PROGRESS AND OPPORTUNITIES IN EUV MASK DEVELOPMENT

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2016 EUVL Workshop (Berkeley, CA, June 16, 2016)

Outline

- EUV masks: Overview and progress
- Pattern inspection
- Pellicle
- Summary

Slide shown at BACUS, Sept 2015

Mask Cycle - a Simplified Flow

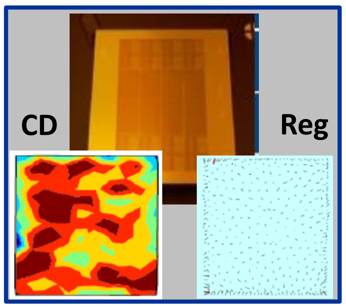
Make | **Check** | **Protect & use**

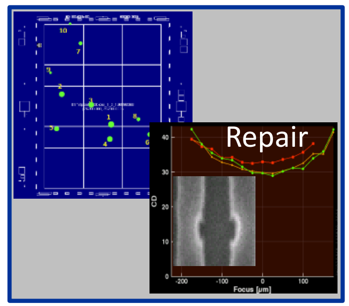
FE: blanks, patterning, metrology → BE: inspection, defect disposition → Protection: POD, pellicle → Usage & Maintenance

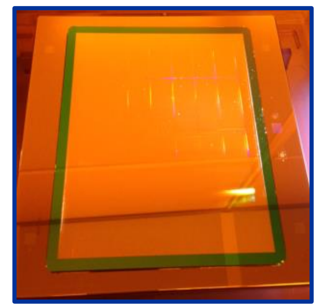
- **Blank inspection**

- **Pattern inspection**
- **AIMS, Repair**

- **Dual POD; Thru-pell Inspection**
- **Backside inspection**





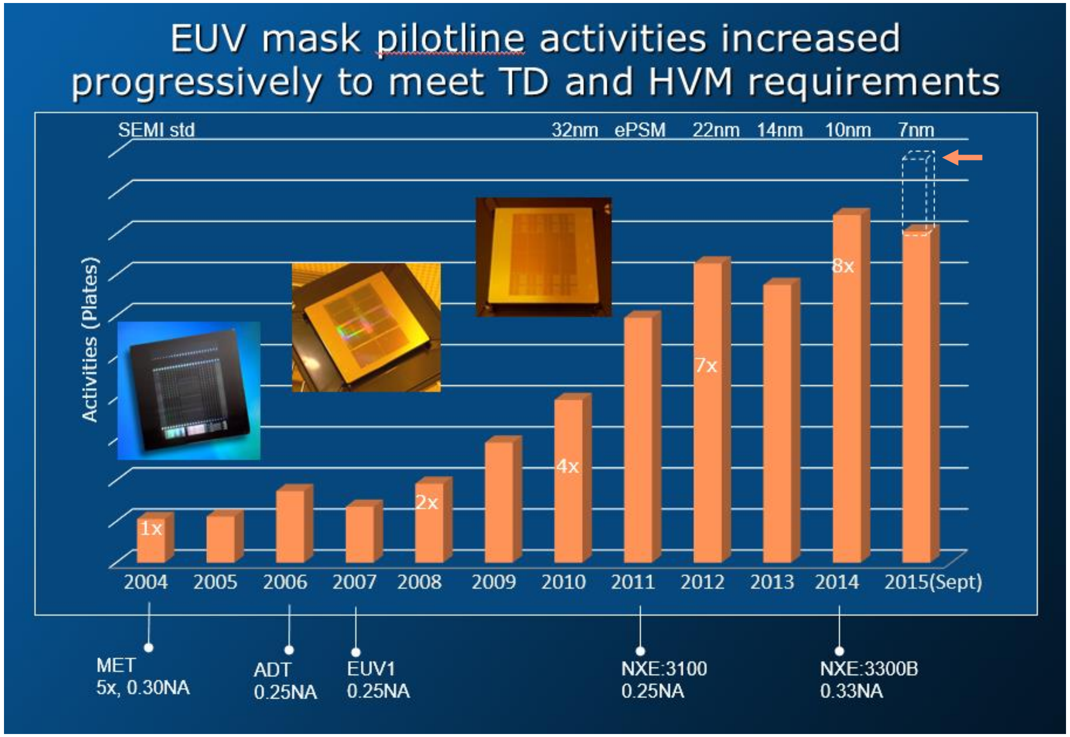


- Synergy and adjacency to ArF: Continue to maximize the sharing of existing <u>infrastructure & best known methods</u> developed during years of continuous improvements
- Divergence from ArF: need industry's concerted efforts to tackle the challenges and <u>close any infrastructure & capability gaps</u>

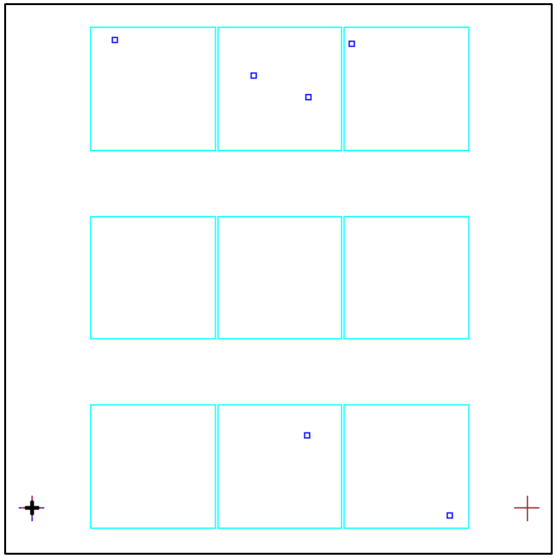
Progress in EUV Mask Fabrication

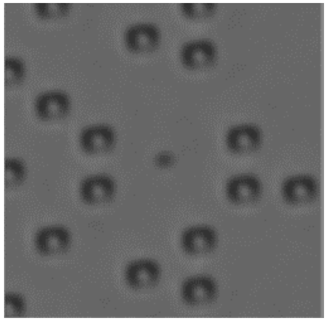
- EUV masks fabrication in quantity and quality to support EUVL development

~10X increase over 10 years



An N7 VIA test mask





All the 6 defects shown are non-printable

Methods of Pattern Inspections

- **DUV lights @193nm: mature platform to support 7nm development**
  - Near resolution limit for tighter patterns (next slides)
  - Not capable for through-pellicle inspection (low transmission)

- **E-beam: high resolution, low throughput**
  - Useful as a stop-gap capability
  - Not useful for through-pellicle inspection

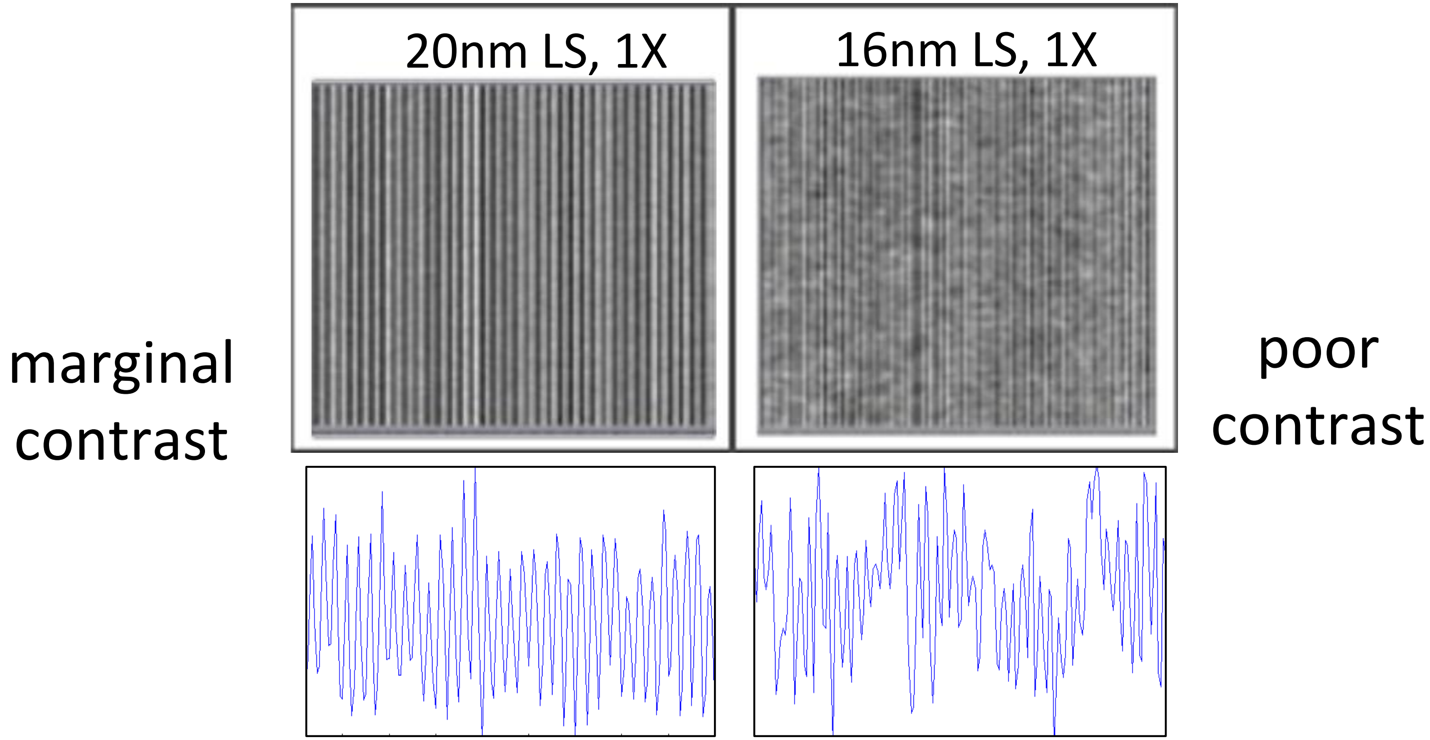
- **Actinic light @13.5nm: a solution with full capability**
  - High and extendable resolution: same resolution as the scanner
  - Through-pellicle inspection
  - Detect what matters: same defects as 'seen' by the scanner

Slide shown at BACUS, Sept 2015

EUV Mask Pattern Inspection

- DUV optical platforms continue to provide capability for pilotline
- But, they are near the resolution limit for tighter patterns

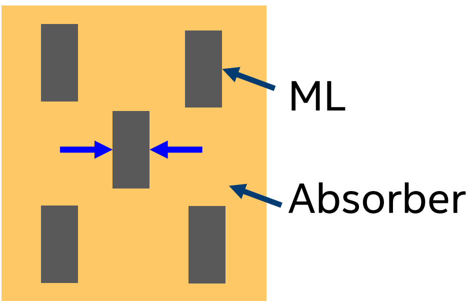
Inspection image contrast



EUV Mask Pattern Inspection (cont'd)

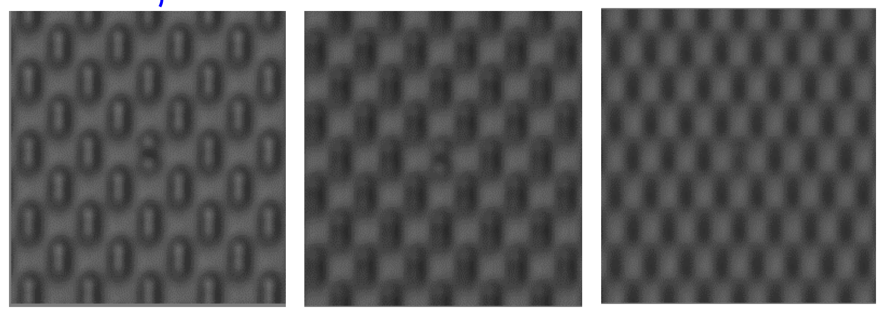
- A closer look: DUV contrast and detection for trench/via

Simple test cell



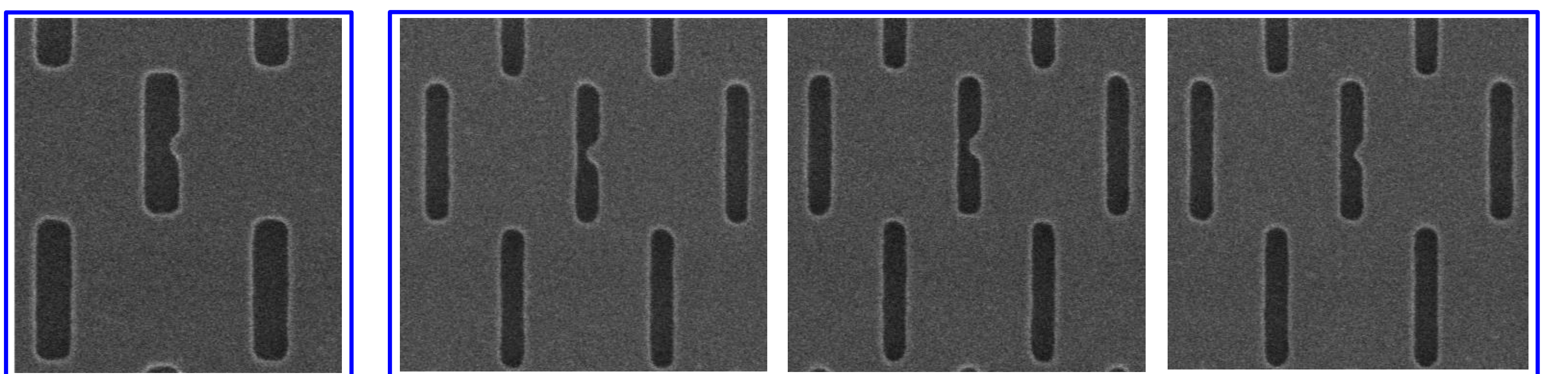
1) Contrast reversal

34nm, 1X | 28nm 1X | 20nm 1X



2) DUV sensitivity loss: intrusion defect (Mask SEM images)

28nm (112nm, 4X) | 20nm (80nm, 4X)

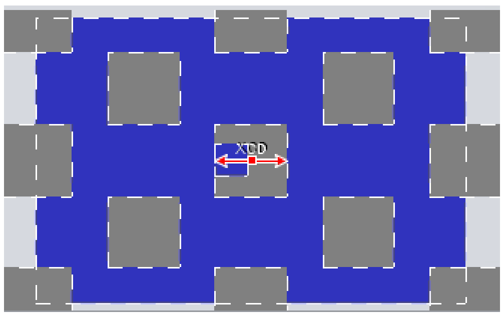


	28nm (112nm, 4X)	20nm (80nm, 4X)		
Printability:	Yes	Yes	Yes	Yes
Inspectability:	Yes	Yes	marginal	No

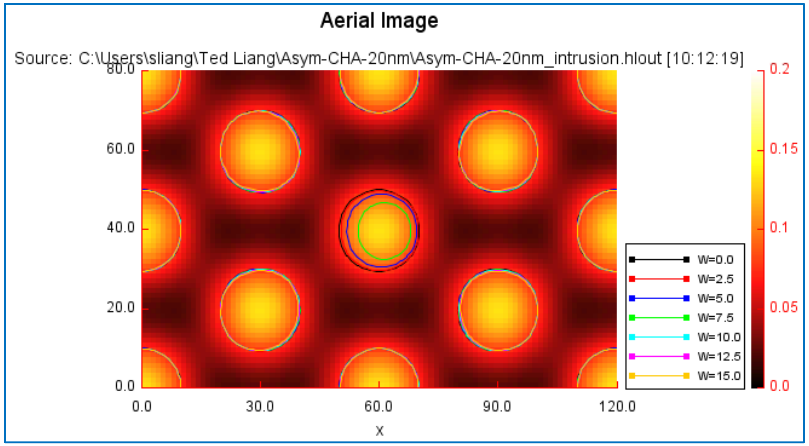
Actinic pattern inspection

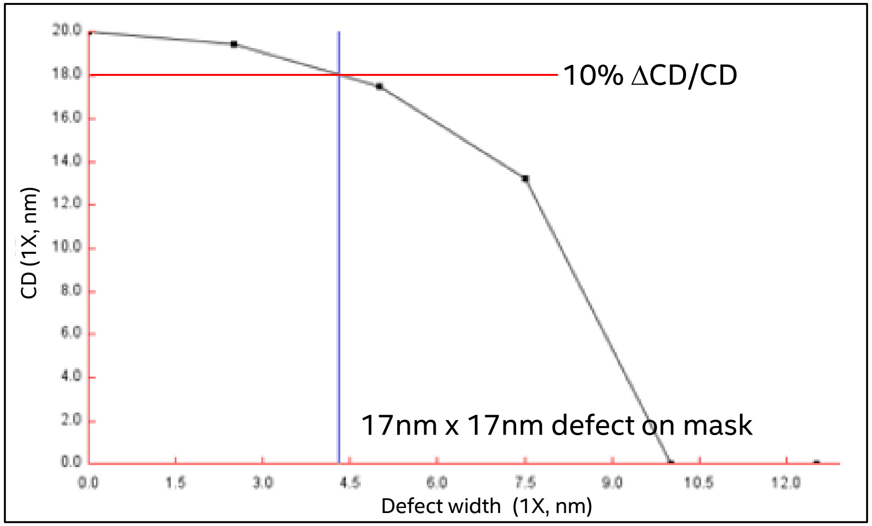
- Inspection wavelength: 13.5nm
- Required sensitivity: detect defects that cause 10%ΔCD/CD on wafer

Example
20nm dense contact holes
Edge intrusion



0.33NA, annular
60nm Abs
Min. printable defect: 17nm (4X)





Actinic pattern inspection (cont'd)

- **EUV source readiness remains a high risk for inspection tool development**
  - Stability in continuous operation
  - High brightness (TPT)
- **The need for high brightness source**
  - Unlike source for scanner, there is significant étnendue mis-match between the source and imaging system
  - >30W/mm^2/sr at IF (2hr TPT)
  - >40W/mm^2/sr for post-pell inspection (85% single pass transmission)
- **Source stability for continuous operation, min. > 2 weeks**
  - Position stability: <10um
  - Rep rate: >10kHz
  - Power stability: <2% (4msec average)
  - Debris mitigation: critical for mask tools
  - Availability: >90%

Current sources

- No sources today meeting all the basic requirements simultaneously

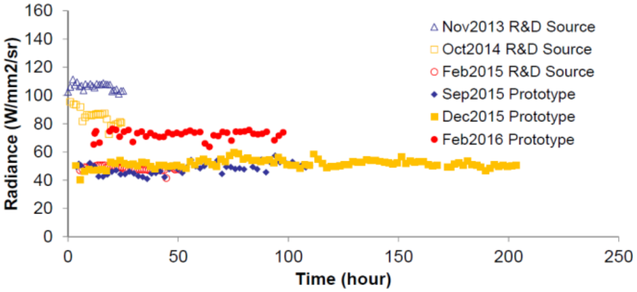
Energetiq, 2015 EUV source workshop

	Existing	Proposed
Bore Diameter: mm	6	1
Length: mm	3	2
Pulse Rate: Hz	2.50E+03	5.56E+04
Brightness: W/mm².sr	4.5	100
Compressed Diameter: mm	0.4	0.07
Compression Ratio:	15	15
Uncompressed Ion Density	1.77E+21	3.53E+21
Bennet current: A	6.64E+03	1.56E+03
Peak/Bennet	1.05	1.05
Peak current: A	6.99E+03	1.65E+03
Time to Reach Peak Current: s	2.51E-07	4.18E-08
Total Inductance: H	1.90E-08	9.49E-09
Resistance: Ω	9.87E-02	9.87E-02
Capacitance: F	2.38E-06	8.96E-08
Voltage: V	-1200	-666
Power to Plasma: W	4.21E+03	1.66E+03

Reliability: tests ongoing — USHIO

2016 SPIE

- The prototype machine is dedicated to days-long non-interrupted operation test.
- Several days-long operations were carried out.
- Output radiance will be increased by (1) increasing operation frequency and (2) parameter optimization, and stabilized by (3) applying stabilization control.



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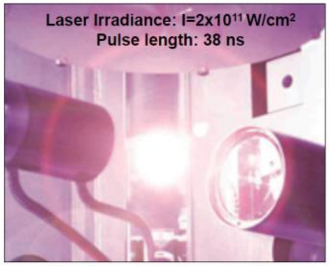
ETH zürich — LEC

2015 EUV source workshop

Plasma EUV Source Characteristics (ca 2013)



Parameters	Value
Laser power on target (W)	1100
Laser frequency (kHz)	>6
Laser focal spot size (µm)	70 (FWHM)
Conversion Efficiency (CE)	> 1%
EUV source size (µm)	60 (FWHM)
Source power at the source (W)	>12
Source brightness (W/mm²sr)	>350

Recent System level advancements:

- Emission stability using droplet control in both in time and space
- Debris mitigated EUV collector and Cleanliness validation of tin-based LPP source after IF
- Characterization of source emission (both radiation and debris) with several plasma diagnostics (Langmuir Probe array, EUV pinhole camera, VUV spectrometer)
- Long-term efforts towards other wavelengths, alternative fuels

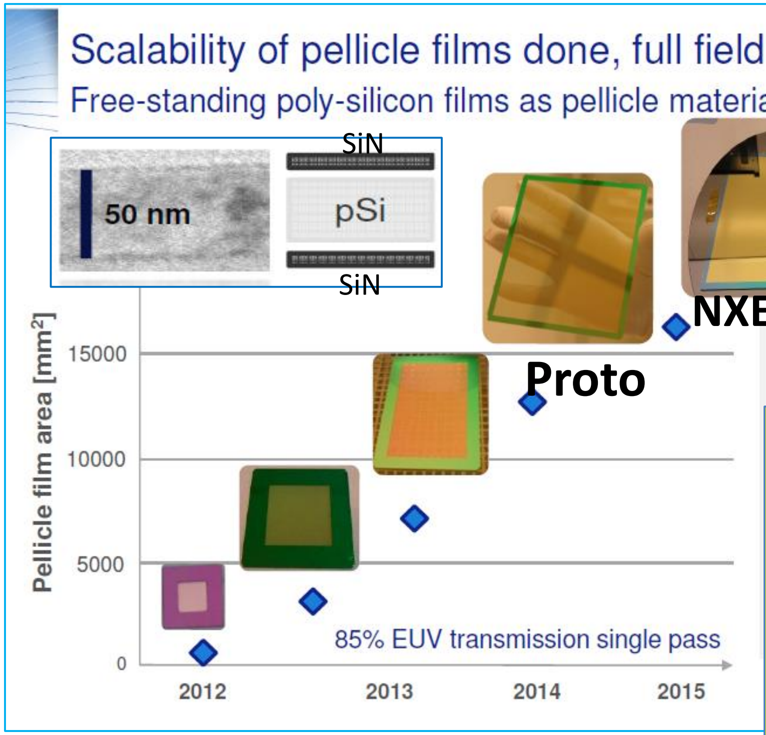
Laboratory for Energy Conversion
www.lec.ethz.ch/plasma
11/10/15 6

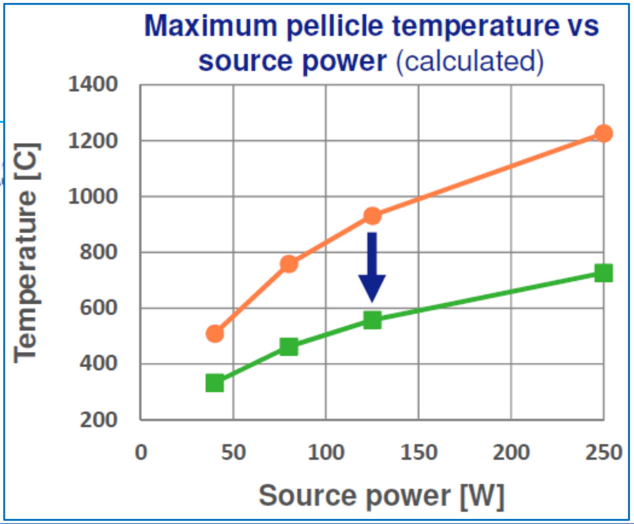
Other Sources…

Updated slide shown at BACUS, Sept 2015

EUV Pellicle is Becoming a Reality

- Prototype full-size pellicle imaging demonstrated on NXE3100 (Dec’14)
  - Nearly 1000 wafers exposed on pelliclized reticles
- NXE full-size pellicle fabrication demonstrated





Zoldesi/ASML: PMJ & EMLC 2015

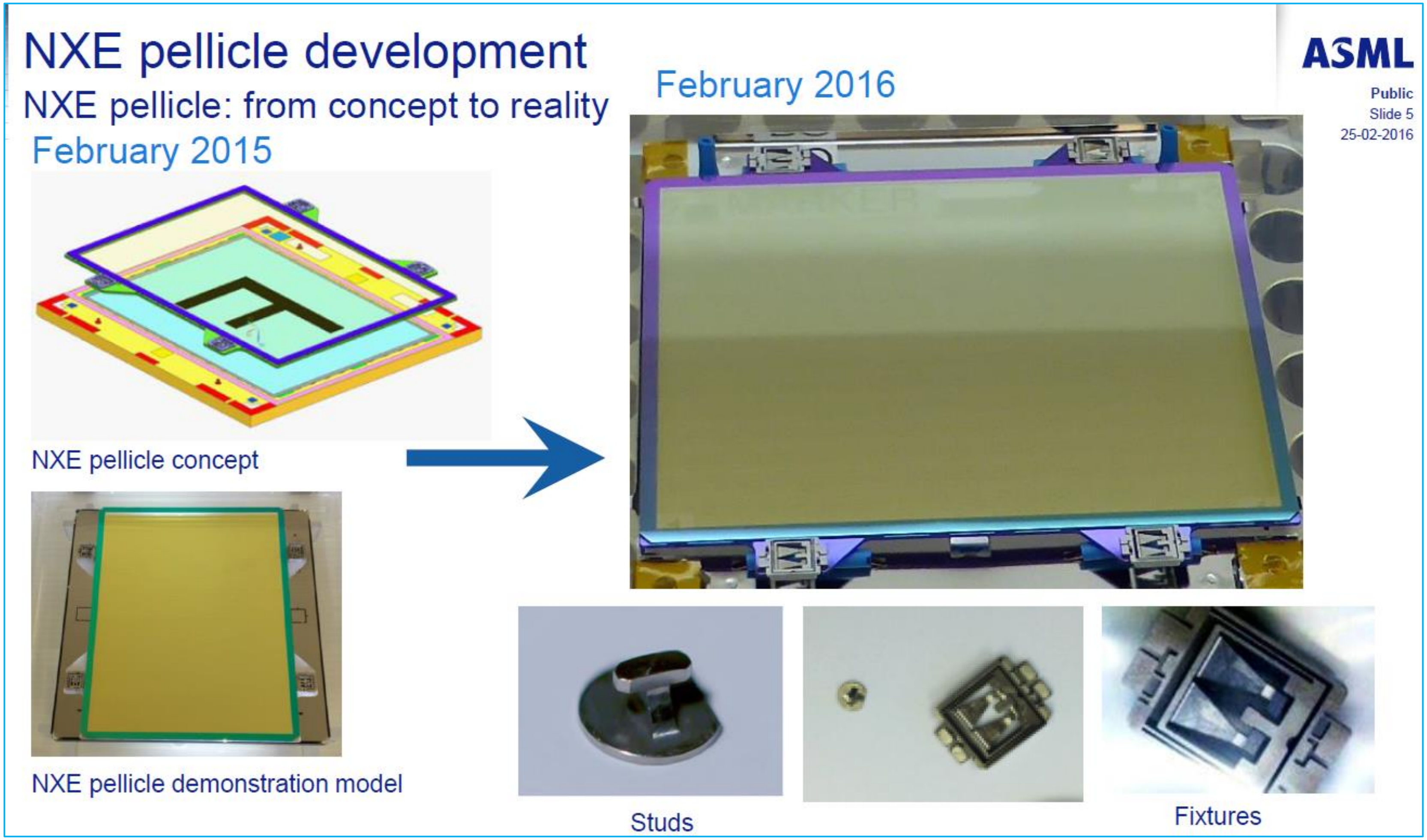
Pellicle film scaling for HVM

- Full-size pSi film mechanically robust
- Transmission: @85%, target 90%
- Thermal stability: Reliable @40W; demonstrated @125W; target 250W
- Pellicle cleanliness: no printable particles

Pellicle Assembly

- Basic set up in place to mount pellicles

Derk Brouns/ASML, 2016 SPIE



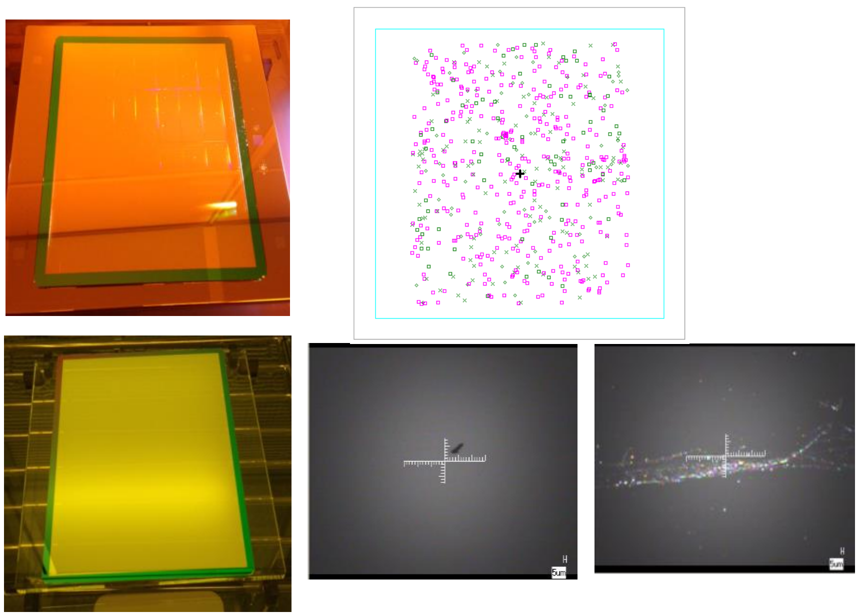
Slide shown at EUV Pellicle TWG 2/21/2016

EUV Pellicle Metrology Infrastructure

- **Basic tool and capability exist today to support pellicle materials development and quality control**

Pellicle film inspection

– Inspections demonstrated on multiple pellicles mounted on reticles

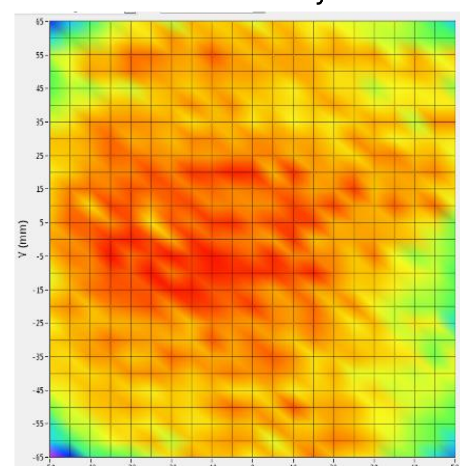


Uniformity measurements

– Tool is available for accurate and precise transmission uniformity measurement

– Demonstrated measurements of full-size pellicle @13.50± 0.03nm

100mm x 130mm
Measured in every 5mm



Courtesy of EUV Tech

Pellicle film for imaging with 250W EUV light

- Spec to be compatible with NXE HVM exposure tool

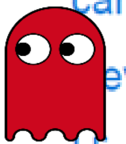
	Product Phase	Target specifications: Transmission	Transmission non-uniformity	Power capability
Pellicle film generations	Prototype	>80%	1%	>40W
	Pilot	>80%	1%	>125W
	Product	88%	0.4%	250W
	Future	≥90%	0.4%	>250W

Derk Brouns/ASML, 2016 SPIE

In parallel, ASML Research investigates ...le robustness, primarily thermal ...stance based upon:

- Graphene/carbon based membranes (...6% transmission achieved on carbon based films)

- ...ew multilayer structures



- High temperature ceramics as capping and base material

- **Innovative materials are needed, and readiness to sync with 250W source operation**

Slide shown at EUV Pellicle TWG 2/21/2016

Messages for 2016:

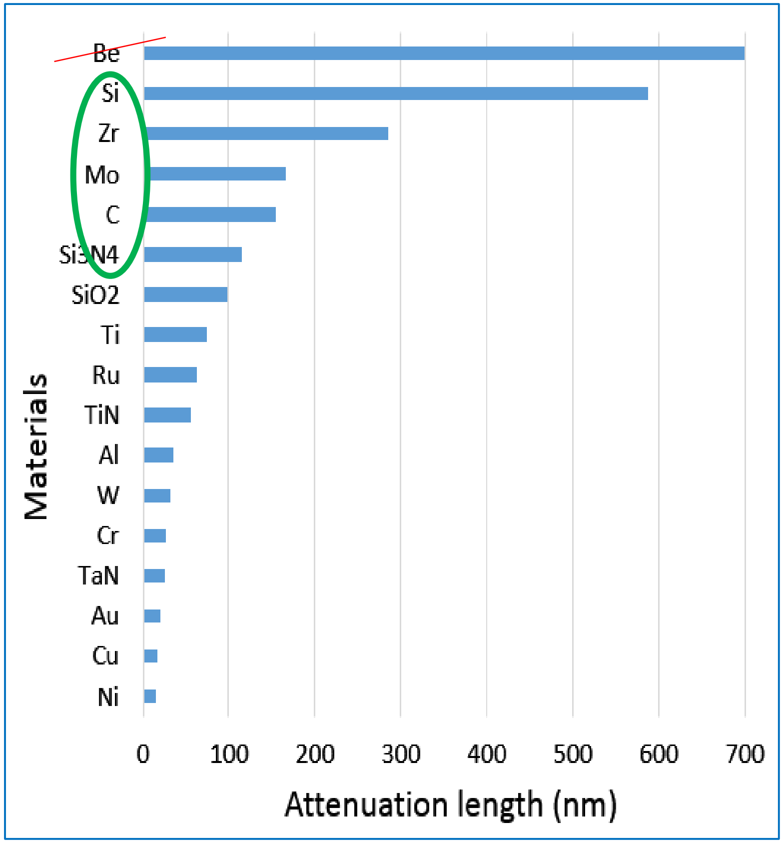
Still apply today

- **Good progress has been made in EUV pellicle development in materials, tooling and infrastructure**
  - Pellicle exposure with global transport and handling demonstrated
  - Basic EUV pellicle infrastructure and capability exist today for pellicle materials development and quality control

- **Pellicle films capable of long lifetime at 250W EUV remain a critical gap in pellicle implementation for HVM**
  - Rapid innovation/invention and development are necessary to intercept schedule
  - Great opportunities exist for engagement in pellicle film production and commercialization

Opportunities in Pellicle Film Innovation

- **Si-based films**: Si, SiN
  - Protective/high emissivity coating
  - Continue to improve transmission, thermal load, chemical durability in H2+EUV
- **C-based films**: CNT, Graphene
  - High transmission possible
  - Chemically inert – Graphene (when perfect)
  - How to make large sheets
  - Mechanical strength/sag, tensile
- **Multi-layered films**: Si, Zr, Mo
- **Structured films**



Summary

- Overall, Intel mask shop have been delivering defect-free EUV masks to support integrated process development for 7nm technology node
- However, for EUVL in HVM, the following key modules need to be fully developed, hence the opportunity for innovation, notably:
  - Pellicle integration: clean and reliable pellicle film, particle-free mounting
    - High transmission, high power pellicle film is a critical enabler and need to be invented
  - Actinic pattern mask inspection tool development needs to start in parallel with EUVL development
    - Extendable resolution
    - Through-pellicle inspection
    - Reliable and high brightness source is a critical component that needs to be improved to maturity

Acknowledgements

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Thank you for your attention!

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