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

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: 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-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

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

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