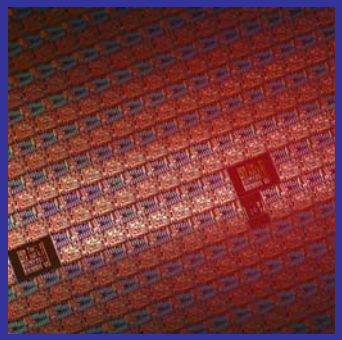
Accelerating the next technology revolution

Overview of EUV Lithography and EUV Optics Contamination

Andrea Wüest



NIST Contamination WS
Gaithersburg, MD
June 2, 2009

Copyright ©2008
SEMATECH, Inc. SEMATECH, and the SEMATECH logo are registered servicemarks of SEMATECH, Inc. International SEMATECH Manufacturing Initiative, ISMI, Advanced Materials Research Center and AMRC are servicemarks of SEMATECH, Inc. All other servicemarks and trademarks are the property of their respective owners.

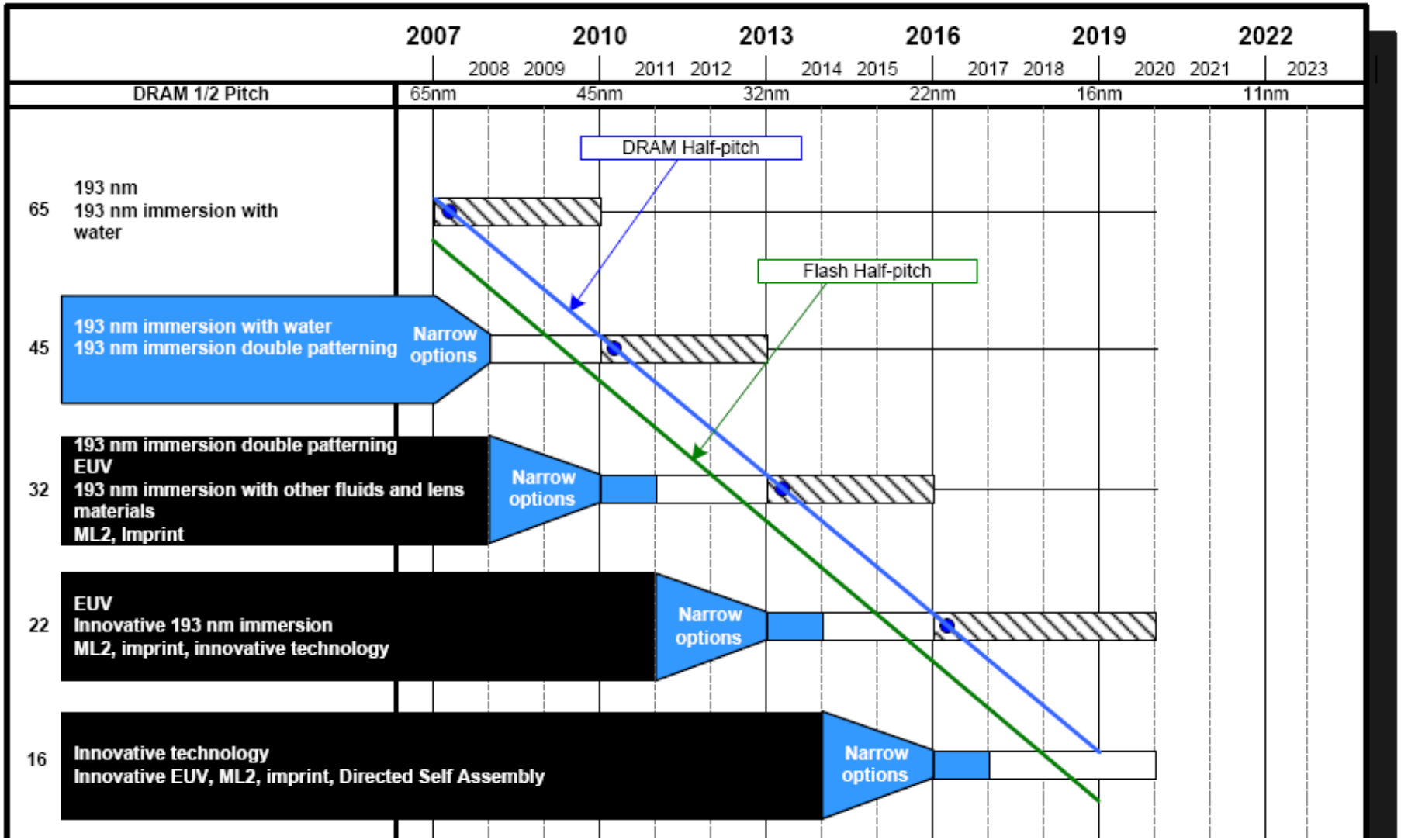
Outline

- Overview of potential solutions for next generation lithography, including EUVL
- A closer look at EUV optics contamination
- Summary

Potential Solutions for Next Generation Lithography

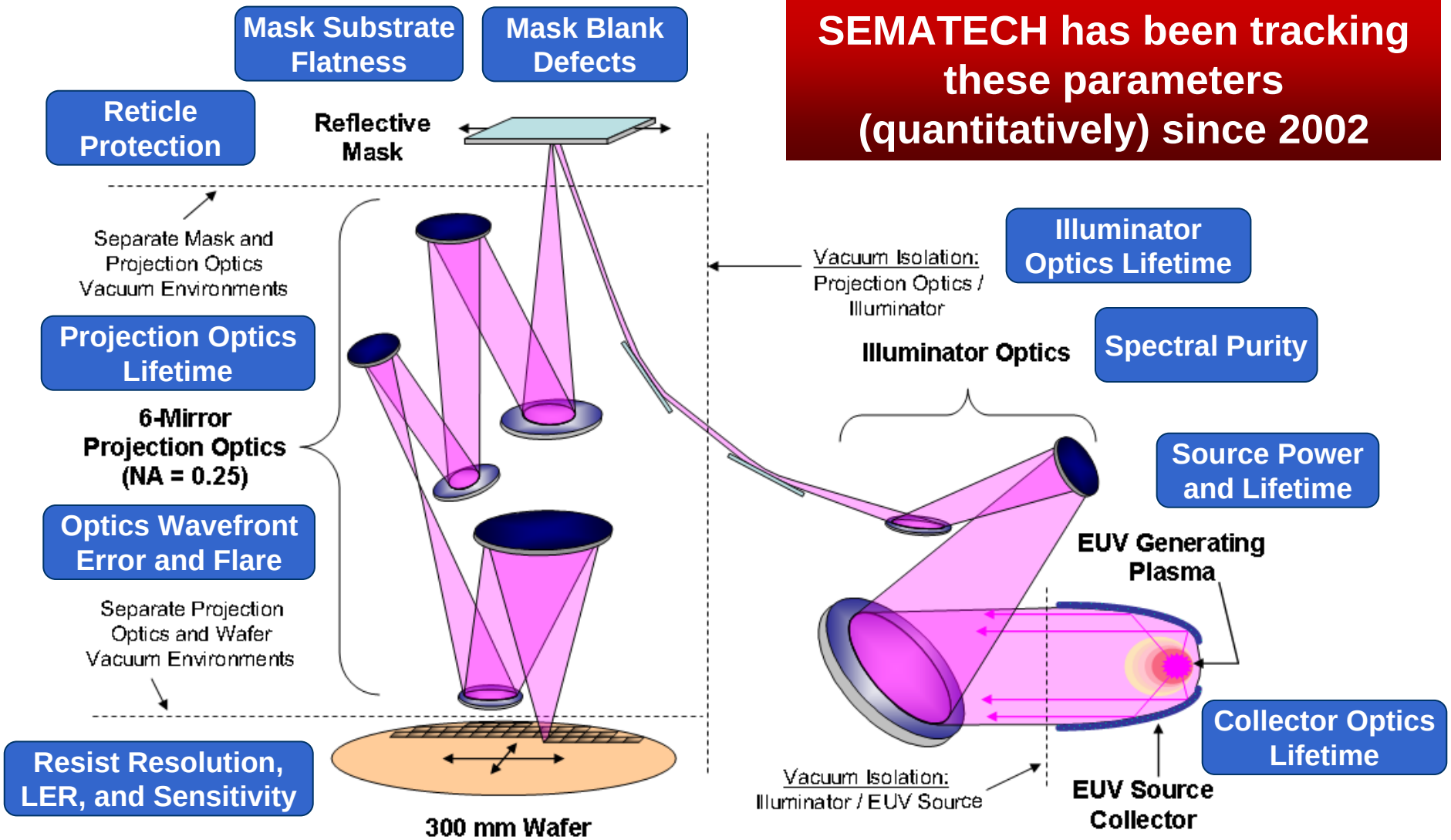
- 193 nm immersion with water
- 193 nm immersion double patterning
- Extreme Ultraviolet (EUV)
- 193 nm with other fluids and lens materials
- Maskless lithography
- Nanoimprint lithography

International Technology Roadmap for Semiconductors (ITRS) - Potential Solutions



EUV Lithography

SEMATECH has been tracking these parameters (quantitatively) since 2002



4X REDUCTION REFLECTIVE IMAGING SYSTEM
(λ = 13.5 nm, NA = 0.25 - 0.3, 0.55 max)

EUVL Manufacturing Requirements

- Productivity
  - >100 wafers/hour
  - High uptime, fast time to recover

→ Reliable, high source power

- Cost-effective
  - High productivity
  - Low mask costs
  - Low consumables cost
  - High defect yield

→ Low mask blank defects

→ Low optics erosion

→ Defect free reticle handling

- Repeatable
  - Overlay <10 nm
  - CD uniformity <4 nm

→ Reticle flatness control

→ Good photoresists and tool control

EUV Optics Contamination

- What is the problem?
- Why does the problem arise?
- How do we solve/tackle the problem?

What is the problem? - Requirement

- EUVL cost of ownership has to be sufficiently low, thus throughput sufficiently high

  → Optics reflectivity must be conserved

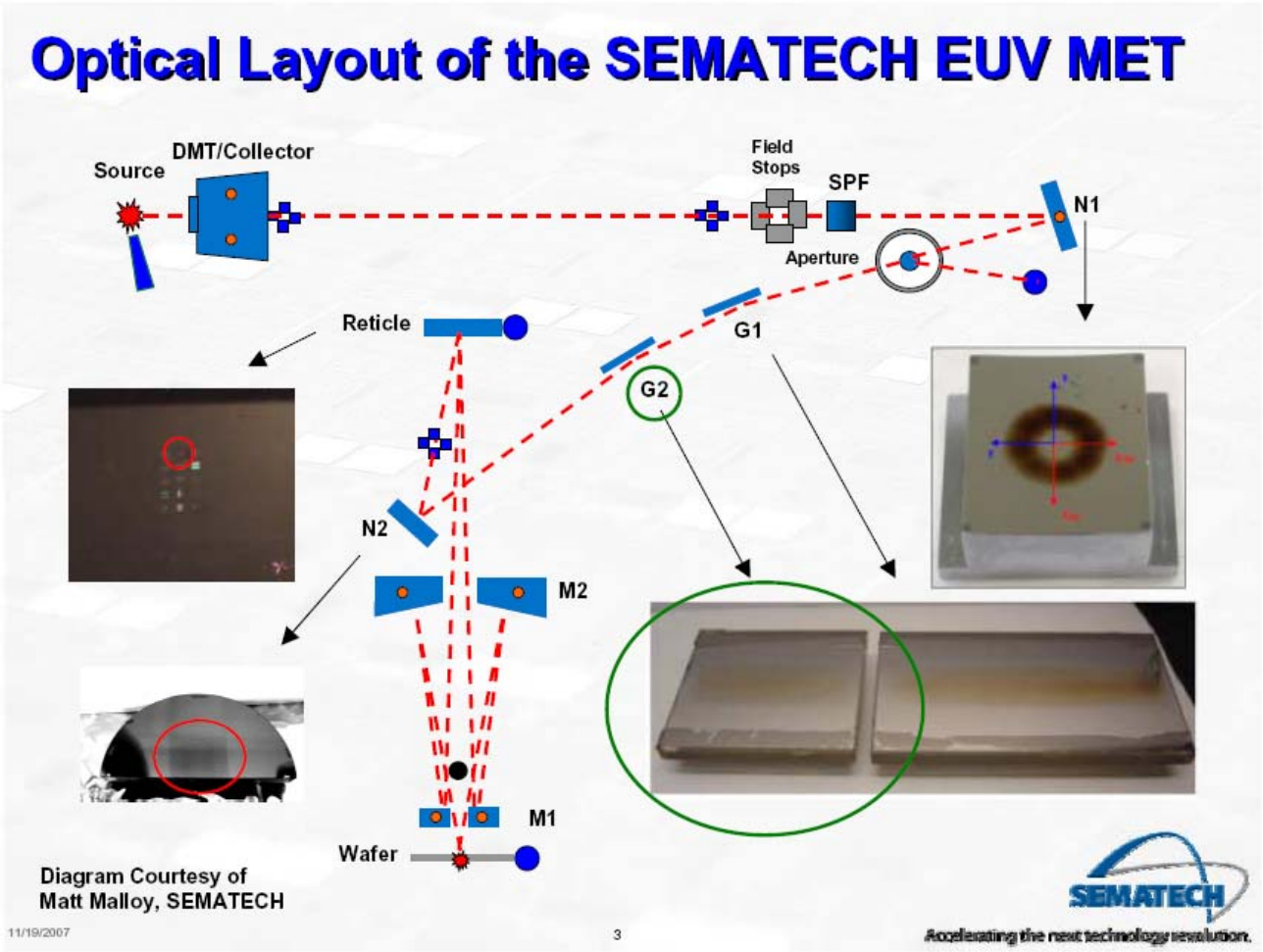
- Optics lifetime requirement:
  - 5 years
  - 30,000 hours under EUV radiation exposure
  - Reflectivity loss = 1 %, non-recoverable

- ΔR = 1 %: ~ 1 nm contamination build-up

EUV Focus Areas 2003-2008,
from EUV Lithography Symposia

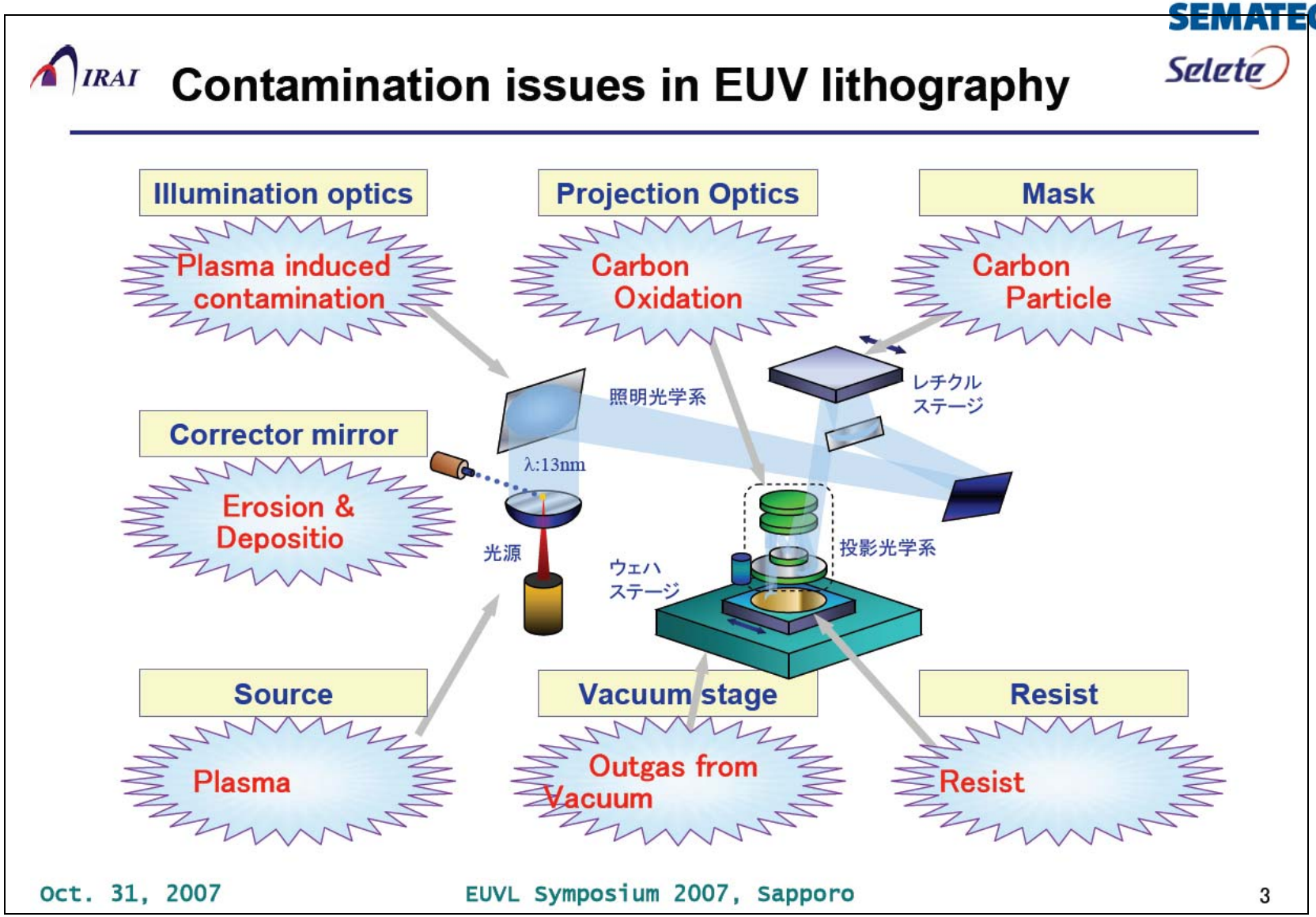
2003	2004	2005	2006	2007	2008
1. Source power and lifetime including condenser optics lifetime	1. Availability of defect-free mask	1. Resist resolution, sensitivity & LER met simultaneously	1. Reliable high power source & collector module	1. Reliable high power source & collector module	1. Long-term source operation with 100 W at IF and 5MJ/day
2. Availability of defect-free mask	2. Lifetime of source components & collector optics	2. Collector lifetime	2. Resist resolution, sensitivity, & LER met simultaneously	2. Resist resolution, sensitivity, & LER met simultaneously	2. defect-free masks through lifecycle & inspection/review infrastructure
3. Reticle protection during storage, handling, and use	3. Resist resolution, sensitivity, & LER met simultaneously	3. Availability of defect-free mask	3. Availability of defect-free mask	3. Availability of defect-free mask	3. Resist resolution, sensitivity, & LER met simultaneously
4. Projection and illuminator optics lifetime	▪ Reticle protection during storage, handling and use	4. Source power	4. Reticle protection during storage, handling, and use	4. Reticle protection during storage, handling, and use	• Reticle protection during storage, handling, and use
5. Resist resolution, sensitivity, and LER	▪ Source power	▪ Reticle protection during storage, handling, and use	5. Projection and illuminator optics quality & lifetime	5. Projection and illuminator optics quality & lifetime	• Projection / illuminator optics and mask lifetime
6. Optics quality for 32 nm half-pitch node	▪ Projection and illuminator optics lifetime	▪ Projection and illuminator optics quality & lifetime			

Contamination of eMET Illum. Optics



Wüest, "Analysis of Optics and Mask Contamination in SEMATECH EUV Micro-exposure Tools," IEUVI Optics Contamination TWG, Nov 2007

Why does the problem arise?



Nishiyama et al., “Atomic Hydrogen Cleaning for EUV Optics Contamination," EUVL Symposium 2007

Types of Contamination

Mo/Si multilayers capped by TiO_2

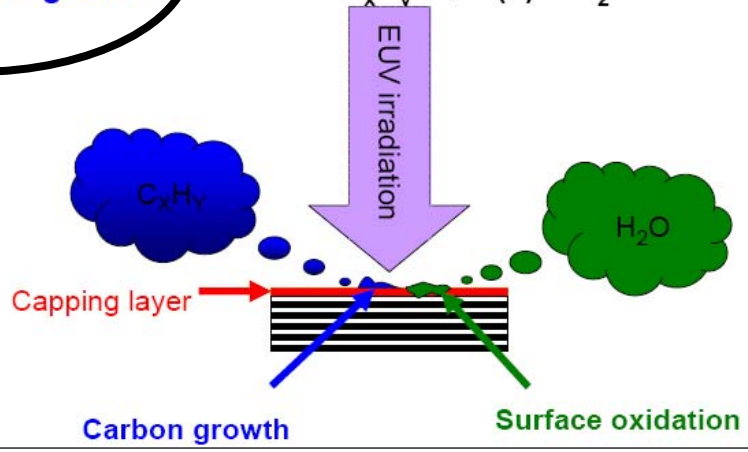
Degradation of EUV multilayers

Damage caused by two mechanisms:

- potentially irreversible **surface oxidation**: $Si + H_2O \rightarrow SiO_2 + H_2$
- demonstrably reversible **surface carbon growth**: $C_xH_y \rightarrow C(s) + H_2 + CH + \ldots$

Main impacts of contamination:

- Drop of peak reflectivity
- Degradation of reflectivity uniformity



EUVL Symposium, 15 – 18 October 2006

Fraunhofer Institut Angewandte Optik und Feinmechanik

6

Yulin et al., "Mo/Si Multilayers capped by TiO_2," EUVL Symposium 2006

How do we solve/tackle the problem? - Overall Strategy

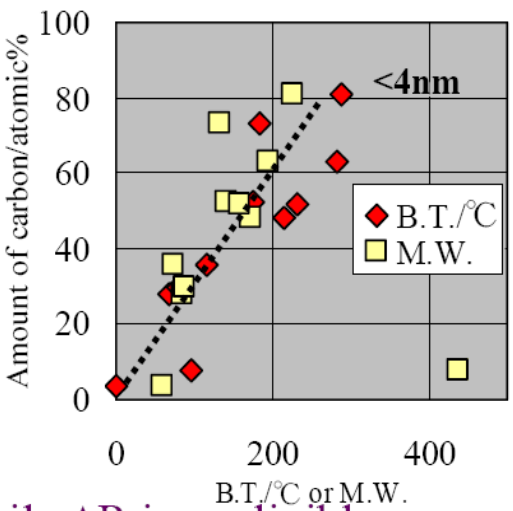
- Make tool as clean as possible – vacuum quality
  - Identify contaminants and their origins
- Understand contamination mechanisms (to find parameter space that prolongs optics lifetime)
  - Perform experiments
  - Perform modeling to predict contamination rates
- Apply mitigation strategies:
  - Use capping layers
  - Protect mirrors with gas curtains
  - Create local environments to achieve equilibrium (contamination and removal)
- Clean mirrors

Tool: BP and MW of contaminants

Dependence on Organic Gas Species

Amount of deposited carbon was measured by XPS
Condition: 1E-5Pa organic gas pressure, 180J/mm^2 EUV dose

Organic gas	B.T./℃	M.W.
Buthane	-1	58
Buthanol	117	74
Methyl propionate	79	88
Hexane	69	86
Perfluoro octane	97	438
Decane	174	142
Decanol	231	158
Methyl nonanoate	214	172
Diethyl benzene	183	134
Dimethyl phtalate	283.7	194
Hexadecane	287	226



- ✓ XPS can revealed the difference while ΔR is negligible.
- ✓ Organic gases with higher boiling temperature or heavier molecular weight show larger carbon deposition rates.

Nikon Canon

2006 International Symposium on Extreme Ultraviolet Lithography 8

Aoki et al., "Carbon Deposition on Si-capped Multilayer Mirrors by Extreme Ultraviolet Ray Irradiation," EUVL Symposium 2006

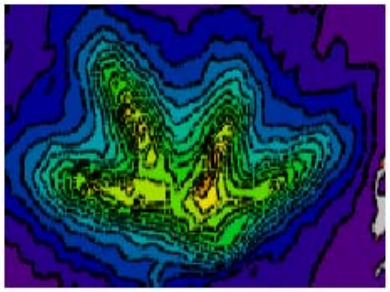
Radiation: Intensity

Lithography Optics Division

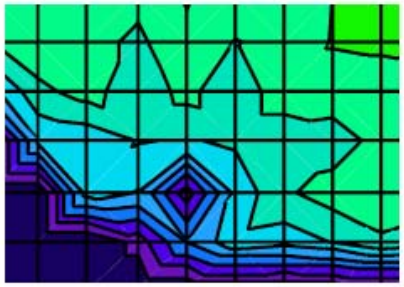
CARL ZEISS SMT

Amount of C-growth on mirrors depends on EUV intensity

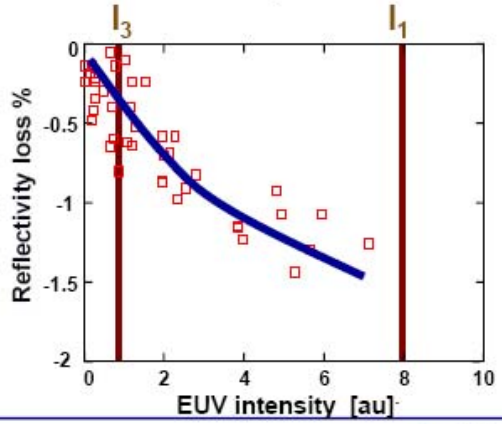
Illumination profile



reflectivity map



Local reflectivity loss vs EUV power



- the first mirrors in the illuminator see the highest EUV intensity and thus the highest carbon growth rate
- Intensity at the POB mirrors is substantially lower

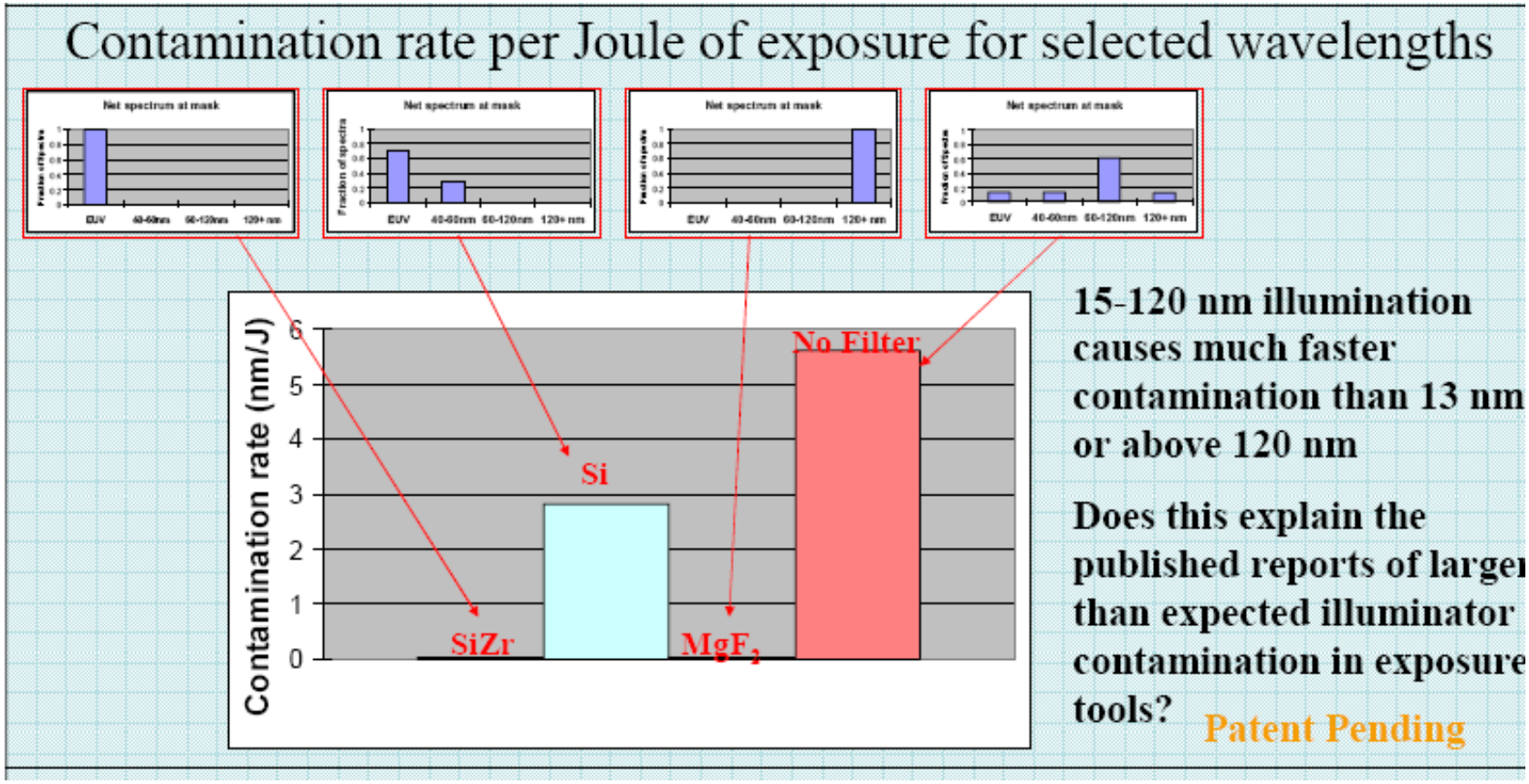
T. Stein, IEUVI Optics Contamination/Lifetime TWG, Barcelona, 19.10.2006

Enabling the Nano-Age World®

Page 8

Stein, "EUVL optics lifetime and contamination European update," IEUVI Optics Contamination TWG, October 2006

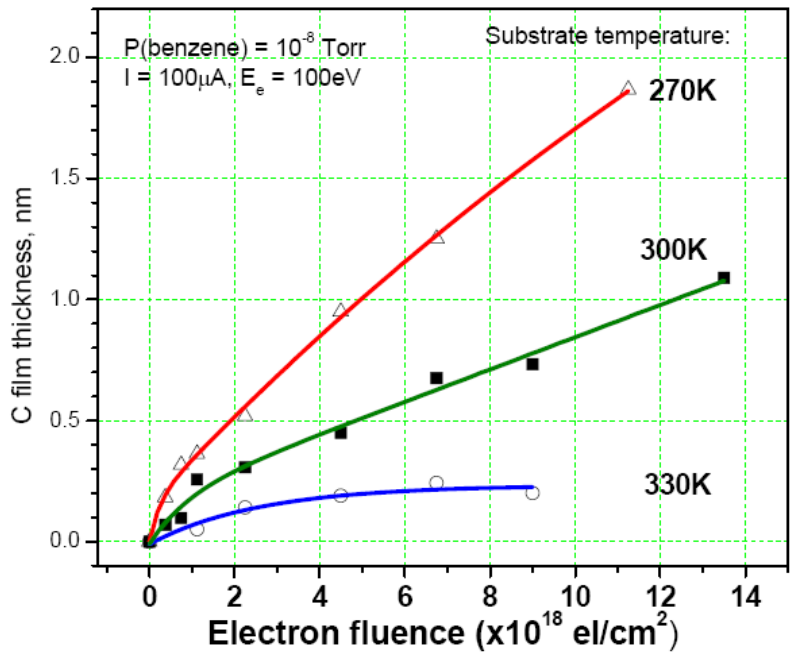
Radiation: Wavelength



Denbeaux et al., “EUV Optics Contamination from Resist and Tool Components," EUVL Symposium 2007

Mirror: Temperature

C growth on TiO_2 under electron irradiation in benzene vapor: effects of substrate temperature

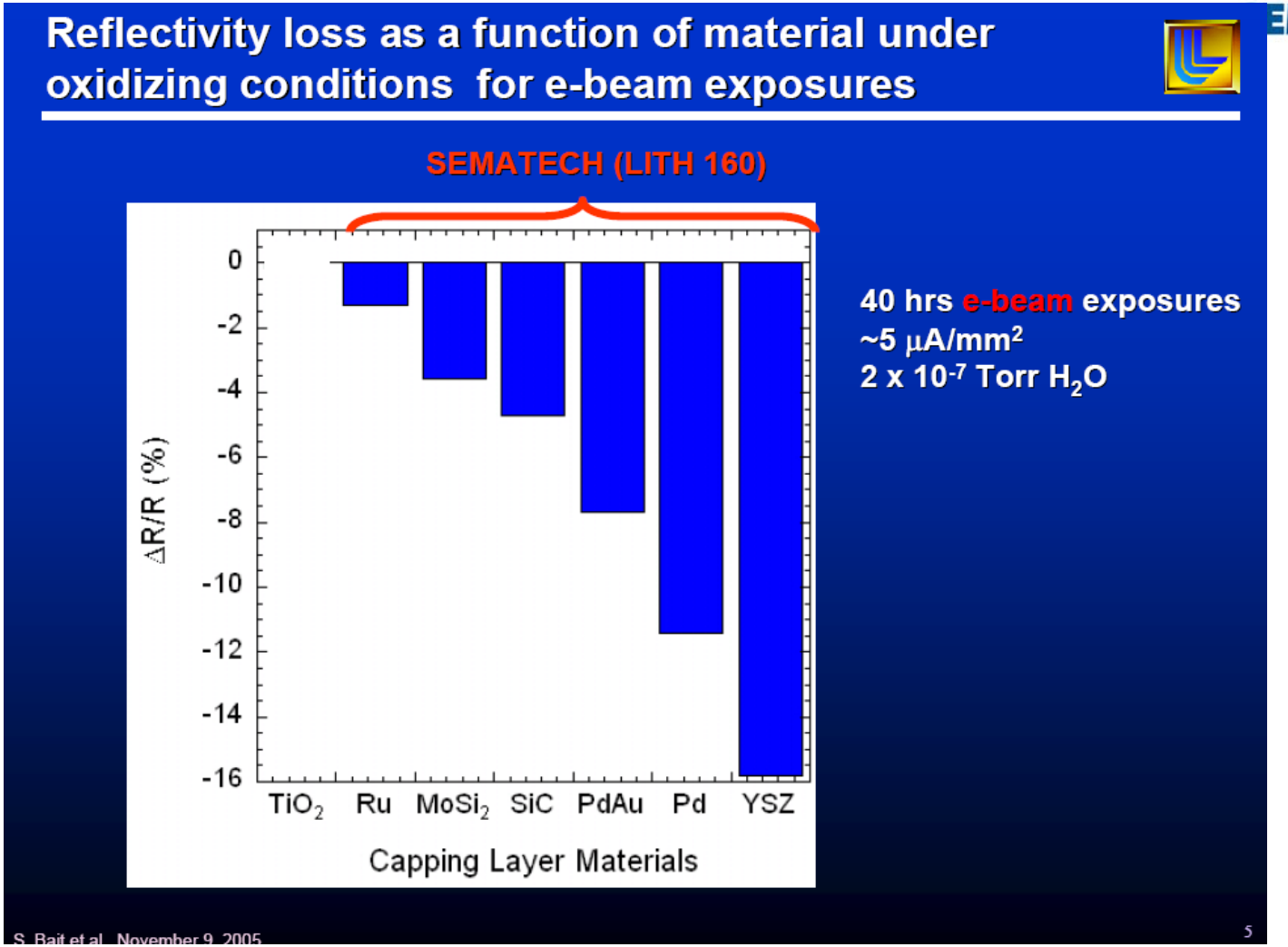


Surface concentration, lifetime

9

Yakshinskiy et al., "Carbon accumulation on model MLM cap layer: Interaction of benzene vapor with TiO2 surface," EUVL Symposium 2008

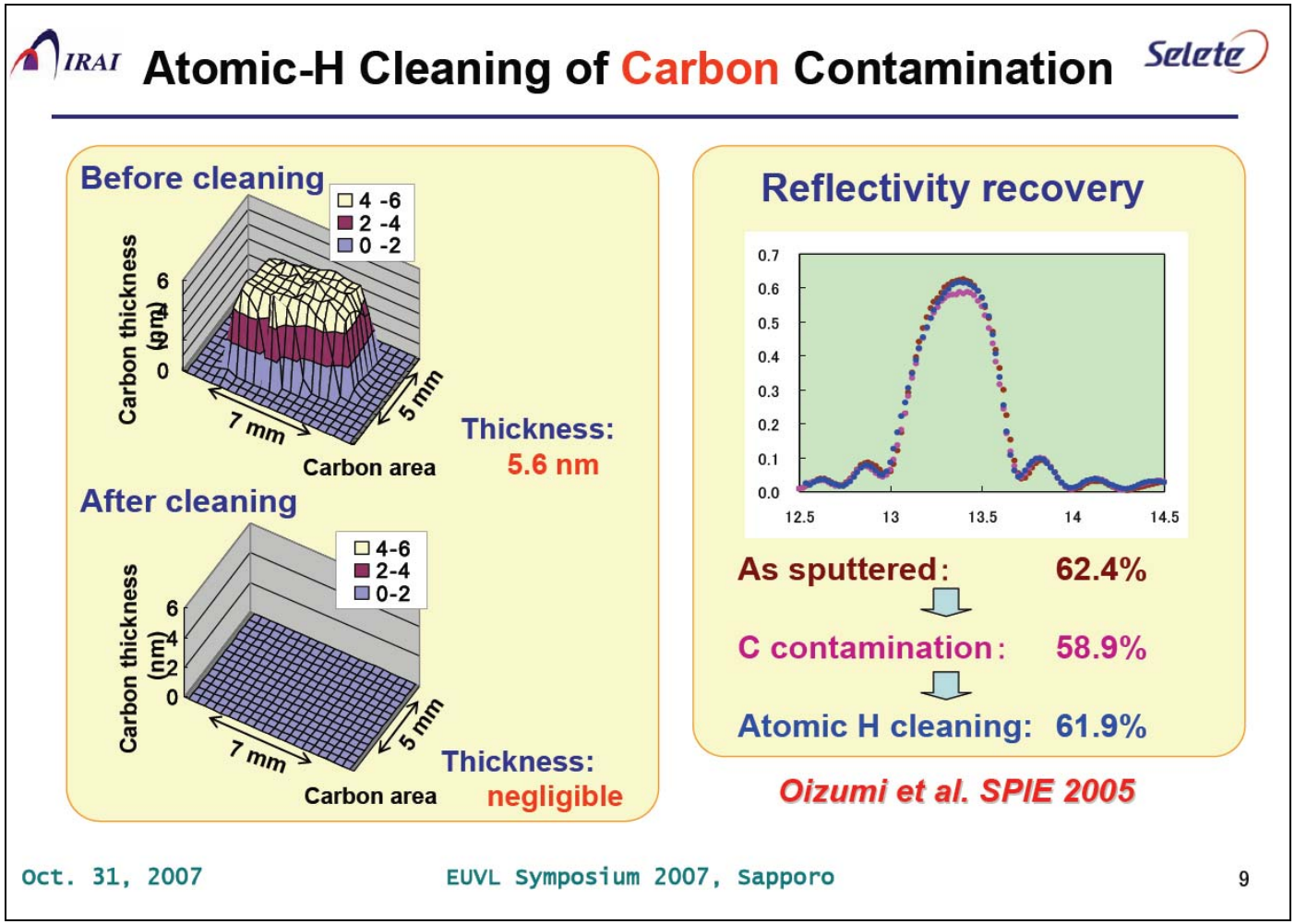
Comparison of Capping Layers



- Others also suggested, foremost metal oxides: RuO_2, ZrO_2, HfO_2, V_2O_5, etc

Bajt, "Benchmarking test results on SEMATESCH ML1 Ru-capped optics test sample," IEUVI Optics Contamination TWG, November 2005

Cleaning of Carbon-contaminated EUV Mirrors



Nishiyama et al., "Atomic Hydrogen Cleaning for EUV Optics Contamination," EUVL Symposium 2007

Projection Optics Critical Issues

(IEUVI Optics Contamination TWG, Oct 2008)

Ranking (10/08)	Critical Issue	Gap Analysis
1	Carbon deposition (outgassing from vacuum components, wires, and other materials)	
2	Optics cleaning (in situ)	
3	Carbon deposition (resist outgassing)	
4	Oxidation (residual water)	
5	Accelerated lifetime testing/understanding scaling laws	
6	Availability of quantitative contamination model	
7	Other	
8	Contamination due to EUV source	
9	Out-of-band radiation	

Survey: 18 Responses

For HVM Implementation of EUVL

Manufacturable solutions exist, and are being optimized	
Manufacturable solutions are known but needing further development	
Manufacturable solutions are not known.	

Summary

- EUVL is one of the next-generation lithography options
- EUVL is feasible – Alpha Tools, Pre-production tools
- EUVL still faces focus areas:
  - Long-term source operation
  - Defect-free masks
  - Resist LER, sensitivity and resolution
  - Reticle protection
  - Optics lifetime
- EUV optics contamination not ranked as top focus area – nonetheless, cannot be neglected

Acknowledgements

- Bryan Rice, Intel/ SEMATECH
- Stefan Wurm, GlobalFoundries/ SEMATECH
- Frank Goodwin, SEMATECH