ASML

# High-NA EUV Lithography Exposure Tool

## For EUV roadmap extension

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# EUV product roadmap



| | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 |
|---|---|---|---|---|---|---|
| **EUV** 0.55NA, 8 nm | | | | **EXE:5000** 1.1 nm \| 185 wph[1] | | **EXE:5200** <1.1 nm \| >220 wph |
| **EUV** 0.33 NA, 13 nm | **NXE:3400C** 1.5 nm \| 135 wph[2] / 145 wph[3] | | **NXE:3600D** 1.1 nm \| 160 wph | | **NEXT** <1.1 nm \| >220 wph | |

0.55NA enabling affordable scaling beyond current decade

0.33NA continuous imaging, overlay and productivity improvements in line with customers advanced node HVM requirements.

wafers/hours (wph) are based on 30mJ/cm²
1) 185wph@20mJ/cm² / 150wph@30mJ/cm²
2) 170wph@20mJ/cm²
3) Throughput upgrade

**Product:** Matched Machine Overlay (nm)|Throughput(wph)

**Product status** Released | Development | Definition

# NXE productivity reached 170 wafers per hour

## Productivity at higher exposure dose continues to increase

ATP test: 26x33mm², 96 fields, 20mJ/cm² / 30mJ/cm²

# EUV collector transmission degradation meeting target

## Average degradation rate 0.1%/GP on NXE:3400B/C

# Wafers exposed on EUV systems grows exponentially

# Customer flagship products are powered by EUV

Source: https://www.samsung.com/semiconductor/minisite/exynos/products/mobileprocessor/exynos-9825/, https://consumer.huawei.com/en/campaign/kirin-990-series/

# Outline

High-NA agenda

- **Why High-NA**
- Infrastructure
- Architecture
- High-NA manufacturing

Summary

# Over 35 years 2 orders of magnitude resolution reduction

## by working on Wavelength, NA and k1



$$CD = k_1 \frac{\lambda}{NA}$$

# EXE platform to further enable affordable shrink (3 nm Logic)



## Total patterning cost comparison: immersion, NXE, EXE

Source: Jan van Schoot et al. (ASML) 'High-NA EUV lithography exposure tool progress' SPIE 2019

# High-NA contrast reduces Local CDU

## key to continue Moore's law: Resist, Dose, Contrast

**Resist** (blur/chemistry) **Dose** **Contrast**

$$LCDU = 3 \cdot \sqrt{\frac{hv}{f \cdot \alpha \cdot Area}} \cdot \sqrt{\frac{1}{D_{size}}} \cdot \frac{2}{ILS}$$

Whereby:
σ = resist blur
$D_{size}$ = dose to size
ILS = image log slope
p = pitch

EUV comes with less photons/J

10nm CH, 20mJ/cm2 → 1000 photons

30% absorption → 300 photons

30% determines the edge → 100 photons

- Minimize Local variation by
  - Improved resist: absorption ↑, blur ↓ , chemical shot noise ↓
  - Maximize contrast: high-NA, advanced mask

# High-NA contrast reduces Local CDU and defects

## Key to continue Moore's law: Resist, Dose, Contrast



$$LCDU\ [3\sigma, nm] = 3 \cdot \underbrace{\sqrt{\frac{hv}{f \cdot \alpha \cdot Area}}}_{\text{Resist}} \cdot \underbrace{\sqrt{\frac{1}{D_{size}}}}_{\text{Dose}} \cdot \underbrace{\frac{2}{ILS}}_{\text{Contrast}}$$

Whereby:

| | | |
|---|---|---|
| $\alpha$ | = | resist absorption |
| $f$ | = | proportionality factor with eg QE |
| $D_{size}$ | = | dose to size |
| $ILS$ | = | image log slope |
| Area | = | area containing photons contributing to LCDU |

### High-NA: smaller CH's at same dose

### 20nm 1:1 Contact Holes

### 20nm 1:1 Contact Holes

Yen, Hansen, EUVL workshop (2018)

- **Edge photons and contrast determine hole size variability**
- **Center photons open developer path to bottom "pipe cleaners"**
- **High-NA improves both aspects**

# 20nm CH's: Defects down by several orders

## Impact of High-NA 2: more center photons

Gijsbert Rispens, SPIE AL (2020)

# 14nm CH's: 0.55NA/SE expected to be better than 0.33NA/DE

## Based on aerial images



**0.33 NA** Double Expose

+

**0.55 NA** Single Expose

Slope 1.35x and local photons 1.4x

**Prediction: LCDU and defectivity better despite SE at smaller resolution**

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# Continuous resist improvement for multiple use cases

## Progress is needed moving forward



| | 2018 | 2019 | 2020 |
|---|---|---|---|
| **Resist type[1]** | **Non-CAR** | **Non-CAR** | **Non-CAR** |
| **Resolution:** (P26 Linesand Spaces) | | | |
| Dose [mJ/cm²] | 57 | 45 | 39 |
| $LWR_{unb}$ [nm] | 3.1 | 3.0 | 2.9 |
| **Z-factor [$10^{-6}$mJ nm³]** | **1.2** | **0.9** | **0.7** |

| | 2018 | 2019 | 2020 |
|---|---|---|---|
| **Resist type[1]** | **Non-CAR** | **Non-CAR** | **CAR** |
| **Resolution:** (P40 Hexagonal Pillars/CH) | | | |
| Dose [mJ/cm²] | 66 | 65 | 53 |
| LCDU [nm] | 2.7 | 2.2 | 2.1 |
| **Z-factor [$10^{-6}$mJ nm³]** | **3.8** | **2.5** | **1.9** |

### Lines and Spaces

***Z-factor** = $Res^3 \times LWR^2 \times Dose$

Z-factor comparison only valid at equal contrast

● Non CAR ● CAR

### Contact Holes

[1]Resist system: CAR Chemical Amplified resist

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**Lines and Space**

| | 2018 | 2019 | 2020 |
|---|---|---|---|
| Resist type[1] | Non-CAR | Non-CAR | CAR |
| Resolution: (P40 Hexagonal Pillars/CH) | | | |
| mJ/cm²] | 66 | 65 | 53 |
| DU [nm] | 2.7 | 2.2 | 2.1 |
| 6mJ nm³] | **3.8** | **2.5** | **1.9** |

**Contact Holes**

**HP12nm Lines and Spaces**

Non-CAR

CAR

*Z-factor = Res³ x LWR² x Dose

Z-factor comparison only valid at

CAR

[1]Resist system: CAR Chemical Amplified resist

# PSI High-NA resist evaluation for lines and pillars/CH



| Resolution [hp] | 13nm | 12nm | 11nm | 10nm | 9nm | 8nm |
|---|---|---|---|---|---|---|
| Inorganic Resist | 62 mJ/cm² | 58 mJ/cm² | 75 mJ/cm² | 59 mJ/cm² | 82 mJ/cm² | |
| Chemically Amplified Resist (CAR) | 58 mJ/cm² | 52 mJ/cm² | | | | |

| Resolution [hp] | 24nm | 22nm | 20nm | 18nm |
|---|---|---|---|---|
| Inorganic Resist | | 22 mJ/cm² | 19 mJ/cm² | 33 mJ/cm² |
| Chemically Amplified Resist (CAR) | 16 mJ/cm² | 17 mJ/cm² | 21 mJ/cm² | |

Ongoing imaging benchmarking of High-NA tools (PSI, BMET5, NXE)

**Reference:**
Contrast-loss investigation for the charactierization of resist and exposure tool performances Timothée Allenet, SPIE-AL, 11517-16

# CXRO/LBNL shows resist capability for Lines and Pillars

ASML



| Resist & Feature | Illumination | Resolution (nm) | | | |
|---|---|---|---|---|---|
| | | 11nm | 10nm | 9nm | 8nm |
| **Inpria Resist Lines and Spaces** | F2X frequency doubling | | | | |
| | | 13nm | 12nm | 11nm | 8nm |
| **Inpria Resist Regular Pillars** | F2X frequency doubling | | | | |
| | | 14P28 | 14P35 | | |
| **Inpria Resist Tip-2-Tips** | SMO | | | | |
| | | 13nm | 12nm | | |
| **CAR Lines and Spaces** | MP | | | | |

CXRO THE CENTER FOR X-RAY OPTICS

C. Anderson et al., CXRO, SPIE 2020

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# High-NA system architecture finalized



**Lens & illuminator**
- NA 0.55 for high contrast
- High transmission

**Mask Stage**
4x increase in acceleration

**Improved Source position**
Allows for larger transmission, compatible with 0.33 NA

**Improved metrology**
2~3x improvement in overlay/focus

**Wafer Stage**
2x increase in acceleration

**New Frames**
Improved thermal and dynamic control with larger optics

# EUV High-NA requires an anamorphic lens



Mask MoSi Multilayer

ML reflection

Note: for simplicity M3D effects are ignored, only multi-layer effect taken into account

# High-NA brings throughput >185 wph

## Fast stages enable high throughput

Acceleration of mask stage ~4x

Acceleration of wafer stage ~2x

# Recent EUV power improvement allows higher dose

## Servicing concept for high-NA identical to 0.33NA source

**Continuous source improvements:**

- Allow for more throughput
- Allow for more dose
  - Improved Local CDU

# High-NA projection optics design available

## Larger elements with tighter specifications

Extreme aspheres enabling
**further improved wavefront / imaging performance**

Obscuration enables
**higher optics Transmission**

Big last mirror driven by
**High-NA**

High NA optics design supports
**significant reduction in wavefront RMS**

# Full wafer and tool-to-tool CD control well below 10% CD

## Balanced performance budgets for many different use-cases and pupils

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# Top Module Shift-in Shift-out test successful

## 18 tons moves at mm-level accuracy

# Reticle stage short stroke module manufacturing progressing

Manufacturing of cooling channels

Finalized bottom plate

First Reticle Stage short stroke

# Long stroke motor mask stage risk build-down

Moving at NXE:3400 profile

Moving at EXE:5000 profile (4x)

Model verification

# Wafer stage cable slab guiding concept in test

## Dynamical testing ok

Slab test Y-axes

Slab test X-axes

Crash test

# Wafer stage modules being manufactured

Wafer stage design ready

Wafer stage position module manufactured

Proto Actuator Coils for testing

Mirror block manufacturing started

# First images taken with High-NA ILIAS proto sensor

## New ILIAS-sensor with improved marks for High-NA

# Good progress with EXE frame development

## Large frames modeled, improved welding

**Traditional welding:**
**4 weeks / frame**

**Robotized E-beam welding:**
**3 days / frame**

Ensure impact of Main Frame on POB in spec

# Bottom Base Frame manufacturing has started

System for final machining

Pre-machining started April ‘20

- Sub blocks pre-machined
- Welded to one piece with Electron Beam welding
- After welding the total frame is fine machined on large milling center
- Final machining planned later this year

# Top Frame machining on track

## Status May 2020



**Phase 1 (May 2020):**
top frame mono rough machining

Above is a picture of the first top frame being prepped for rough machining

# First mirror ground

## At this moment many more mirror in manufacturing

# EXE:5000 mirror metrology is operational

## Measuring a 1000kg anamorphic mirror with picometer accuracy

**Mirror flatness measurement**

# Mirror Metrology results



**1st crosscheck with known NXE:3400 mirror**

**High-NA metrology** − **3400 metrology** = **difference**

**High-NA mirror**

1st polishing loop

**Part corrected during 1st polishing loop**

# Reproducibility tests

## Air turbulences successfully eliminated by transition to vacuum

Air turbulences

Tilts due to rigid body vibrations

**Further improve dynamics effects by**

- **Better mounting**
- **Rigid body movement correction**
- **Optimizing exposure time and number of images**

# EXE:5000 system global design completed

## Solid progress on system design and optics development and – manufacturing

# High-Na cleanroom constructions in progress

Wilton

**Wilton Factory EXE:5000 Addition**

Veldhoven

**High-NA Cabins to be delivered according plan**

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**EUV 0.33NA is used in volume production, adoption continues to grow**

- Adoption continues to grow to reduce pattering complexity and cost
- Used for 7nm and 5nm Logic nodes, 10nm-class DRAM
- Productivity is improving to beyond 3000 WpD capability

**High-NA is logical roadmap extension by improving contrast**

- LCDU and defect print rate reduced by improved contrast, dose and resist
- Contrast is improved by a new anamorphic lens; imaging well controlled
- Throughput at higher dose maintained by transmission and source power

**High-NA EUV Scanner realization is in full progress**

- Feasibility of stages, sensors and many more demonstrated
- System design available, manufacturing of modules ongoing
- Optics design finalized, mirror metrology in place, manufacturing has started

# Summary



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- LCDU and defect print rate reduced by improved contrast, dose and resist
- Contrast is improved by well controlled
- Throughput at higher dose maintained by transmission and source power

**High contrast puts the photons where you need them**

**High-NA EUV Scanner realization is in full progress**

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- System design available, manufacturing of modules ongoing
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# Thank you for your attention

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