EUV High-NA scanner to extend EUV single exposure

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15 June 2016, EUVL Workshop, Berkeley
Public quotes from major customers on EUV adoption

**Intel**

EUV to shorten time to yield in the next 5 yrs

*Brian Krzanich CEO Intel*

**TSMC**

EUV will be adopted for production at N5

*Mark Liu, Co-CEO TSMC*

**Samsung**

Intend do deploy EUV for 7 nm

Sources: Transcript, Intel Credit Suise Media conference, Brian Krzanich, December 2015, Source: Transcript, TSMC Q1 2016 earnings call, Mark Liu, April 2015, Joshua Ho, Anand tech, “Samsung Foundry Updates: 7 nm EUV, 10 LPP, and 14LPC, April 22 2016
Critical exposures for critical logic
Further reduction of # exposures using EUV 0.55 NA

Source: Luc van den Hove, IMEC, "Technologies for the intuitive internet of everything", ITPC 2015,
Larger NA reduces Local CDU
Due to larger aerial image contrast

Jo Finders et al, SPIE 2016

Resist dose:
- 17mJ ± 5mJ
- 35mJ ± 10mJ
- 70mJ ± 20mJ

Non-CAR resist, Quasar Illumination
Larger NA results in higher effective throughput 
NA limits dose and # of LE steps

* Effective throughput = throughput / # LE steps
Overview main System Changes High-NA tool

New Frames
• Larger to support Lens

Mask Stage
• 4x current acceleration
• Same for REMA

Source
• Increased power

Improved leveling

Illuminator
• Improved transmission

Wafer Stage
• 2x current acceleration

Lens
• NA 0.55, high transmission
• Improved Thermal Control
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Improved leveling
EUV: it’s all about the angle
High-NA comes with large angles

MoSi Multilayer

ML reflection

NA=0.5

30deg!!
EUV Optical Train

Two key-area’s where High-NA imposes large angles

W. Kaiser, J. van Schoot, Sematech Workshop on High-NA, 9 July 2013
Simple model of the optical column
Bending out the light cones at the mask reduces contrast strongly

\[ NA_{\text{mask}} = \frac{NA_{\text{wafer}}}{Mag} \]

We have to limit the angles on the mask! → increase magnification
Image contrast increases with a larger magnification
But only needed in one orientation

NXE:3300

**Horizontal Lines**

- 13 nm L/S, 0.33 NA ($k_1=0.318$)
- 8 nm L/S, 0.55 NA ($k_1=0.326$)

**Vertical Lines**

- 13 nm L/S, 0.33 NA ($k_1=0.318$)
- 8 nm L/S, 0.55 NA ($k_1=0.326$)

*NILS* = Normalized Image Log Slope, measure for image contrast

Anamorphic magnification needed for High-NA

High-NA >0.5NA 4x/8x anamorphic magnification

Chief Ray Angle at Mask can be maintained

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

The pattern at the mask needs to change
High-NA Anamorphic Lens prints a half field
By utilizing the current 6” mask

- **4x Conventional lens**
  - Full Field (FF)
  - Mask field size: 104 mm x 132 mm
  - Wafer field size: 26 mm x 33 mm

- **New Half Field (HF)**
  - Mask field size: 104 mm x 132 mm
  - Wafer field size: 26 mm x 16.5 mm

Note: rectangular slit shown for illustration purposes
Anamorphic optics are used in cinematography

“Don’t change the mask”

Anamorphic Camera

“The Mask” (24x36mm$^2$)

Anamorphic Projector
High-NA optics design concepts available
Larger elements with tighter specifications, no showstoppers

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

Wafer level

NA 0.25
NA 0.33
NA >0.5

Design examples

Imaging verification of the new Half Field concept
Logic N5 clip Metal-1, 11nm lines, SMO is done at 8x

Note: pictures at same scale, smaller mask reflection is also visible

Aerial Image Intensity in Hyperlith
High-NA optics has ~2x transmission
Smaller angles enable transmission gain vs non-obscured NA 0.33

Standard EUV coatings cannot handle these large angles

And even better: The smaller angular range increases the transmission
Proven imaging performance with High-NA optics
Spaces through pitch with small annular illumination

- Start pitch: 24nm for high-NA, 40nm for NA 0.33 \( \Rightarrow k1 = 0.49 \) in both cases.
- Anamorphic high NA w/ central obscuration: comparable exposure latitude, @ smaller pitches.
- Lower Best Focus variation for high NA.
Overview main System Changes High-NA tool

- **New Frames**: Larger to support Lens
- **Mask Stage**: 4x current acceleration, Same for REMA
- **Illuminator**: Improved transmission
- **Source**: Increased power
- **Wafer Stage**: 2x current acceleration
- **Improved leveling**
- **Lens**: NA 0.55, high transmission, Improved Thermal Control
Principle NXE:3300/3400 illuminator can be reused
For anamorphic lithography pupil facet mirror becomes asymmetric

Field Facet Mirror

Intermediate Focus

Pupil Facet Mirror

isomorphic

dipole x
dipole y

anamorphic
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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 Mask Stage solution for increased acceleration

Improved motor technology & different architecture

Current RS in High-NA
Power: ref

Current RS No solution

Improved RS motor
Power: 9 x ref

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
High-NA Field and Mask Size productivity
500W enables throughput of >150wph with anamorphic HF

Throughput for various source powers and doses

500W Watt 60mJ/cm²

500W Watt 30mJ/cm²

High NA anamorphic

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

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

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

Rayleigh

EUV depth of focus

- \( k_2 = 1 \)
- NXE:3300
- focus control budget at introduction
- High-NA
Focus latitude scales according expectation
Spaces through pitch with small annular illumination

**NA 0.33, 20nm spaces**

**NA 0.55, 12nm spaces**
Overlapping process window @ 8%EL → 45nm
NA=0.55, Random cuts, 24nm minimum pitch

- Combined set of 4 building blocks, 24nm minimum pitch
  - Annular illumination used
  - Overlapping process windows calculated
High-NA system has smaller M3D effects than 0.33NA
Smaller mask angles of incidence due to anamorphic system

Two-bar trenches are a canary for M3D effects

*L. de Winter, Understanding the Litho-impact of Phase due to 3D Mask-Effects when using off-axis illumination, EMLC 2015
Way forward to 30 nm focus control

Focus Control [nm]

- 3300 performance
- Machine improvements (level sensor, stages, etc.)
- Optics improvements
- Product wafer flatness
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 identified measures to meet the tight focus budget
The authors would like to thank the High-NA teams in:
- Oberkochen
- Wilton
- Veldhoven

Thank you for your attention