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Evaluation of EUVL Readiness for Mass Productions

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Toshiba Group contributes to
the sustainable future of planet Earth.

Outline

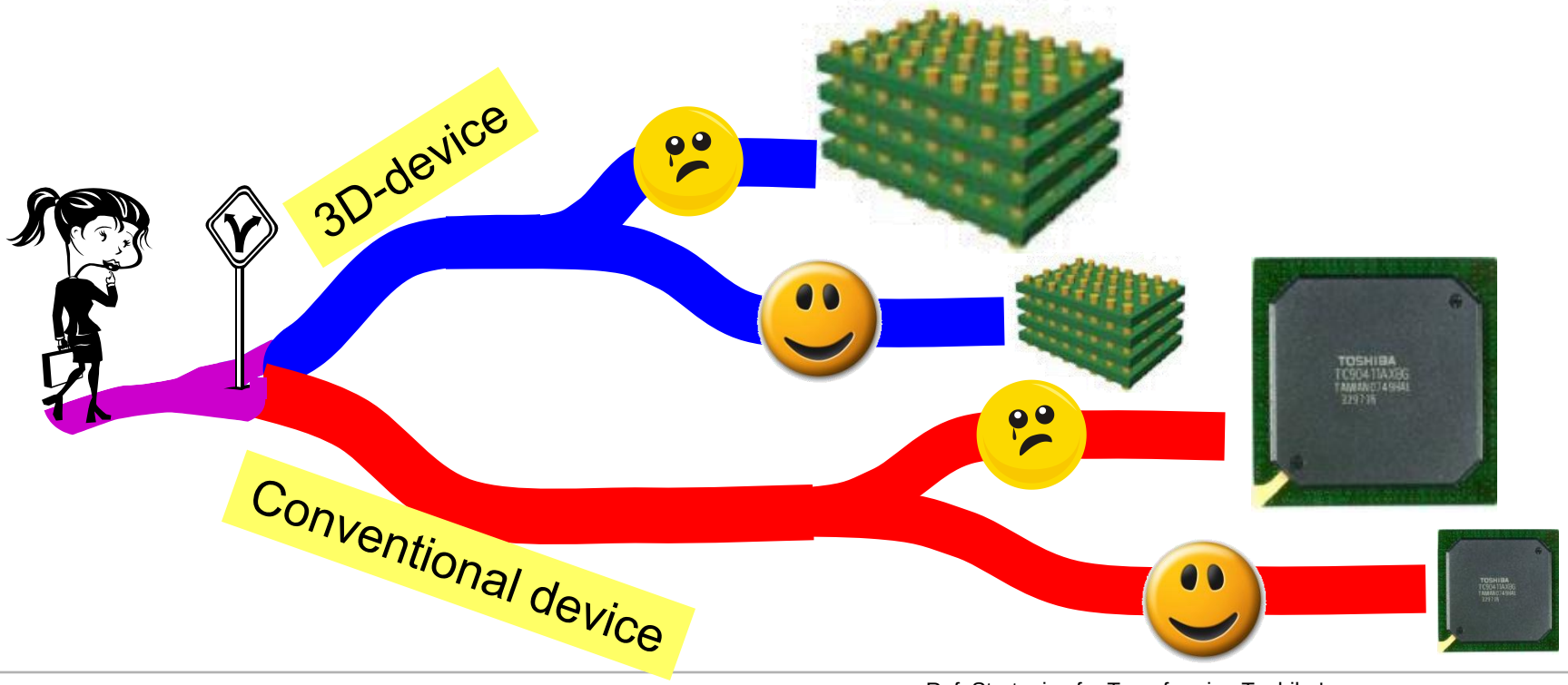
1. EUVL requirements for semicon. business
2. EUVL readiness for mass production
   - Lithographic performance
   - Productivity
3. Technology challenges aiming at higher productivity
4. Conclusions

Outline

1. **EUVL requirements for semicon. business**
2. EUVL readiness for mass production
   - Lithographic performance
   - Productivity
3. Technology challenges aiming at higher productivity
4. Conclusions

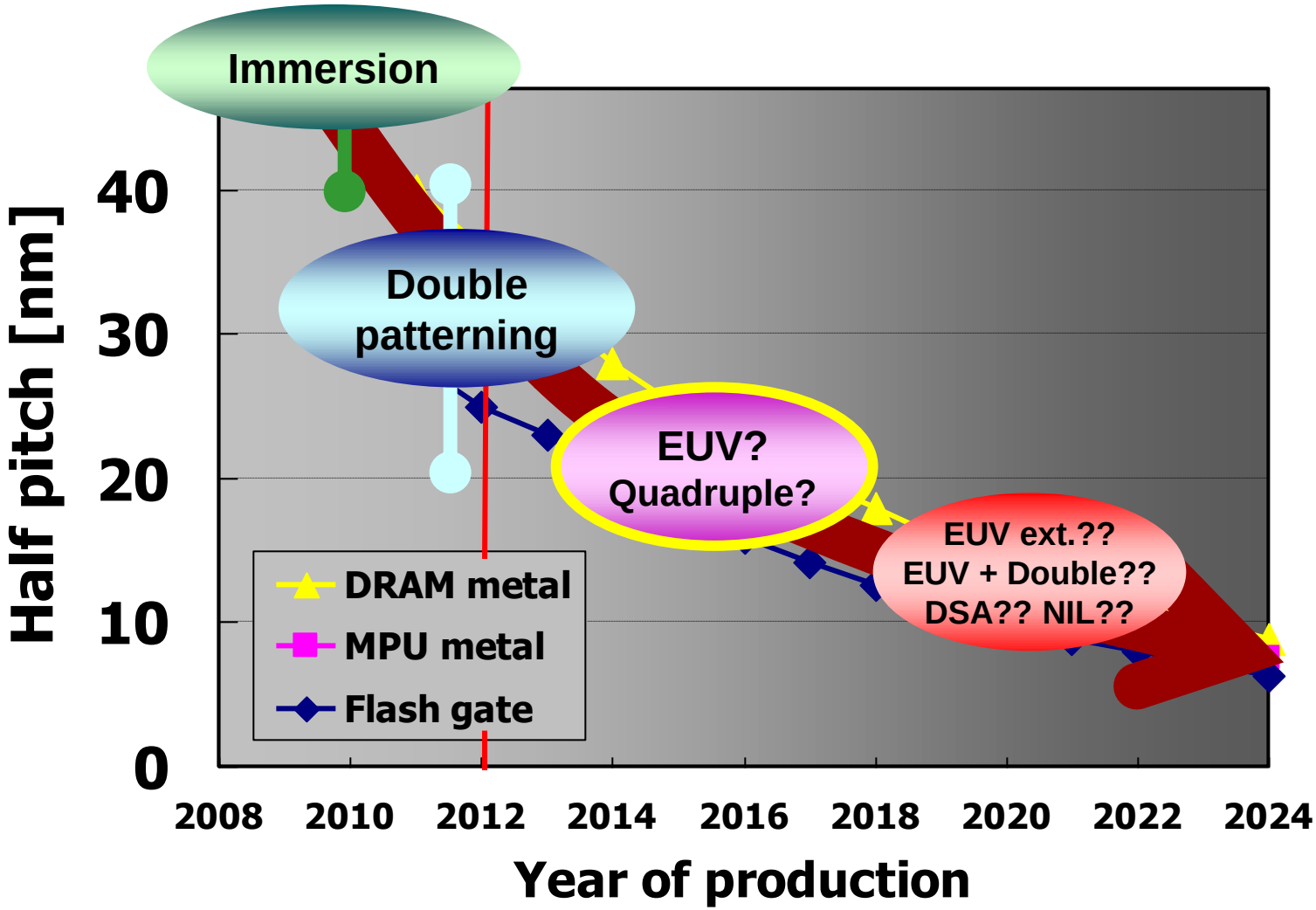
For the prosperity of semicon. business

- **Semiconductor industry win continuous revenue growth by spreading its applications. *"Realizing higher performance with reduced costs"* is always the goal in the past, now and future.**
- **Pattern size scaling requirement seemed to stand at the corner.**
  - –Can 3D-devices relax the speed of scaling?
  - –Scaling will certainly bring fruitful successes both in conventional and in 3D-devices.



Ref: Strategies for Transforming Toshiba's Business Structure - May 11, 2010 (IR report)

Scaling Road Map



Ref: ITRS 2009 Edition Table B "*Key Lithography-related Characteristics by Product* "

EUVL Readiness for mass production

Pattern size scaling down is required to respond market demands. In this coming 5 years, mass production of 20 nm half pitch will be started and EUVL is recognized as a promising candidate.

EUVL is still the candidate……

How ready EUVL is for mass production?
What make EUVL from the candidate to a principal dancer?

- **Lithographic performance**
- **Productivity**

Lithographic performance

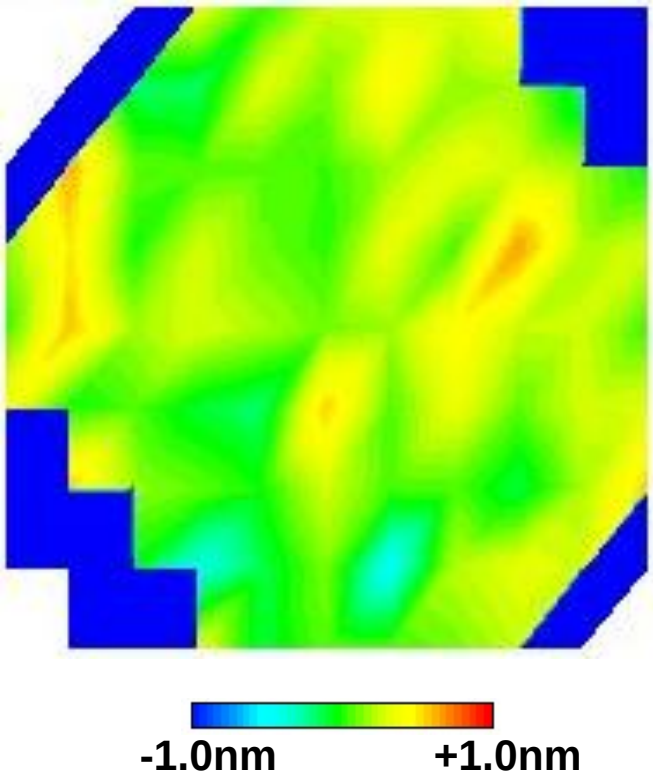
Performance check for mass production

Items	Status	Tech. gap
CD uniformity	✔	☹
Overlay	✔	☹
Defectivity	✔	☺ ☹
Mask	✔	☺ ☹
Extendibility	✔	☺ ☹

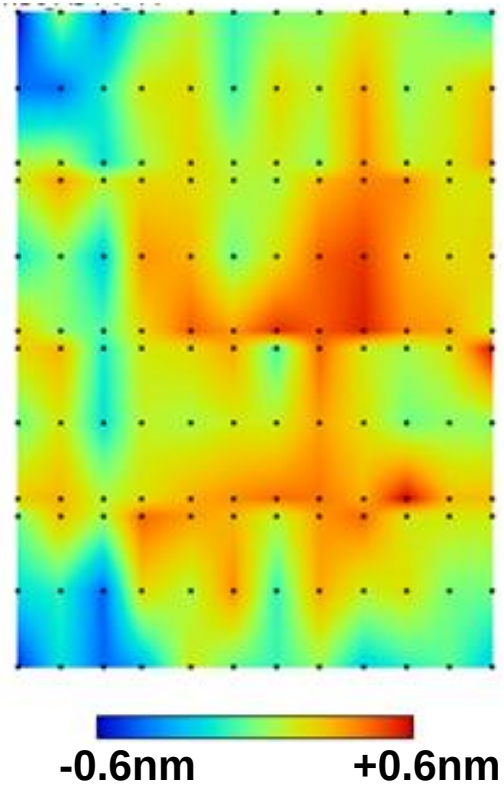
Position of Prima seems not to be far away…

CD evaluation ~ intra wafer, intra fields

Intra-wafer
3σ : 0.62 nm



Intra-Fields
3σ : 0.72 nm

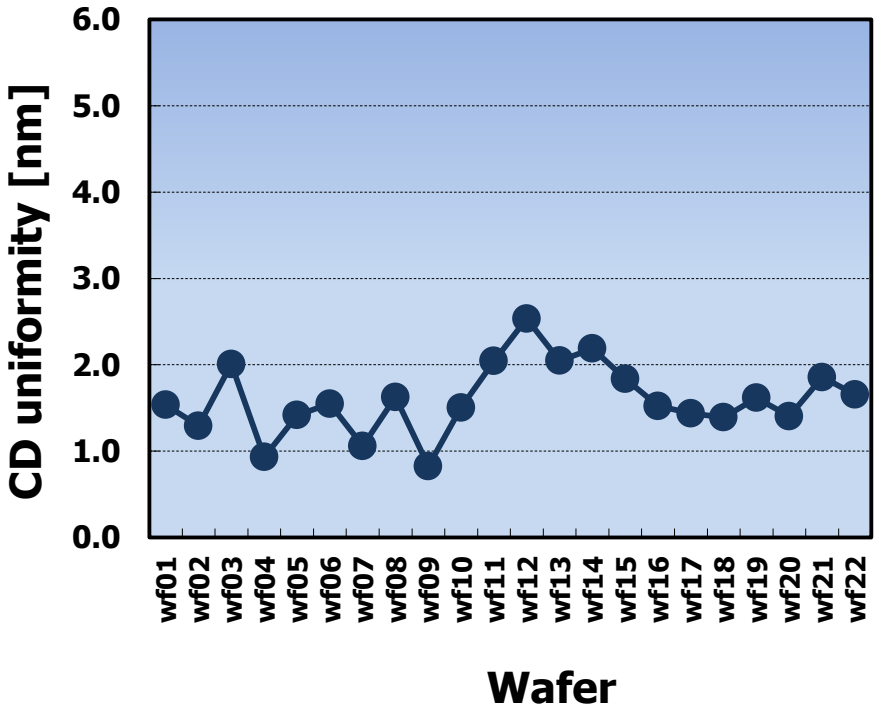


Estimated CD uniformity
0.95 = $(0.62^2+0.72^2)^{0.5}$

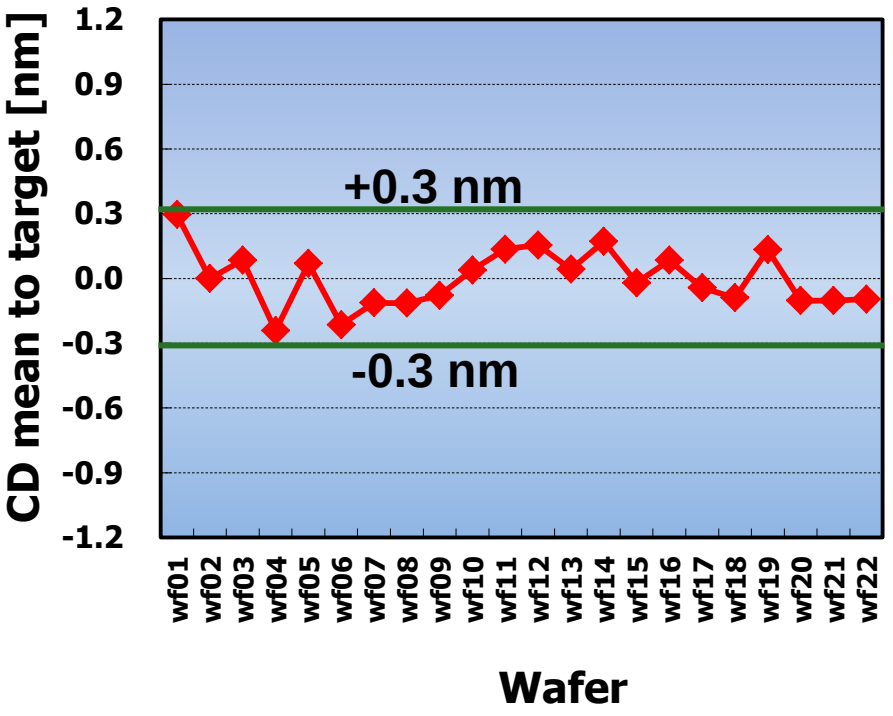
CD uniformity < 1 nm was obtained both in intra wafer and fields.
Possibility of < 1 nm CD uniformity across a wafer was demonstrated.

CD uniformity and stability through a lot

CD uniformity: intra wafer



Averaged CD stability

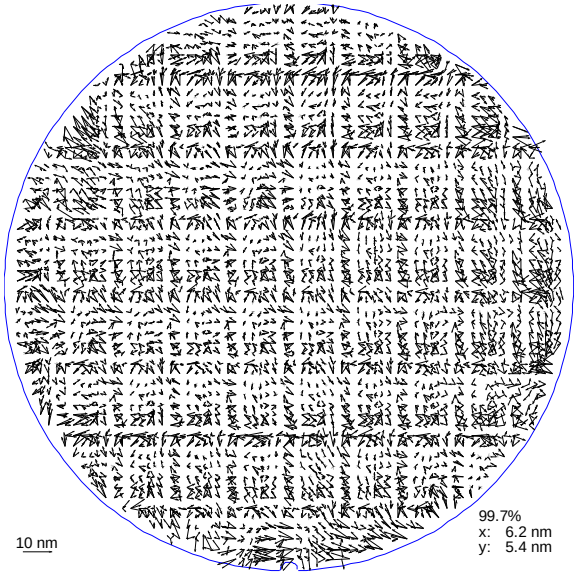


Best CD uniformity was < 1 nm, though exceed 2 nm in some wafers. More investigation is required. Average CD was very stable and all wafers ranged in ≤0.3 nm.

Overlay precision and stability

Matched Machine Overlay(MMO)

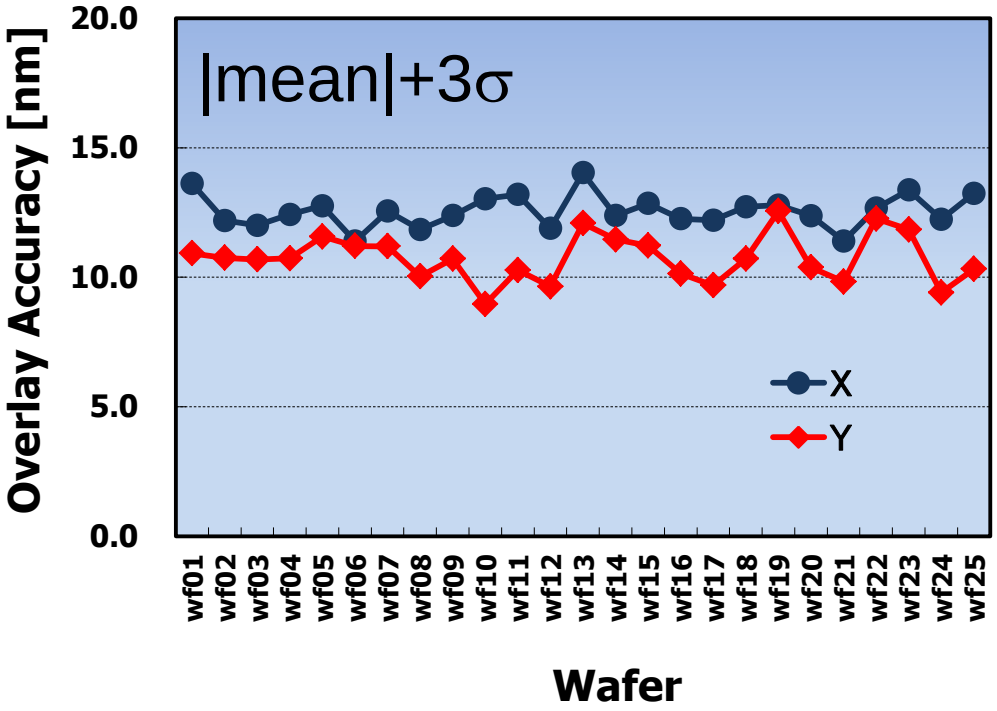
Champion data with higher order and individual shot correction



X : 6.2 nm, Y : 5.4 nm

Courtesy to ASML

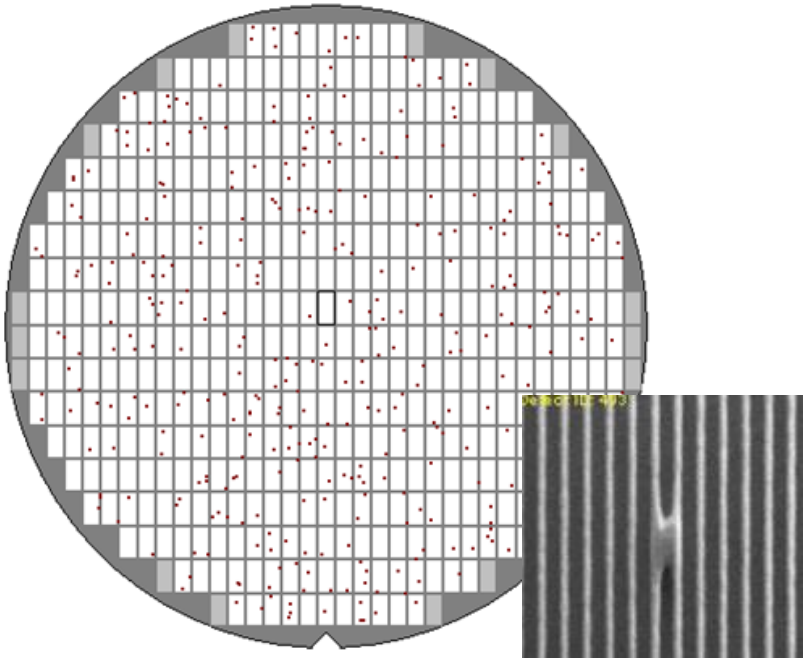
MMO stability check with simple corrections

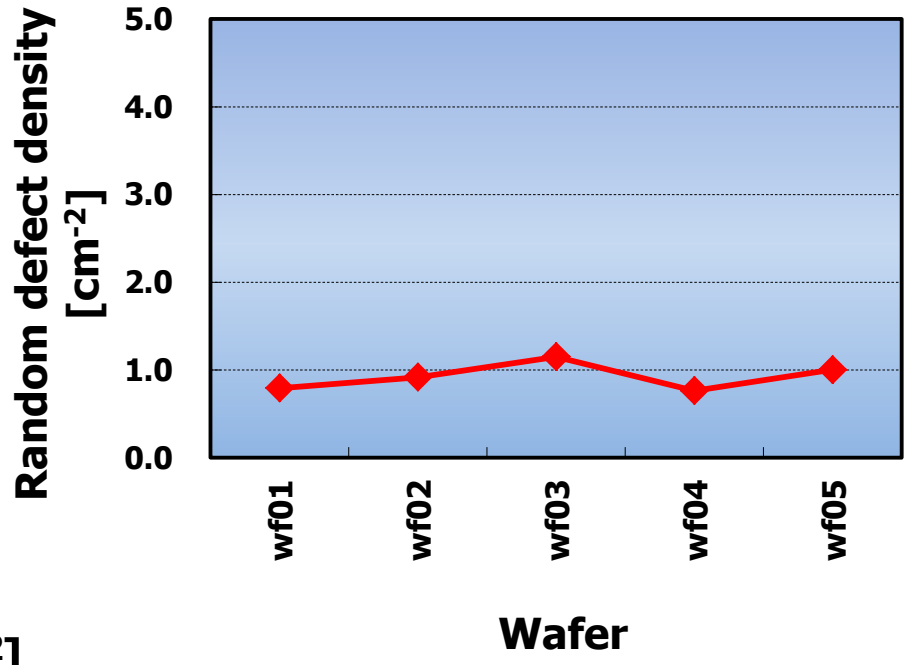


MMO overlay precision of 6.2 nm was obtained with advanced correction. Also, stable 14 nm overlay precision obtained with simple correction through 25 wafers.

Defect control on a whole wafer

Defect map after development



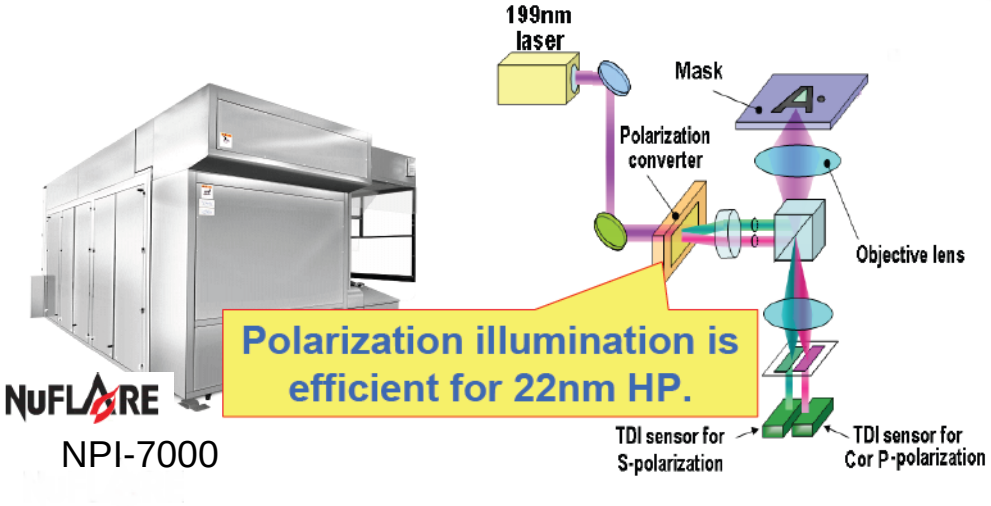


Defect Density : 0.77 [pcs/cm^{-2}]

Random defect density is around unity. Defects detected were mainly categorized to short defects. Resist and process improvement is required.

Recent Mask developments

Patterned mask inspection by DUV



NPI-7000

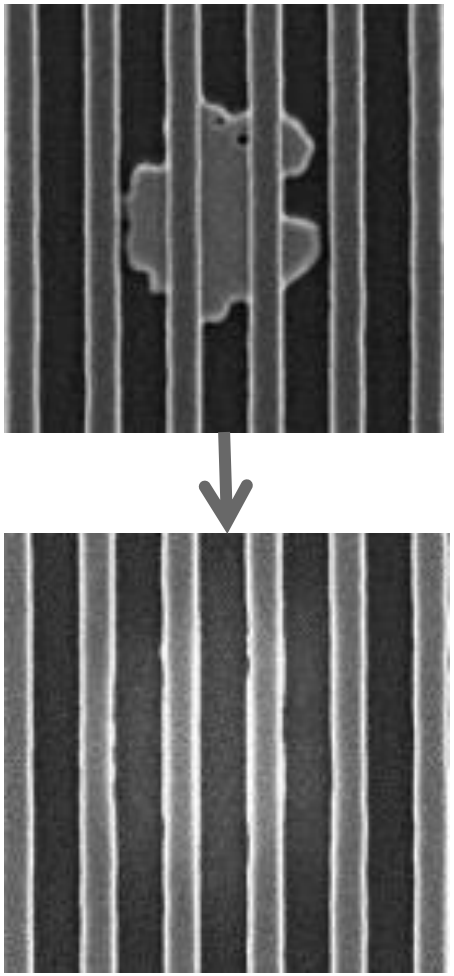
Base Pattern	Defect Type	Inspection Mode	Defect size nm (Square root of area) 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5
32nm HP	Edge extrusiton	D2D	
		D2DB	
	Edge intrusion	D2D	
		D2DB	
27nm HP	Edge extrusiton	D2D	
		D2DB	
	Edge intrusion	D2D	
		D2DB	
22nm HP	Edge extrusiton	D2D	
		D2DB	
	Edge intrusion	D2D	
		D2DB	

PI is ready.

10% CD error

Hirano et. al, 2011 BACUS

Repaired results of Absorber



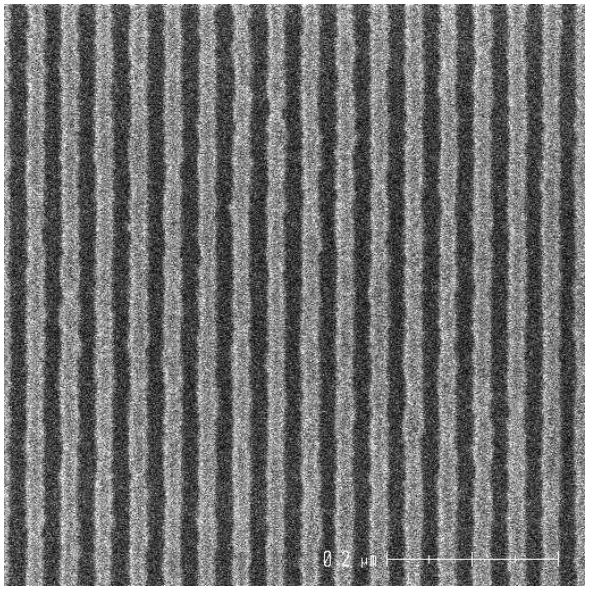
Absorber Defects

Repaired

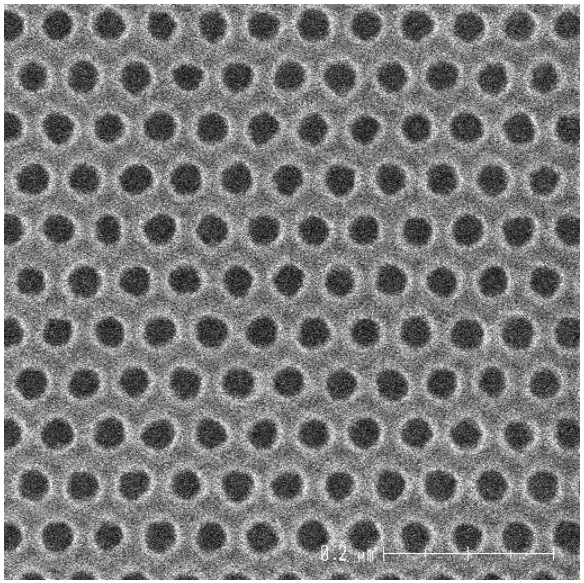
Kanamitsu et. al, 2011 BACUS

Extendibility toward 1x nm half pitch

Fine pattern resolved with practical resist thickness



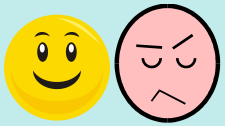
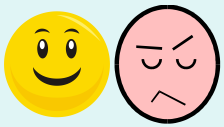
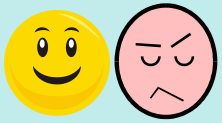
20 nm hp
Thickness: 50 nm
Dipole illum.



30 nm hp
Thickness: 60 nm
Conventional illum.

Aspect ratio over 2 is obtained both in lines/spaces and contact hole patterns in near resolution limit half pitch. The value is recognized as practical for following processes.

Performance check for mass production

Items	Status	Tech. gap	Comments
CD uniformity	✔		Stable uniformity < 1 nm required
Overlay	✔		Tool performance proven, need more investigations
Defectivity	✔		Further improvement required for mass production
Mask	✔		Patterned inspection and repair tech. are proven
Extendibility	✔		Fine pattern resolution with practical resist thickness

Productivity

Productivity check for mass production

Items	Status	Tech. gap	Comments
Throughput	✔		10W source power, Several wafers per hour
Availability	✔		Far from our target, unscheduled down <10%

Exercising hard, dreaming to be a Prima…

Throughput comparison: immersion and EUV

Immersion

NSR-S621D

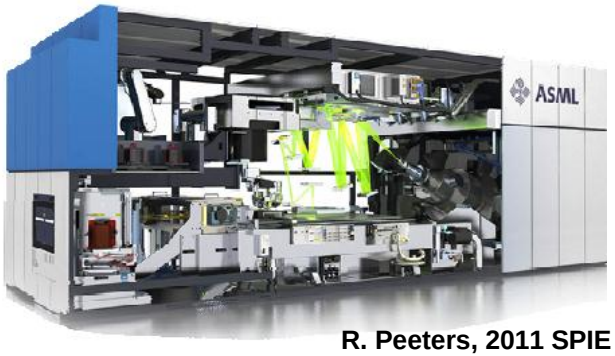
Throughput	200 wafers / h

NXT:1950i

Throughput	175 wafers / h

>

EUV



R. Peeters, 2011 SPIE

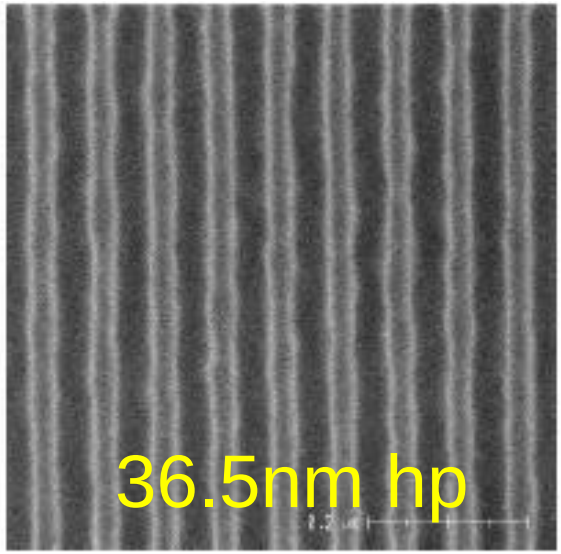
NXE:3300B

Throughput	125 wafers / h

Production EUV tool cannot defeat the immersion in throughput. EUV still be on the way to maturity.

Resolution limit: immersion and EUV

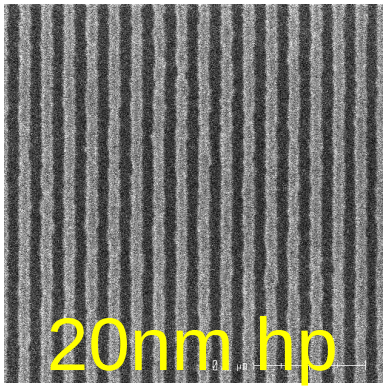
Immersion

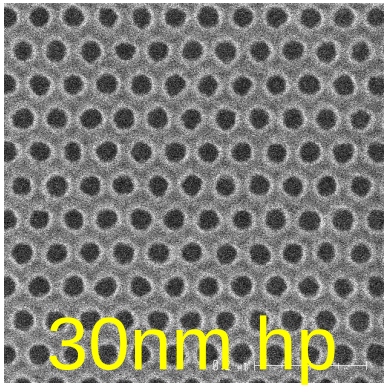


J. D. Klerk ,2007 SPIE

<

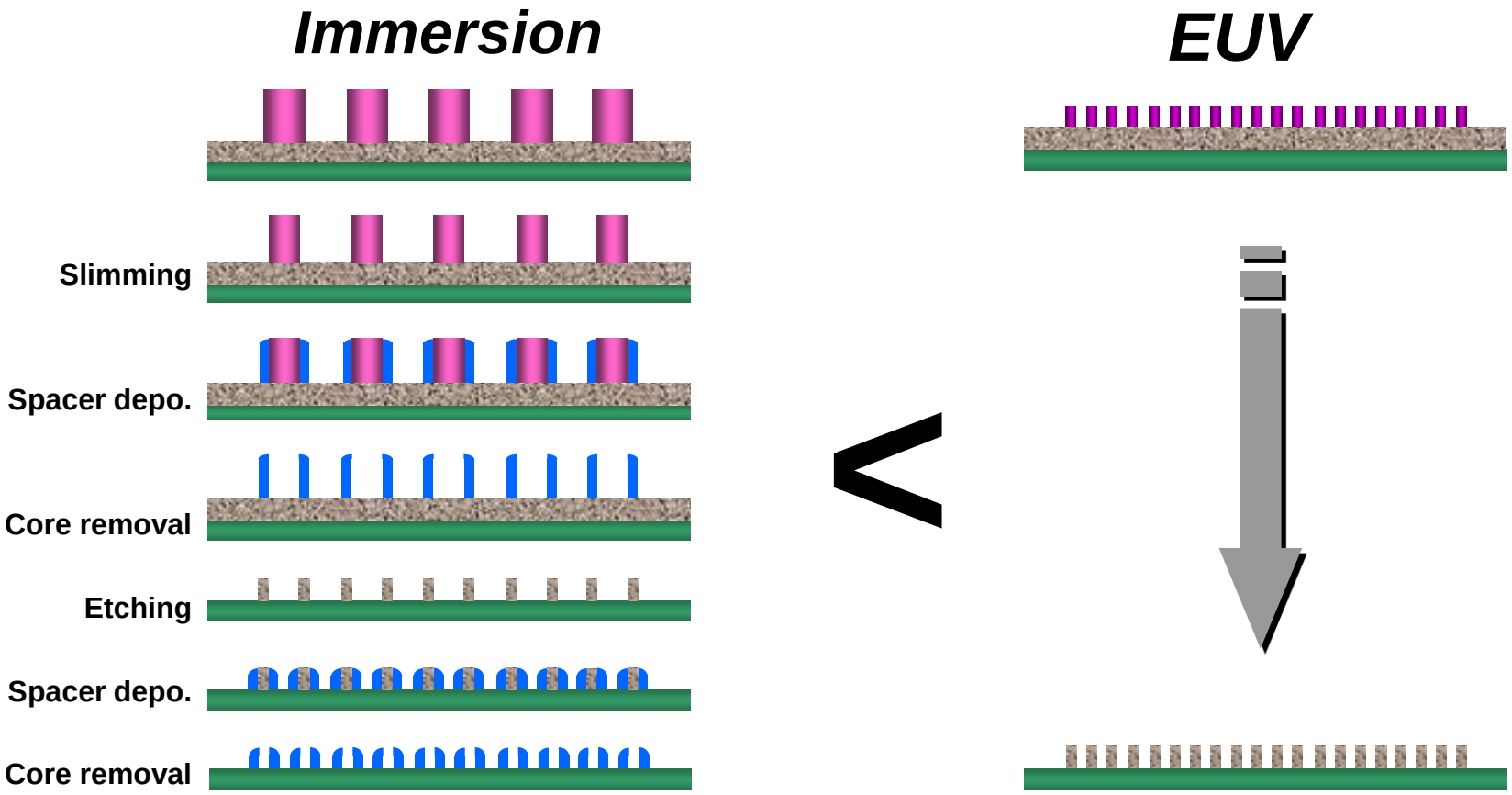
EUV





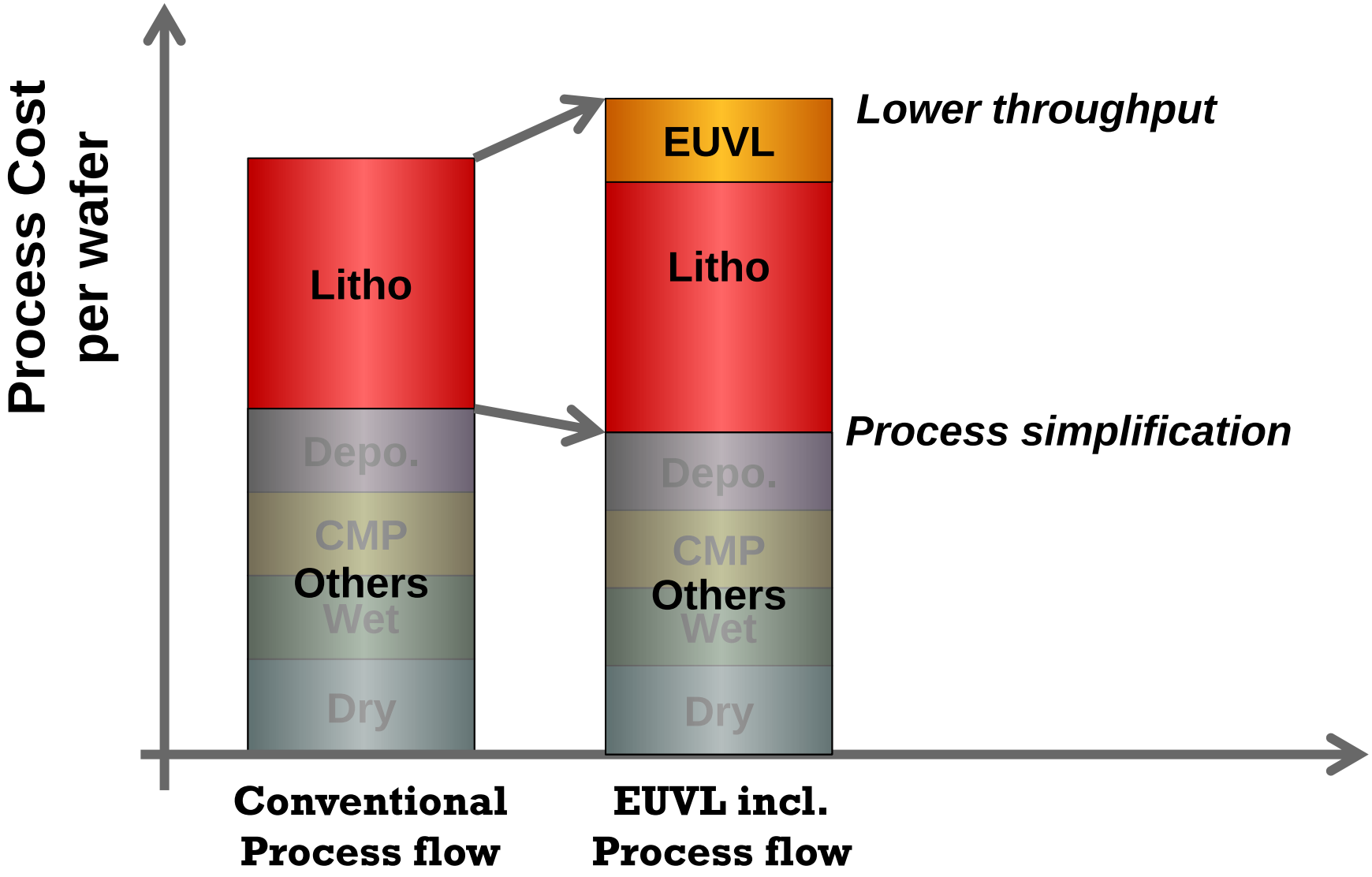
Resolution limit of DUV can be broken by EUV.
Also, EUV brings fruits of low k1 lithography.

Process simplicity: immersion and EUV

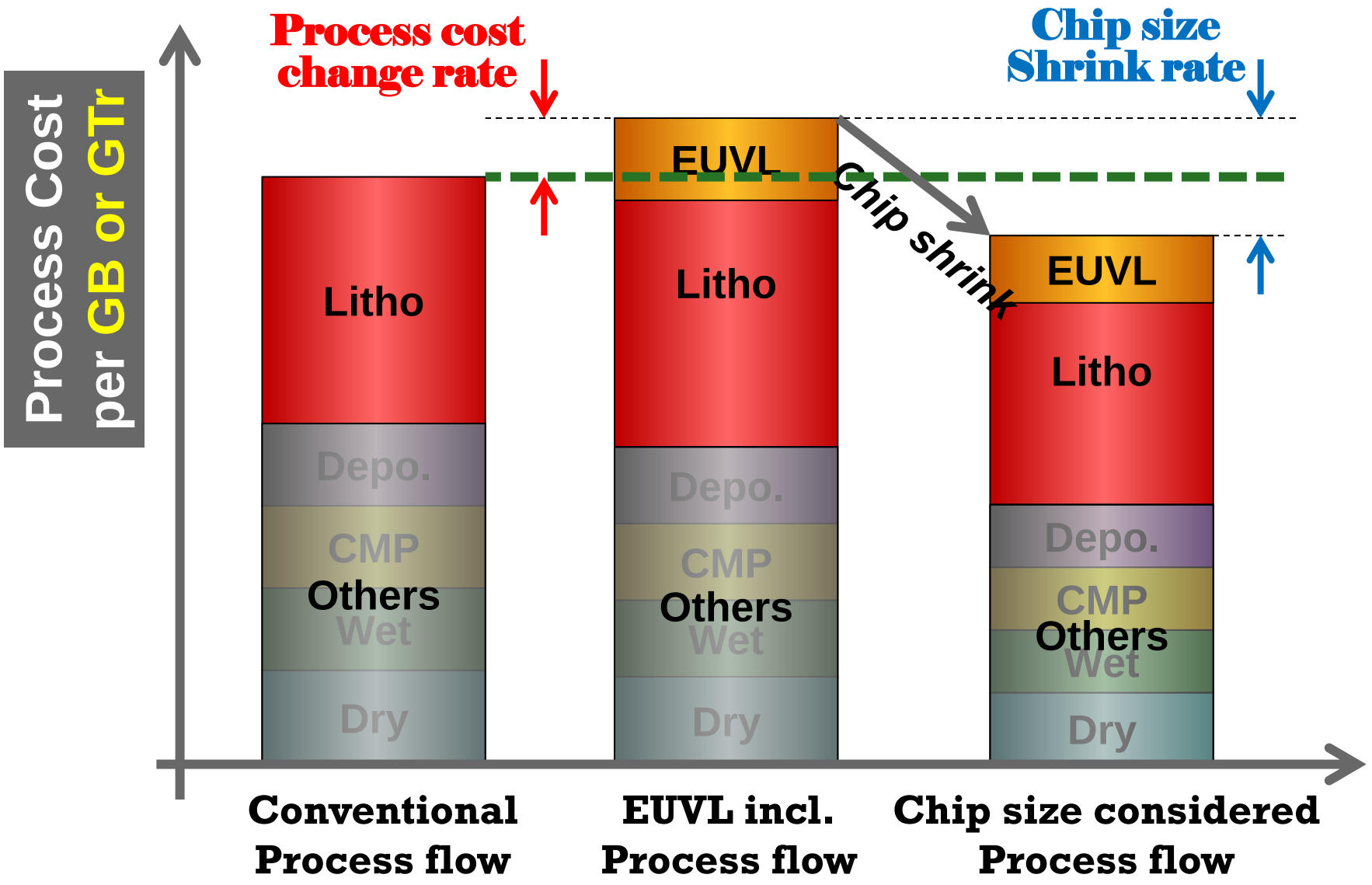


In EUV, higher resolution brings simpler process flow. That can reduce following process costs.

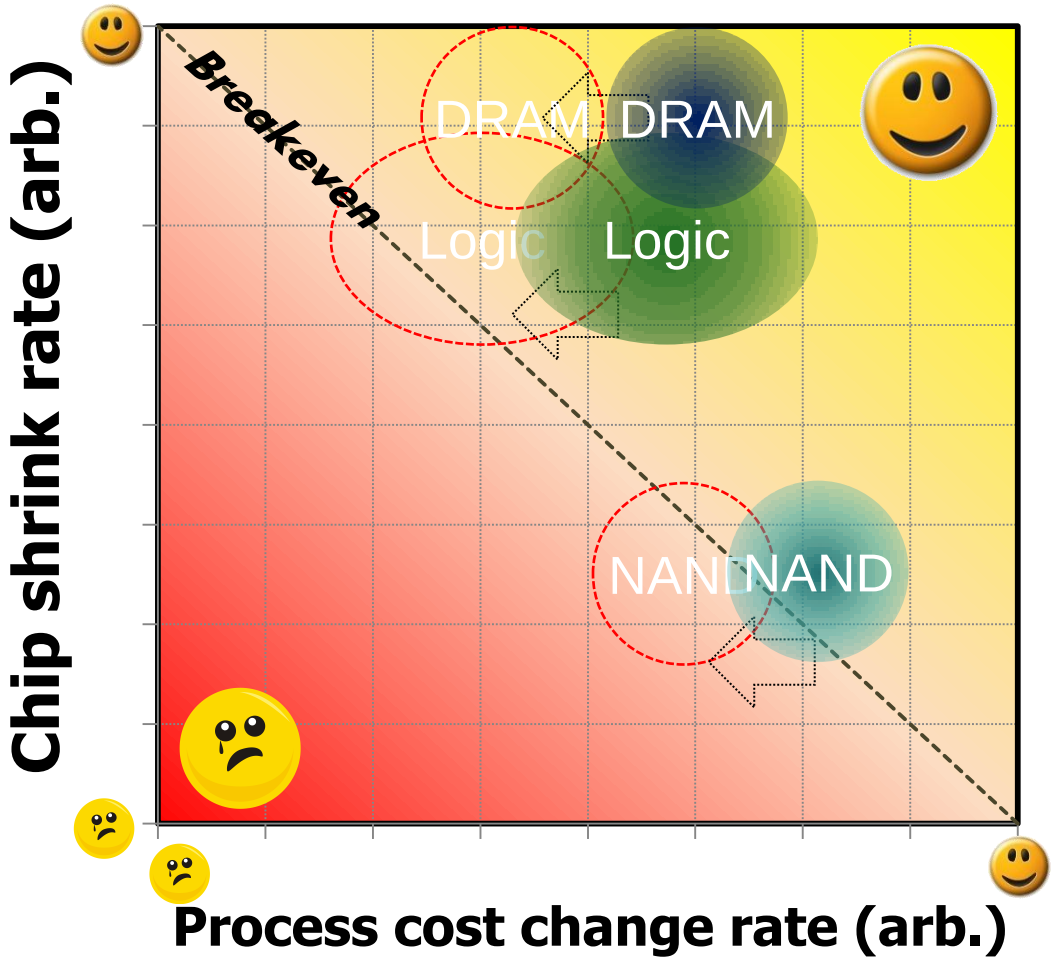
Process cost comparison of front-end device

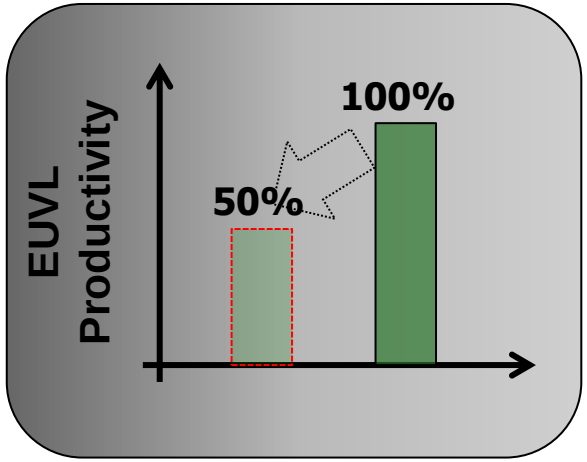


Functional cost comparison



EUVL necessity from business viewpoints





In every front-end device, EUVL can show its cost effectiveness. Productivity loss reduces that merit.

Productivity check for mass production

- **EUVL can show cost effectiveness in every front-end devices by chip size shrink compensating for its lower throughput**
- **The effectiveness is very sensitive to exposure tool productivity, especially in NAND device.**

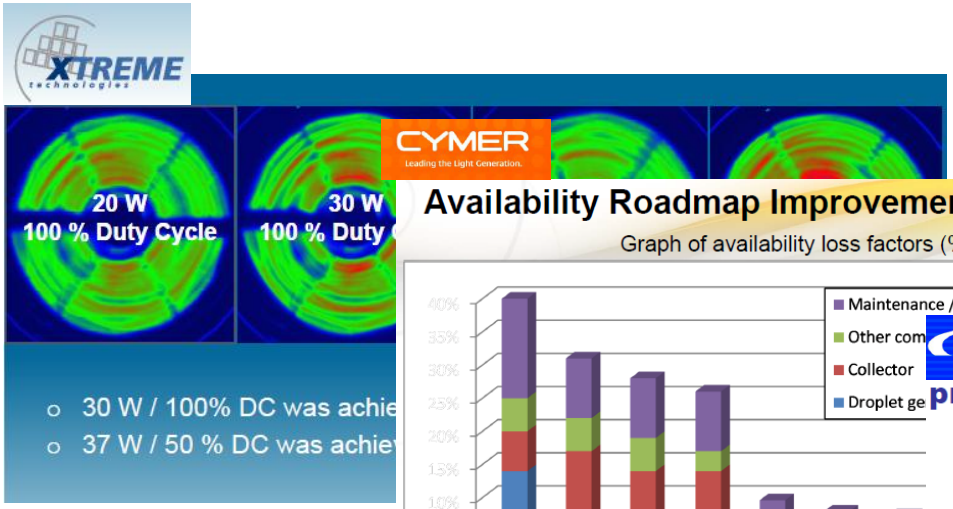
Productivity improvement with maximum effort!!!

Outline

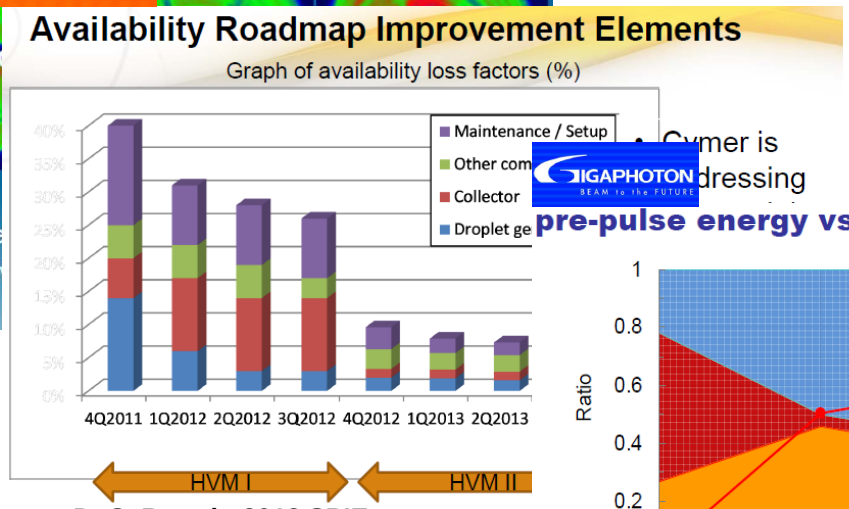
1. EUVL requirements for semicon. business
2. EUVL readiness for mass production
3. **Technology challenges aiming at higher productivity**
   - Source
   - Mask
   - Resist
   - Scanner
4. Conclusions

EUV source for higher productivity

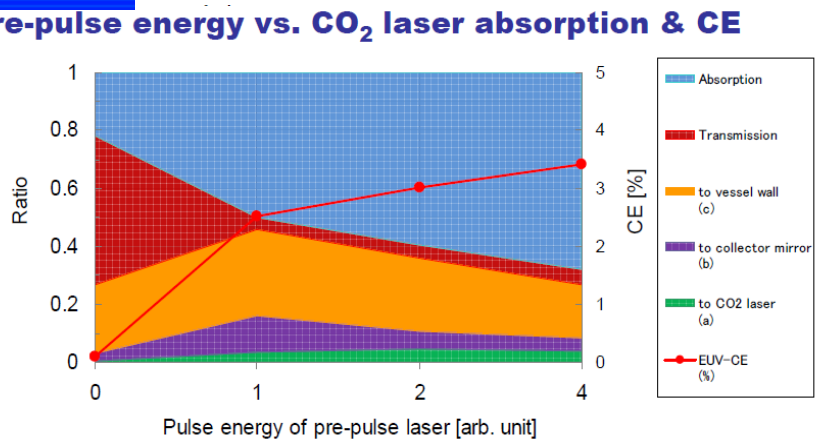
- 250W achievement with sufficient dose reproducibility
- Increasing availability to 95% by improvement of modules
- Reduction of energy consumption by effective EUV emission and collection



M. Corthout, 2012 SPIE



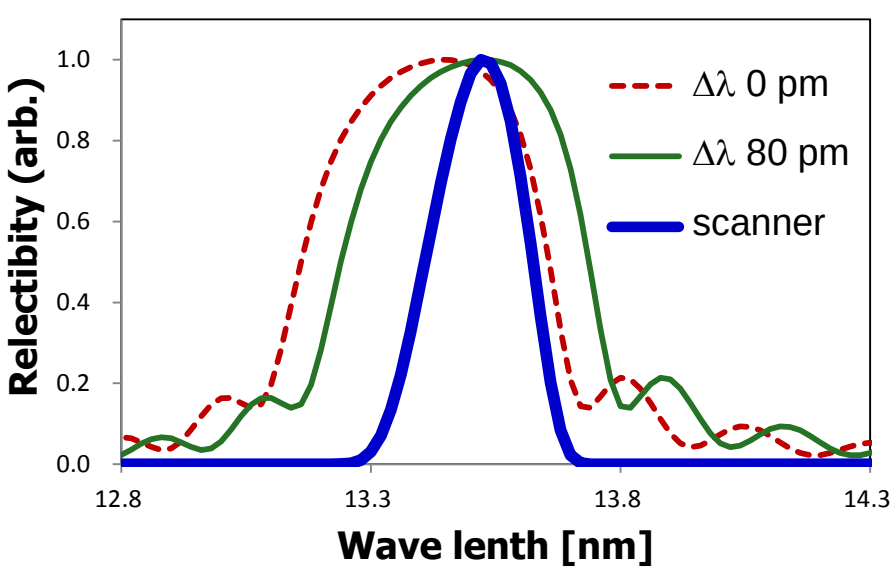
D. C. Brandt, 2012 SPIE

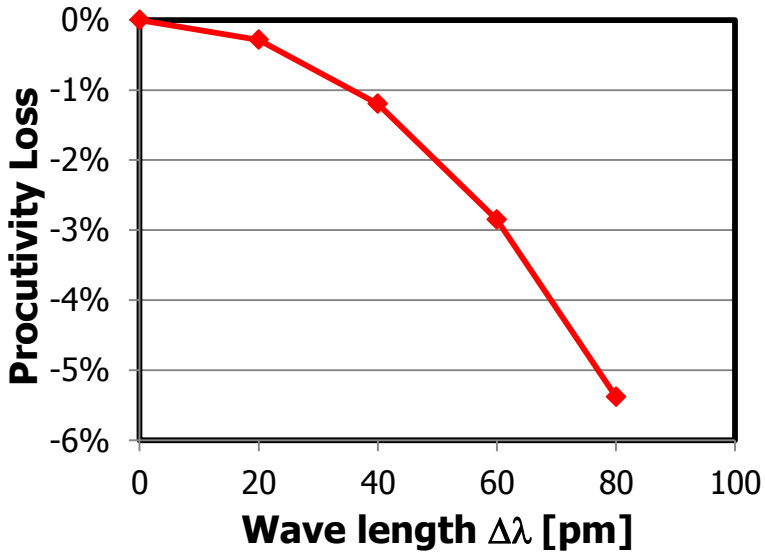


J. Fujimoto , 2012 SPIE

EUV mask for higher productivity

- Higher transmission of EUV light through the system
- Center wave length matching with scanner optics
- Experiments required with a real exposure tool and masks

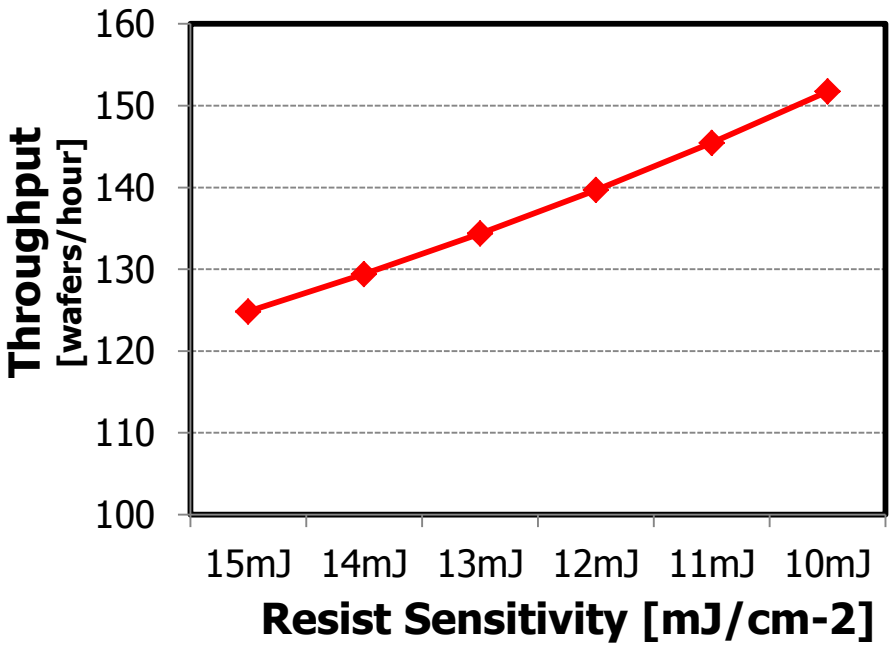




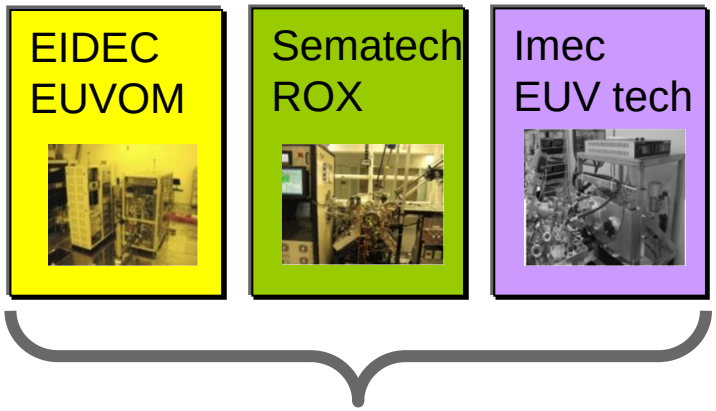
EUV resist for higher productivity

- Higher sensitivity shows better productivity
- Easier outgas measurements to accelerate resist developments required

Expo. tool throughput vs. resist sensitivity



Open system for resist outgas measurements



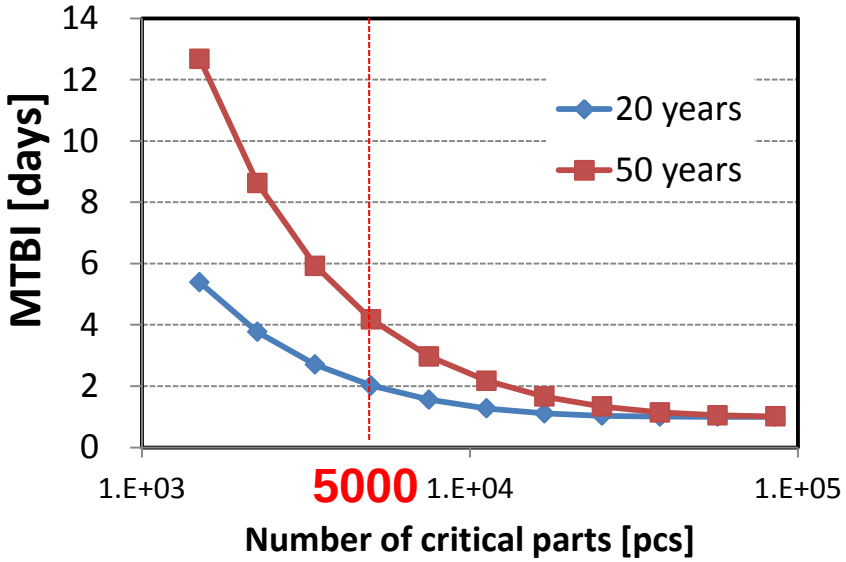
Several samples / day

Outgas measurement is critical path of resist developments

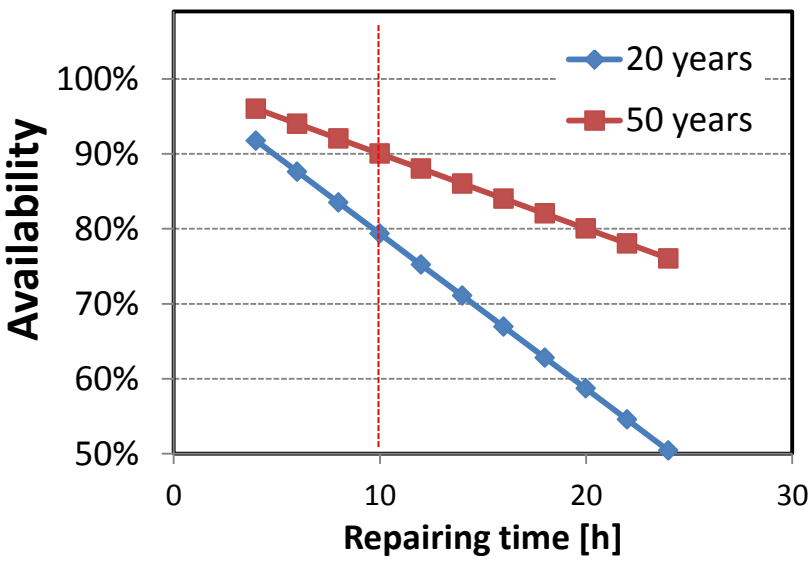
EUV scanner for higher productivity

- **Higher tool availability will results in higher productivity**
- **To maintain high level availability of over 90%**
  - Reliability of critical parts should be longer than 20 years
  - Repairing time should be less than 10 hours

Mean time between tool interruption



Tool availability



Conclusions

- **We installed pre production EUV exposure tool and checked the readiness for mass production.**
- **Major lithographic performance items were confirmed. Items, CD uniformity, overlay and defectivity, shows good progress from alpha-tool, but still on the way.**
- **Productivity consists of exposure tool is the key issue to apply EUVL for mass production.**
- **To enlarge productivity, following items are discussed.**
  - Increase power and availability in source
  - Resist of higher sensitivity
  - Center wave length matching between mask and exposure tools
  - Parts reliability enhance and shorter repairing time

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