Ultimate 3D e-Beam Lithography for nano/micro-structuring with NanoMaker
NanoMaker Features

Hardware (can expose w/o a beam blanker):
- High Speed Pattern Generator
- PCI card

Software (Windows™ OS):
- Hierarchical Multilayer Graphical Editor
- 2D/3D Proximity Effect Correction
- Predictive EBL Results Through Simulation
- Scanning Distortion Corrections
- Creation of 3D Structures
- Field Stitching and Alignment

www.nanomaker.com
NanoMaker Goals

- Create & Design Structures as little as 10nm
  - SEMs, FIBs \rightarrow NanoMaker \rightarrow Litho
- Work with 2D & 3D multilayer structures
  - Zone Plates, Kinoforms, Holograms, etc.
- Overcome proximity effects in 2D & 3D
- Reduce exposure time by suppressing “dynamic” e-beam deflections on-the-fly
- Compensate “static” distortion of the e-beam deflection system
- Provide seamless stitching of exposure fields
NanoMaker Hardware

Hardware comprises two units:
- High Speed Pattern Generator & PCI Card

PG Supports all SEMs and FIBs
Input and Output voltages can be tuned in the ± 10.0 V range

PG Provides:
- Beam Position Control by means of two 16-bit DACs (60ns Settling Time)
- Image acquisition by one 8-bit ADC
- Beam Blanker On/Off Switch (TTL output level)
- Internal/External scan mode Switch (TTL output level)

PG and PCI Card are connected by means of fiber optic communication
NanoMaker Software

- Provides easy to use interface screens to create nanostructures
  - Fully integrated editor to create new design or to reduce steps in conversion from external layout
  - Control exposure and stage functions
  - Acquire images to provide alignment control at multilayer writing
  - Proximity Effect Correction
  - Compensate distortion and dynamic delays
  - Simulate and predict results of exposure
Proximity Effect

- Becomes apparent in small areas when back scattering starts to make a strong impact
  - This leads to overexposure, resulting in breaking the accuracy of the structure
- Correction is important for closely packed, differently sized pattern elements

\[ \alpha_0 \] – e-beam width when reaching resist (desired width)
\[ \alpha \] – e-beam width when reaching substrate
\[ \beta \] – e-beam width when leaving resist (actual exposed area)
Proximity Effect: a simple example

- FET: Field Effect Transistor
- Total area about 20µm x 20µm
- Shape consists of two rectangles
  - all line widths and gaps equal to 0.2 microns, respectively
- 500 nm PMMA Resist on Silicon
- 25kV acceleration voltage
How Proximity Effect Impacts

Simulation

Photo of the exposed pattern
(after Al deposition and lift-off)

- When Proximity Effect is not corrected
  - Top line (upper left) is missing due to insufficient radiation dose
  - Contrary, excessive dose between rectangles results in a merger, where the line/gap vanishes
NanoMaker provides functions to calculate the dose distribution along the area.

Figure shows the areas depicted by isolines (zones with uniform dose rates):
- Each zone has an ascending dose from 105% to 125% against an initial 155% dose.
With NanoMaker it is possible to output the simulated image on screen:
- Various dose/time parameters can be modified and previewed on-screen, as if resist development has taken place.
- The NanoMaker “on-screen” simulation process saves time and physical resources.
- NanoMaker maintains a database of recommended parameters for most common types of substrates, layers and resists.

Simulation shows satisfactory results. As does the actual process.
PEC for 3D Structures (Example 1)

3D structures for optical applications are coming into consideration more often.

Simulation of exposure dose. Isolevels after correction

An AFM image of a relief of transparent polymer DOE after copying from metal replica.

Topographic expression of 3D structure
PEC for 3D Structures (Example 2)

Kinoform Optics

Using 3D Proximity Effect Correction, objects with arbitrary 3D shapes can be created with a single exposure session.
Distortion Compensation

The NanoMaker is able to compensate distortions

- Static distortion of the deflection system
- Dynamic distortion of e-beam long jumps
Static distortions arise from electromagnetic lens imperfections.

NanoMaker provides a function to measure the distortions of a SEM field and store the deviated values. These values are used to correct the e-beam trajectory for subsequent pattern generation.

Ideal scanning shape

Actual scanning shape

Distortion Compensation (static)
Distortion Compensation (dynamic)

- With NanoMaker exposure can be fulfilled w/o beam blanker
  - Distortion is compensated by creating a target trajectory to offset the actual trajectory, resulting in a straight line.
- This reduces exposure time
  - As there is no need to wait for the e-beam to settle.
  - Calculated exposure time is the pure time of the total exposure.
Distortion Compensation (dynamic)

Example: A structure with long jump of e-beam

No compensation

With compensation

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Alignment

- Used to create multi-layer structures
- **NanoMaker enables:**
  - The acquisition of an existing lithography image
  - An exposure in a new coordinate frame
  - Rotation and compress/stretch of the image
  - Alignment of a new layer with existing objects of the image, per the given markers

**Example:**

GaAs Hetero-structure
Alignment Sequence - Example (GaAs Device)

With the NanoMaker; dimensions of the contacts were measured, depicted and aligned with the given layers, then gold was deposited on the GaAs hetero-structure.

Deposition of metallic ferromagnetic material in the places marked by cross lines.
NanoMaker fabricated AFM tips for high accuracy measurements.

Fig. a). SEM image of tip specially designed for measurement of samples with near vertical sidewalls.

Fig. b). SEM image of four tips grown on the silicon tip in accordance with preset sketch.

NanoMaker is able to grow carbon tips on a standard silicon cone tip.
The line widths are 10 - 20 nm.

The smallest map of the world.
Neture Materials - published the photo to illustrate the macroscopic adhesive properties by showing a spider-man toy clinging with one of its hands to a horizontal glass plate. The toy (15 cm high; weighing 40 g) has its hand covered with the microfabricated gecko tape, which provides a 0.5 cm\(^2\) contact with the glass and a carrying capacity of >100 g.
Photo Gallery (Rainbow Hologram)

Kinematic rainbow hologram produced at Bessy II using a LEO 1560 SEM controlled by NanoMaker (courtesy of A. Firsov). 400 nm PMMA resist covered by 50 nm of Al.
## The NanoMaker Solution

The NanoMaker system can be delivered both complete and module-wise in accordance with the requirements:

<table>
<thead>
<tr>
<th>Feature</th>
<th>NanoMaker Complete deliverable</th>
<th>NanoMaker Workbench to prepare data on offline PC</th>
<th>NanoMaker Writer to perform exposure and image acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graphics Editor (specialized CAD system)</td>
<td>✅</td>
<td>✅</td>
<td>☐</td>
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<tr>
<td>Import of lithographic structures and images from:</td>
<td>☐</td>
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<tr>
<td>*.DXF, *.CSF, <em>.GDS, TIFF Image Files (</em>.TIF),</td>
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<tr>
<td>Bitmap Image Files (*.BMP)</td>
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<tr>
<td>Export of lithographic structures and images to:</td>
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<td>*.DXF, *.CSF, *.GDS, * .ELM</td>
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<tr>
<td>Recommended Parameters Reference Table (specialized Database)</td>
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<td>Postprocessing (Negative, Union, Frame, Shrink, Erase,</td>
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<td>☐</td>
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<tr>
<td>Overlaps Out, Dividing, Dose Stratification)</td>
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<tr>
<td>Proximity Effect Correction (including 3D structures)</td>
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<tr>
<td>Resist Development Simulation</td>
<td>☐</td>
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<tr>
<td>Dose Curves (for 3D structuring)</td>
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<tr>
<td>Exposure</td>
<td>☐</td>
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<tr>
<td>Image Acquisition</td>
<td>☐</td>
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<tr>
<td>Stitching and Alignment of Exposure fields</td>
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<tr>
<td>Job Processing</td>
<td>☐</td>
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<tr>
<td>Active Compensation for Distortion and Dynamic delays</td>
<td>☐</td>
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<tr>
<td>User Guide in electronic form</td>
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<tr>
<td>Pattern Generator + Drivers</td>
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<tr>
<td>Stage Control Drivers (optional)</td>
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</tbody>
</table>
## Characteristics of Add-on SEM-based EBL Systems

(Competitive references taken largely from Table 2.1 - [www.cnf.cornell.edu/cnf_spie54.html](http://www.cnf.cornell.edu/cnf_spie54.html))

<table>
<thead>
<tr>
<th>Model</th>
<th>Interface Ltd.</th>
<th>JC Nabity Lithography Systems</th>
<th>Raith GmbH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximity correction</td>
<td>Yes</td>
<td>No</td>
<td>Yes (optional)</td>
</tr>
<tr>
<td>Development simulation</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>3D structure editor</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Alignment</td>
<td>Automated or manual</td>
<td>Automated or manual</td>
<td>Automated or manual</td>
</tr>
<tr>
<td>Stitching</td>
<td>Automated, accuracy limited by stage</td>
<td>Automated, accuracy limited by stage</td>
<td>Automated, 0.1 um accuracy with laser stage</td>
</tr>
<tr>
<td>Energy</td>
<td>0-40 kV for typical SEM, but depends on target instrument</td>
<td>0-40 kV for typical SEM, but depends on target instrument</td>
<td>0-40 kV for typical SEM, but depends on target instrument</td>
</tr>
<tr>
<td>DAC speed</td>
<td>Mid-range, 150 ns per exposure point (7 MHz)</td>
<td>Mid-range, 200 ns per exposure point (5 MHz)</td>
<td>Mid-range, 166 ns per exposure point (6 MHz)</td>
</tr>
<tr>
<td>Throughput (limited by)</td>
<td>DAC speed, PC performance, not with scan coils (due to Dynamic Compensation)</td>
<td>Settling time of scan coils</td>
<td>Settling time of scan coils</td>
</tr>
<tr>
<td>Stage</td>
<td>Support for any automated stage</td>
<td>Support for any automated stage</td>
<td>Optional laser controlled</td>
</tr>
<tr>
<td>Control computer</td>
<td>PC compatible, PCI/PC bus / Windows</td>
<td>PC compatible, PCI/PC bus / Windows</td>
<td>PC compatible, SCSI data link to PC / Windows</td>
</tr>
</tbody>
</table>
Summary

The NanoMaker is capable of converting any SEM into an EBL system.

Unique features of the NanoMaker include:
- Proximity Effect Correction for 2D & 3D structures
- Simulation of Proximity Effects and resist development
- Distortion compensation (Static and Dynamic)
- New features for hologram/kinoform applications

NanoMaker is the result of an on-going collaborative effort between Interface Ltd. and a team of scientists at the Institute of Microelectronics Technology - Russian Academy of Sciences (IMT - RAS).

Interface Ltd. has recently signed a contract with SEMTech Solutions to exclusively promote the NanoMaker in North America.
About SEMTech Solutions

We specialize in e-Beam Products and Services

U.S. Sales & Service Locations, and Existing SEM Contract Areas

With over 100 SEMs under service contract, our customers range from universities to start-ups to Fortune 100 Companies