Jan van Schoot\textsuperscript{1}, Kars Troost\textsuperscript{1}, Alberto Pirati\textsuperscript{1}, Rob van Ballegoij\textsuperscript{1}, Peter Krabbendam\textsuperscript{1}, Judon Stoeldraijer\textsuperscript{1}, Erik Loopstra\textsuperscript{1}, Jos Benschop\textsuperscript{1}, Jo Finders\textsuperscript{1}, Hans Meiling\textsuperscript{1}, Eelco van Setten\textsuperscript{1}, Bernhard Kneer\textsuperscript{2}, Bernd Thuering\textsuperscript{2}, Winfried Kaiser\textsuperscript{2}, Tilmann Heil\textsuperscript{2}, Sascha Migura\textsuperscript{2}, Jens Timo Neumann\textsuperscript{2}

\textsuperscript{1} ASML Veldhoven, The Netherlands
\textsuperscript{2} Carl Zeiss Oberkochen, Germany

15 June 2017, EUVL Workshop, Berkeley
Outline

Why high-NA?

Anamorphic Optics

Imaging

System Architecture

Conclusions
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>
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<tr>
<td>2013</td>
<td>NXE:3300B</td>
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<td>2015</td>
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<td>NXE:next</td>
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<td>High NA</td>
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Overlay <3

products under study
EUV roadmap extension: High NA

- HF 0.55NA anamorphic optics, higher transmission, fast stages, offer attractive wafer cost / process simplification proposition
Larger NA reduces Local CDU
Due to larger aerial image contrast

Non-CAR resist, Quasar Illumination

- 0.33NA
- 0.55NA

18nm CH
LCDU=15% ADI

20mJ/cm²

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Edge Placement Error determining factor in litho performance

\[ EPE_{\text{max}} = \text{'systematics'} + \text{'local'} + \text{'global'} \]

\[ EPE_{\text{max}} = \frac{HR_{\text{OPC}}}{2} + \frac{3\sigma_{\text{PBA}}}{2} + \frac{6\sigma_{\text{LWR}}}{\sqrt{2}} + \sqrt{(3\sigma_{\text{OVL}})^2 + \left(\frac{3\sigma_{\text{CDU}}}{2}\right)^2} \]

With \( \sigma_{\text{LWR}} = \sqrt{\sigma_{\text{LWR, line}}^2 + \sigma_{\text{LWR, cuts}}^2} \)

and \( \sigma_{\text{CDU}} = \sqrt{\sigma_{\text{CDU, lines}}^2 + \sigma_{\text{CDU, cuts}}^2} \)

Bring system at EPE specifications by adapting the dose \( \rightarrow \) Throughput
Larger NA results in higher effective throughput
NA limits dose and # of LE steps

* Effective throughput = throughput / # LE steps

Jan van Schoot et al, EUV roadmap extension by higher Numerical Aperture, EUVL conference 2016, Hiroshima, Japan
Anamorphic Optics
EUV: it’s all about the angle
High-NA comes with large angles

MoSi Multilayer

ML reflection

NA=0.55

Jan van Schoot et al, EUV roadmap extension by higher Numerical Aperture, EUVL conference 2016, Hiroshima, Japan
Light cones at the mask for a 0.33NA Scanner
Enabling a solution with 26 mm slit on 6” masks

Reticle
Reticle layout compatible with today 6” mask production

Projection with 0.33 NA
Mag X: 4x
Mag Y: 4x

Source: Jan van Schoot, ASML, “EUV roadmap extension by higher Numerical Aperture”, 2016 international symposium on EUV, 24 October 2016, Hiroshima
Anamorphic High-NA EUV reduces the angles
Enabling a solution with 26 mm slit on 6” masks

Multilayer Reflectivity

Reflectivity [%]

Angle of incidence on the mask [deg]

0.33NA – Mag 4x

0.55NA – Mag 4x/8x

X

Y

Y - 4x

Y - 8x

16.5 mm

26 mm

Wafer

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Slide 11
High-NA anamorphic Half Field concept
Faster stages required to obtain high productivity half-field scanner

Projection: 0.33 NA  
Projection: > 0.5 NA

Acceleration of wafer stage ~2x
Acceleration of mask stage ~4x

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

Half Field yields 2x more fields:
2x wafer stage acceleration maintains overhead while going to twice number of scans
High-NA Field and Mask Size productivity
Throughput of >185wph with anamorphic HF

Throughput for various source powers and doses

Source Power/Dose [W/(mJ/cm²)]

Throughput [300mm/hr]

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

High-NA anamorphic
NXE:3300

High-NA Half Field scanner
needs 500W for
150wph at 60mJ/cm²
Source power: 250W demonstrated, 10x improvement in five years

EUV Power History

- Research
- Shipped
- To be shipped in 2017

250W with dose in specifications obtained on development source
High-NA optics design available
Larger elements with tighter specifications

\[
\text{Resolution} = k_1 \times \frac{\lambda}{\text{NA}}
\]

Reticle level

- Extreme aspheres enabling further improved wavefront / imaging performance
- Tight surface specifications enabling low straylight / high contrast imaging
- Big last mirror driven by High-NA
- Obscuration enables higher optics transmission ➔ Potential of up to 2x vs 3300

Wafer level

- NA 0.33
- NA >0.5

High-NA flexible illuminator
Principle NXE:3300/3400 illuminator can be reused

Illuminator elliptical pupil is projected in a circular pupil at the wafer

See Joerg Zimmermann et al. “Flexible illumination for ultra-fine resolution with 0.33 NA EUV lithography”, EUVL Symposium 2016
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
Imaging evaluation of key lithographic structures: comparable performance as 0.33 NA at ~40% lower resolution

Comparable Exposure Latitude at 40% lower resolution

Simulations based on high-NA lens Jones pupil; mask 3D effects included

DOF at equivalent $k_1$ factor

Follows NA scaling $\rightarrow \left(\frac{0.33}{0.55}\right)^2$
Good overlapping process window for customer relevant structures

8nm spaces through pitch

- 8nm CD, pitch 16nm
- 10nm CD, pitch 20nm
- 12nm CD, pitch 24nm

**DoF @ 10% EL (H,V) = 68 / 56nm**

12nm staggered CHs

- 12nm Hex-30 CHs
- 12nm Hex-60 CHs

**DoF @ 10% EL = 73nm**

Multi-pitch L/S pattern

Logic cutmask

Simulations based on high-NA lens Jones pupil; mask 3D effects and curved exposure slit included
High-NA system has smaller M3D effects than 0.33NA
Smaller mask angles of incidence due to anamorphic system

*L. de Winter, Understanding the Litho-impact of Phase due to 3D Mask-Effects when using off-axis illumination, EMLC 2015
System Architecture
High-NA system architecture available

- **Improved metrology**: 2~3x improvement in overlay/focus
- **Mask Stage**: 4x increase in acceleration
- **Lens & Illuminator**: NA 0.55 for sub-10nm resolution, High transmission
- **New Frames**: Improved thermal and dynamic control with larger optics
- **Wafer Stage**: 2x increase in acceleration
- **Source**: Compatible with 0.33 NA sources, power improvements opportunities over time

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High-NA Mask Stage solution for increased acceleration
Improved motor technology & different -light weight- architecture

Power \sim i^2 \cdot R
= k \cdot (acc \cdot mass)^2 \cdot R_{motor}

Limiting increasing power by:
- Improved motor technology (k, R)
- Reduce mass

Further Optimizing power consumption:
- New stage architecture with lower mass

Courtesy Chris Hoogendam, ASML
Reticle stage acceleration
4 x 3400 acceleration

3400 reticle stage

High-NA reticle stage
Mask stage short-stroke motor: demonstrated improved accuracy at high acceleration

<table>
<thead>
<tr>
<th></th>
<th>Measured</th>
<th>Required</th>
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<tr>
<td>Actuators force (N)</td>
<td>ref</td>
<td>1.2x</td>
</tr>
<tr>
<td>Positioning accuracy (MA-Y, nm)</td>
<td>0.37</td>
<td>≤1.1</td>
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Cooling Hood as Wafer Heating Solution

Extract heat from wafer using a cold body & gas pressure outside exposed area

Top Cooler working principle:
- Heat from wafer to cold body via gas
- Match $P_{cool}$ with exposure load,
- Switch cooling on/off between scans → gas pressure switching

Modelled raw distortions

NXE:3500 without Top Cooler

NXE:3500 with Top Cooler (“Cooling Hood”)

$P_{cool} = HTC(p, z) \cdot A \cdot dT$

$P_{cool}$ = Cooling power [W]
$A$ = Top cooler area [$m^2$]
$dT = T_{wafer} - T_{hood}$ [K]
$HTC = \text{heat transfer coefficient}$ [W/(m$^2$K)]
Wafer Heating NXE:3500 without cooler

-300 .. 300 mK
Wafer deformation (F2N)

-30 .. 30 mK
Clamp

ΔT (mK)

Overlay (F2N)
Wafer Heating NXE:3500 with cooler

-300 .. 300 mK  
Wafer deformation (F2N)

-30 .. 30 mK  
Clamp

ΔT (mK)

LCW

Overlay (F2N)
Mechanical layout
Modularity key for manufacturing, shipment and service
High-NA surface metrology

- Accuracy of mirror surface metrology is key for imaging quality
- High-NA wavefront needs improvement of factor $\sim 2\times$ compared to 3300 $\rightarrow 2\times$ better measurement accuracy required
- For larger mirrors: Diameter of mirrors about doubled

vacuum chambers

Courtesy Carl Zeiss SMT GmbH, 2016-09-20
Non-design but leadtime critical components ordered
Chamber flanges
Non-design but leadtime critical components ordered
Chamber doors
New grinding technology and machinery
Facility construction Zeiss in Oberkochen started
Summary

- **High-NA extends Moore’s Law into the next decade**
  - Larger contrast of High-NA helps mitigating LCDU
  - New anamorphic concept enables good imaging with existing mask infrastructure resulting in a Half Field image
  - New stages technologies and high transmission enable throughput ~185WpH
  - We are closing the feasibility, optics in design phase, first HW in place
The authors would like to thank the High-NA teams in
- Oberkochen
- Wilton
- Veldhoven

Thank you for your attention

Parts of these developments were funded by ECSEL JU projects SeNaTe, TAKE5 and TAKE-MI5

We thank the Federal Ministry of Education and Research (Germany) for funding of the BMBF project 16N12256K „ETIK“ and the projects 16ES0255K „E450LMDAP“, 16ESE0036K “SeNaTe”, 16ESE0072K “TAKE5” within the framework of the ENIAC and ECSEL programs, respectively.