EUV Lithography Industrialization and future outlook

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Outline

- NXE Roadmap
- NXE:33x0B litho performance and productivity
- NXE:3400B
- High NA EUV system
### EUV extension roadmap

<table>
<thead>
<tr>
<th>Year</th>
<th>55 WPH</th>
<th>125 WPH</th>
<th>145 WPH</th>
<th>185 WPH</th>
<th>Overlay [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>NXE:3300B</td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>2015</td>
<td>NXE:3350B</td>
<td></td>
<td></td>
<td></td>
<td>3.5</td>
</tr>
<tr>
<td>2017</td>
<td>NXE:3400B</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

- **At customer upgradable**
- **New platform**
- **High NA**
- **products under study**

Roadmap: October 2016
EUV reduces multi-pattern process complexity

# Process steps per layer

LOGIC

- ArFi LE3
- ArFi LE4
- ArFi spacer grating w/ 2 cuts
- EUV single exposure

DRAM

- ArFi Cross-spacer
- EUV single exposure

**LE3**=Litho+Etch+Litho+Etch+Litho+Etch
7 nm study with leading Logic chip maker projects lower wafer cost for EUV based processes

<table>
<thead>
<tr>
<th>Design</th>
<th>Critical litho</th>
<th>Total Wafer Processing Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Base</td>
</tr>
<tr>
<td><img src="image1.png" alt="Design" /></td>
<td><img src="image2.png" alt="Critical litho" /></td>
<td><img src="image3.png" alt="54x ArF immersion" /></td>
</tr>
</tbody>
</table>
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NXE:3350 Imaging: 16nm dense lines and 20nm iso space consistently achieve <1.0nm Full Wafer CDU at 80W source power

Overlay and focus performance NXE:3350B
Well in specification due to Hardware improvements and new calibrations
Demonstrated 85 wafers per hour on NXE:3350B
Achieved with 125W source configuration

- NXE:3350B ATP test: 26x33mm2, 96 fields, 20mJ/cm2
7 systems achieved over 80% availability (4 wk average)
Consistency to be improved

Graph showing the maximum availability of each system over a 4 week period
Productivity improvement also available to customers
3-day average of >1500 WpD achieved on NXE:3350B

Source: L.J. Chen (TSMC), EUVL Symposium, Hiroshima, Japan (24-26 Oct 2016).
EUV Source - Principle of operation

- Droplet Generator
- Vessel
- Collector
- Scanner
- CO2 system
- Power Amplifiers
- PP&MP Seed unit
- Source Pedestal
- Fab Floor
- Sub-fab Floor
- Scanner Pedestal
- Interior Focus Unit
- Vanes
- Tin catch
- Beam Transport
- metrology for source to scanner alignment

12/13/2016
Third generation Droplet Generators: average lifetime ~600 hours. Achieved >1000 hrs on multiple systems at multiple customers.

Type 3:
- capability of tin refill and restart
- enhanced particle elimination

- Average lifetime and maintenance time improved by factor >3

Droplet generator run 1400 hr as of Oct 2016

EUVL 2015
Typical collector lifetime improved by factor 1.5 in 2016
Data from 80W configuration in the field

-0.4%/Gp (EUVL 2016)
-0.6%/Gp (SPIE 2016)

Reflectivity [%]

250W configuration (development source)

Reflectivity [%]

Gigapulse

-0.1%/Gp
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NXE:3400B illuminator: increased pupil flexibility at full throughput
2D clips: pitch 32nm in x- and y- direction, $k_1=0.39$
Better pattern fidelity with lower Pupil Fill Ratio

SPIE 9776, Jo Finders “Contrast optimization for 0.33NA lithography”
Exposures done on a NXE:3350B system. On NXE:3350B, 20% PFR leads to loss of light.
Matched Machine Overlay 1.8nm, meets NXE:3400B specification
NXE:3400B overlay improvements include calibrations and new wafer table

NXE:3400B-like system. Matching to etched reference wafers exposed on immersion
Productivity roadmap towards >125 WPH in place

Throughput at targeted availability (>90%) sufficient for HVM insertion

- Throughput at 20 mJ/cm²
- Target availability (>90%)

- Source power increase
- Transmission improvement
- Faster wafer swap

- Good progress in source power supporting productivity roadmap to >125 WPH
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High-NA: large resolution step in line with our history

New product introductions providing step in resolution $\lambda/\text{NA}, \text{um}$

- Major technology step (e.g. source, mirror)
- Engineering optimization of numerical aperture resulting in a resolution step comparable to historical wavelength transitions
Overview main System Changes High-NA tool

- **Mask Stage**
  - 4x current acceleration
  - Same for REMA

- **Illuminator**
  - Improved transmission

- **Source**
  - Increased power

- **Lens**
  - NA 0.55, high transmission
  - Improved Thermal Control

- **Wafer Stage**
  - 2x current acceleration

- **New Frames**
  - Larger to support Lens

- **Improved leveling**
EUV Optical Train

- Reticle (mask)
- Field facet mirror
- Intermediate focus
- Plasma
- Pupil facet mirror
- Collector
- Wafer

Key-area where High-NA imposes large angles

W. Kaiser, J. van Schoot, Sematech Workshop on High-NA, 9 July 2013
Anamorphic magnification solves the problem at the mask

Multilayer Reflectivity

Reflectivity [%]

Angle of incidence on the mask [deg]

0.33NA – Mag 4x

0.55NA – Mag 4x/8x
High-NA >0.5NA 4x/8x anamorphic magnification
Chief Ray Angle at Mask can be maintained

- Anamorphic optics $\rightarrow$ half field:
  8x Magnification in scan
  4x Magnification in other direction
- Chief ray angle ok $\rightarrow$ Imaging ok

The pattern at the mask will be 2x larger $\rightarrow$
Scanner prints half fields
Anamorphic optics are used in cinematography
“Don’t change the mask”
Imaging verification of the new Half Field concept
Logic N5 clip Metal-1, 11nm lines, SMO is done at 8x

Aerial Image Intensity in Hyperlith

Note:
pictures at same scale, smaller mask reflection is also visible
High-NA Anamorphic Lens prints a half field
By utilizing the current 6” mask

Note: rectangular slit shown for illustration purposes
High-NA anamorphic Half Field concept
Faster stages enable high productivity

Half Field yields 2x more fields
• 2x wafer stage acceleration maintains overhead while going to twice number of scans

Y-magnification 4x → 8x
• 2x wafer acceleration results in 4x mask acceleration

Acceleration of wafer stage ~2x
Acceleration of mask stage ~4x
High-NA Field and Mask Size productivity
500W enables throughput of >150wph with anamorphic HF

Throughput for various source powers and doses

Throughput [300mm/hr]

Source Power/Dose [W/(mJ/cm²)]

WS, RS current performance
WS 2x, RS 4x

High-NA Half Field scanner needs 500W for 150wph at 60mJ/cm²
High-NA calls for tight focus control
High-NA scanner will be introduced in line with focus scaling

\[ \text{DoF} = k_2 \frac{\lambda}{NA^2} \]

\[ k_2 = 1 \]

Rayleigh

EUV depth of focus

focus control budget at introduction

High-NA
Way forward to 30 nm focus control

- **3300 performance**
- **Machine improvements (level sensor, stages, etc.)**
- **Optics improvements**
- **Product wafer flatness**
Summary

EUV into production in 2018-2019

- More than 1,500 wafers per day (WpD) exposed on a NXE:3350B at a customer site on average over three days at 85WpH configuration. Roadmap in place to secure >125WpH
- Best performance is four-week average above 90% on a NXE:3300B system
  - consistency between tools and across sites still needs to be significantly improved
  - Roadmap to >90% availability, with consistent performance, in place
- ASML expects that customers will take EUV into production in 2018-2019 timeframe

High-NA extends Moore’s Law into the next decade

- New anamorphic concept enables good imaging with existing mask infrastructure resulting in a Half Field image
- New stages technologies and high transmission optics enables cost effective litho-scaling
- On going feasibility studies support design targets