International Workshop on Advanced Patterning Solutions

ASML

Immersion and dry scanner innovations to support next generation device nodes.

"Mo(o)re Shrink, Better Performance, Continuous Innovation"

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ASML, the Netherlands

IWAPS, Xiamen, China
October 2018

ASML boosts patterning performance and process control

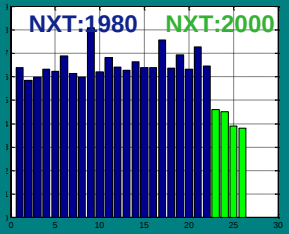
OPC: Optical Proximity Correction; OPO: On-Product Overlay; EPE: Edge Placement Error; CD Critical Dimension

TWINSCAN NXT:2000i key improvements

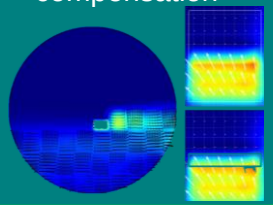
Improving on-product overlay and focus performance

2 ORION alignment sensor
4 colors x 2 pol. modes =
8 independent signals for
Optimal Color Weighting

3 Projection lens
smaller aberration residuals
new lens control model



4 Wafer heating control
In-line feedforward
compensation



1 UVLS-2 level sensor
eliminates process dependency
for better focus accuracy

Wafer Table
Improved matching to EUV
Reduced distortion during wafer load
Improved flatness & endurance

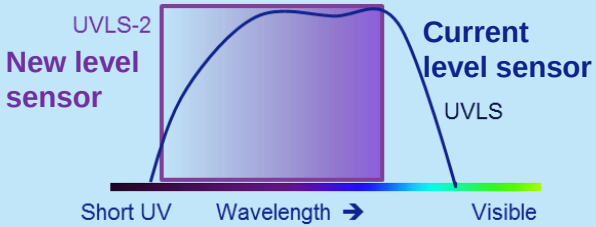
ArFi Laser
Supports latest
generation of ArFi Lasers

Legend:
Overlay
Imaging/Focus

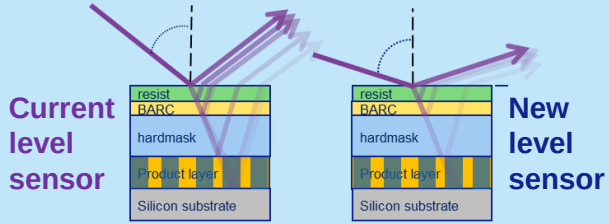
UVLS-2: New level sensor with deeper UV spectrum

Improves leveling performance and enhances process robustness

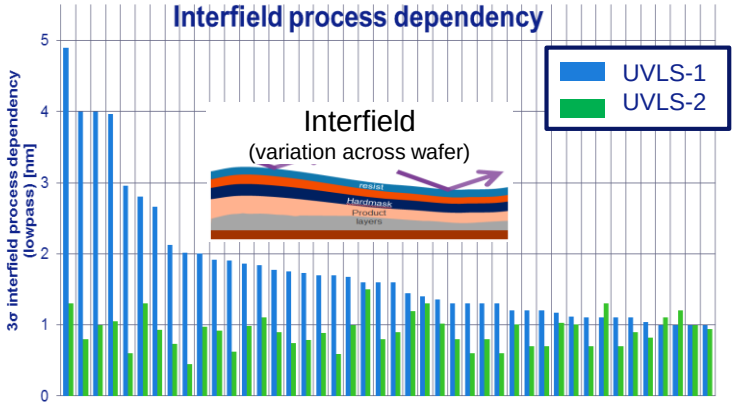
Reduced process sensitivity by **optimized illumination spectrum** to improve absorption in stack

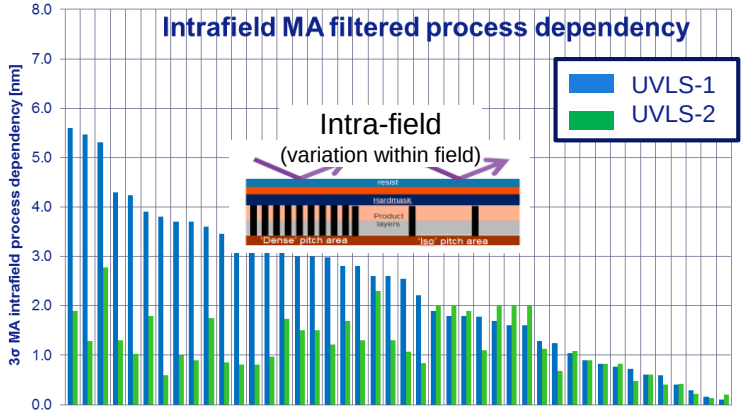


Reduced process sensitivity by **increased angle of incidence** resulting in more reflection from top layer



New **fine-focus calibration** for reduced machine-2-machine variation

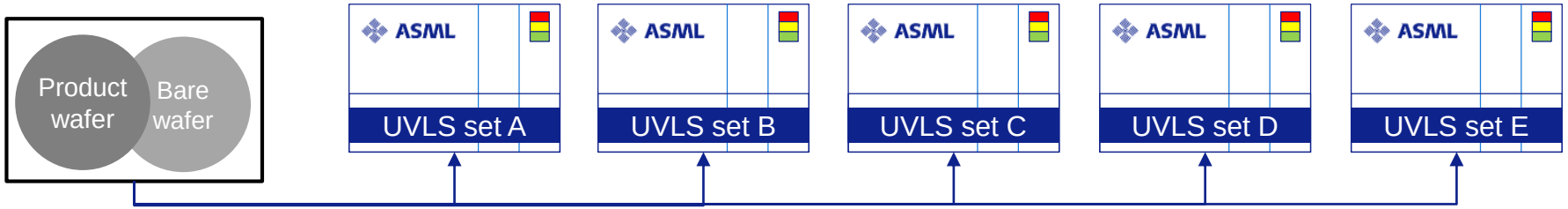


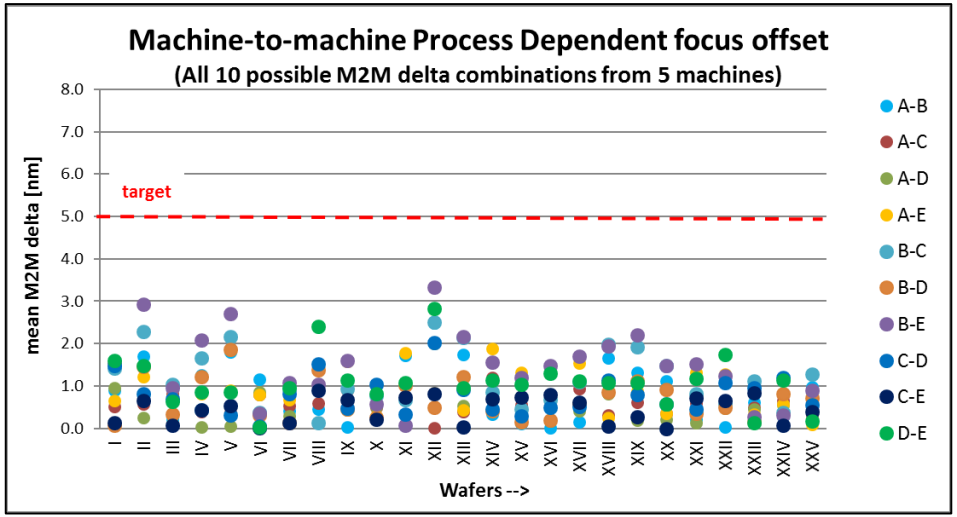


Machine to Machine Matching Results

UVLS-2 process dependency matching shows excellent performance

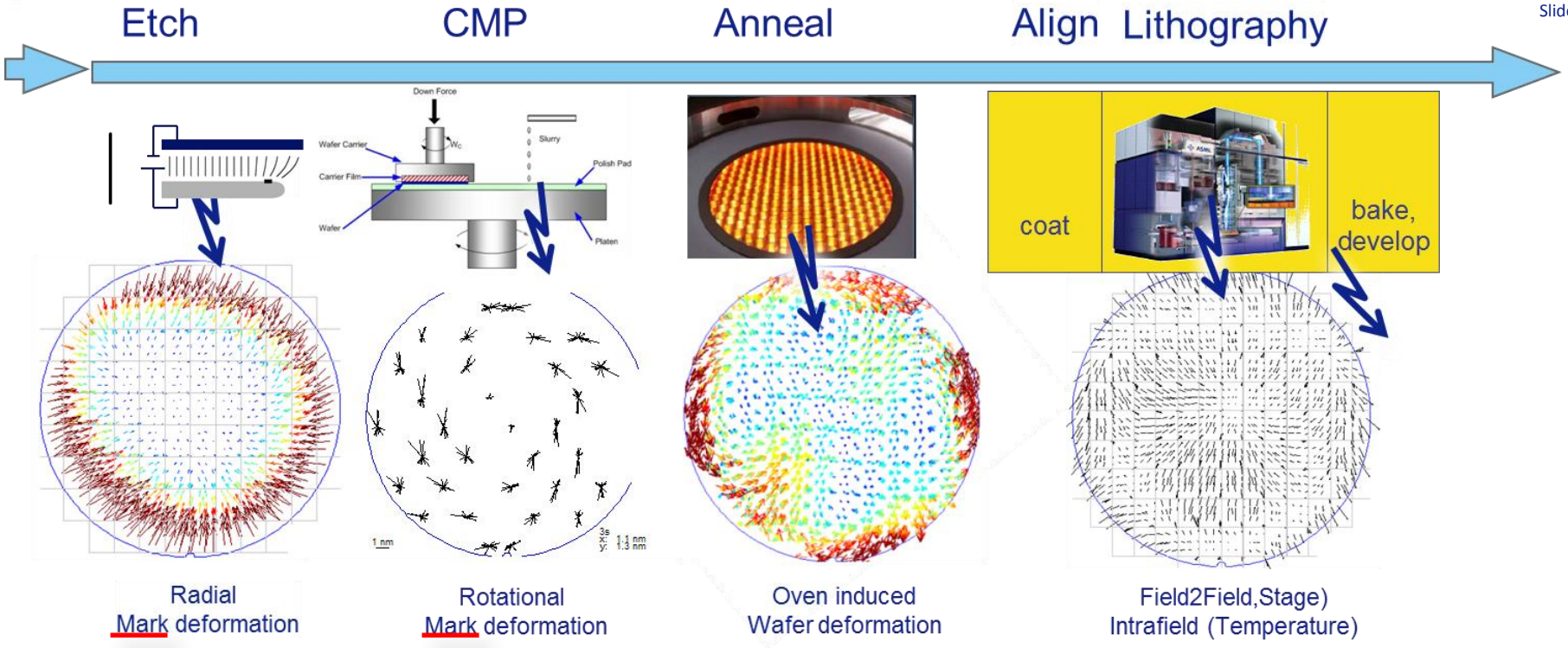
Measurement Method: accurate wafer maps on 5 different hardware sets





Process effects deform wafer ***and*** alignment marks

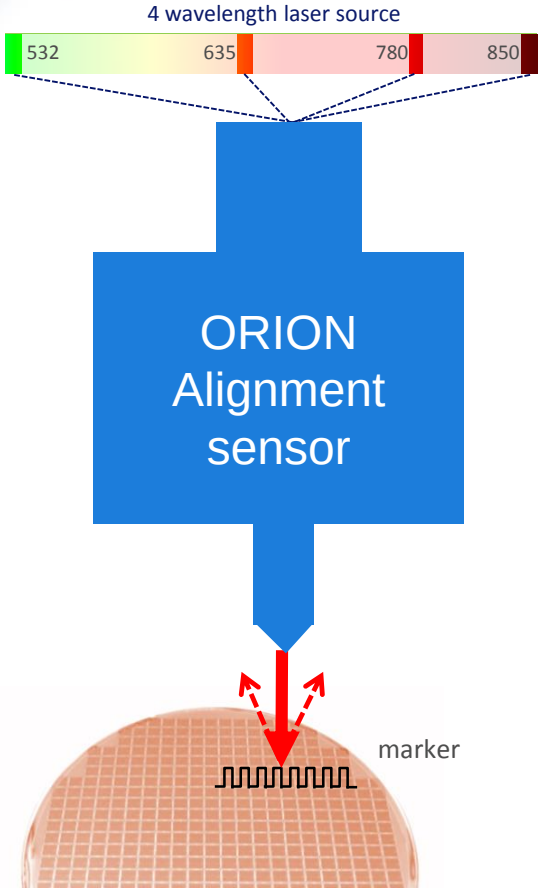
Process robustness of alignment marks a crucial factor in overlay



ORION alignment sensor with Optimal Color Weighting algorithm distinguishes mark deformation from (product) overlay effects

ORION wafer alignment sensor

Improves alignment performance and enhances process robustness

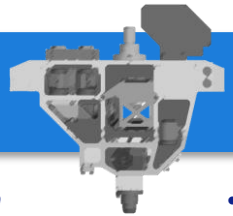


Customer benefit	Features	ORION sensor design
Reduced Wafer to Wafer (process/layer stack thickness) variation	Always 4 colors available with high Wafer Quality Choice of polarization	**Polarization independent sensor** dual interferometer & dual polarization output Improves process robustness
Mark Asymmetry suppression	Optimal Color Weighting (OCW)	
Reduced mark height and tilt variation sensitivity (6DoF)	Low aberration sensor design No mark overfill, reduced process cross talk Reduced sensitivity for TELE	**Improved sensor optics & mechanics design** better aberrations, larger NA, smaller spot size & improved opto-mechanical stability
Improved stability	improved opto-mechanics	

Alignment sensor improvements on the NXT platform

From mark versatility to contrast improvements to process robustness

2010~ (NXT) *SMASH*



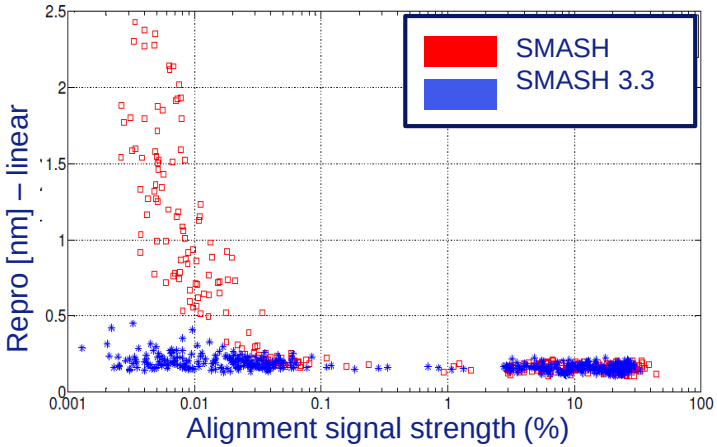
- *Support alignment on multiple marktypes*

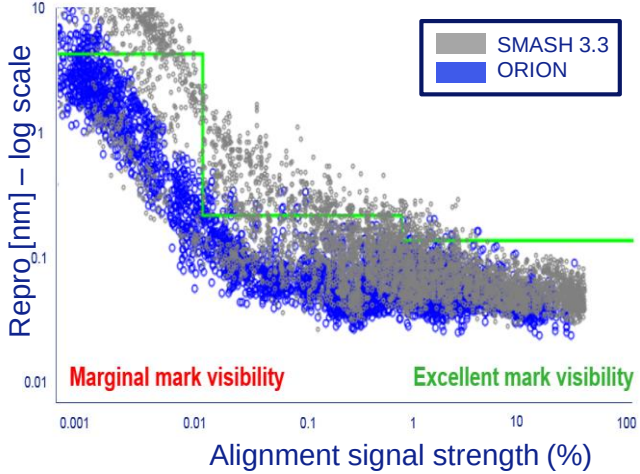
2016~ *SMASH 3.3*

- *Zero-order block for better contrast*
- *Low wafer-quality marks*

2018 *ORION*

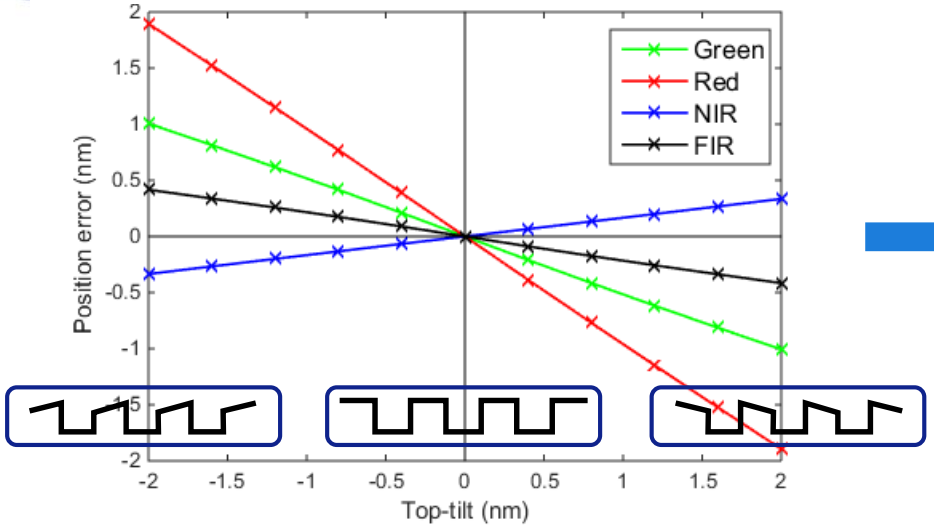
- *Improvement of optical design*
- *Doubling of nr of signals for discriminating process effects*

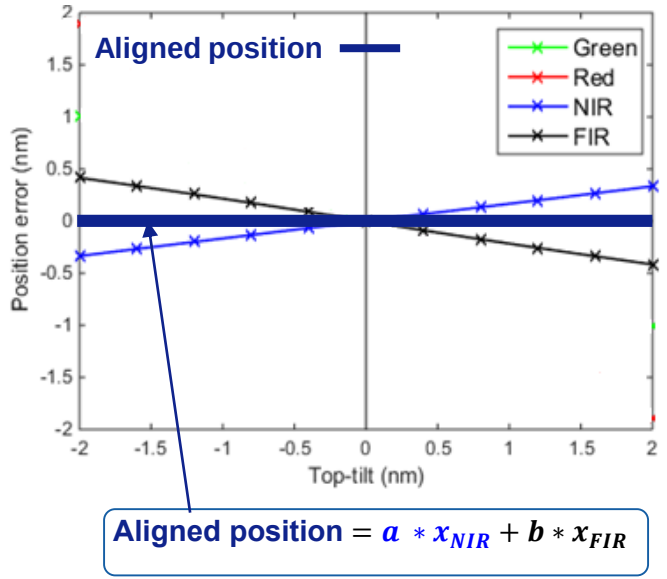




Optimal Color Weighting suppresses mark asymmetry

4 colors x 2 polarizations = 8 independent signals for optimal color flexibility





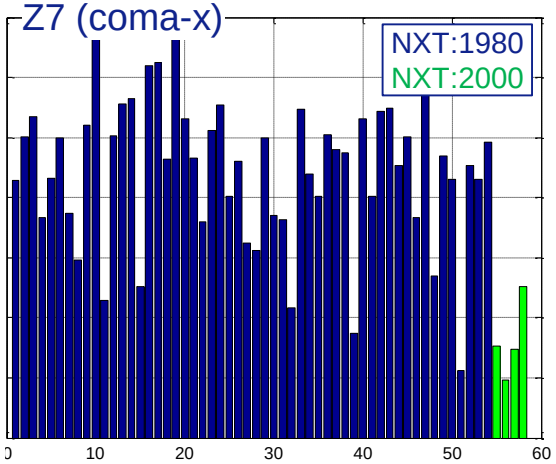
Example: alignment position error depends linearly on top tilt asymmetry

Aligned position $= a * x_{NIR} + b * x_{FIR}$

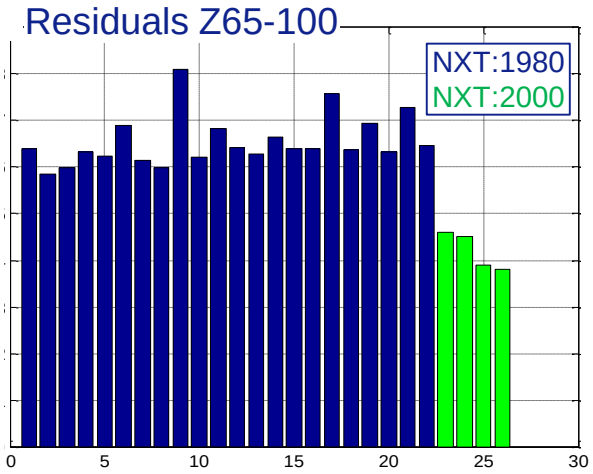
- Mark asymmetry introduces a color-dependent alignment error. Combining different colors and/or polarizations during wafer alignment reduces the sensitivity to process-induced mark asymmetry variations.
- Optimal Color Weighting (OCW) makes alignment readout insensitive to mark asymmetry by combining alignment signals. Orion enables OCW by providing more color signals.

Improved lens aberration performance

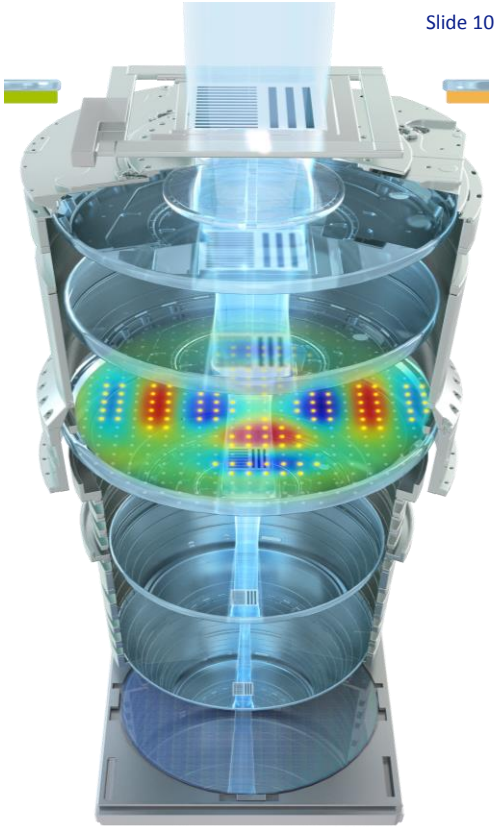
Reduce aberrations, smaller coma fingerprints; tighter population control



Z7 (coma-x) content up to 3rd order significantly reduced

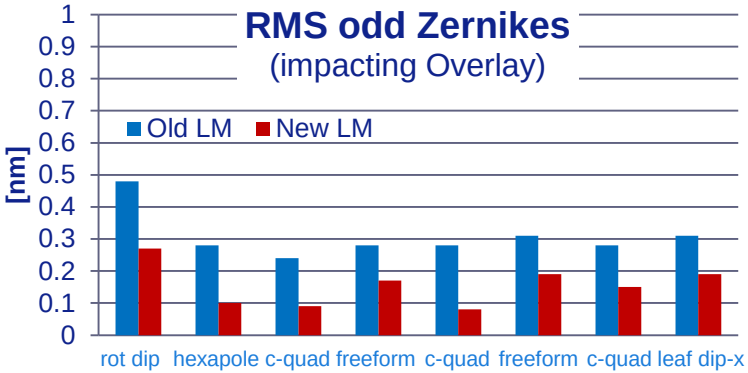


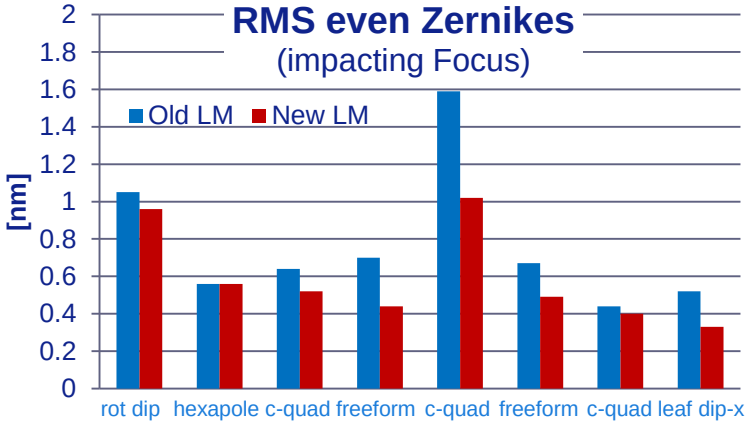
Residual wavefront improvement of ~40% with respect to NXT:1980 population

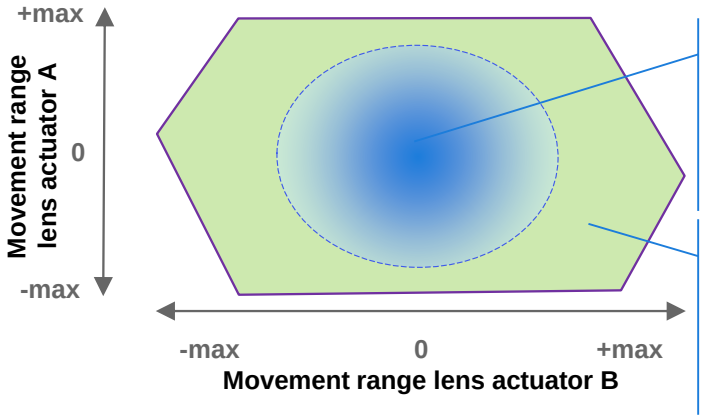


NXT:2000 Lens model utilizes more of lens actuator range

Significant correction potential gain by fully utilizing actuator extremes

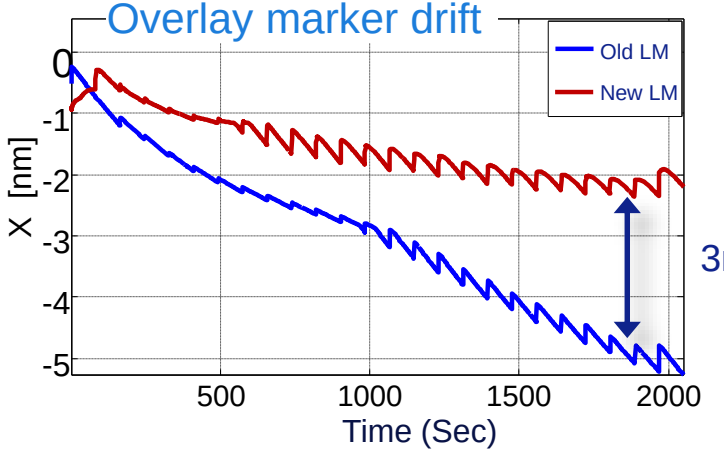






Current lens model restricts actuator to prevent range clipping.

NXT:2000i lens model utilizes all degrees of freedom of the lens to its full extends.



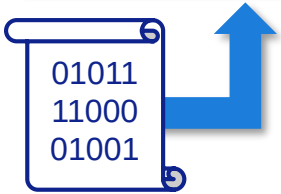
3nm gain

LM: Lens Model that drives/controls lens actuators

On-Scanner Heating Control (reticle, lens, wafer)

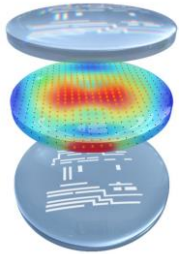
Wafer Heating FeedForward : the next step in thermal control

2005	2008	2010	2013	2015	2018
XT:1400 *LHFF / ASCAL*	XT:19x0i *TOP-RC*	NXT:1950 *FlexWave*	NXT:1970i *PARIS*	NXT:1980i *RHFF*	NXT:2000i *WHFF*

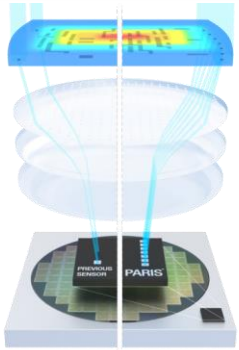


ASCAL:
Application-specific
Lens heating calibration
as subrecipe
(LH correction feedforward).

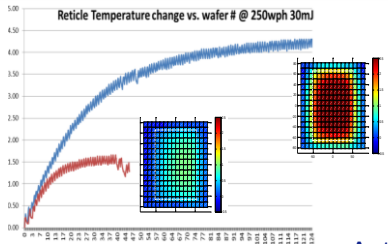
Reticle
Temperature
Sensor
measures thermal profile and models reticle distortion fingerprint



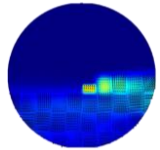
FlexWave
increases lens-heating aberration correction potential to Z64



PARIS sensor
measures overlay and aberration fingerprint at 7 points in the slit.



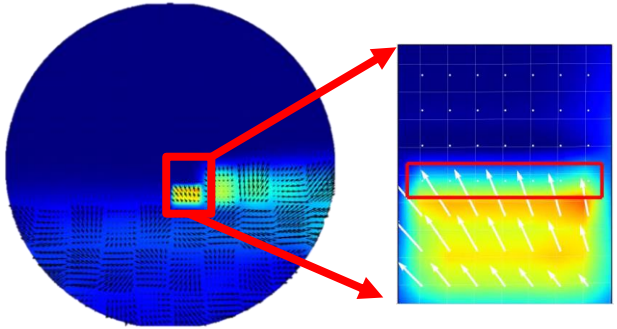
Active Reticle Cooling
(Reticle Heating FeedForward)
reduces reticle heating



Active Wafer heating control
Reduce overlay impact
of dose-sensitive layers

On-Scanner Wafer Heating Control

Wafer Heating FeedForward : the next step in thermal control



Wafer Heating: thermo-mechanical deformation of the wafer due to exposure light.

$$U_{wh} = D \cdot RT \cdot x(t)$$

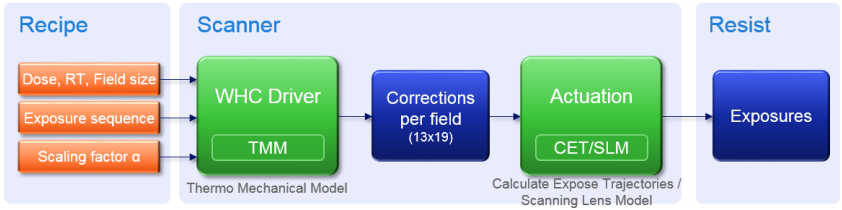
D: dose, RT: reticle transmission, x(t): position (expose meander)

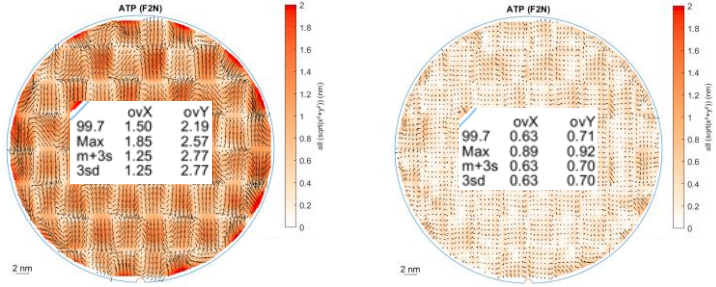
Dose difference between layers results in overlay fingerprint effects across wafer/die.

Thermo-mechanical model (TMM):

1- *displacements are computed during scan at slit location*

2- required corrections are determined and sent to lens and stage actuator





Wafer heating impact: reduced from **2.2nm to 0.7nm** for 21mJ/cm^2 effective Δ dose

Supporting EUV to DUV cross-platform matching

Hardware and design differences give rise to cross-matching overlay penalty

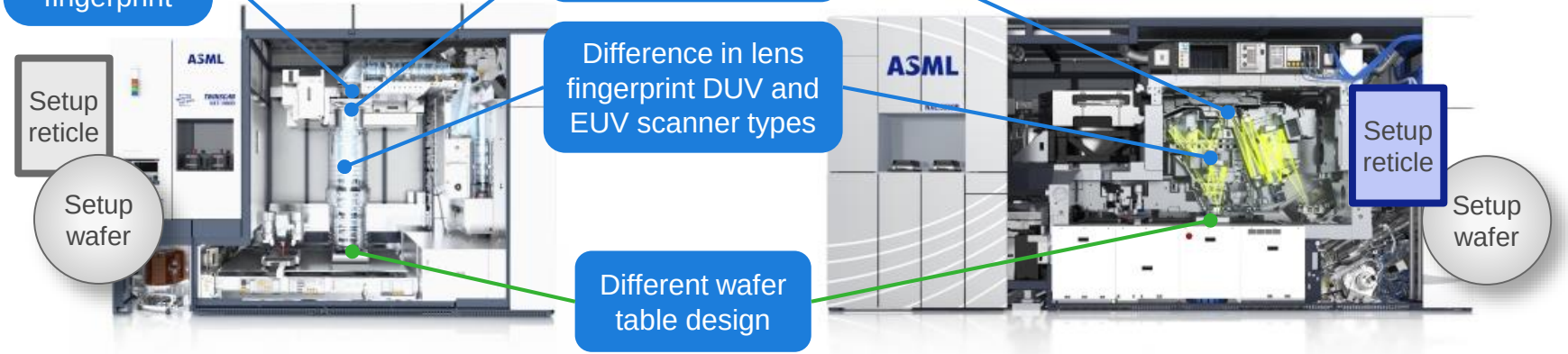
DUV pellicle induces scan dependent fingerprint

DUV: NXT:2000i

Different reticle stage design in DUV and EUV system

EUV: NXE:3400B

Difference in lens fingerprint DUV and EUV scanner types



Different wafer table design

Deep UltraVolet lithography:

- Wavelength: 193nm
- Refractive optics (lenses)
- Refractive reticle
- Reticle + wafers clamped via gravity and vacuum

Setup and drift control wafers need to be straight/matched

Setup and drift control reticles need to be matched.

Extreme UltraViolet lithography:

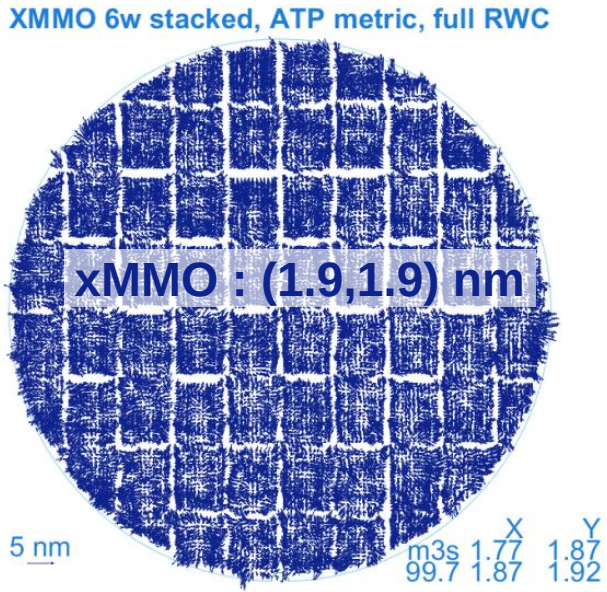
- Wavelength: 13.5nm
- Reflective optics (mirrors)
- Reflective reticle
- Reticle + wafers clamped electrostatically

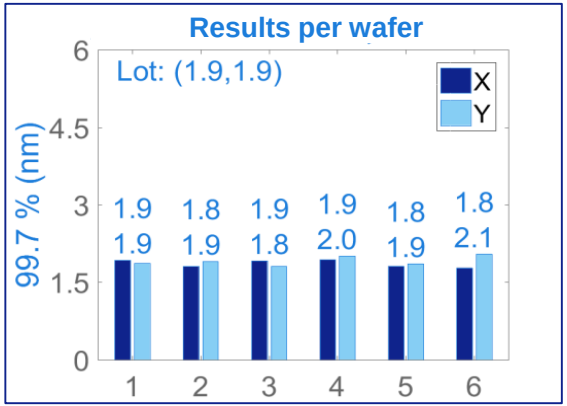
NXT:2000i optimized for critical layer matching to EUV

Less than 2.0 nm Matched Overlay demonstrated for NXT:2000i to NXE:3400B

- Setup done with latest grid reference wafers
- NXT2000i layer exposed with pellicle
- NXT (average population) lens fingerprint correction and reticle clamping fingerprint embedded in Reticle Writing Corrections

NXT:2000i – NXE:3400B full wafer





	OVL (X,Y)
NXT:2000i MMO to ref	1.8,1.6 nm
NXE:3400 MMO to ref	1.2,1.3 nm
NXT to NXE matching	1.9,1.9 nm

TWINSCAN DUV Scanner Roadmap - Immersion

Current Product status
Released
Development
Definition
Study

TpT | MMO	2016				2017				2018				2019				2020				2021				2022				2023			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
ArFi	NXT:1980i								NXT:2000i								NXT:2050i								Next Gen							
	275 WpH | 2.5 nm								275 WpH | 2.0 nm								285 WpH | 1.5 nm								>285 WpH | <1.5 nm							

NXT:2000i

- Optimized matching to EUV
- Improved on-product performance
- Suppressing wafer heating effects

NXT:2050i

- Productivity boost with new wafer stage
- Improved Edge Placement control
- Better higher-order intrafield overlay

TWINSCAN DUV Scanner Roadmap - Dry

ASML

IWAPS, Xiamen, China
October 2018

Current Product status: Released | Development | Definition | Study

Continuous innovation brings latest NXT technology to dry tools performance

TpT | MMO	2016 Q1	Q2	Q3	Q4	2017 Q1	Q2	Q3	Q4	2018 Q1	Q2	Q3	Q4	2019 Q1	Q2	Q3	Q4	2020 Q1	Q2	Q3	Q4	2021 Q1	Q2	Q3	Q4	2022 Q1	Q2	Q3	Q4	2023 Q1	Q2	Q3	Q4
ArFi	NXT:1980i												NXT:2000i								NXT:2050i								Next Gen			
	275 WpH | 2.5 nm												275 WpH | 2.0 nm								285 WpH | 1.5 nm								>285 WpH | <1.5 nm			
ArF	XT:1460K																NXT:1470															
	205 WpH | 5 nm												BOOST 220 WpH | 7 nm UVLS				300 WpH | 4 nm														

NXT WAFER STAGE
- Magnetic planar drive
- Productivity optimized sensor locations

Alignment & Level Sensors
- UV-Level-sensor
- SMASH alignment sensor

Dry NXT Wafer Table
- EUV matching, wear resistant

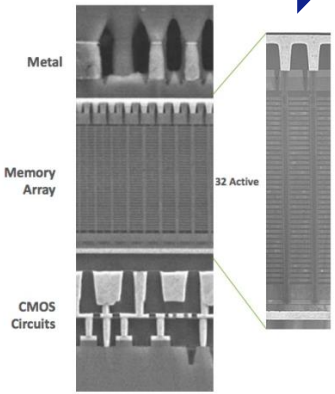
Projection Lens
- Reduced heating (coatings & materials)
- Lens distortion reduction

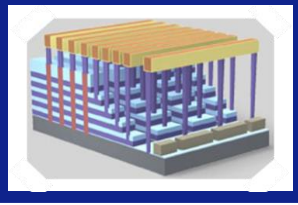
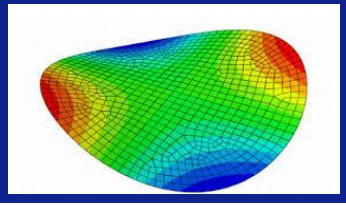
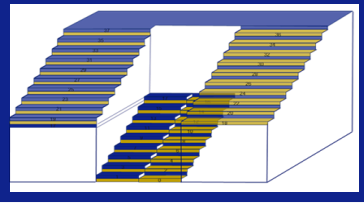
System Metrology & Control
- New lens model with less restrictions
- Fading optimization
- PARIS based lens control
- Accurate grid setup from immersion

3D NAND manufacturing enabled on XT and NXT

High aspect ratios, wafer stress and topologies require tool changes

Device scaling drives…



Higher Aspect Ratio Processes	Increased Wafer Stress	Larger Topology
		
Process Stack, Hard Mask	**Warpage & In-die Stress**	**Leveling**
Smash Mk3.3, ORION	Handling Capability	Large Range Level Sensor
Extend alignment colors	High Warp Performance	UV Level Sensor NXT, XT
Overlay Optimizer 2	Overlay Optimizer 3	Intrafield Fingerprint Correction
Optimal Color Weighting	PEP-Align	KrF High Dose

Focus Control: Leveling Advisor, Imaging Optimizer 2, YieldStar DBF, Pattern Fidelity Control

Overlay Control: YieldStar After Develop (ADI), After Etch (AEI), In-Device (IDM), Litho Insight

Legend:

Released

In Development

ASML's suite of scanners enable product versatility at lowest per-wafer cost

Performance

Cost

Shrink
(Geometric scaling)

Special Applications
(3D NAND)

CAPEX

OPEX

CAPEX saving through TwinScan NXT Upgrades

NAND
DRAM
Logic
32-28
20-16
10
7
5-3

190 WpH	230 WpH	250 WpH	275 WpH	MMO	OPO
NXT:1950i	PEP NXT			5.5nm	7nm
	NXT:1960Bi	NXT:1965Ci	PEP C	4.5nm	6.5nm
	UVLS			4.5nm	6.5nm
SNEP to 1970		NXT:1970Ci	PEP C	3.5nm	5nm
		OFP 1970		2.7nm	4nm
	SNEP to 1980		NXT:1980i	2.5nm	3.5nm
	SNEP to 2000		NXT:2000i	2.0nm	2.5nm

CAPEX saving through TwinScan NXT Upgrades

PEP-Output enhances wafer-per-day scanner output.

NAND
DRAM
Logic
32-28
20-16
10
7
5-3

190 WpH | 230 WpH | 250 WpH | 275 WpH | +3-10% WPD*

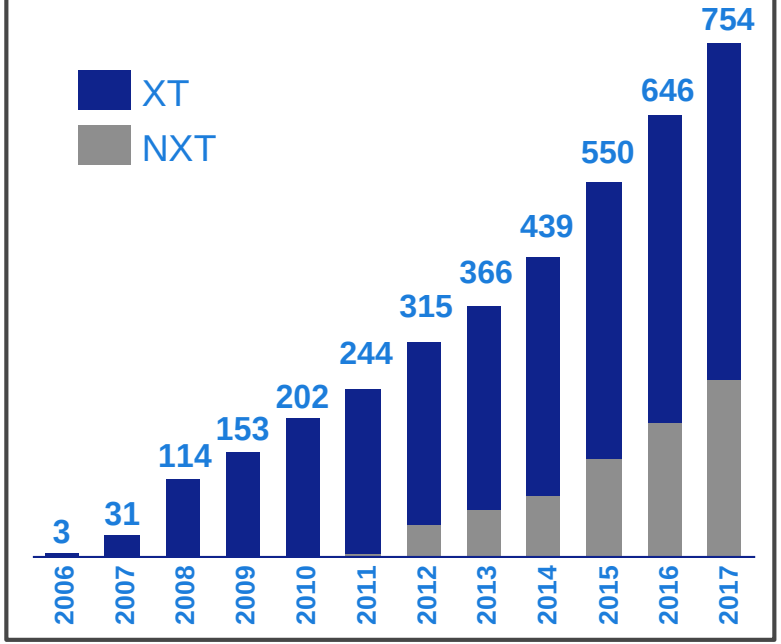
NXT:1950i
PEP NXT
PEP Output
NXT:1960Bi
NXT:1965Ci
PEP C
PEP Output
UVLS
4.5nm
6.5nm
SNEP to 1970
NXT:1970Ci
PEP C
PEP Output
OFP 1970
2.7nm
4nm
SNEP to 1980
NXT:1980i
PEP Output
SNEP to 2000
NXT:2000i
PEP Output

* Actual gain depends on customer usage (Rate Efficiency)

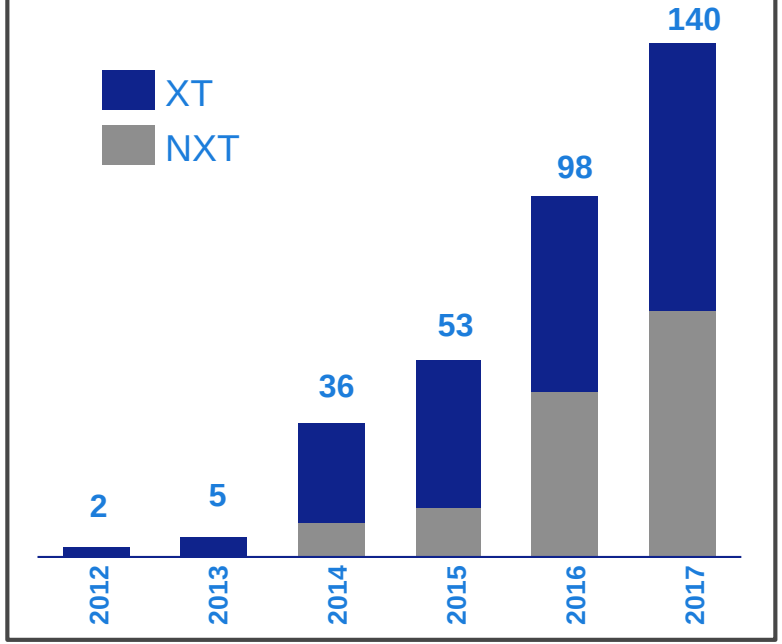
140 Tools Achieved >1.5 Million wafers/year in 2017

More than 750 systems reached above 1 million WpY

Number of tools > 1 million WpY



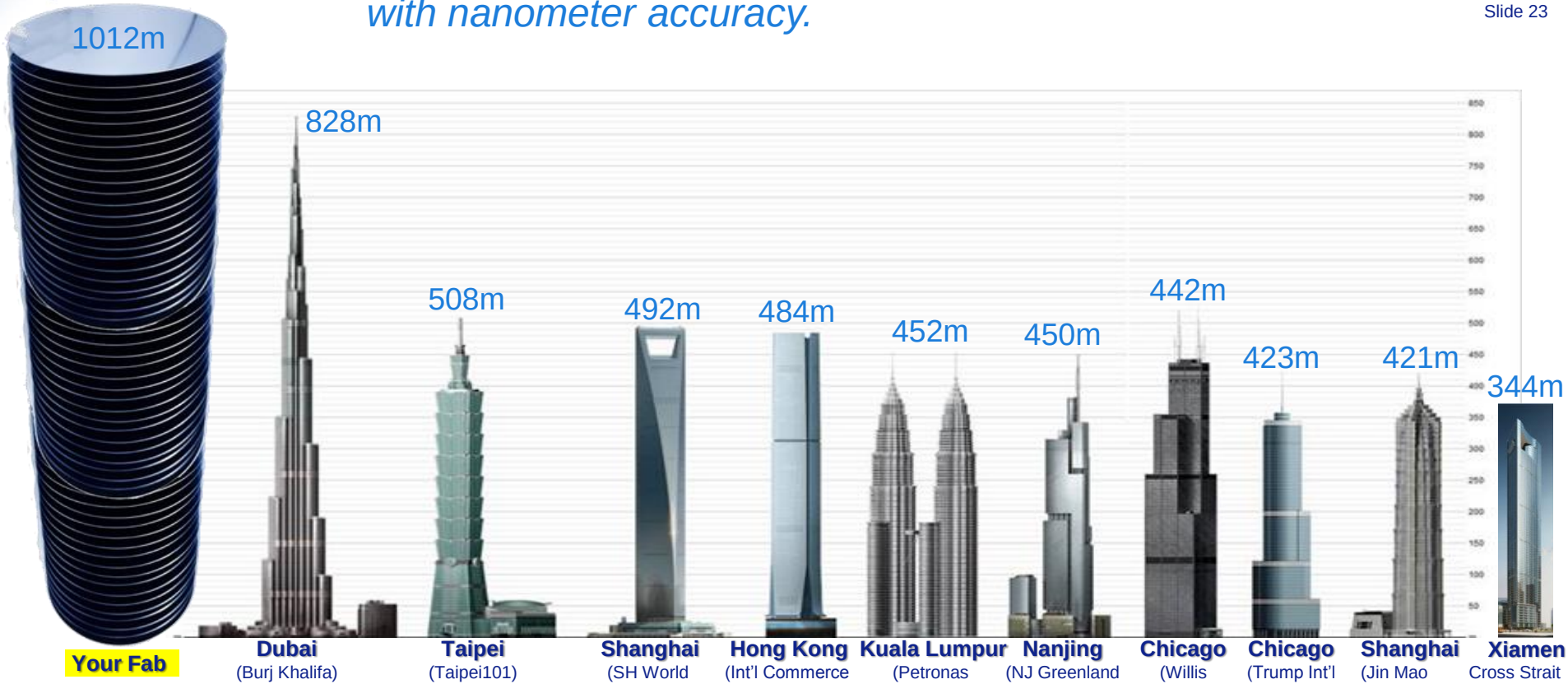
Number of tools > 1.5 million WpY



Holistic productivity approach will soon bring the 1st tool above 2 million WPY

These gigantic towers took years to build…

ASML scanner's annual output: > 1km in wafers/tool (record: 1.4-1.5km) with nanometer accuracy.*



* >1.5M Wafers/year/scanner

Conclusions

- NXT immersion system extensions for n5 nodes and beyond.
  - Continuously extend on-scanner overlay and focus improvements.
  - Solutions in place for cross-platform matching DUV to EUV.
- Transfer of immersion NXT technology to a dry platform
  - Drive productivity and overlay; maintain economic viable cost levels
- Solutions for 3D-NAND specific challenges
  - Various alignment- & focus-control and dose (laser power) packages available.

Thank You