Deep Learning (DL) Applications in Photomask to Wafer Semiconductor Manufacturing

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Company: Advantest Corporation

Product and/or Application

Mask metrology system
DL techniques used: Deep convolutional neural networks (DCNNs) and etc.
DL benefits: Improving processing speed and accuracy for image recognition

Company: ASML

Product and/or Application

Newron Model
DL techniques used: Deep convolutional neural networks (DCNNs)
DL benefits: Significantly improves resist and etch model accuracy by capturing additional physical effects missed by conventional OPC models

Newron SRAF
DL techniques used: DCNNs
DL benefits: Generates SRAF placements based on inverse OPC at full chip application speed, thus significantly improves process window at similar compute cost

Newron OPC
DL techniques used: DCNNs
DL benefits: Accelerates OPC runtime significantly by reducing the number of iterations needed to achieve convergence

Company: Canon

Product and/or Application

Auto alignment function in lithography tool
DL techniques used: Convolutional neural networks (CNNs) – VGGNet and transfer-learning are used
DL benefits: Reducing unscheduled downtime with judging alignment target image usability, better and quicker than humans

NEW: **Image processing and parameter tuning in lithography tool**
DL techniques used: CNNs or RCNN
DL benefits: Reducing optimization time and expansion of search area.

Company: CEA-LETI

Product and/or Application

Data preparation for grayscale lithography
SEM contour and CD metrology extraction on 2D & 3D features
SEM image denoising
DL techniques used: Deep learning solution developed internally
DL benefits: Accuracy improvement, treatment speed

Company: D2S

Product and/or Application

TrueMask® ILT GPU-accelerated, curvilinear full-chip ILT
DL techniques used: DCNNs and skip-connection (such as ResNet) based U-Net for the image-to-image translation
DL benefits: Speeds up full-chip ILT with a better starting point

TrueMask DLK Quick start DL kit
DL techniques used: DCNNs based deep Autoencoders (AE) for representing images
DL benefits: Robust deep learning applications created quickly with neural networks pre-trained for semiconductor manufacturing applications

CD-SEM Digital Twins
DL techniques used: Generative Adversarial Networks (GAN), Neural Image Synthesis
DL benefits: enables automated applications that analyze CD-SEM such as defect categorization, model extraction, etc.

Company: Fraunhofer IPMS

Product and/or Application

Simultaneous contour edge image prediction and SEM image denoising (please refer to https://ieeexplore.ieee.org/abstract/document/9185250 joint paper with Texas A&M University)

DL techniques used: CNN LineNet2 trained with simulated training data set consisting of 32760 noisy SEM images with the corresponding original images and edge images
DL benefits: The method can be useful for real SEM image denoising, roughness estimation, and contour geometry estimation tasks

Company: Hitachi High-Tech Corporation

Product and/or Application

Defect Review SEM
DL techniques used: DCNNs, etc.
DL benefits: Image quality enhancement for defect detection with high sensitivity

Company: Holon

Product and/or Application

New: Mask metrology system
DL techniques used: Deep convolutional neural networks (DCNNs) and etc.
DL benefits: Improving processing speed and accuracy for leading-edge masks such like ILT masks

Company: imec

Product and/or Application

Deep learning applied to SEM images
DL techniques used: DCNNs, Residual Neural networks, Generative Adversarial Neural Networks
DL benefits: Super resolution enabled with faster acquisition, noise reduction with Generative Adversarial Networks *(Proceedings Volume 10959, Metrology, Inspection, and Process Control for Microlithography XXXIII; 1095916 (2019) https://doi.org/10.1117/12.2515182)*

Deep learning for improved process window analysis
DL techniques used: Autoencoder Neural Network
DL benefits: Provides fast proxy for CD metrology defining process window. Improves classification for OPC metrology needs.

Deep learning for defect classification and detection
DL techniques used: Deep fully connected neural networks, DCNNs
DL benefits: Automatic localization and classification of defects in SEM images enabling enhanced defect inspection for aggressive pitches. Pitch and noise invariant.

Deep learning-based SEM image denoiser
DL techniques used: Deep fully connected neural networks, DCNNs
DL benefits: Unsupervised deep learning training scheme without requirement clean noiseless images. Denoising reduces noise level only without altering the (real) information; no digital artefacts are introduced. Key process for working with thin resist or enabling contour detection capability.

Company: NuFlare Technology, Inc.

Product and/or Application

SEM defect classifier
DL techniques used: Deep convolutional neural networks (DCNNs), skip-connection (such as ResNet) and Pix2Pix GANs
DL benefits: Reduce the downtime by speeding up the defect analysis and improving the classification accuracy. Defect analysis training, especially for young experts.

New: B-SPline Control Point generation tool
DL techniques used: Convolutional neural network (U-net)
DL benefits: Reduce the polygon image data size using B-SPline method.

Log analysis
DL techniques used: Natural Language Processing (NLP)
DL benefits: Automatically detect the abnormalities from log with high accuracy.

Beam drift Prediction
DL techniques used: Long short-term memory (LSTM)
DL benefits: Improve mask drawing quality with automatic abnormal search and prediction.

Company: Siemens Industries Software, Inc.; Siemens EDA

Product and/or Application

Calibre Neural Network Assisted Modelling
DL techniques used: DCNNs for predicting, post exposure, post development and post etch contours
DL benefits: Improves accuracy as well as predictability of the models

Calibre Machine Learning OPC
DL techniques used: Neural networks with supervised learning for speeding up OPC
DL benefits: Up to 3X improvement in OPC speeds

Calibre LFD with Machine Learning
DL techniques used: Neural networks and data enrichment techniques for yield-limiters detection in the design flow
DL benefits: Order of magnitude speedup and improved coverage over standard techniques that result in improved design yield and reliability

Calibre Wafer Defect Engineering with Deep Learning
DL techniques used: Feature vector driven neural networks for layout analysis and hotspot detection
DL benefits: Robust applications that speed up test chip development and improves yield and reliability in the fab by quickly and efficiently detecting yield limiter

Company: STMicroelectronics

Product and/or Application

Fab Digital Twin - automatic defect classification (ADC)
DL techniques used: CNNs
DL benefits: Corrective action in real time and defects are caught before other processes are added

Company: TASMIT

Product and/or Application

New: Semiconductor wafer metrology and inspection system
DL technique used: Deep convolutional neural networks (DCNNs) for image denoising and super-resolution
DL benefits: Acceleration of inspection throughput

Semiconductor wafer metrology and inspection system
DL technique used: Recurrent neural networks (RNNs) for modeling time-series data such as historical logs, the sequence of events
DL benefits: High-speed quantitative estimation of photo resist shrinkage, charging, etc.

Semiconductor wafer metrology and inspection system
DL technique used: Generative Adversarial Networks (GANs) to create new data including images, text, etc.
DL benefits: High speed and high accuracy for CAD based image processing, CAD to SEM contour matching, and defect inspection performance

Semiconductor wafer metrology and inspection system
DL technique used: Anomaly detection using Gaussian Mixture Models (GMM), Generative Adversarial Networks (GANs) to identify irregularities, undesirable patterns in the data
DL benefits: Simple parameter setting for defect inspection

Semiconductor wafer metrology and inspection system
DL technique used: Extremely Randomized Trees (ERT) technology for the SEM contour extraction
DL benefits: High speed with lower cost of computer system for pattern edge detection