Status and challenges of EUV Lithography

SEMICON Europa
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Contents

Introduction
NXE:3100
NXE:3300B
Summary and acknowledgements
Industry roadmap towards < 10 nm resolution
Lithography roadmap supports continued shrink

Resolution / half pitch, “Shrink” [nm]

Year of Production start *

* Note: Process development 1.5 ~ 2 years in advance
EUV reduces **Cost** and **Cycle Time** vs. Multiple Patterning

<table>
<thead>
<tr>
<th>Relative to EUV</th>
<th>LE(^2)</th>
<th>SADP</th>
<th>SAQP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process Steps</td>
<td>x2</td>
<td>x4</td>
<td>x5</td>
</tr>
<tr>
<td>Process Cost</td>
<td>+10%</td>
<td>+30~50%</td>
<td>+&gt;50%</td>
</tr>
<tr>
<td>Cycle Time</td>
<td>x2</td>
<td>x4</td>
<td>x5</td>
</tr>
</tbody>
</table>

**LE** = Litho-Etch, \(n\) = number of iterations

SADP = Self Aligned Double Patterning

SAQP = Self Aligned Quadruple Patterning
EUV enables 50% **Scaling** for the 10 nm node

Layout restrictions and litho performance limit shrink to ~25% using immersion

**Normalized die size [%]**

- Reference N20/16
- Double patterning
- Triple patterning
- EUV

EUV meets all litho requirements

Triple patterning does not show a process window

Source: ARM, Scaled 20nm flip-flop design
NXE technology roadmap has extendibility to <7nm

<table>
<thead>
<tr>
<th>Resolution [nm]</th>
<th>Under study</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>13</td>
</tr>
<tr>
<td>27</td>
<td>10</td>
</tr>
<tr>
<td>22</td>
<td>7</td>
</tr>
<tr>
<td>16</td>
<td>&lt;7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wavelength [nm]</th>
<th>13.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA</td>
<td>0.25</td>
</tr>
<tr>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>0.33NA DPT</td>
<td>&gt;0.5 DPT</td>
</tr>
</tbody>
</table>

| Lens flare      | 8%   |
|                 | 6%   |
|                 | 4%   |

| Illumination    | σ=0.5 |
|                 | σ=0.8 |
|                 | σ=0.2-0.9 |
|                 | Flex-OAI |
|                 | Extended Flex-OAI |
|                 | reduced pupil fill ratio |

<table>
<thead>
<tr>
<th>Overlay</th>
<th>DCO [nm]</th>
<th>MMO [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>4.0</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>3.0</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>1.2</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TPT (300mm)</th>
<th>Dose [mJ/cm²]</th>
<th>Power [W]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>10 - 105</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>80 - 250</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>500</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Throughput [w/hr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 - 60</td>
</tr>
<tr>
<td>50 - 125</td>
</tr>
<tr>
<td>125</td>
</tr>
<tr>
<td>125</td>
</tr>
<tr>
<td>165</td>
</tr>
</tbody>
</table>
## ASML’s NXE:3100 and NXE:3300B

<table>
<thead>
<tr>
<th></th>
<th>NXE:3100</th>
<th>NXE:3300B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NA</strong></td>
<td>0.25</td>
<td>0.33</td>
</tr>
<tr>
<td><strong>Illumination</strong></td>
<td>Conventional 0.8 σ</td>
<td>Conventional 0.9 σ</td>
</tr>
<tr>
<td></td>
<td>Off-axis illumination</td>
<td></td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>27 nm</td>
<td>22 nm</td>
</tr>
<tr>
<td><strong>Dedicated Chuck Overlay / Matched Maching Overlay</strong></td>
<td>4.0 nm / 7.0 nm</td>
<td>3.0 nm / 5.0 nm</td>
</tr>
<tr>
<td><strong>Productivity</strong></td>
<td>6 - 60 Wafers / hour</td>
<td>50 - 125 Wafers / hour</td>
</tr>
<tr>
<td><strong>Resist Dose</strong></td>
<td>10 mJ / cm²</td>
<td>15 mJ / cm²</td>
</tr>
</tbody>
</table>
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General
NXE:3100
NXE:3300B
Summary and acknowledgements
NXE:3100 in use at customers for cycles of learning

EUV processing of metal layer of logic circuit

After hard-mask etch-through

Resolution Limit of NXE3100 with dipole illumination

Pitch = 42 nm
Pitch = 40 nm
Pitch = 38 nm
Pitch = 36 nm
Pitch = 34 nm
Pitch = 32 nm

Data courtesy of TSMC
NXE:3100 shows stable performance

**LONG TERM WAFER STABILITY OF 27nm V LS - NOV’12-APR’13, CONV.ILL. 14MJ/CM2, YIELDSTAR S200**

71 fields/wafer, 26x33mm², 5x3 intrafield sampling

5 months

**FULL BATCH CD UNIFORMITY OF 27nm LS**

23 wafers, 83 fields/wafer, 1 point/field, Hitachi CG-4000

Full batch CDU:
Avg. CD V: 24.7nm, 3σ: 1.1nm
Avg. CD H: 25.2nm, 3σ: 1.2nm

Data courtesy of imec
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NXE:3100
NXE:3300B
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Eleven NXE:3300B systems in various states of integration

- System 1: Qualified
- System 2: Qualified
- System 3
- System 4
- System 5
- System 6
- System 7
- System 8
- System 9
- System 10: Training
- System 11
Eleven NXE:3300B systems in various states of integration

System 1  Qualified
System 2  Qualified
System 3
System 4
System 5
System 6
System 7
System 8
System 9
Development tool
Building extension started
System 10  Training
System 11
NXE:3300B imaging and overlay beyond expectations
matched overlay to immersion ~3.5nm

Scanner qualification

Full wafer CDU = 1.5nm

Scanner capability

Single exposure

EUV Spacer

Matched Machine Overlay

NXE- immersion [nm]
Lens performance consistent and exceeds requirements

*population for NXE:3300B*

*Every bar is an individual lens*

Data courtesy of Carl Zeiss SMT GmbH
Resolution shown on NXE:3300B for dense line spaces, regular and staggered contact holes; all single exposures

**14nm HP**

**13nm HP**

**Dipole30, Chemically Amplified Resist (CAR)**

**14nm HP**

**13nm HP**

**Dipole45, Inpria Resist**

**18nm HP**

**17nm HP**

**Quasar 30 (CAR)**

**19nm HP**

**18nm HP**

**Large Annular (CAR)**
NXE:3300B enables single exposure random logic metal layer with large DoF

*minimum HP 23 nm (N10 logic cell)*

**EUV**
- Node: N10 (23nm HP)
- 1\textsuperscript{st} insertion point for EUV
- Single Exposure
- Conventional illumination
- Best focus difference ~10nm
- Overlapping DoF current 100..120nm (expected to improve after further optimization (e.g. OPC))

**ArF immersion**
- Node: N20 (32nm HP)
- Double Patterning (design split)
- Best focus difference up to 40-60nm
- Overlapping DoF typical ≈ 60nm

**Position in the exposure slit**

-12\text{mm}  
0\text{mm}  
+12\text{mm}

Excellent print performance over the full exposure slit
EUV enables aggressive shrink on 2D logic

shrink possible beyond N7 node requirement

* using high dose resist @ ~50mJ
NXE:3300B FlexPupil enhances process window
Enabling further shrink at 0.33-NA

Custom pupil definition enabled by mirror addressing programmability

Field Facet Mirrors

Bi-state 2x positions in pupil

Intermediate Focus

Pupil Facet Mirrors

Logic N7 example

Simulations by Tachyon SMO NXE
NXE:3300B FlexPupil enhances process window
Enabling further shrink at 0.33-NA

Custom pupil definition enabled by mirror addressing programmability

Field Facet Mirrors

Bi-state
2x positions
In pupil

Intermediate Focus

Pupil Facet Mirrors

Logic N7 example

Standard
Advanced
Optimized

Local interconnect layer
Bright field
Feature width = 12 nm
Feature pitch = 32 nm

0 20 40 60 80 100 120 140

0 2 4 6 8 10

Exposure latitude (%)

Depth of focus (nm)

Simulations by Tachyon SMO NXE
With Off-axis illumination required dose lowered by 16% 

*tip2tip printed gap size down to ~30nm with Quasar illumination*

- Tip2tip print gap sizes down to **30nm** with Quasar illumination
- With off-axis illumination
  - printed T2T gap can be reduced on average by ~5nm, as compared to conventional illumination.
  - Printed T2T gap of 35nm can be printed at **~16% lower dose**, as compared to conventional illumination.
EUV source concept: CO2 drive laser hitting tin droplet, generating a plasma that emits 13.5nm light

CO2 system

Power Amplifiers

PP&MP Seed unit

Sub-fab Floor

Fab Floor

Source Pedestal

Scanner Pedestal

Vessel

Droplet Generator

Collector

Tin catch

EUV&droplet Metrology

Intermediate Focus Unit

metrology for source to scanner alignment

Scanner

Droplet Trajectory (Schematic)

CO2 beam

pre-pulse

main pulse

Droplet Trajectory (Actual shadow graph images)

pre-pulse

main pulse

Courtesy of Cymer
40W stable dose control performance for six 1-hours for MOPA-PrePulse

Data taken under demonstrated collector protection conditions

- 196 equivalent wafer exposures with 99.99% die yield

Data courtesy of Cymer
50W MOPA Prepulse EUV Power and Dose Stability

Dose Stability $\leq \pm 0.5\%$, Die Yield $>99.7\%$

Data courtesy of Cymer
EUV SOURCE POWER PROGRESS
50W Repeatable Power, Dose In Spec, ~40Wafers/Hour, 250W Target To Be Reached In 2015

80W enabled by 3300 drive laser

250W enabled by high-power drive & seed laser, independent pre-pulse, 80kHz repetition rate
The mask defect challenge

ASML achieved 10x per year improvement for pellicle-less operation (pellicle would reduce defect requirements substantially)

Progress made on ASML machines on added particles per reticle exchange over the past few years

Added particles > 92 nm per reticle pass

EUV Reticles (13.5nm)

- Reflective multilayer
- Absorber pattern
- Reflected illumination
- Particle (nm size)

Target performance for full production without pellicle @ 20 nm
The mask defect challenge

ASML achieved 10x per year improvement for pellicle-less operation (pellicle would reduce defect requirements substantially)

Progress made on ASML machines on added particles per reticle exchange over the past few years

- NXE:3100
- NXE:3300B

- Required for full production with pellicle @ 20 nm
- EUV Reticles (13.5nm)
- Reflective multilayer
- Absorber pattern
- Pellicle
- Reflected illumination

Particle (μm size)

24 hr test time limit @ 96 nm
@ 30 nm

Added particles > 92 nm per reticle pass
The mask defect challenge

**EUV pellicle considered as backup with minimum transmission and imaging loss**

- **Target full size**
  - 110x144 mm²
- **Transmission:**
  - Required >90%
  - Achieved ~80%

---

**EUV Reticles (13.5nm)**

- Reflective multilayer
- Absorber pattern
- Pellicle
- Particle (µm size)

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**Poly Silicon pellicle**
- 55 nm thickness
- > 80% transmission
- 80x80 mm

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**Multi Lattice pellicle**
- 25 nm thickness
- 60 mm

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**Wafer with 80*80 mm² membrane**
The mask defect challenge

EUV pellicle considered as backup with minimum transmission and imaging loss

- Target full size
  - 110x144 mm²
- Transmission:
  - Required >90%
  - Achieved ~80%

EUV Reticles (13.5nm)

- Reflective multilayer
- Absorber pattern
- Pellicle
- Reflect illumination
- Particle (μm size)
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Summary and acknowledgements
Conclusions

- Several EUV scanner in use at customer for cycles of learning and showing stable performance

- EUV imaging and overlay performance meets customer requirements for 1x node and below

- Roadmap towards 250W source power enabling exposures at 125 wafers per hour in place

- EUV mask defectivity improvement by 10x/year achieved over past years
  - Target remains to be build a particle free system; pellicle development ongoing as backup solution
The work presented today, is the result of hard work and dedication of teams at ASML and many technology partners worldwide including our customers.

Special thanks to our partners and customers for allowing us to use some of their data in this presentation.

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