Electron Beam Lithography - key enabling technology in nanofabrication

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Moore’s Law

(x2/2 yr)
Moore's Law
Electron Beam Lithography -
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- Principles of Electron Beam Lithography (EBL)
- Throughput
- Applications in production
- Applications in research
- Conclusion
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EBL configuration

(Electron Beam Lithography)
Characteristics of EBL

- High resolution < 10 nm
- Flexible: direct write, maskless
- Relatively slow

Typical characteristics:
EBL exposure process

Trend in research machines: 100 keV machines.
less forward scattering, higher currents, higher dose, more back scattering
Gaussian Beam writing strategy

- Pattern split into fields
- Stage moves from field to field
- Primitive shapes filled by rastering
- Beam jumps between shapes
- Fast writing of sparse patterns

- Low throughput due to settling time
- Combination of high-res low-current and low-res high-current beams

Application: R&D
Spot size determines maximum beam current
e.g. for 20 nm features spot size < 5 nm
Split exposure

Automated switching
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**Throughput**

\[ T \times I = D \times A \]

- \( T \) = time (s)
- \( I \) = beam current (A)
- \( D \) = dose (\( \mu \text{C}/\text{cm}^2 \))
- \( A \) = area (\( \text{cm}^2 \))

CASE: 1 cm\(^2\) writing with 20 nm resolution:
(excl. stage movements and beam settling)

\( I = 1 \text{ nA} \)
\( D = 500 \text{ (}\mu\text{C}/\text{cm}^2\text{)} \) \( \text{Minimum dose in order to avoid “shot noise”} \)
\( A = 1 \text{ cm}^2 \)
\( T = 5 \times 10^5 \text{ (s)} \) = 6 days !!!!!

Writing 10% of a 300 mm wafer: \( T > 1 \text{ year} \) !!!!!
Shaped Beam writing

• Expose large areas with single "shots" of a shaped beam
• Programmable slits instead of aperture
• Extremely complex electron optical column
• Much faster than Gaussian spot systems
• Throughput limited by the pattern density

– Application: Mask writing

Cell projection writing

• Use hole masks with more complex patterns ("cells") to shape the beam
• Multiple cells in selectable aperture array

– Useful for highly repetitive designs with small unit cells
Summary of EBL writing methods

(a) Point Beam System
(b) Fixed Beam System
(c) Variable Shaped Beam System
(d) Cell Projection System
(e) Multiple Parallel Beam
Multi-beam

13,260 beams
×
7x7 sub-beams
=
649,740 beams

10 WPH (300mm)
Gaussian Beam
Crestec (Jp)
Elionix (Jp)
Jeol (Jp)
Nanobeam (UK)
Raith (Ge/NL)

Shaped Beam
Advantest (Jp)
NuFlare (Jp)
Vistec Semi (Ge)

Multi-beam
Mapper (NL)
IMS/Jeol (A)

SEM +

0.1 M€
0.5 -1 M€
1-3 M€
10 M€
Market data

Market share
Lithography Market 10.000 M€  CARG ≈ 10%
EBL < 1.000 M€
Gaussian Beam EBL 100 M€  CARG ≈ 3%

Cost  eUV  EBL
Wafer Size 300  100  mm
Fab 1000  < 50  M€
Litho tool 100  < 5  M€
Mask-set > 10  0  M€
Throughput > 100  < 1  WPH (300 mm)

LVM  Research
EBL at KavliNanolab Delft

1x Raith EBPG5000+ & 1x Raith EBPG5200
both with 10 holder load lock
24/7 operation
120 users
5000 hrs per machine for 6000 jobs (2015)
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Product applications -
T-gates for HEMTs (High Electron Mobility Transistors, high-power RF)
Blazed stacked X-ray zone plates
Example, Multiple-Step HSQ Lithography

Three consecutive e-beam exposures by a Vistec EBPG 5000plus tool for a two-level structure

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Building a Quantum Computer

Spin qubits

quantum dots in GaAs and Si devices

Group Lieven Vandersypen – QuTech -TUDelft
Quantum Mediator

double spin interaction through empty QD exchange the information between the two spins over a larger distance.
Building a Quantum Internet
the instantaneous entanglement link - a radically new form of secure communications

Loophole-free Bell test

Group Ronald Hanson– QuTech –TUDelft

NV centers in diamond
Nanofabrication by FIB and EBL
Large Scale Quantum Systems
Mechanical Resonators
for Quantum Optomechanics Experiments at Room Temperature

Group Simon Gröblacher– QN -TUDelft
ultra-thin silicon nitride tethered membranes
- mechanical quality factors of around $10^8$ at RT
- reflectivities >99% (photonic crystal)
Single Molecule Quantum Devices

mechanically controllable break junctions
to study gate-tunable single-molecule diode

Group Herre van der Zant – QN – TUDelft
Conclusions

- Great role for EBL in nanoscale research
- Throughput EBL will remain a challenge
- Opportunity for multi-beam techniques in production and research

Thanks to input from Raith and TU Delft groups in Kavli Institute for Nanoscience Delft
The NanoLabNL locations and their expert technologies

**Zernike NanoLab Groningen**
- Soft molecular landing deposition
- Ultra high vacuum low temperature scanning tunneling microscopy of surfaces
- High resolution photo electron spectroscopy for elemental surface characterization

**MESA+ NanoLab Twente**
- Surface level research and modifications
- Analysis and high resolution nanoimaging
- Device development for bionano and health applications

**Kavli NanoLab Delft**
- Nanostructuring by charged particle beams
- Fabrication of quantum devices
- Bionano imaging and superresolution microscopy

**TNO NanoLab Delft**
- Vacuum cleaning technologies
- Ultraclean handling and particle detection
- Specialized metrology

**Philips Innovation Services**

**NanoLab@TU/e**
- Deposition of organic, magnetic and semiconductor nanostructured material
- Processing of III-V-based integrated nanophotonic devices
- Advanced nanoscale processing
Nanopeople