EXTREME ULTRA-VIOLET LITHOGRAPHY

Extendibility of EUV Lithography Technology for Semiconductor Devices

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Moore's Law

- Number of transistors on a chip doubles about every two years.

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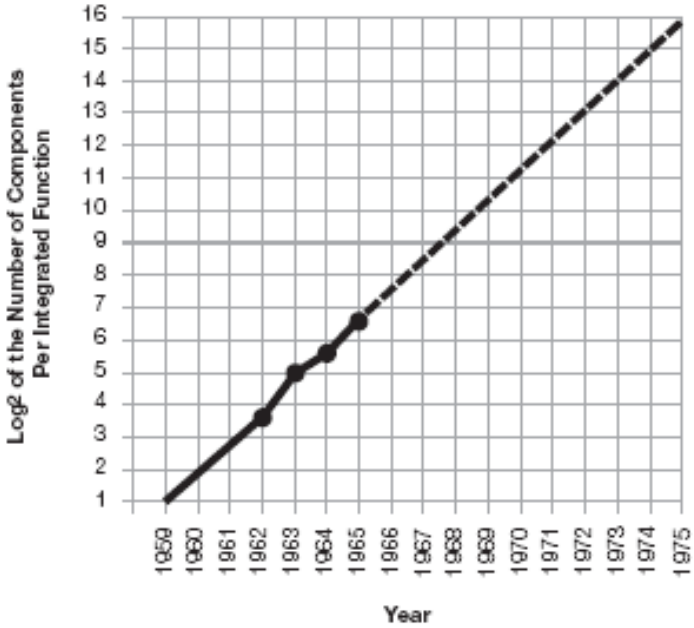

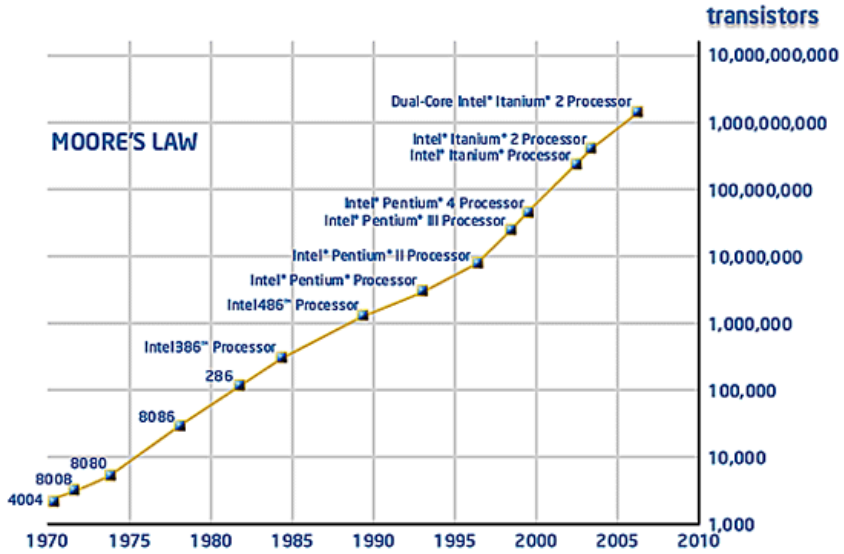

Electronics, Volume 38, Number 8, April 19, 1965

Scaling Enabler: Lithography

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$$\text{Resolution} = k1\,\frac{\lambda}{NA}$$

NA = numerical aperture of imaging optics
n (refractive index) * sin θ

K1	Solution
>0.55	Binary Mask + Simple Illumination
0.45 ~ 0.55	Binary +Attenuated PSM +OPC + Off-axis illumination
0.35-0.45	Alternating / Chromeless PSM +OPC + Complex Illumination + Design Restriction
0.25-0.35	Innovative Solutions
<0.25	Below Diffraction Limit

"Effective k1" can be below 0.25 by using techniques such as "Double Patterning" (via splitting of features or pattern)
Cost effectiveness and overlay are issues for this technology

Wavelength Reduction has been a key Driver of Moore's Law

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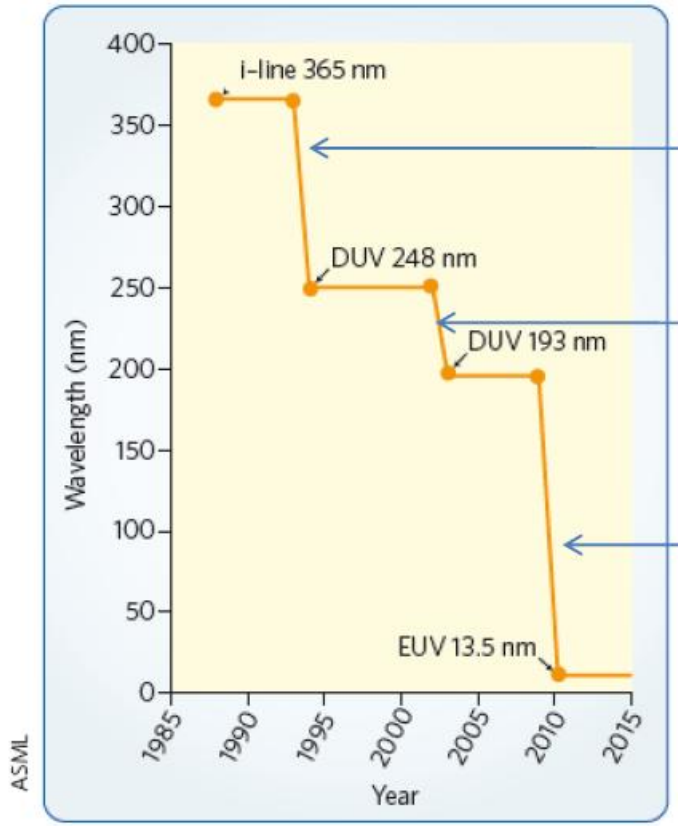

Factor of 1.5

Factor of 1.3

Factor of 14

Figure 1 | Since the mid-1980s, the wavelength of light used in lithography systems has reduced by almost half from 365 nm to 193 nm. The switch to EUV lithography involves a further wavelength reduction factor of almost 15. DUV, deep ultraviolet.

Lithography gets Extreme, Christian Wagener and Noreen Harned, Nature Photonics, Vol. 4, pp. 24-26, January 2010

Lithography Roadmap:
EUVL is the leading Lithography Technology for 22 nm node and Beyond (2012 ITRS)

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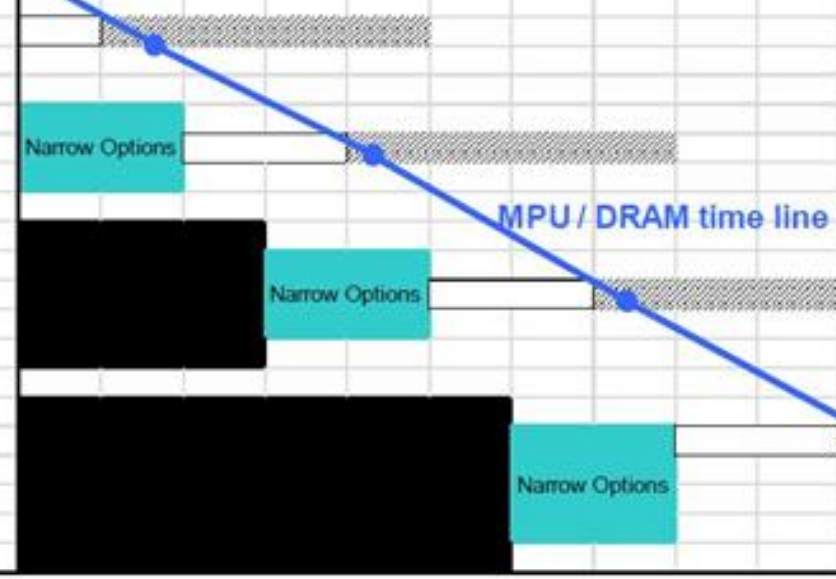
	First Year of IC Production	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
	DRAM ½ pitch (nm) (contacted)	36	32	28	25	23	20.0	17.9	15.9	14.2	12.6	11.3	10.0	8.9	8.0	7.1	6.3
	MPU/ASIC Metal 1 1/2 pitch (nm)	38	32	27	24	21	18.9	16.9	15.0	13.4	11.9	10.6	9.5	8.4	7.5	7.5	7.5
45	193nm Imm																
32	193 nm DP																
22	EUV 193nm MP ML2 (MPU)																
16	EUV 193nm MP ML2 DSA + Litho Imprint																
11	EUV higher NA / EUV + DP ML2 DSA + Litho EUV (new wavelength) Imprint Innovation																



Research Required
Development Underway
Qualification / Pre-Production
Continuous Improvement

What is Extreme UltraViolet (EUV)?

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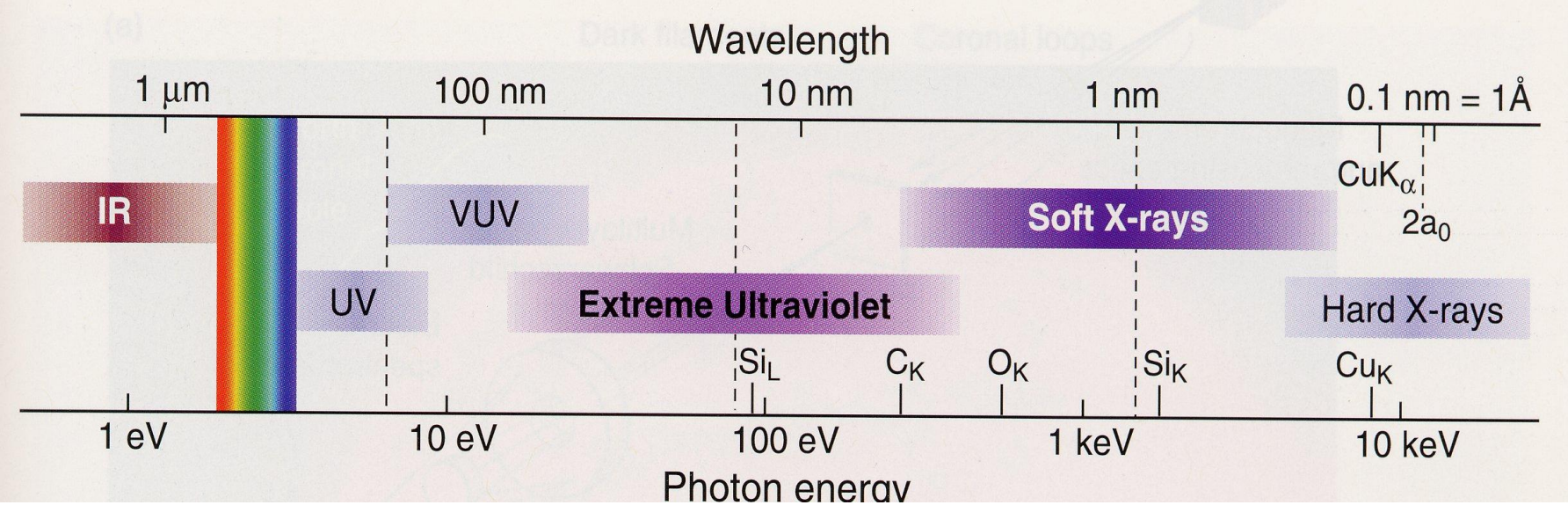

- Last region of electromagnetic spectrum to be developed
- Cause atomic resonance leading to high degree of absorption in all materials
- Short λ enables to see small structures and to write smaller patterns

Why EUV Lithography ?

- Image quality with affordable k1 value

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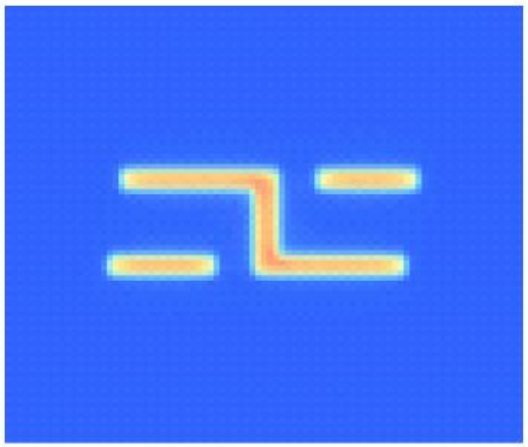

32nm hp

K1=0.59
32nm hp @EUVL NA0.25

K1=0.25
32nm hp @ArF Immersion

22nm hp

K1=0.41
22nm hp @EUVL NA 0.25

Ref: T. Miura, Nikon Corporation,
2006 International EUVL Symposium,
Barcelona, Spain, October 16, 2006

Why EUV Lithography ?
- Cost Effective !

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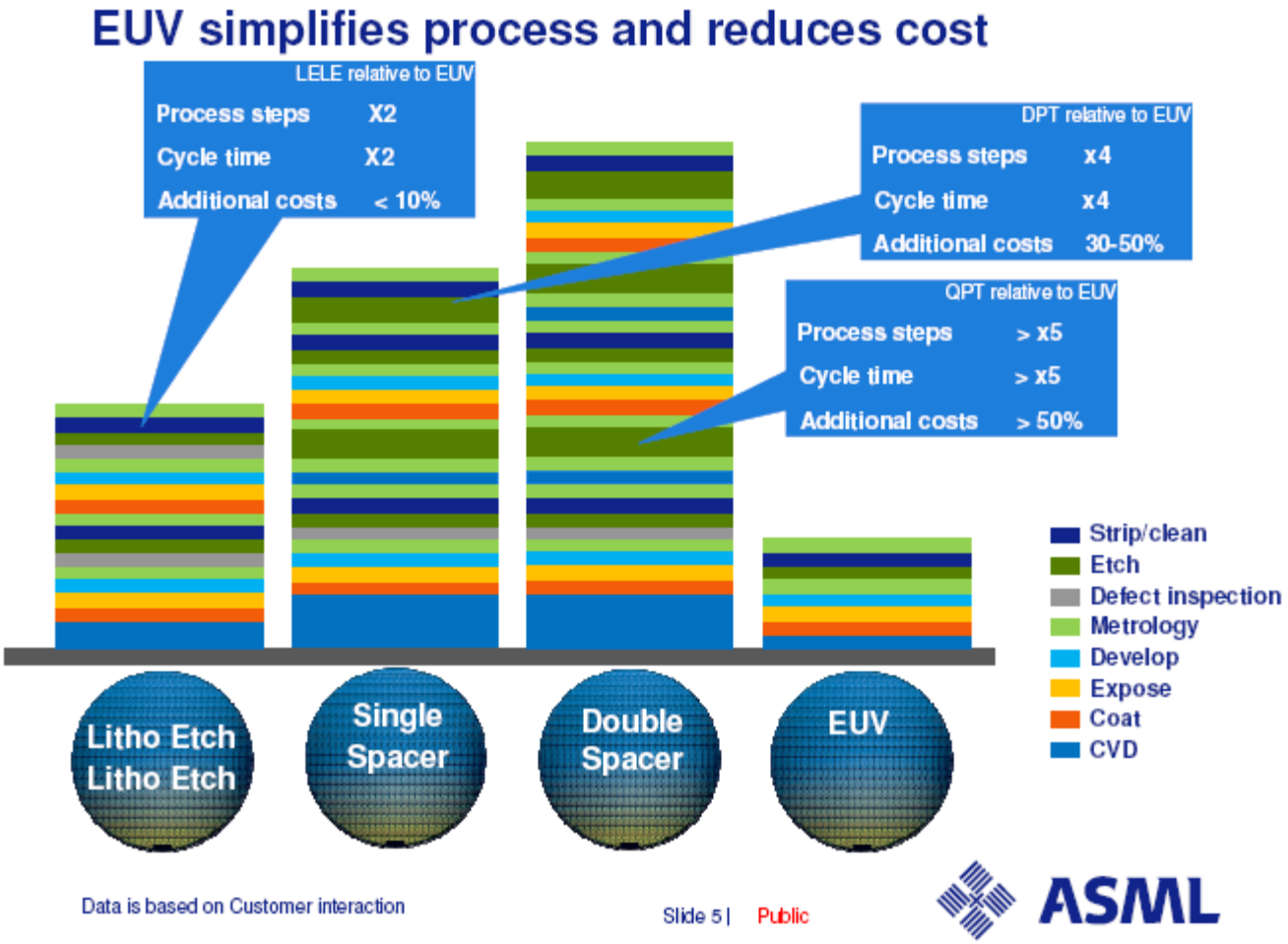

Big Change of Optical System from DUVL to EUVL

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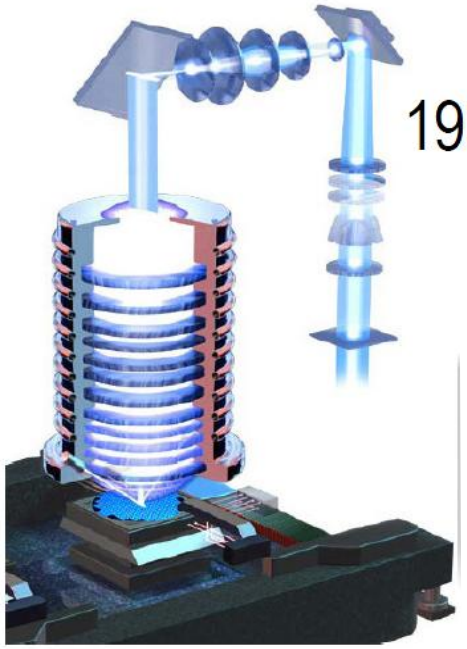
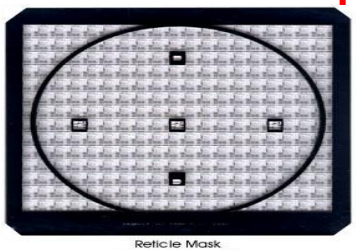


On-axis diffraction optics



EUV Lithography Overview

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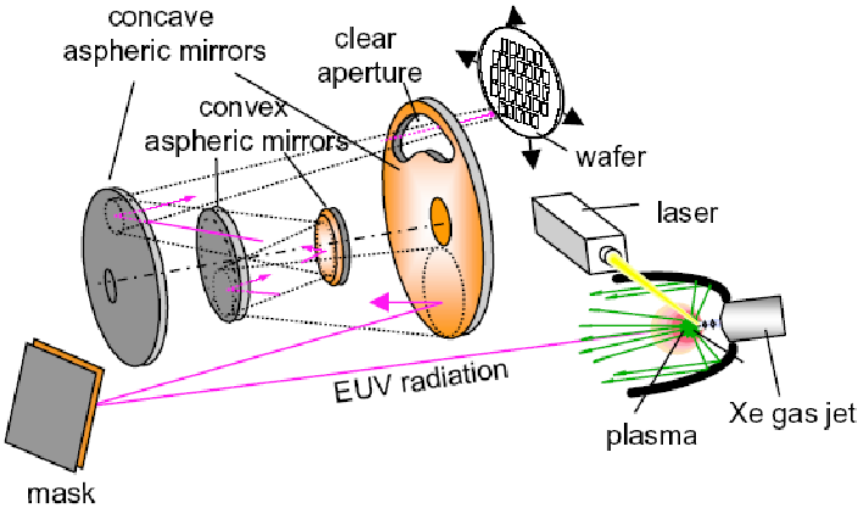
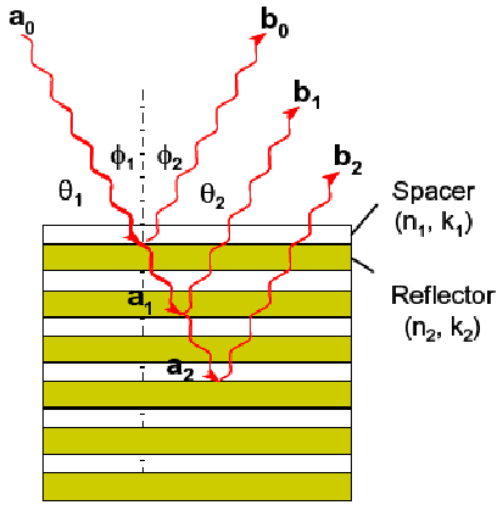
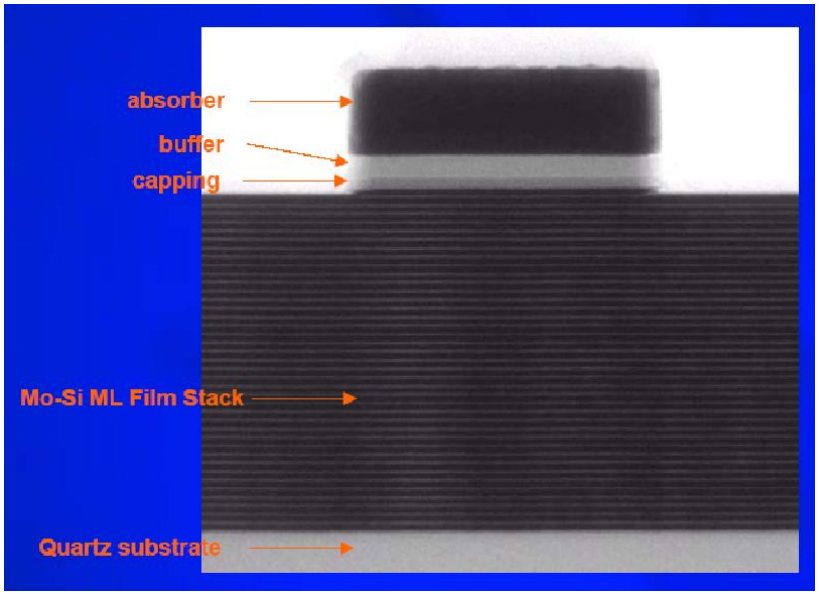
- **Principle**
  - λ = 13.4 – 13.5nm (Xe)
  - 4X all reflecting mirror (Mo/Si),
  - Scanning projection
  - N.A. = 0.1 - 0.30 (max ~ 0.55)





EUV Reflection by multilayer Bragg interference



Wavelength-dependent defectivity

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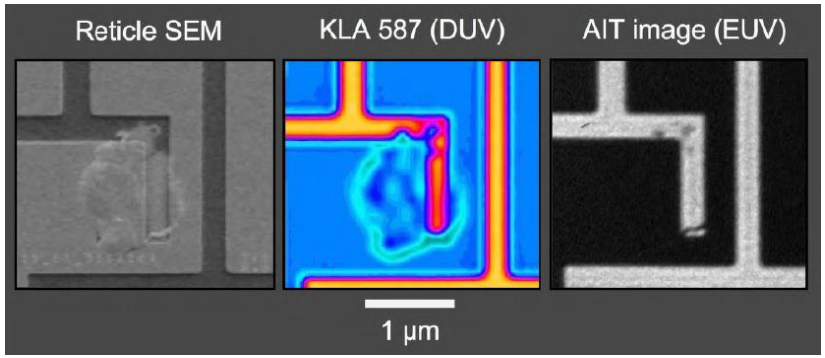
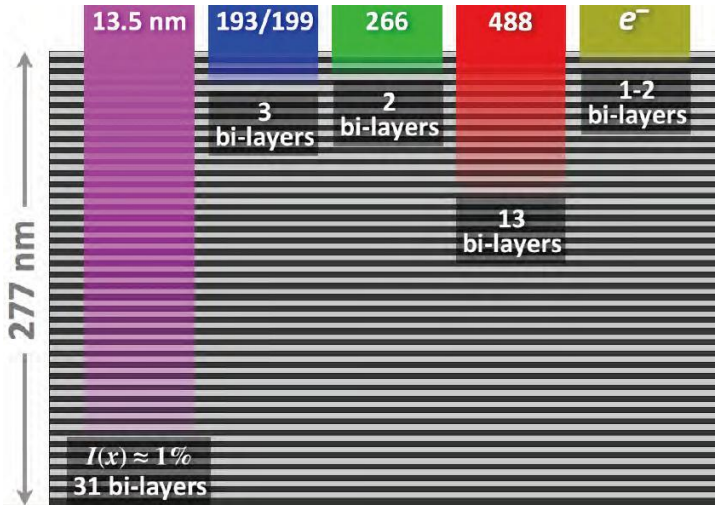
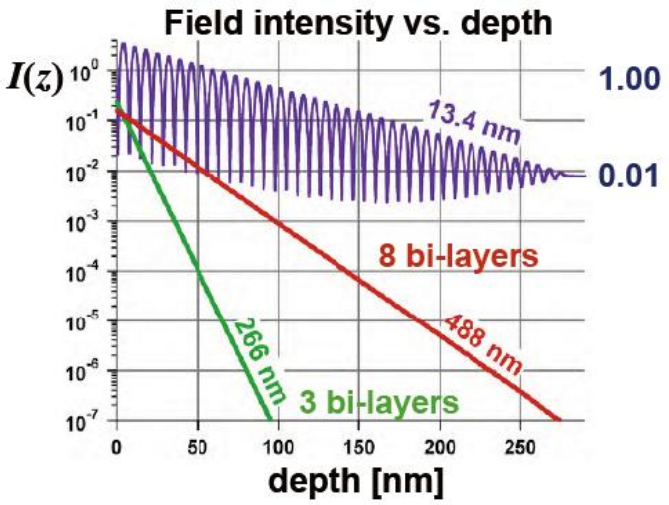
Wavelength-dependent defectivity



Ref.. Mochi, Proc. SPIE 7636 (2009).

Penetration depth of different wavelength





Ref.. Goldberg, EUVL Workshop (2010).

EUV Coherent Scattering Microscope

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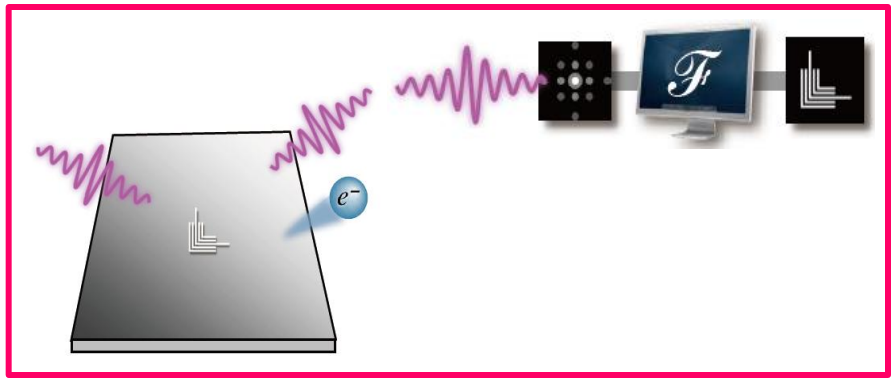
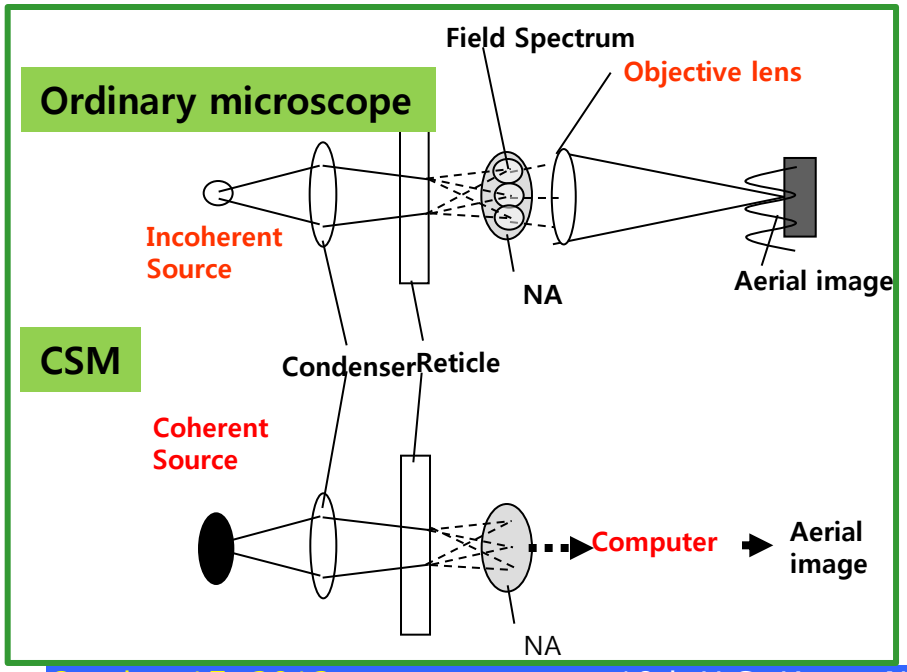
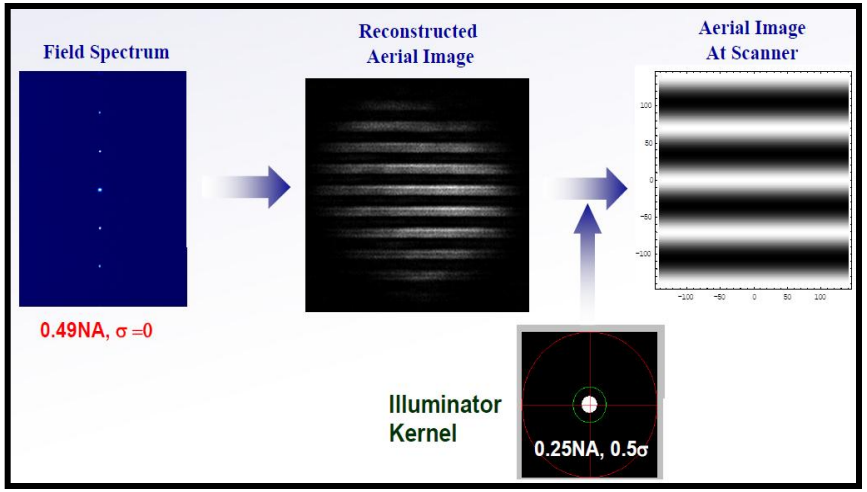


- Simple structure
  - Minimizing imaging limit caused by objective lens
  - Collecting diffraction pattern by CCD pixel
  - Mask image reconstruction by reverse Fourier Transformation
- Simulation capability for various exposure conditions
  - Incident angle and illumination condition
  - Real actinic imaging capability with current and future EUV scanner conditions





Ref. Dong Gun Lee

CSM with HHG EUV source @HYU

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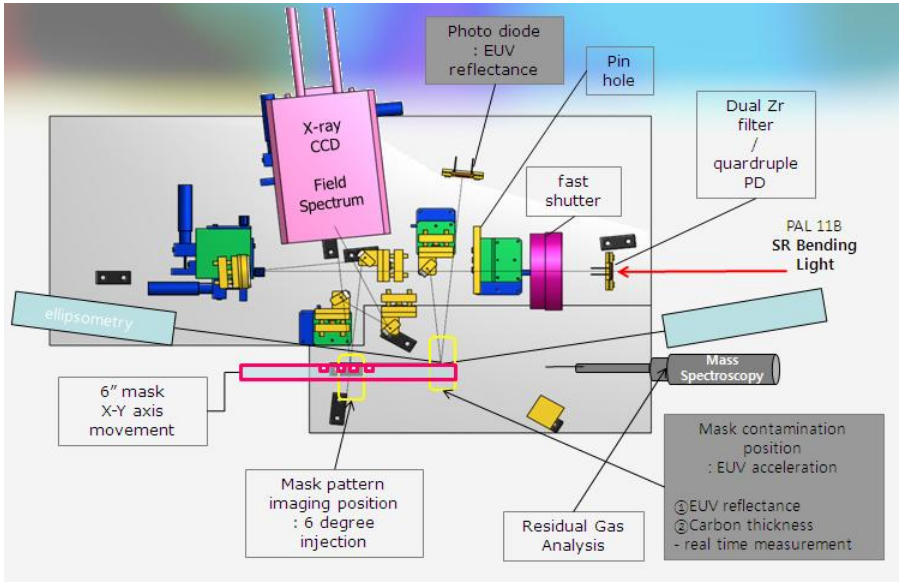
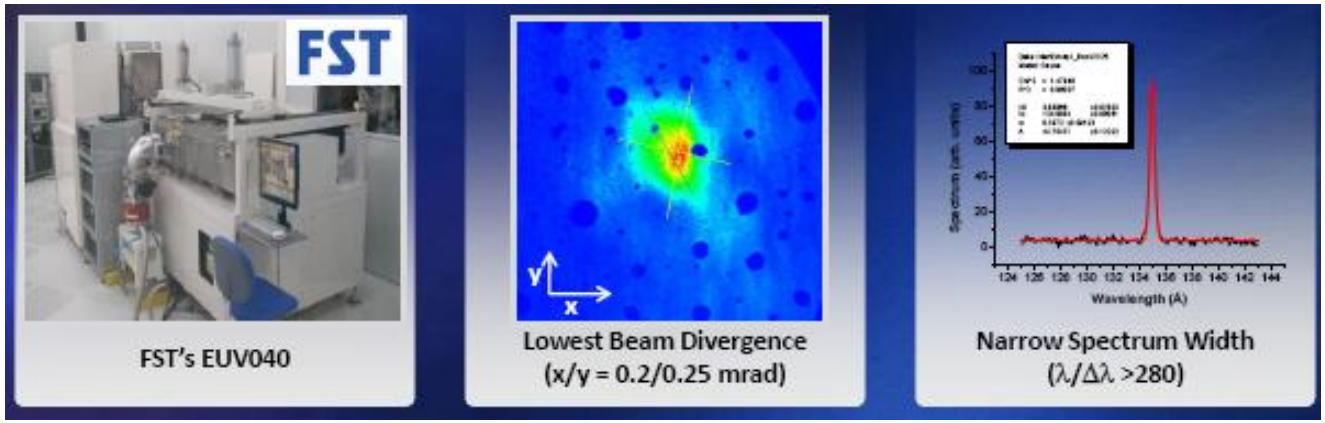
Collaboration with Samsung, FST & Auros





Mask Imaging Results by CSM

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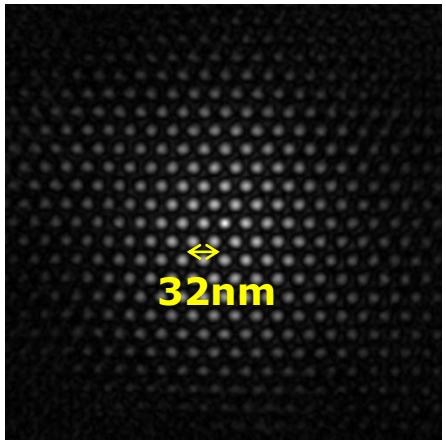
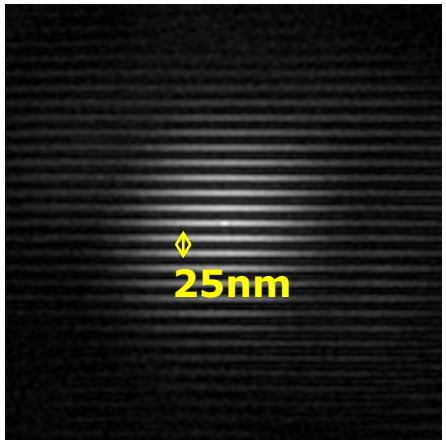
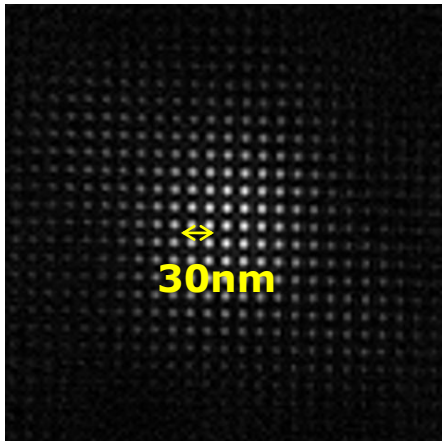


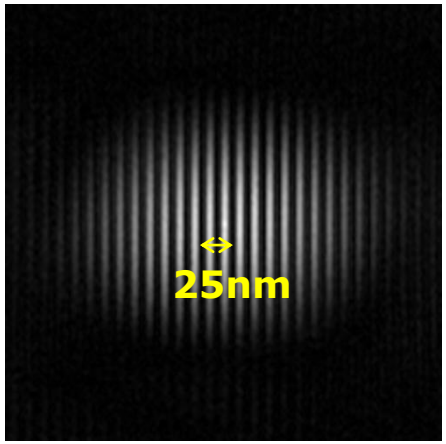
Contact hole (honeycomb)



L/S horizontal



Contact hole



L/S vertical

CSM can detect low-density carbon contamination effect

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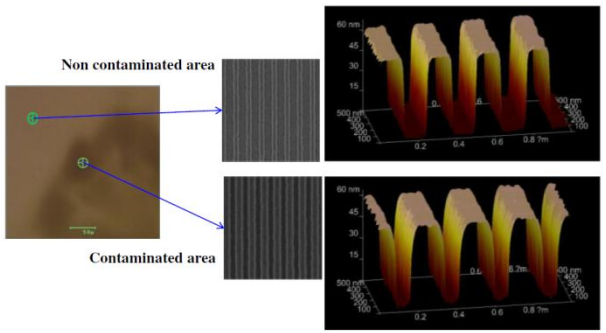
Japanese Journal of Applied Physics **51** (2012) 06FB04

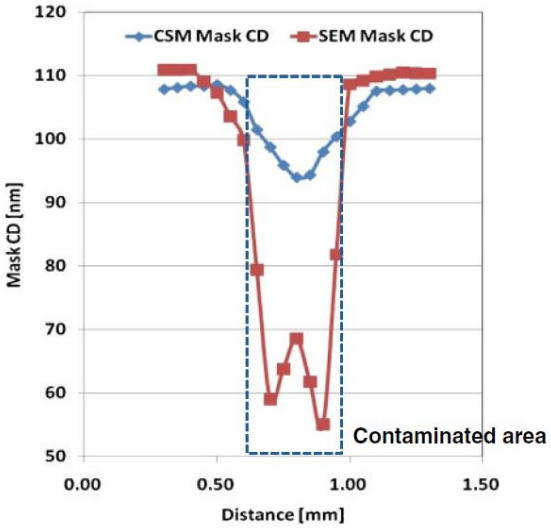
REGULAR PAPER

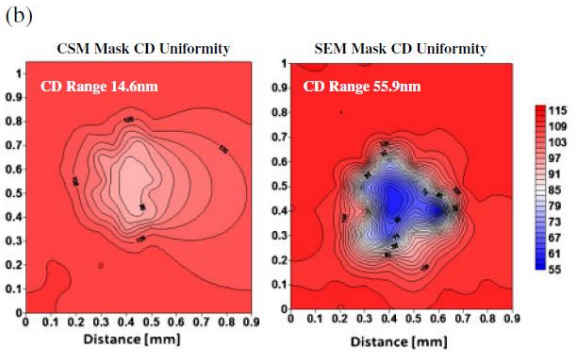
DOI: 10.1143/JJAP.51.06FB04

Effect on Critical Dimension Performance for Carbon Contamination of Extreme Ultraviolet Mask Using Coherent Scattering Microscopy and *In-situ* Contamination System

Jonggul Doh[1,2], Sangsul Lee[1], Jaewook Lee[1], Seongchul Hong[1], Chang Young Jeong[2], Dong Gun Lee[2], Seong-Sue Kim[2], and Jinho Ahn[1*]







Korea EUVL R&D Infrastructure

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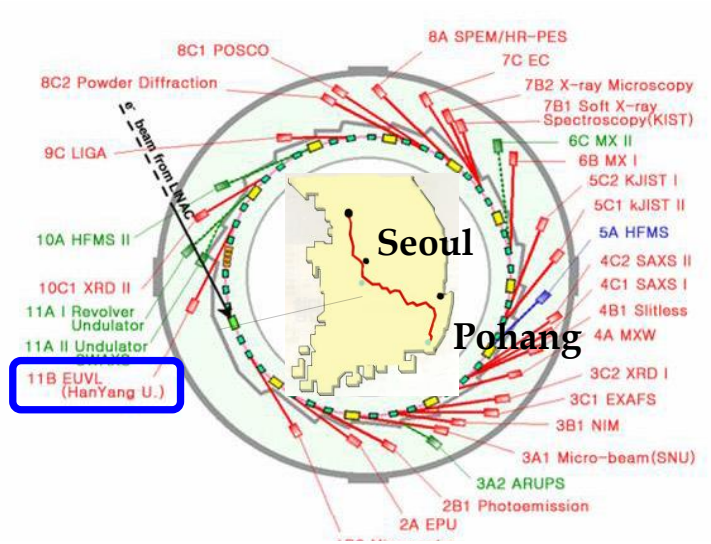
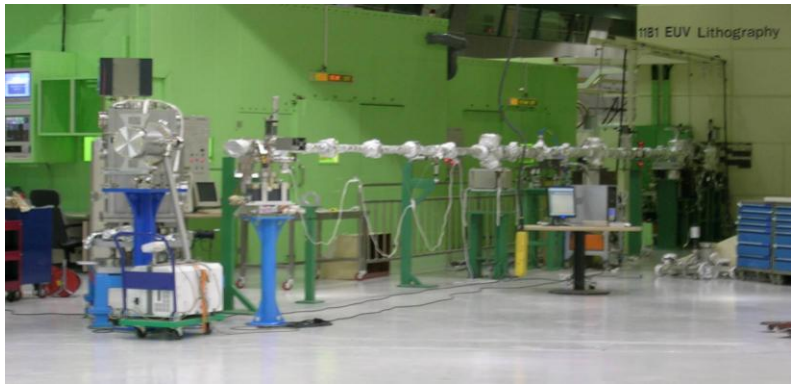
Co-workers:

- Academia - POSTECH, SNU, SKKU, Inha Univ.
- Research Institute – Pohang Accelerator Laboratory, NCNT
- Industry - Samsung Electronics, SK HynixDongjin Semichem, IMT





▷ beam size at mask : <φ 2mm
▷ energy range : 92.5 eV(13.4nm)
▷ energy resolution : > ±1%

Beamline **Micro exposure Tool** **PR Out-gassing** **EUV Microscope** **EUV Reflectometer**

EUVL Beamline & Tools

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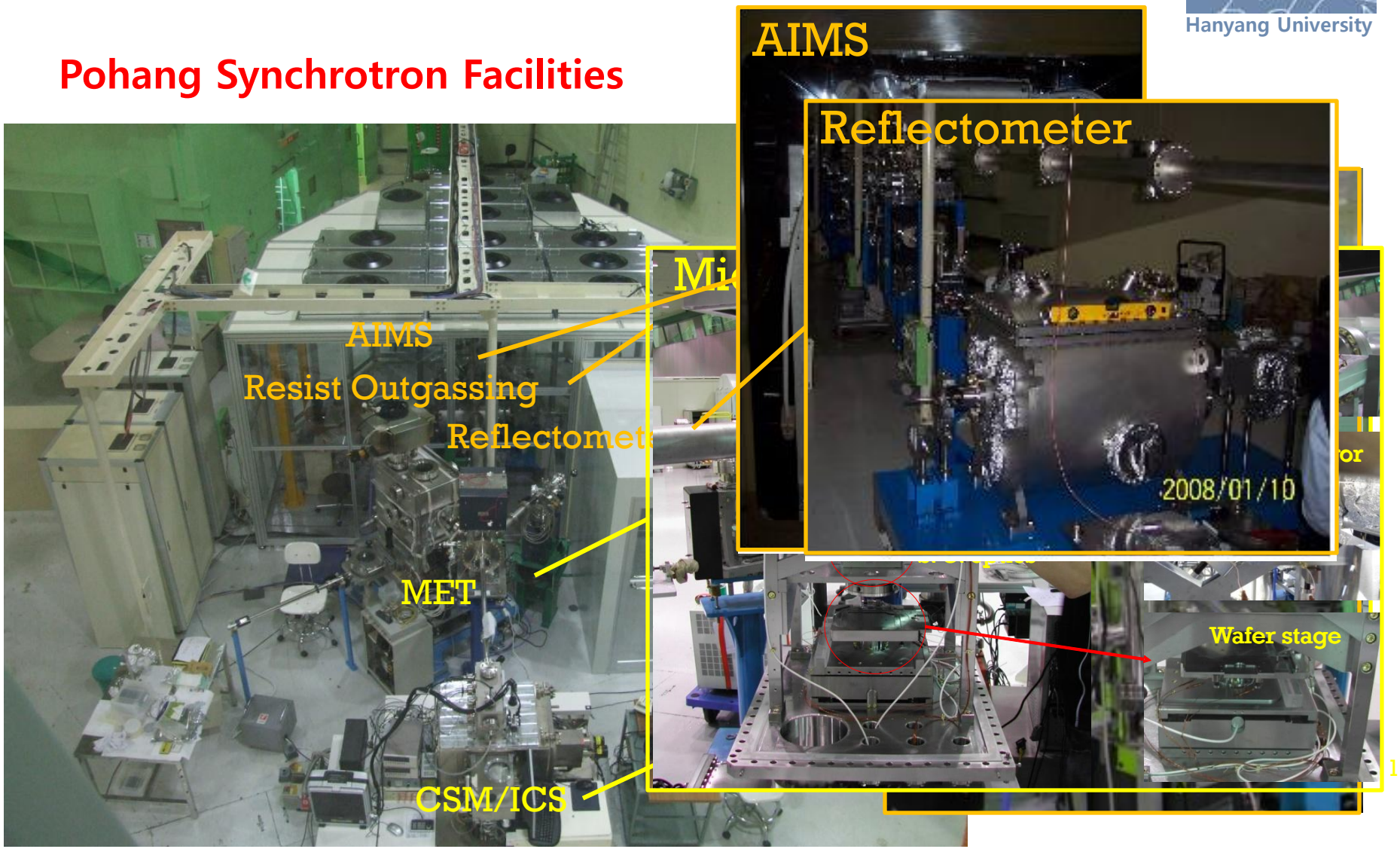
Pohang Synchrotron Facilities



Industry roadmap toward <10nm
Lithography supports shrink

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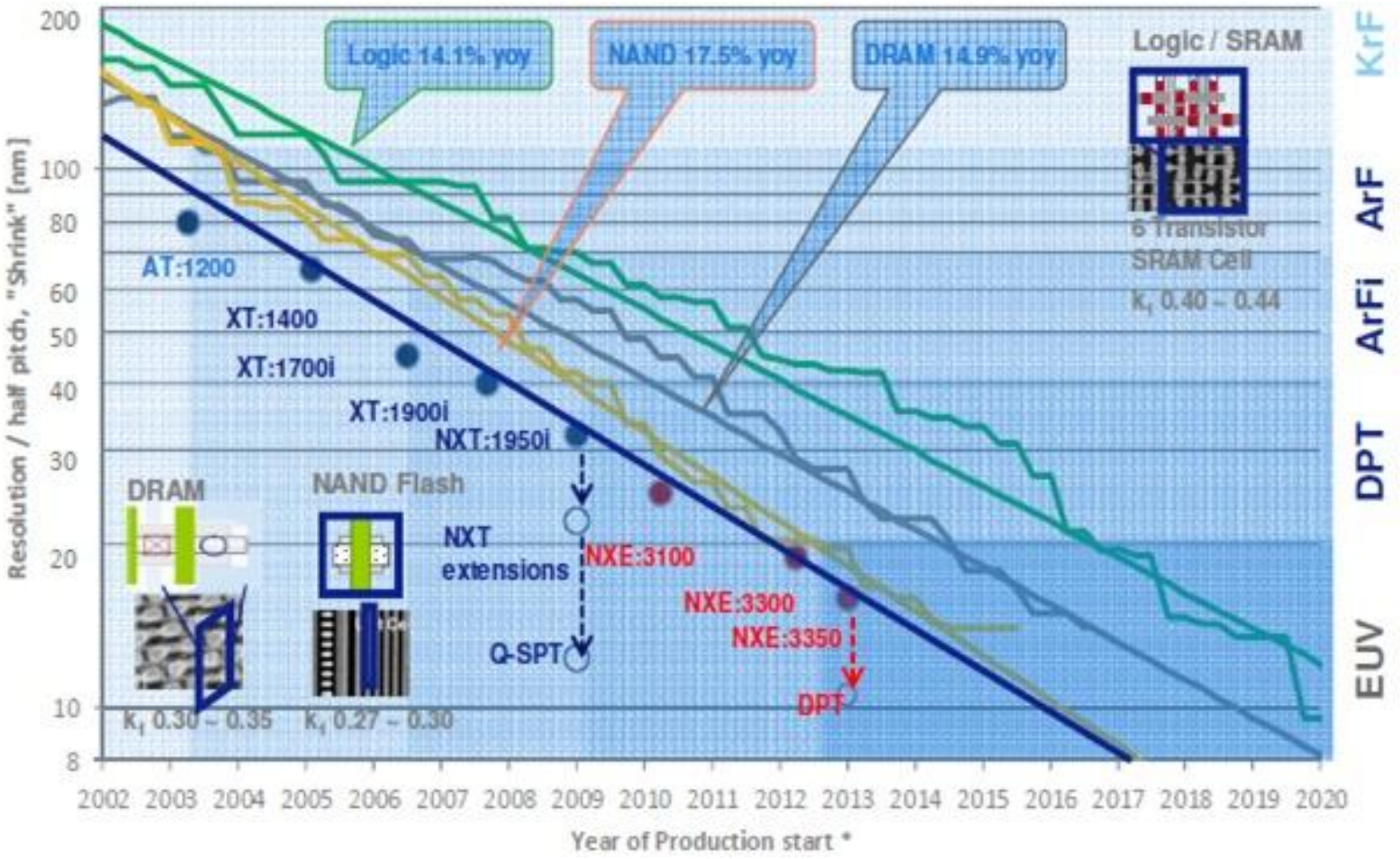

Ref: ASML

Scanner Roadmap Extendibility

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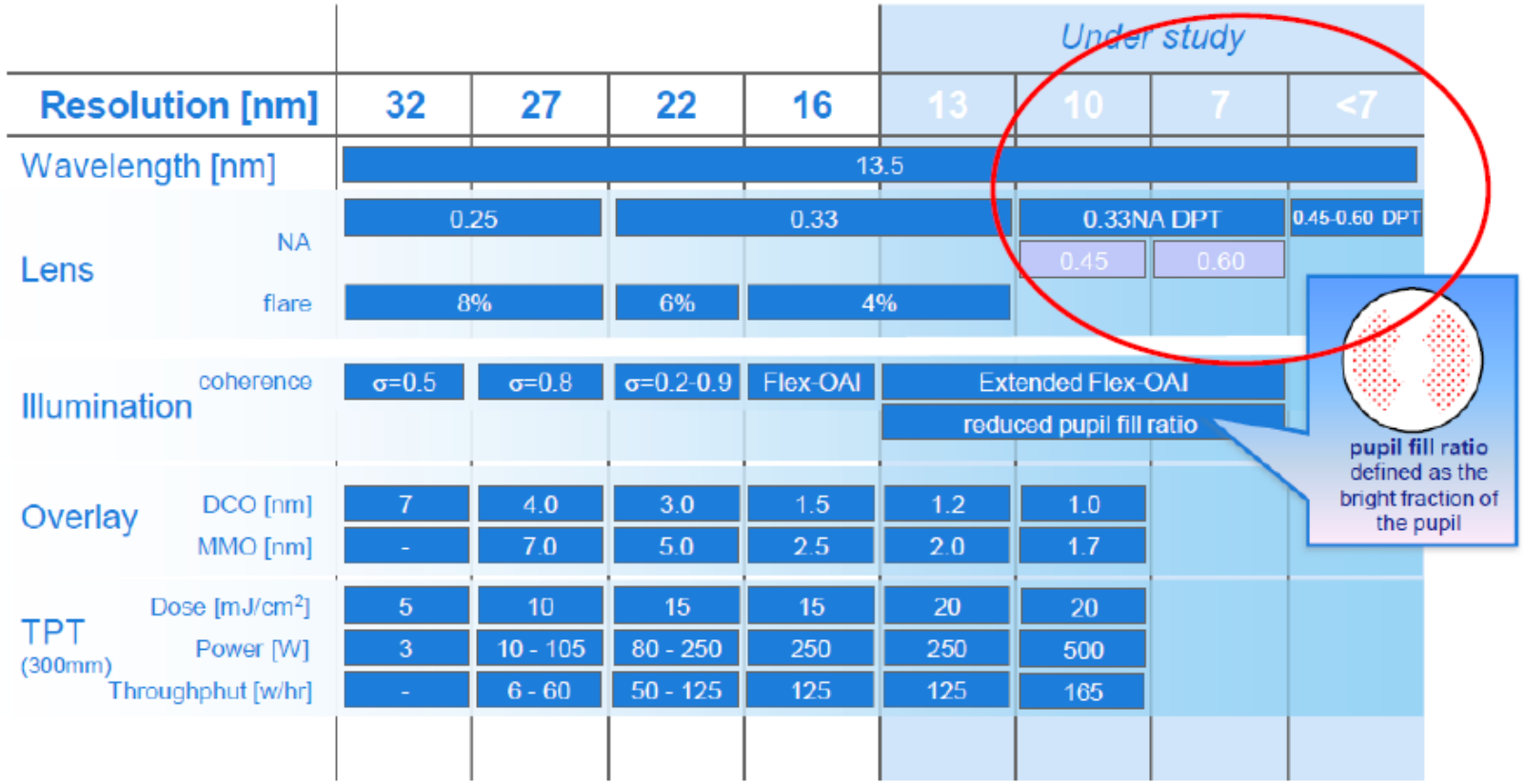
Rudy Peters / ASML, SPIE Microlithography, Feb 2013



- EUVL can be extended to sub-10 nm patterning using double patterning and/or high-NA EUV

Ref: ASML

High-NA Limiting Factor

– Mask structure

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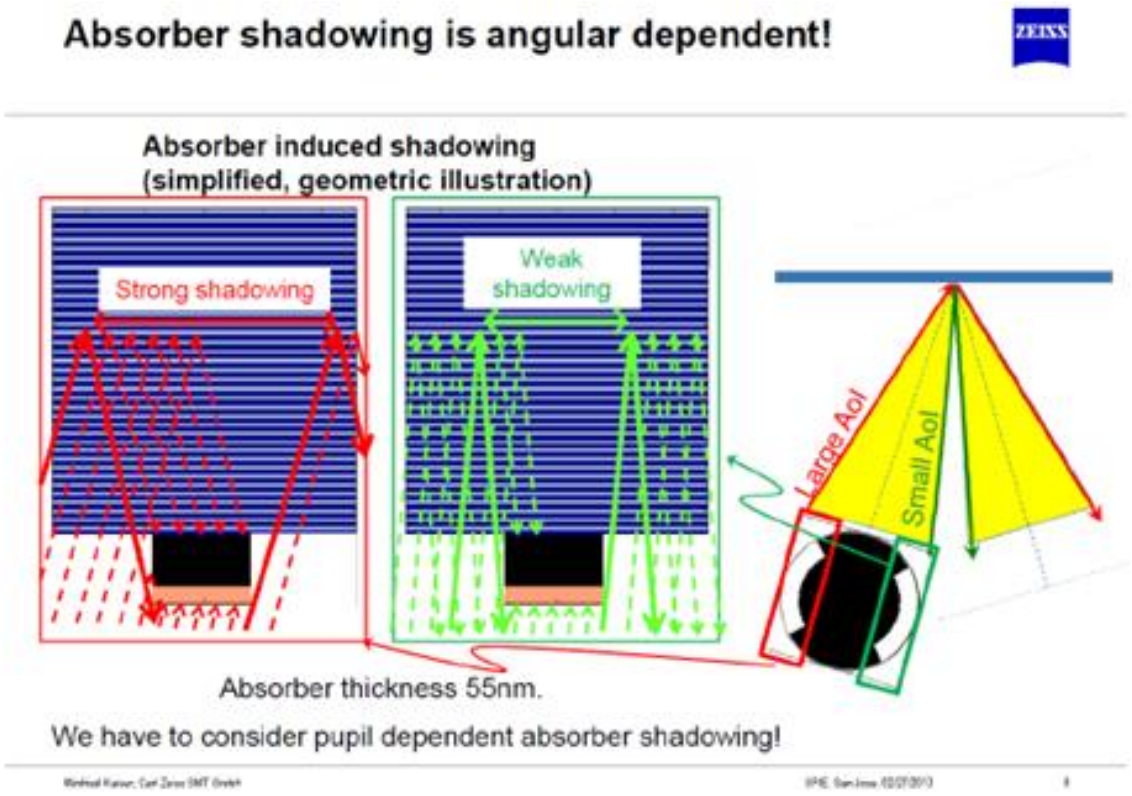
The 3D nature of the EUV mask limits resolution and image quality



New mask structure including re-designed reflector and thin absorber is needed for high-NA system.

Optimizing Mask Structure for high NA

– New reflector and absorber

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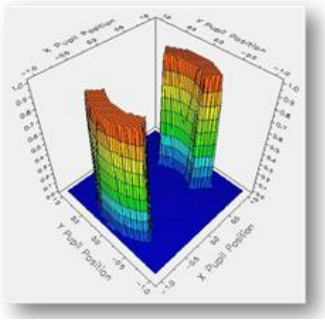
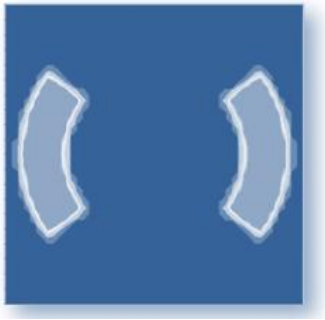
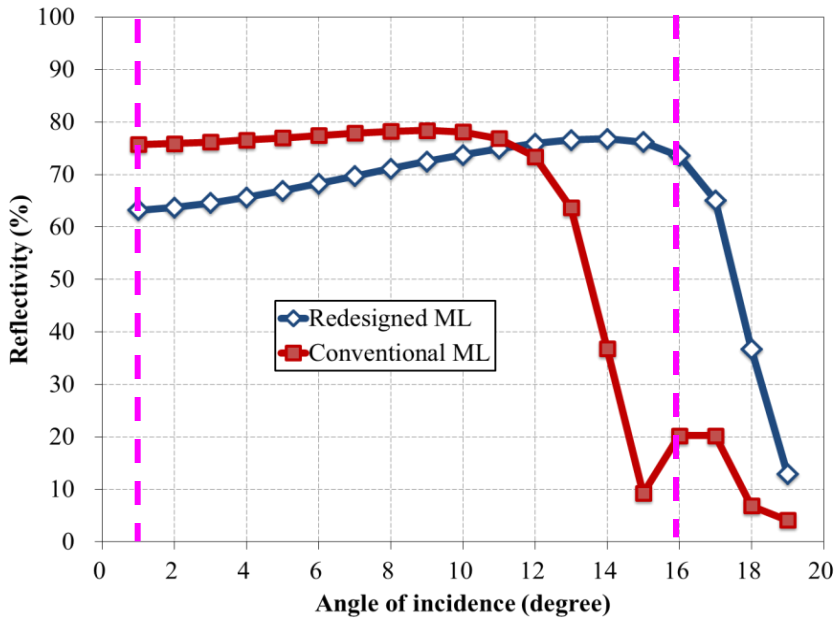




NA	0.45
Outer sigma	0.9
Inner sigma	0.6
Blade angle	75°
AOI	9°



Materials	TaBN	Ni_3N_2	Pd_3N_2	TeO_2
Thickness (nm)	30	24	20	24
Reflectivity (%)	8.6	2.8	6.5	1.8
	Non-shadowing			
Contrast (%)	82	98	97	84
NILS left	2.71	2.91	3.17	2.76
NILS right	2.71	2.91	3.17	2.76
	Shadowing			
Contrast (%)	62	75	78	72
NILS left	1.69	1.82	2.02	2.07
NILS right	1.96	1.92	2.04	1.92
H-V CD Bias (nm)	3.47	4.07	3.36	3.60

Ref: J. Ahn et al. 2013 EUVL Symposium

Att.-PSM for better imaging quality

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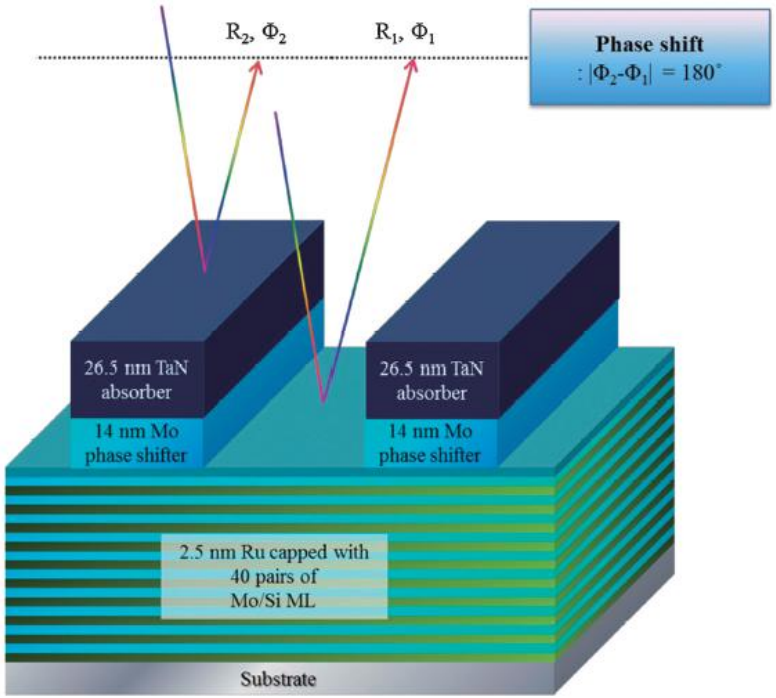
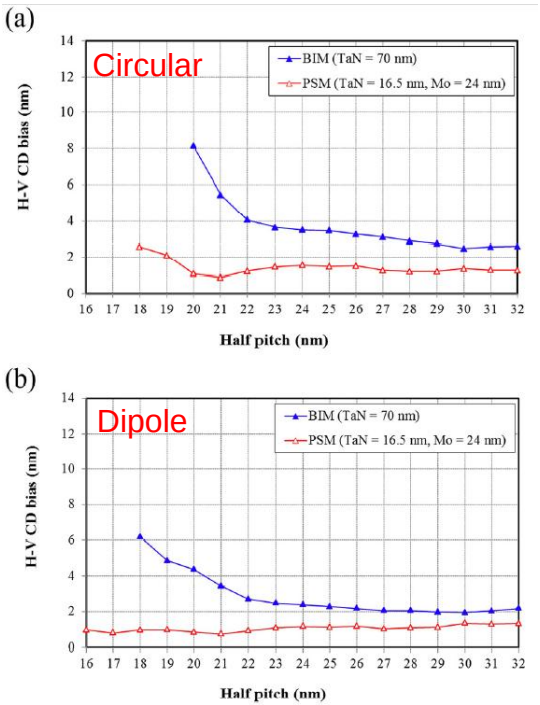
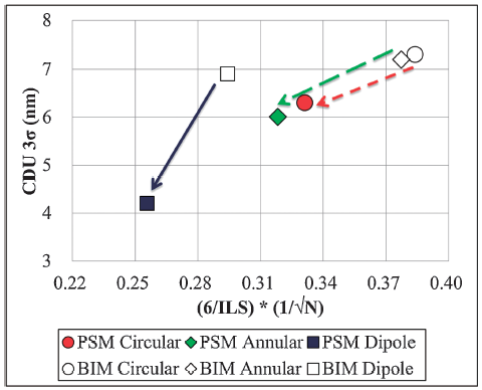
Applied Physics Express **6** (2013) 096501
http://dx.doi.org/**10.7567/APEX.6.096501**

Stochastic Patterning Simulation Using Attenuated Phase-Shift Mask for Extreme Ultraviolet Lithography

Seongchul Hong[1], Seejun Jeong[2], Jae Uk Lee[1], Seung Min Lee[1], and Jinho Ahn[1,2]







Very thin absorber for fine patterning

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Applied Physics Express **6** (2013) 076502

http://dx.doi.org/**10.7567/APEX.6.076502**

Very Thin Extreme Ultraviolet Mask Absorber Material for Extremely Fine Pitch Patterning

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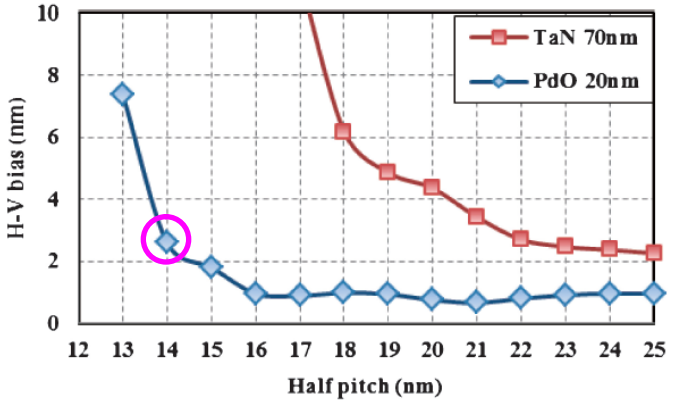
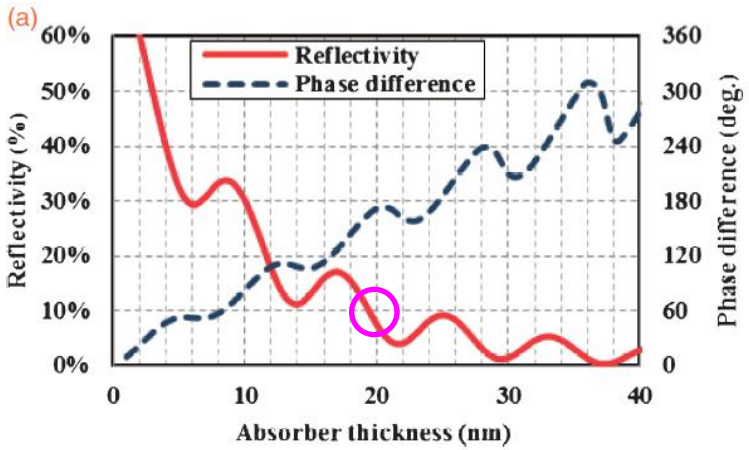
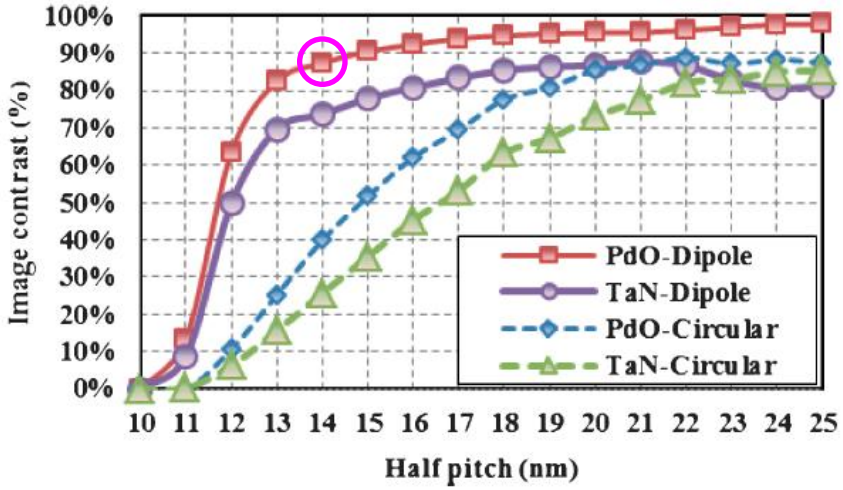
In this report, we propose palladium oxide (PdO) as an absorber material for an EUV mas down to 14 nm. In our simulations, because of its low refractive index ($n = 0.8634$) and phase shift mask with a very thin (~20 nm) PdO absorber can provide an EUV contra illumination. This results in a very limited horizontal–vertical critical dimension bias (≤2.6 (≥2.78) down to a 14 nm half pitch.







Conclusion

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Even though struggling from the source power problems, huge progress is going on to insert EUV lithography into mass production.

Further innovation is underway to extend EUVL resolution limit beyond 10nm.

Continuing trend of device scaling will be realized though EUV lithography.

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Thank you