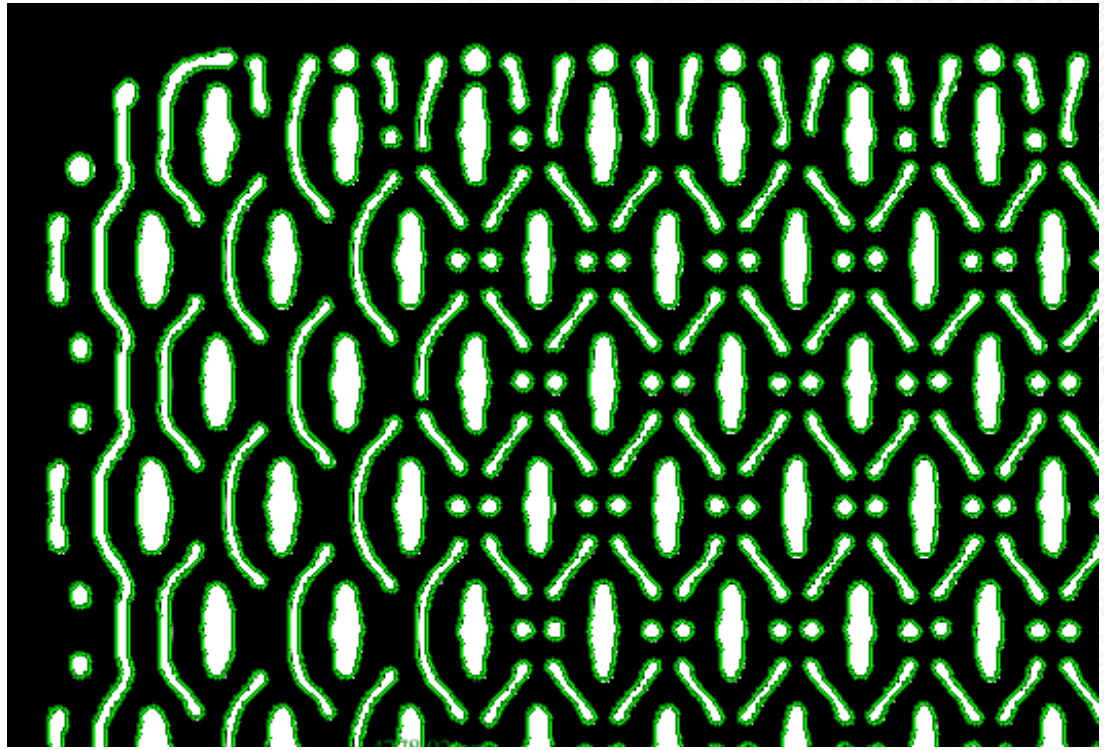
ILT Mask Pattern Generated by TrueMask DLK Digital Twin

TrueMask ILT and Its Digital Twin

TrueMask DLK Digital Twin



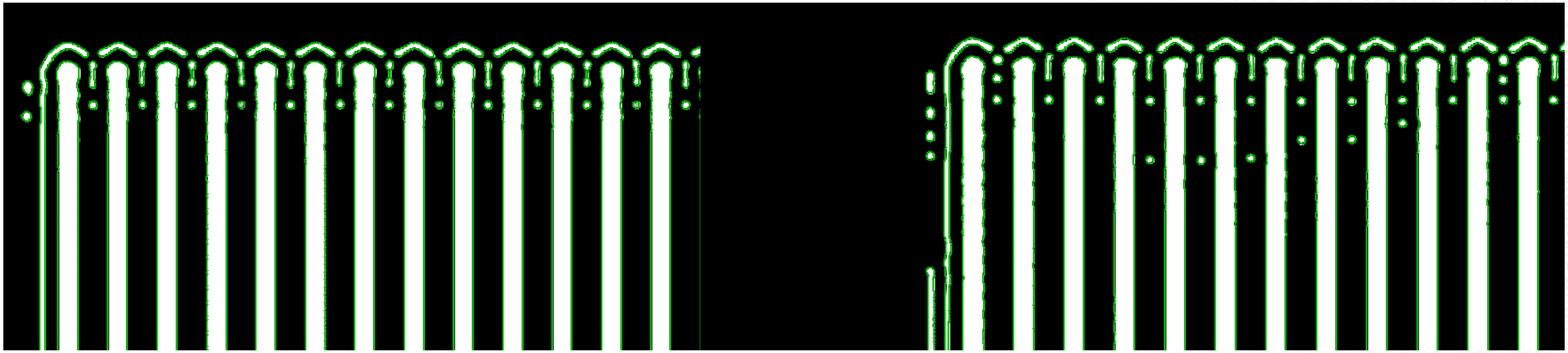
TrueMask ILT



TrueMask ILT and Its Digital Twin

TrueMask DLK Digital Twin

TrueMask ILT



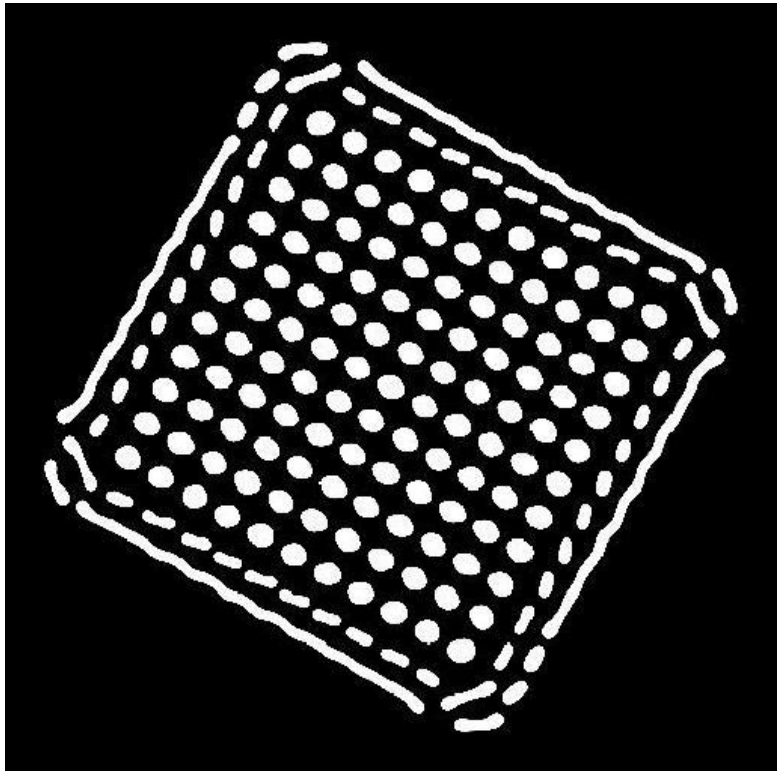
TrueMask ILT and Its Digital Twin

TrueMask DLK Digital Twin

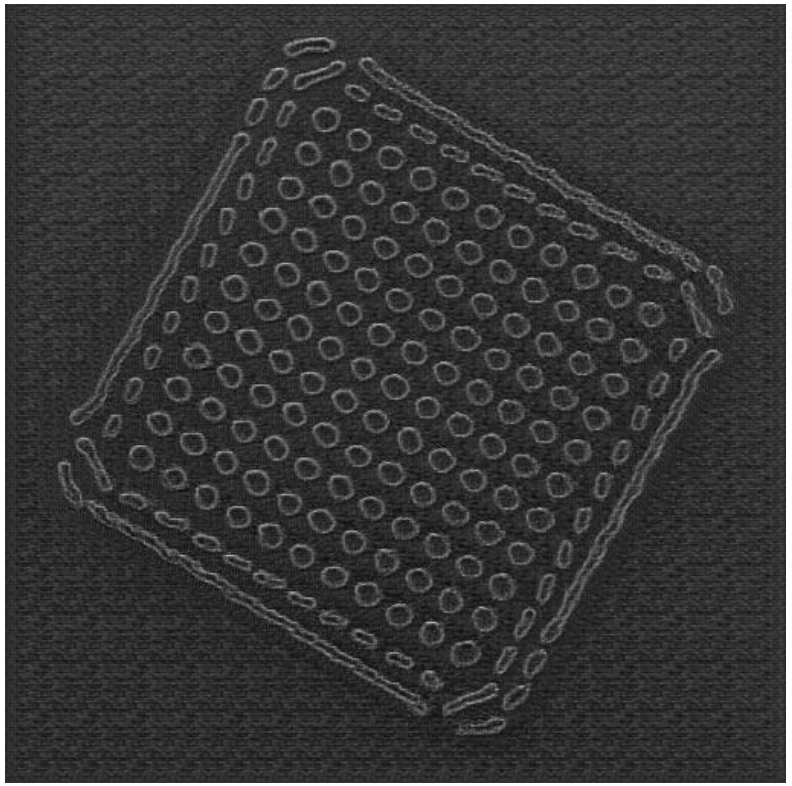
TrueMask ILT

CAUTION: DL-based Digital Twin Not Good Enough for Wafer Print!

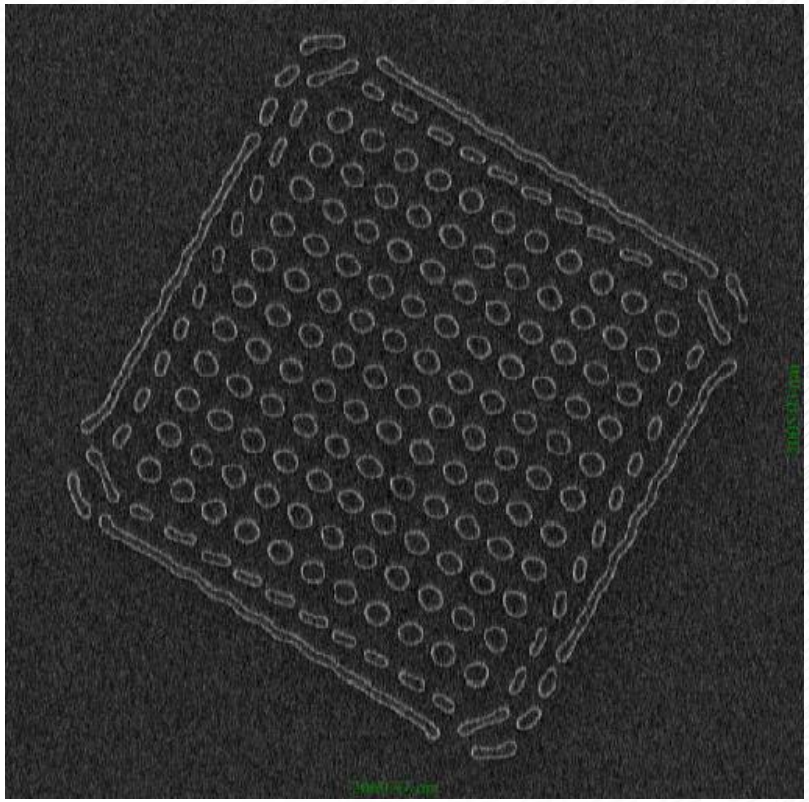
Together with SEM Digital Twin You can Generate Data to Train Your Deep Learning Networks



Simulated Mask Pattern



SEM image by Digital Twin



Real SEM image

The Adoption of Curvilinear Masks has Started

Mask Data Preparation

- MDP
- MPC
- Mask Verification

Mask Writing

- VSB
- Multi-beam

Mask Metrology

- CD SEM
- Wafer Plane Analysis

Mask Inspection

- MPI
- WPI

Mask Review

- AIMS

Mask Repair

- eBeam
- Atomic force

Mask Inspection is Ready for Curvilinear ILT Masks

Mask Inspection

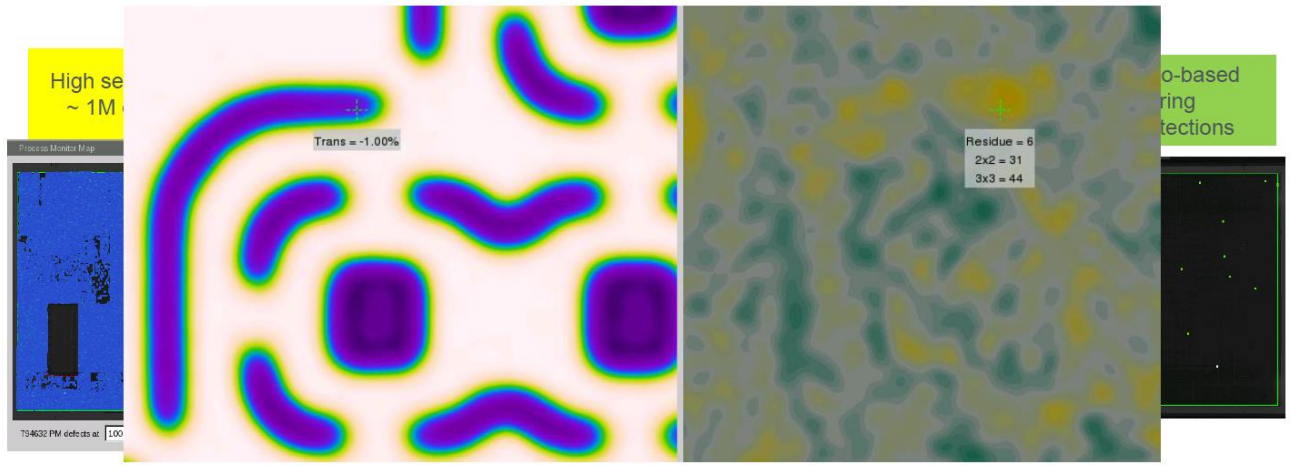
- Contour based
- MPI and WPI

✔

Courtesy of Dr. Sterling Watson at KLA

Teron 640 Dual Imaging Mode

Finds defects of interest – CD / EPE detection (Litho factored in)



Utilizes Strengths of Each Mode

- Highest sensitivity with low nuisance
- Minimizes risk of an escape
- Reduces down-stream work

BACUS 2016 Panel Presentation

KLA-Tencor

Teron SL655

Mask Review is Ready for Curvilinear ILT Masks

Mask Review
- AIMS
- AIA: D2D, D2DB

✓

2.1 Aerial Image Analyzer (AIA): Die-to-Die mode

LAIPH AIA has been used in production at all TSMC EBO locations - one in Hsinchu, and two in Tainan[9]. Figures 7 show the pilot run results of LAIPH at TSMC. In Figure 7(a), the manual measurements performed by the operator and

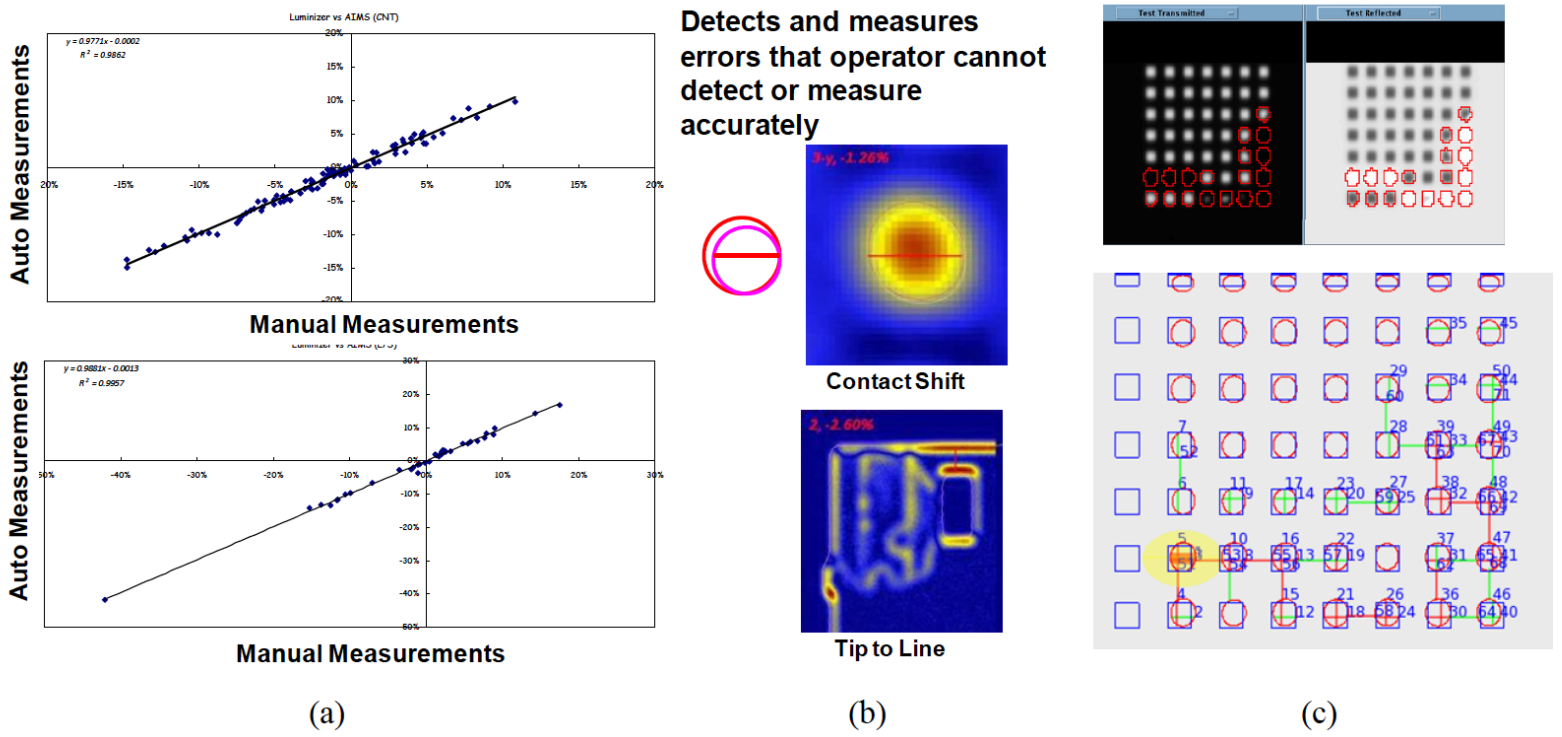


Figure 7. LAIPH AIA pilot run result at TSMC: (a). D2D accuracy, (b) examples showing AIA can detect and measure certain type defects that operators cannot detect or measure accurately; (c) an example of contact measurement coverage and speed.

Source:

"Computational Lithography & Inspection (CLI) and its Applications in Mask Inspection, Metrology, Review, and Repair"

Article in Proceedings of SPIE - The International Society for Optical Engineering · September 2010

DOI: 10.1117/12.868034

Mask Repair is Ready for Curvilinear ILT Masks

Mask Repair

- Reference Pattern Generation

✓

5.1 Reference Pattern Generator (RPG) for Mask Repair Systems

In order to repair a mask, one must know what the perfect pattern looks like. This perfect pattern is called the reference pattern. On the advanced mask repair system, once the reference image is obtained, the system can overlap the defect and reference image (assuming they are perfectly aligned), and calculate the difference, which is the repair area. In the old days, such a reference pattern could be easily found in the nearby region or from another die. This becomes more difficult for ILT and SMO types of masks, where the patterns may look similar but are actually different. Therefore, there is a need to have a Reference Pattern Generator (RPG) for mask repair systems.

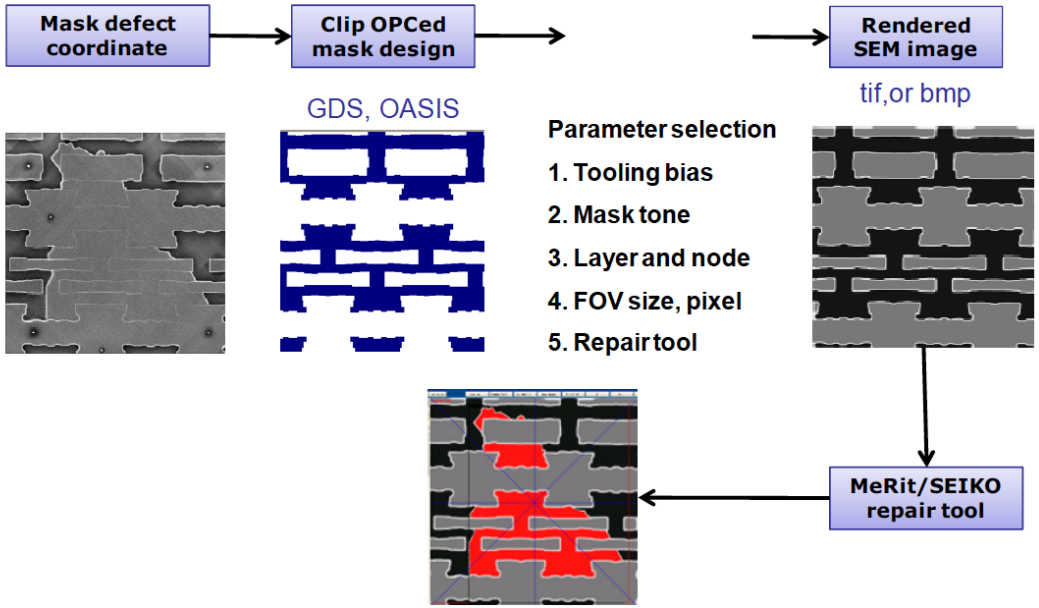


Figure 21. LAIPH Reference Pattern Generator (RPG) for mask repair flow

Source:

"Computational Lithography & Inspection (CLI) and its Applications in Mask Inspection, Metrology, Review, and Repair"

Article in Proceedings of SPIE - The International Society for Optical Engineering · September 2010

DOI: 10.1117/12.868034

Mask Shops & Equipment Makers Can Use Curvilinear ILT Digital Twin to Test for High Volume Manufacturing






Mask Data Preparation
- MDP
- MPC
- Mask Verification

✓

Mask Writing
- VSB: Overlapped shots
- Multi-beam

✓

Mask Metrology
- CD SEM: Contour and EPE
- Wafer Plane Analysis

✓

Mask Inspection
- Contour based
- MPI and WPI

✓

Mask Review
- AIMS
- Analysis: D2D, D2DB

✓

Mask Repair
- eBeam
- Tool: Reference Pattern Generation

✓

Next Year You can Expect to See Curvilinear Data Everywhere