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

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**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

**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
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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](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: 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](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-driven Raman spectra quantification
DL techniques used: Deep fully connected neural networks, DCNNs
DL benefits: Automation of compositional extraction, convolutional approach for more bandwidth and sampling flexibility
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Company: NuFlare Technology, Inc.
Product and/or Application
SEM defect classifier
DL techniques used: DCNNs and skip-connection (such as ResNet) are used for the defect detection and classification. Because of the limitation of the number of real defect images, Pix2Pix GANs converts the SEM Digital Twin images from dose map images to train the network.
DL benefits: Speed up, improve the classification accuracy. It has the advantage of training the defect analysis, especially for young experts.

Log analysis
DL techniques used: Natural Language Processing (NLP) for the sentence analysis
DL benefits: Speed up, improve the accuracy

Beam drift Prediction
DL techniques used: Long short-term memory (LSTM) is used for the abnormal search and prediction
DL benefits: Automatic abnormal search and warning if abnormal event is found. The network will predict the abnormal event during drawing and improve drawing accuracy.

Company: Siemens Industries Software, Inc.; Siemens EDA
Product and/or Application
Calibre Neural Network Assisted Modelling
DL techniques used: DCNNs for predicting post development and 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 limiters
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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: 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