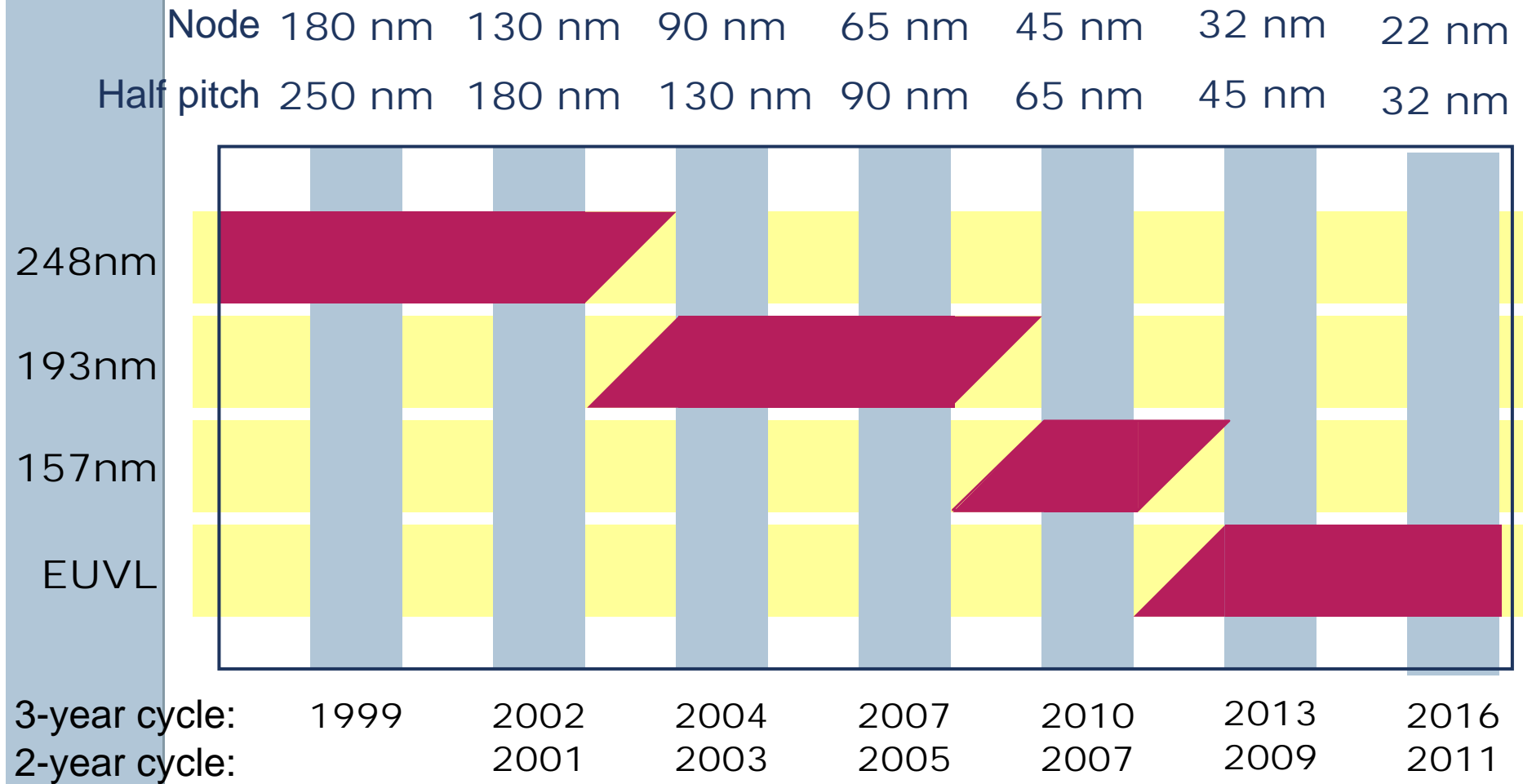




Lithography Roadmap

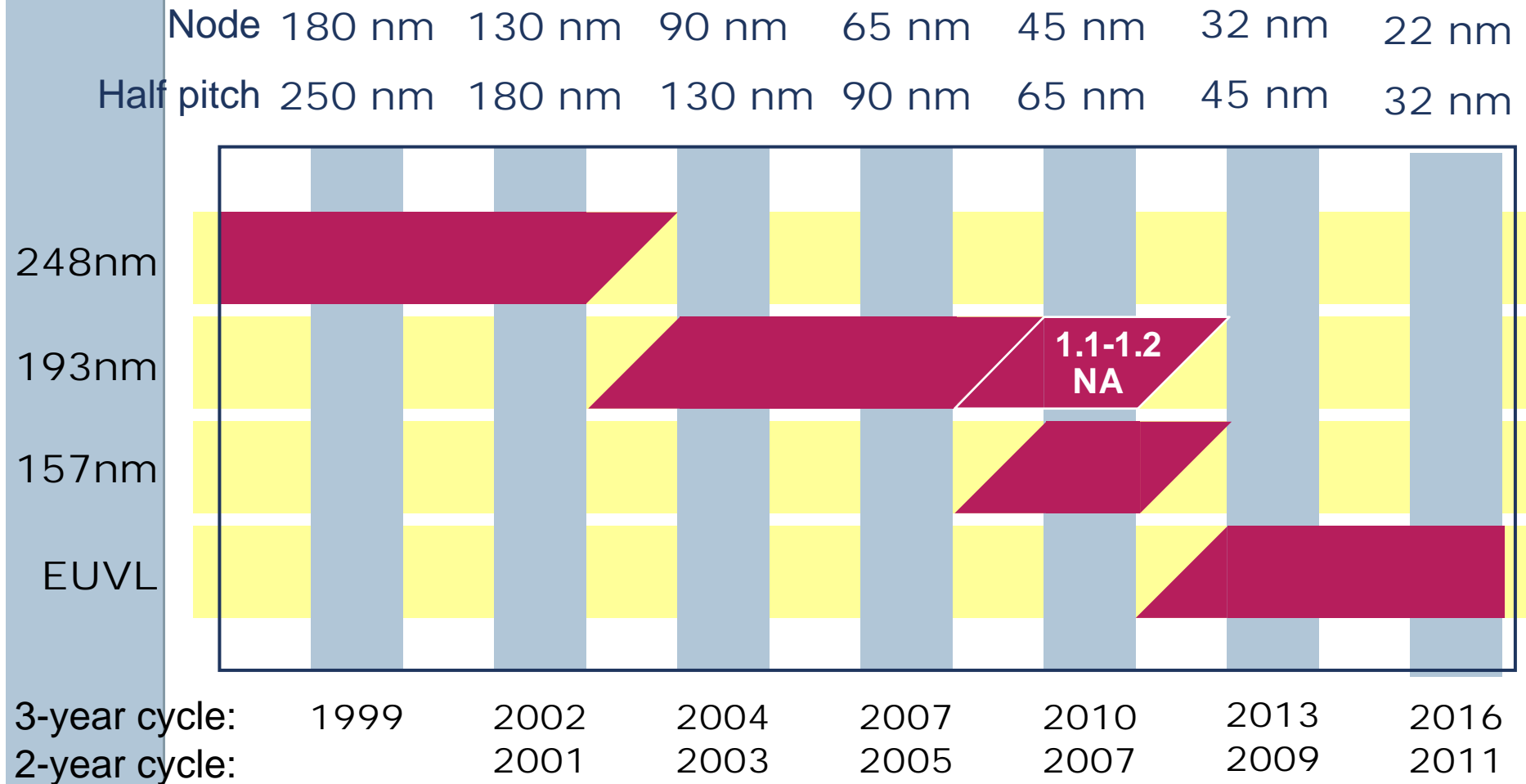
without immersion lithography





Lithography Roadmap

with immersion lithography

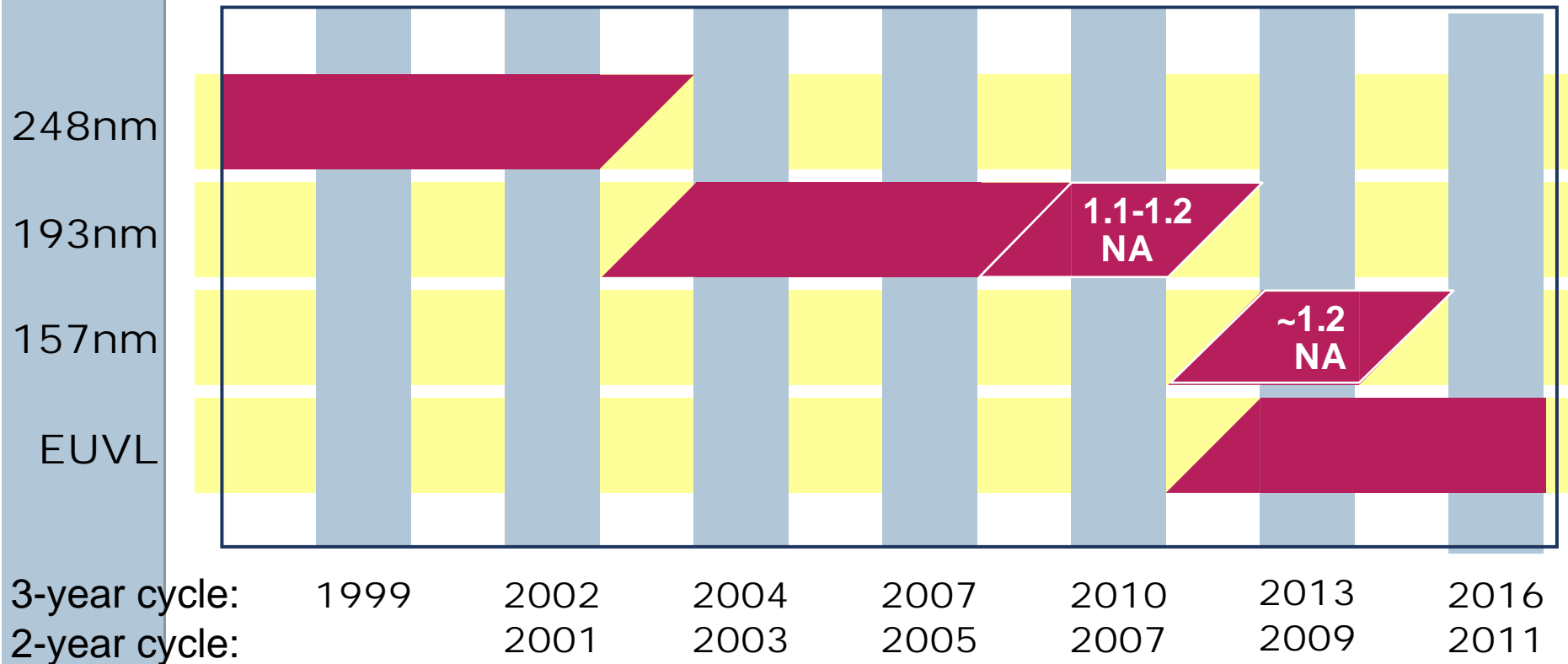




Lithography Roadmap

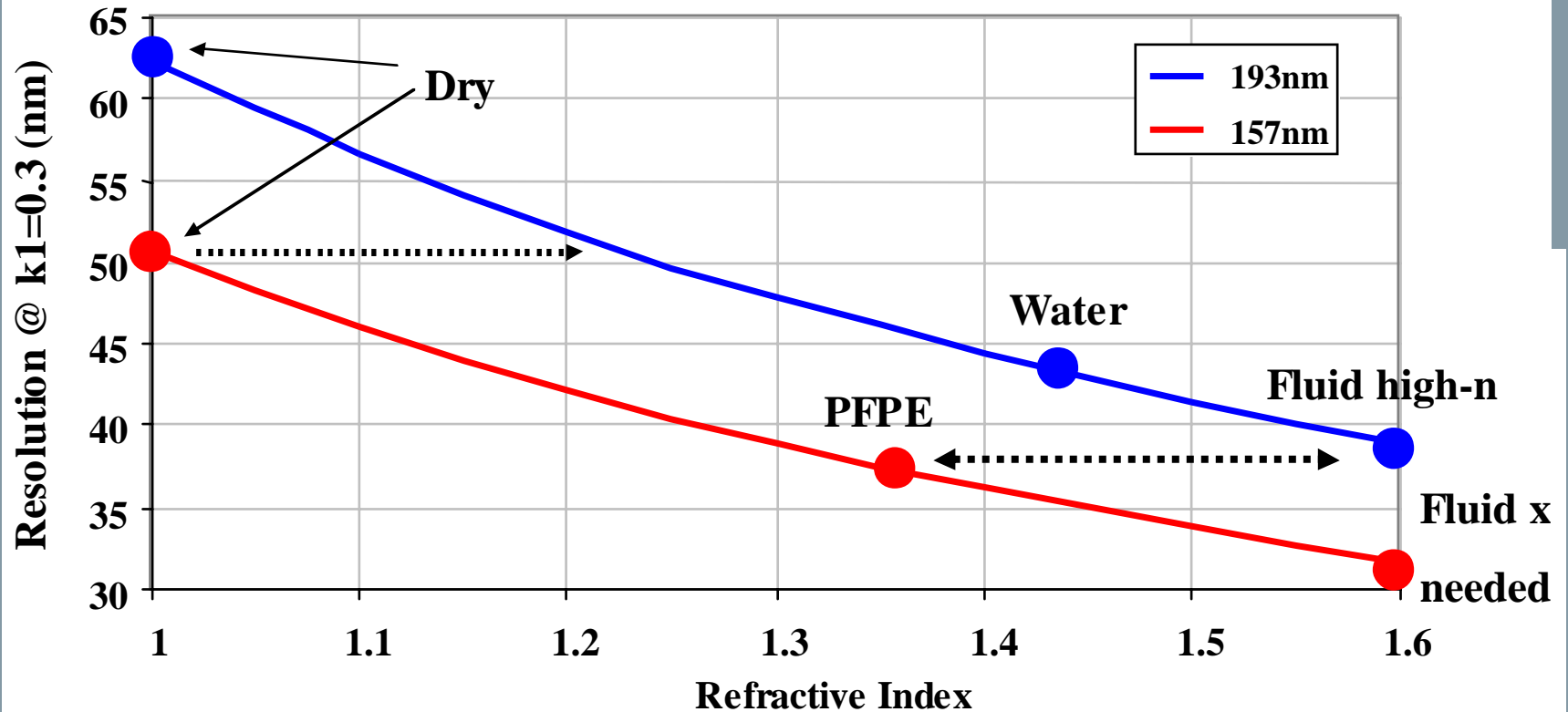
with immersion lithography

Node	180 nm	130 nm	90 nm	65 nm	45 nm	32 nm	22 nm
Half pitch	250 nm	180 nm	130 nm	90 nm	65 nm	45 nm	32 nm



157nm has no window

Max Resolution with High Index Fluids with $\sin\theta=0.93$



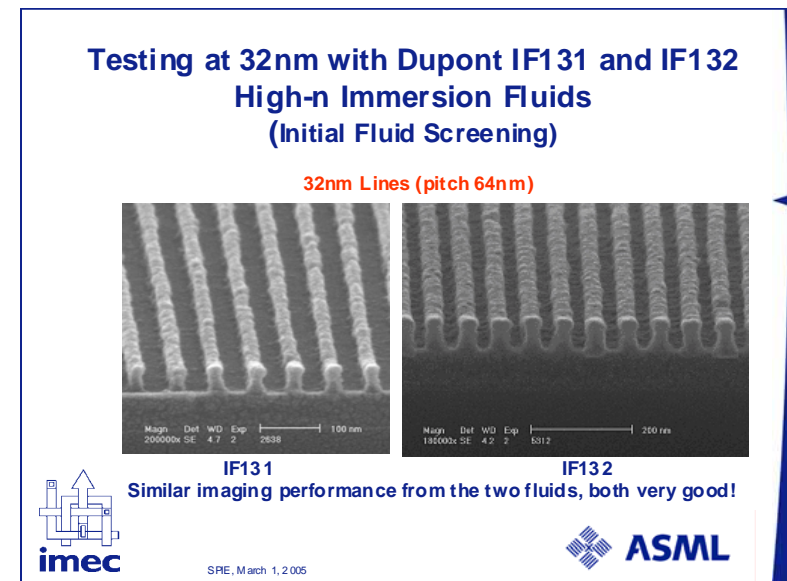
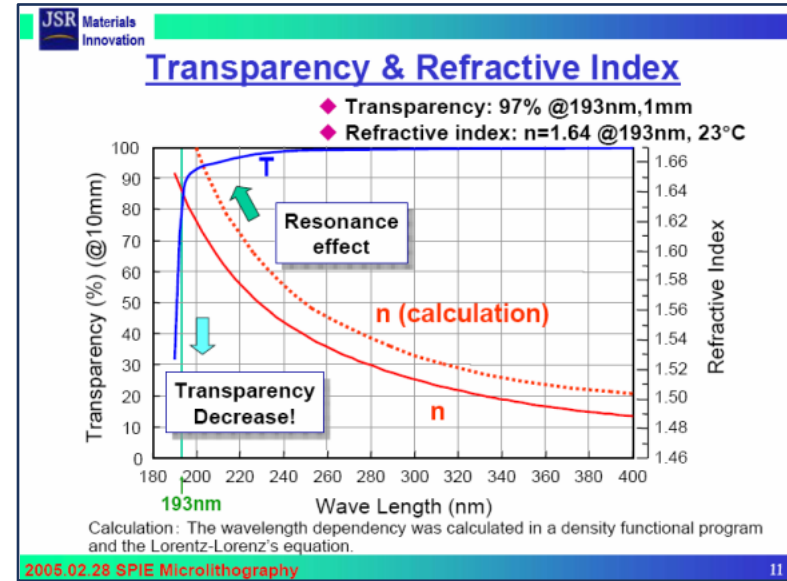
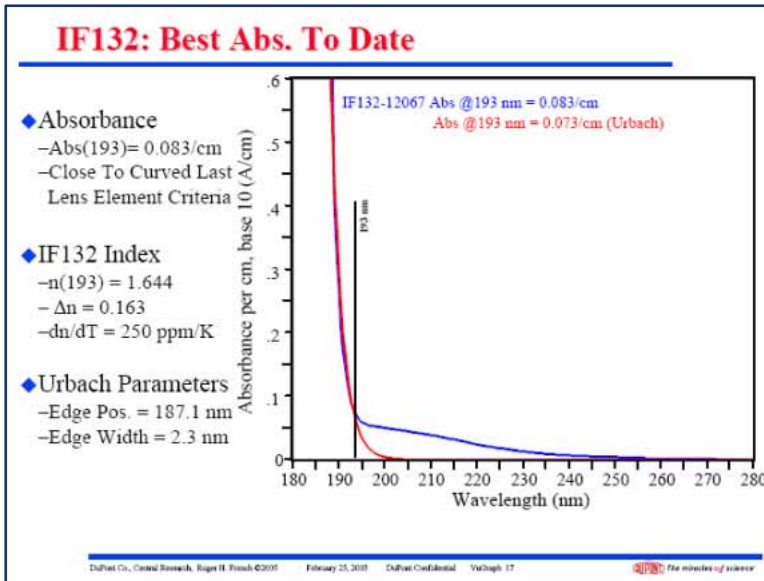
- ArF water immersion replaces F_2 dry
- ArF fluid high-n immersion replaces F_2 -PFPE

SPIE 2005 Fluid highlights

Fluids Refractive index and Absorbance @ 193nm

Immersion Fluids	Refractive index	dn/dT $^{\circ}C^{-1}$	Absorbance cm^{-1}
Water	1.4366	-1.00E-4	0.040
IF 1	1.4450	-1.10E-4	0.317
IF 2	1.4556	+7.90E-5	5.397
IF 3	1.5010	-2.50E-4	0.940
IF 4	1.5154	-	1.939
IF 5	1.5573	-	1.144
IF 6	1.5610	-	>6
IF 7	1.5755	-4.30E-4	2.015
IF 8	1.6441	-7.30E-4	>6

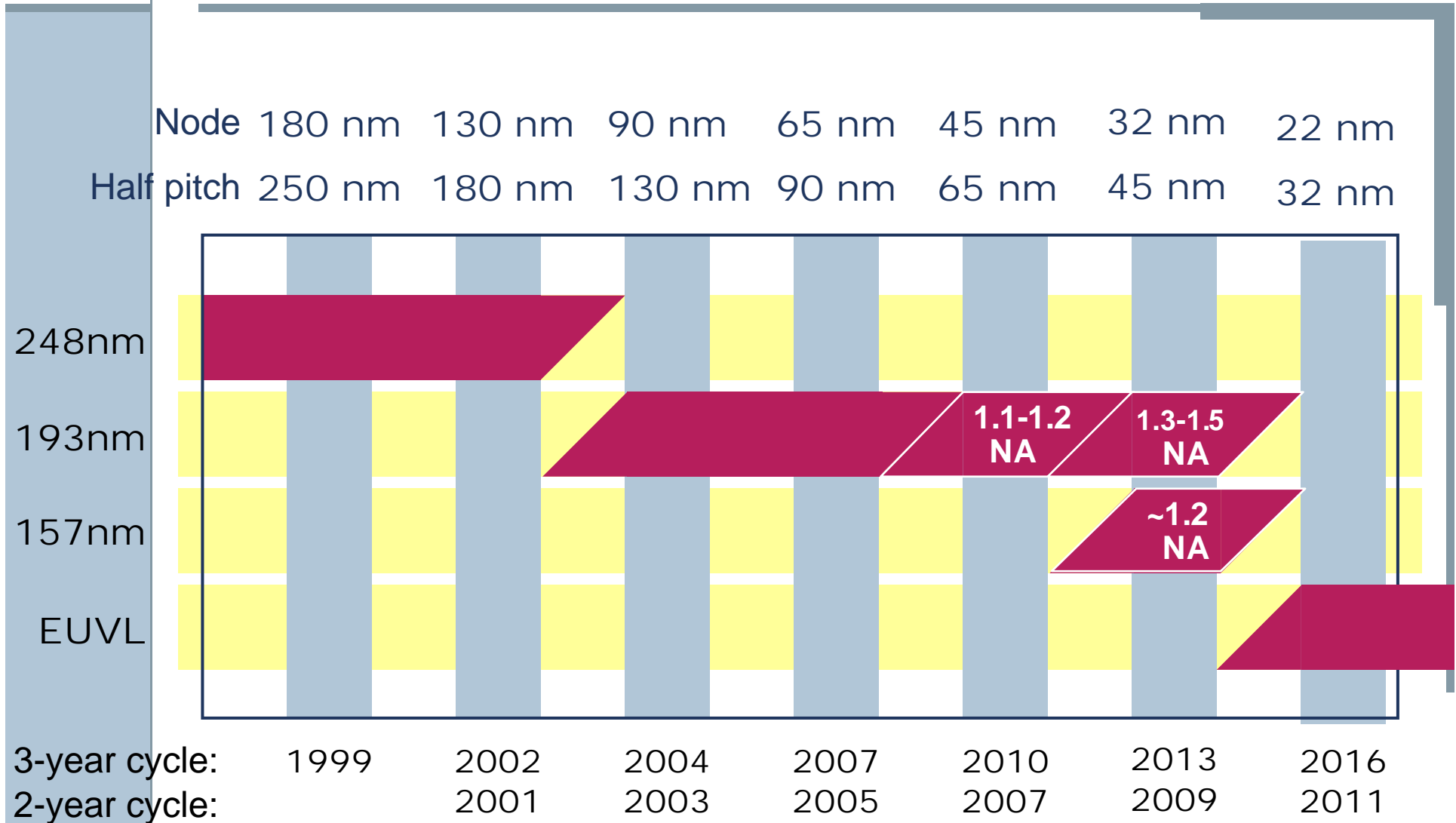
March 3, 2005
 E. Bosthoff
 All Products & Chemicals, Inc. © 2005
 NIST
 National Institute of Standards and Technology
 AIR PRODUCTS
 Outlined by K-K dispersion relating RI and Abs. The design of high index, low abs fluids requires consideration of interatomic bonding & optical properties of materials.
 Despite this technical challenge: good candidates obtained.





Lithography Roadmap

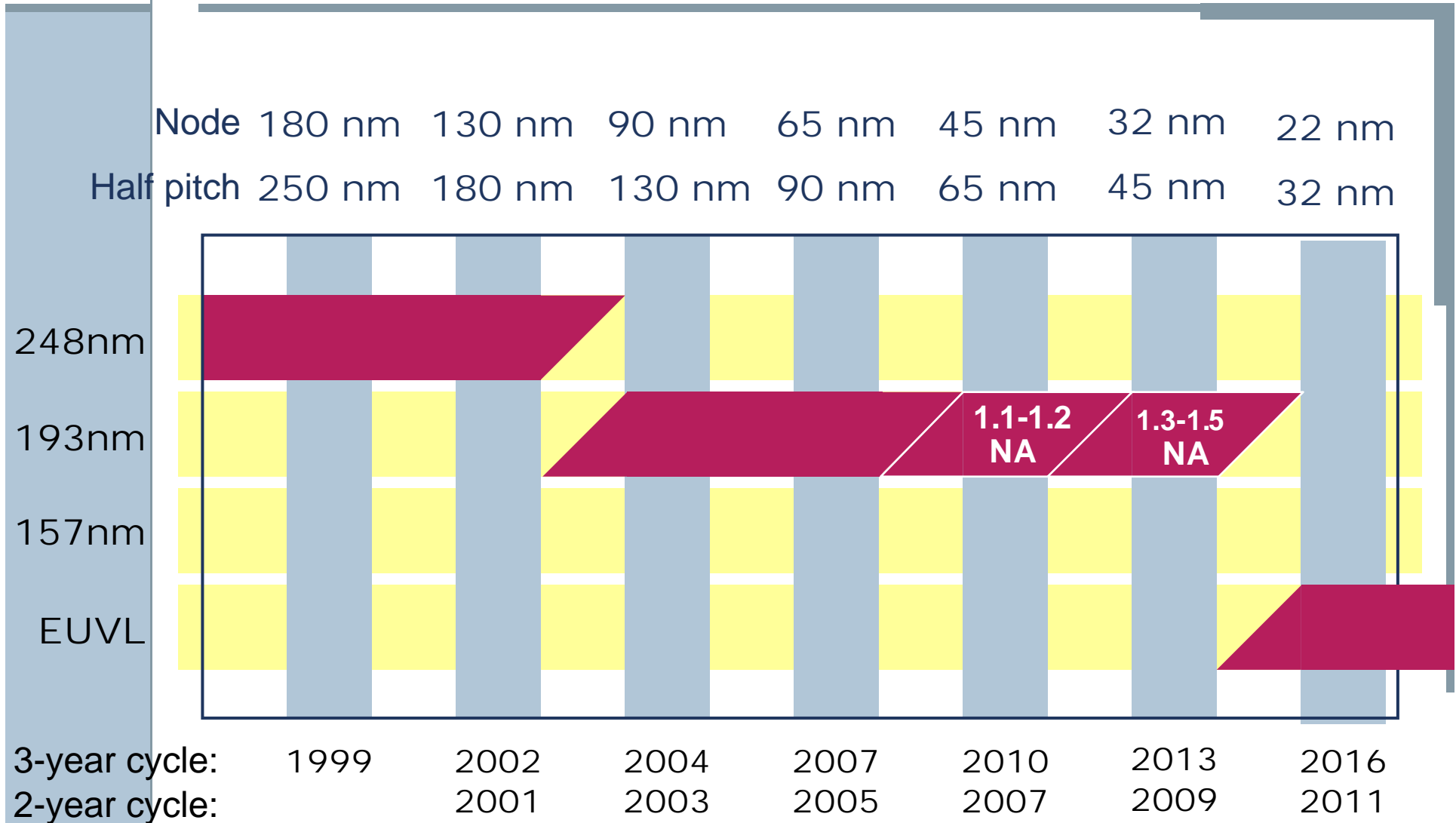
with immersion lithography





Lithography Roadmap

with immersion lithography



$$resolution = k_1 \cdot \frac{\lambda}{NA}$$

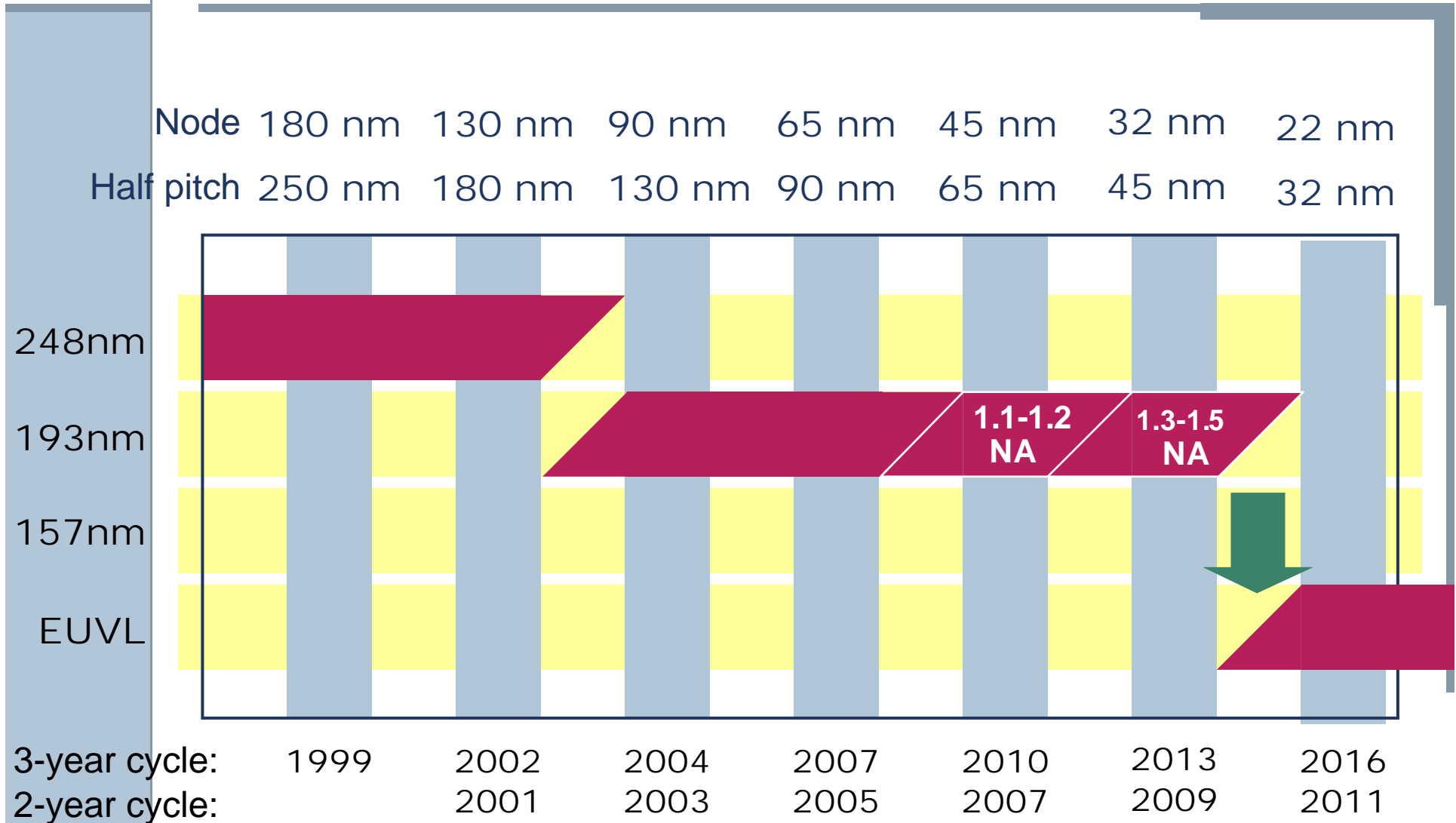
Half Pitch Technology Node [nm]

	90	65	45	32	22
0.75	0.35	0.25	0.17	0.12	0.09
0.85	0.40	0.29	0.20	0.14	0.10
0.94	0.44	0.32	0.22	0.16	0.11
1.05	0.49	0.35	0.24	0.17	0.12
1.2	0.56	0.40	0.28	0.20	0.14
1.35	0.63	0.45	0.31	0.22	0.15
1.5	0.70	0.51	0.35	0.25	0.17
1.65	0.77	0.56	0.38	0.27	0.19
1.8	0.84	0.61	0.42	0.30	0.21



Lithography Roadmap

with immersion lithography





Lord Rayleigh

Rayleigh equation

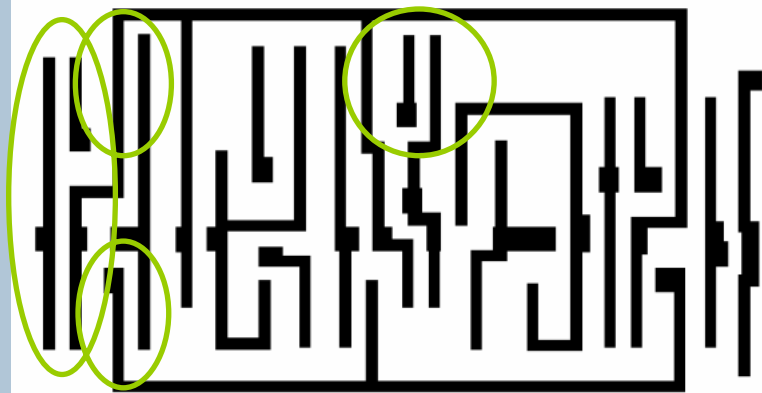
$$\textit{resolution} = k_1 \cdot \frac{\lambda}{NA}$$

k₁ scaling

→ Double exposure techniques

Double dipole imaging

Random logic



DY



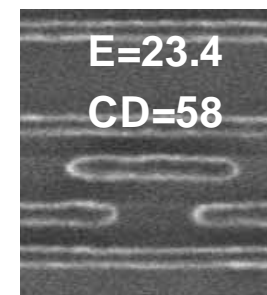
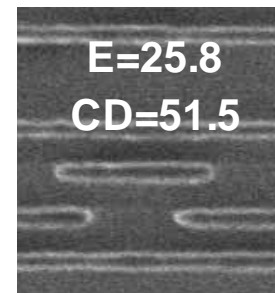
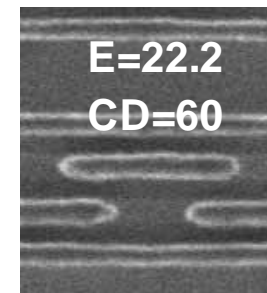
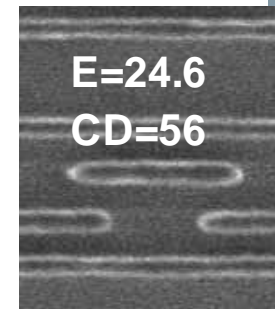
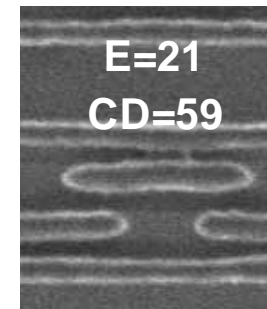
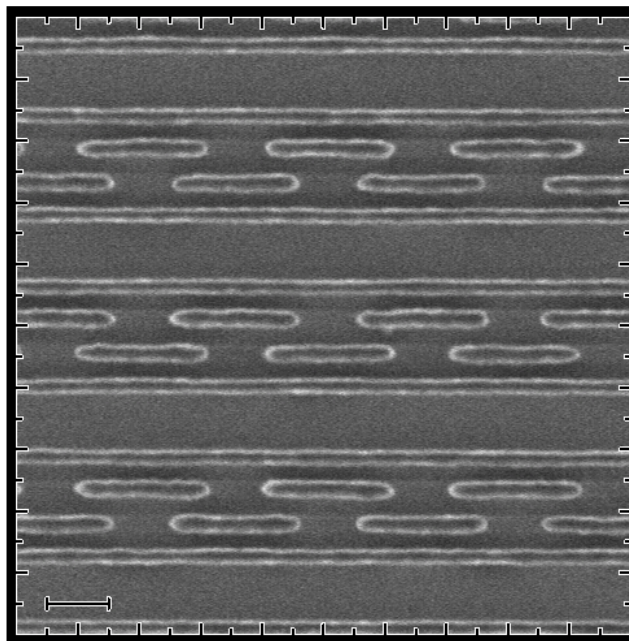
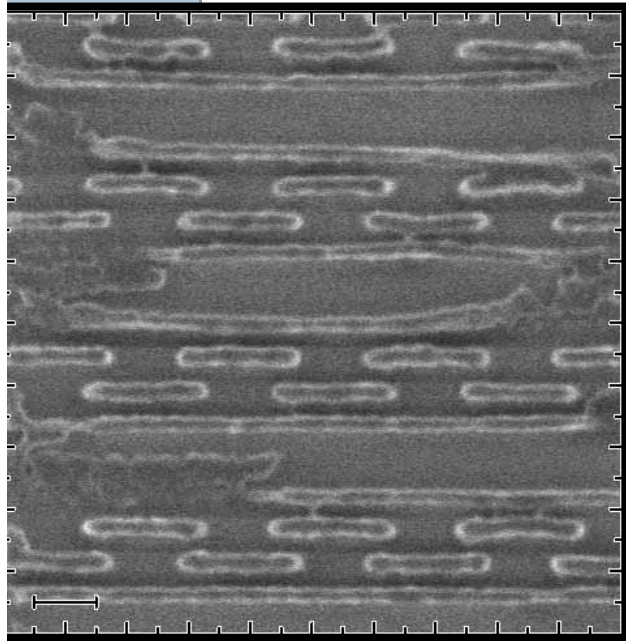
DX



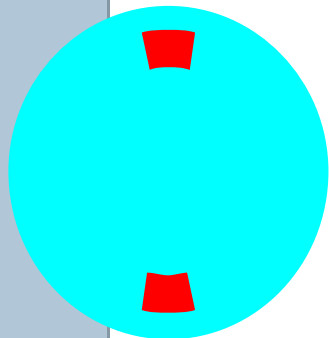
Impact of polarization on SRAM active layer print (110 nm pitch)

Unpolarized

Polarized



23 % EL

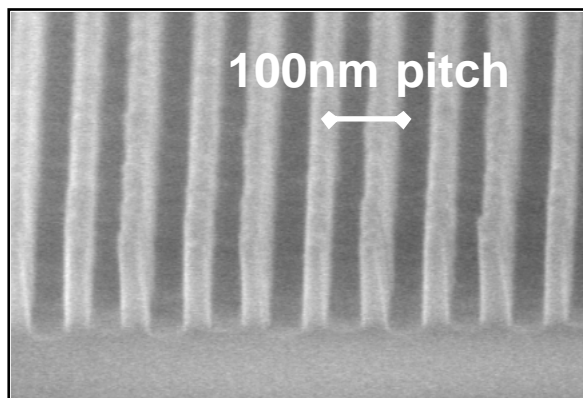
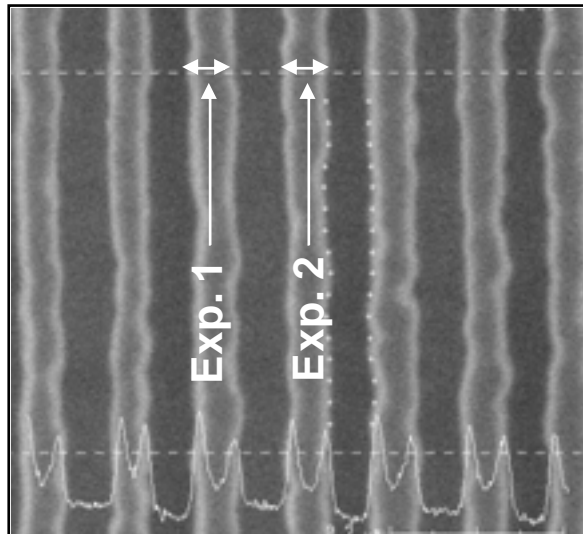


DY40 0.96/0.76

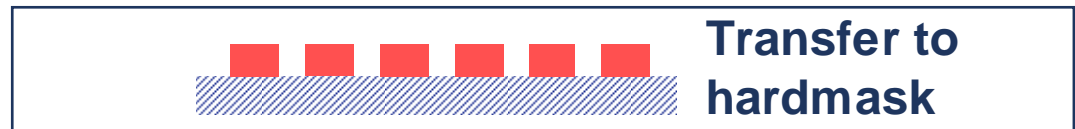
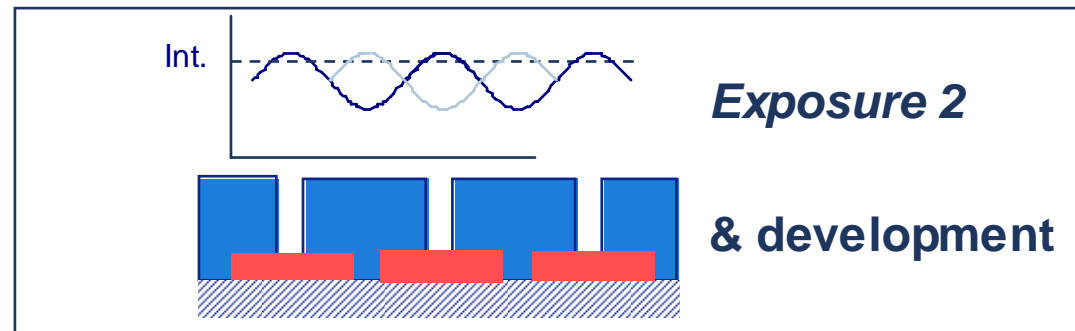
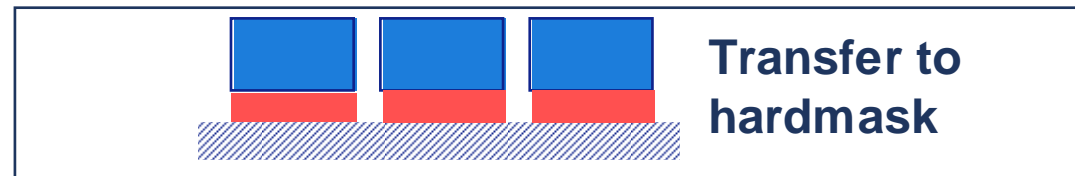
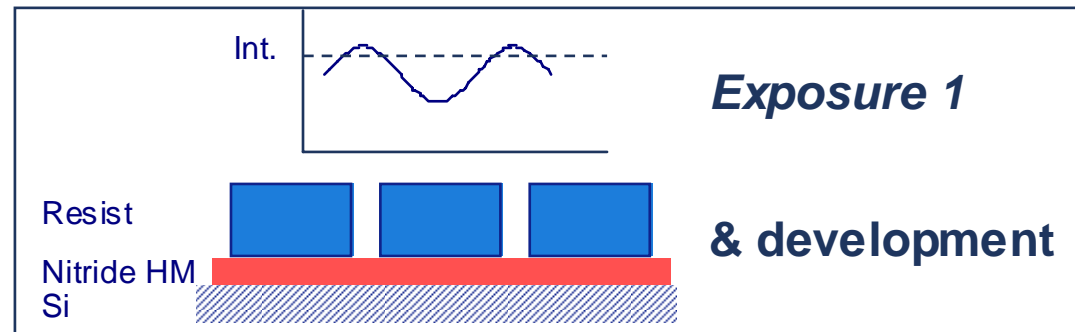
Dry
NA=0.93

Double patterning (2x litho + 2x etch)

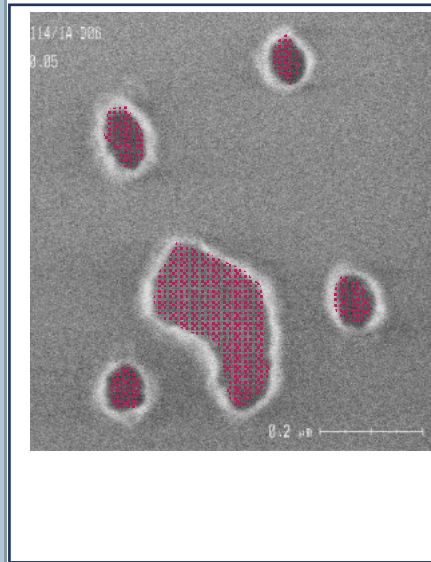
Pitch = 100nm
 CD=50nm
 $k_1=0.19$



50 nm L&S with 0.75NA

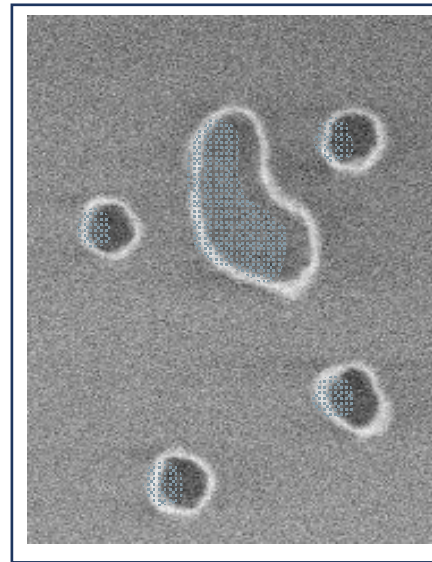


Double patterning complex pattern



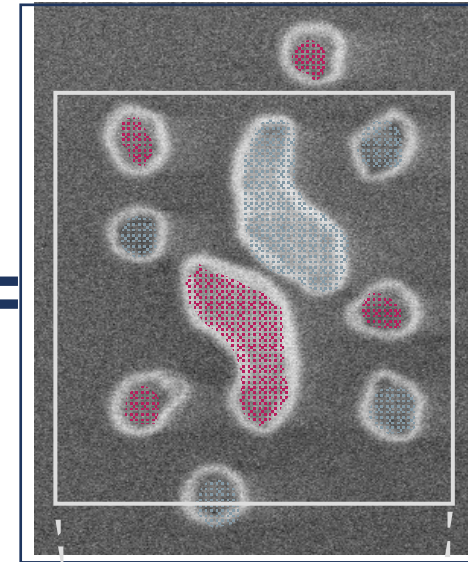
1st exposure
develop and etch

+

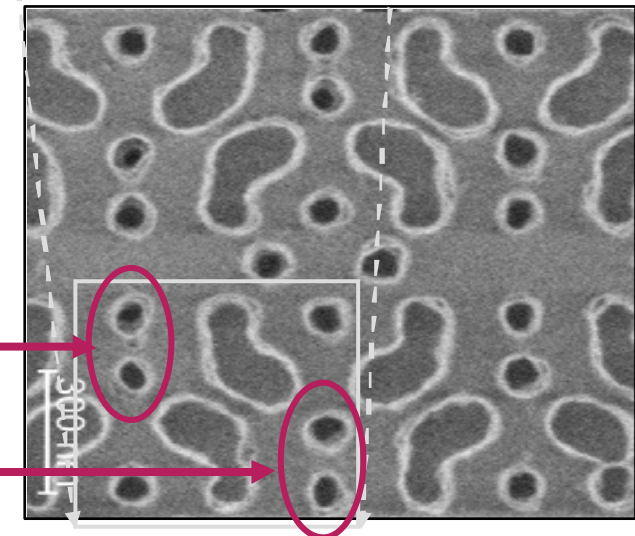


2nd exposure
develop

=



etch



150-nm pitch

NA = 0.75

193 nm

$k_1 = 0.29$

Double exposure technique

CoO considerations

- Requires 2 critical masks
- Reduces throughput (~ factor 2)
- Adds cost of hard mask and etch
- Critical overlay requirement
- Impacts cycle time (additional photo, etch, ...)



Outline

Introduction

193nm immersion lithography

EUV lithography

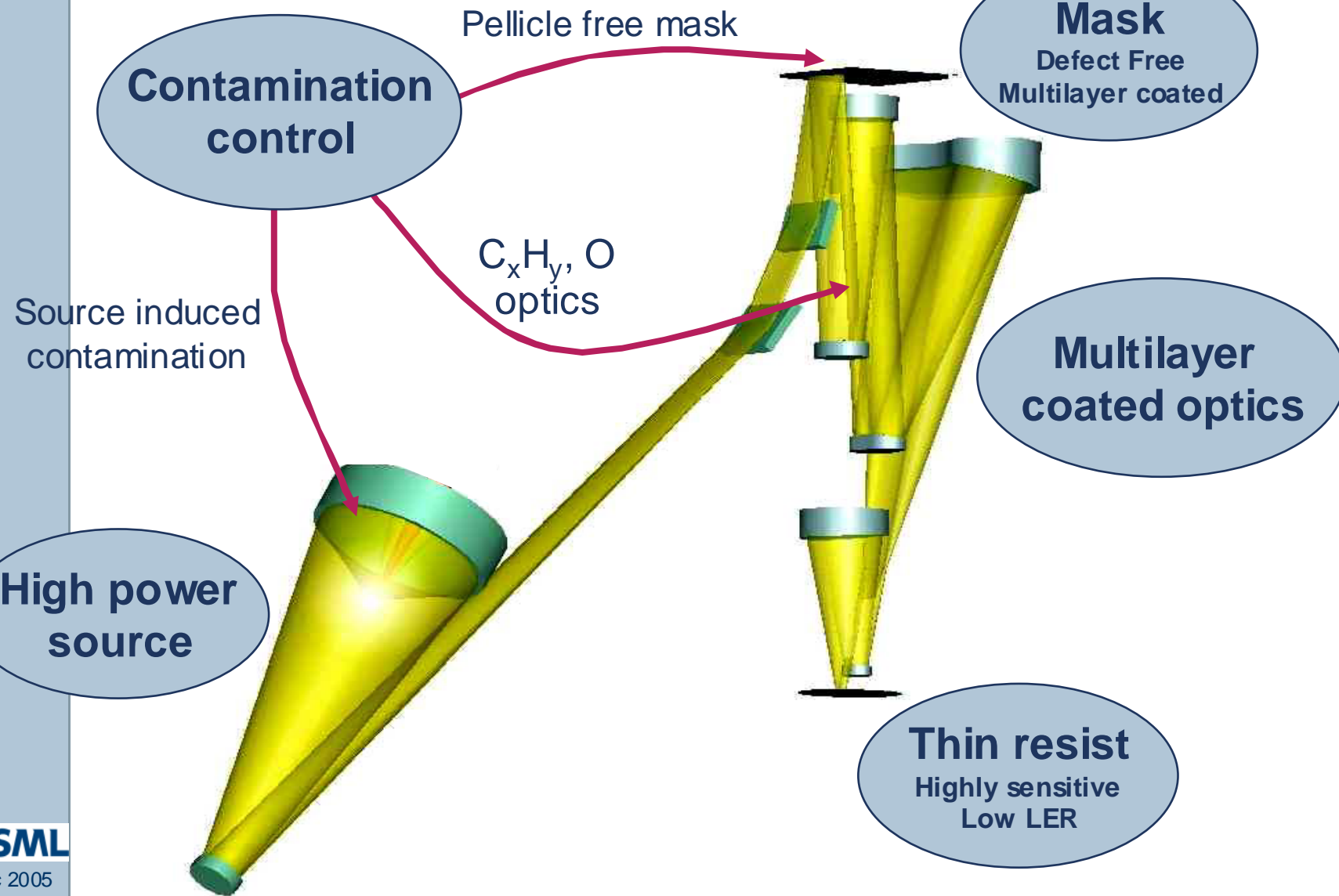
Status, Challenges

Global collaboration

Conclusions

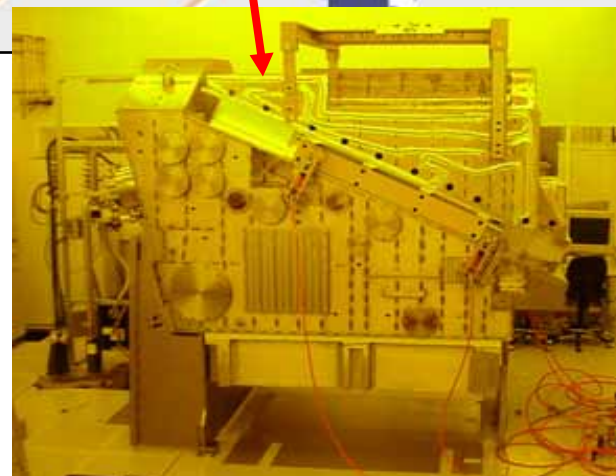
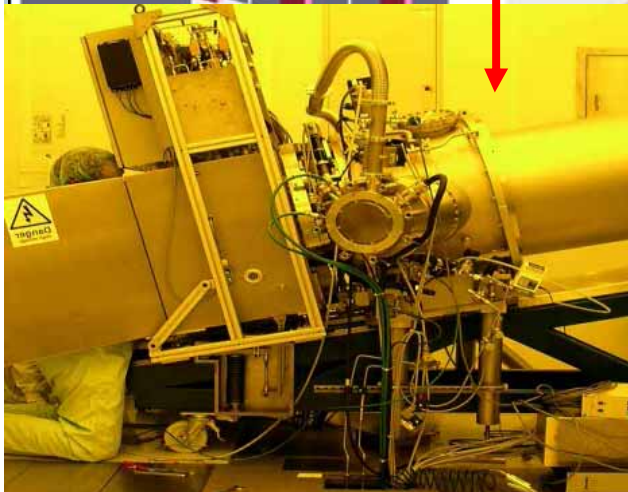
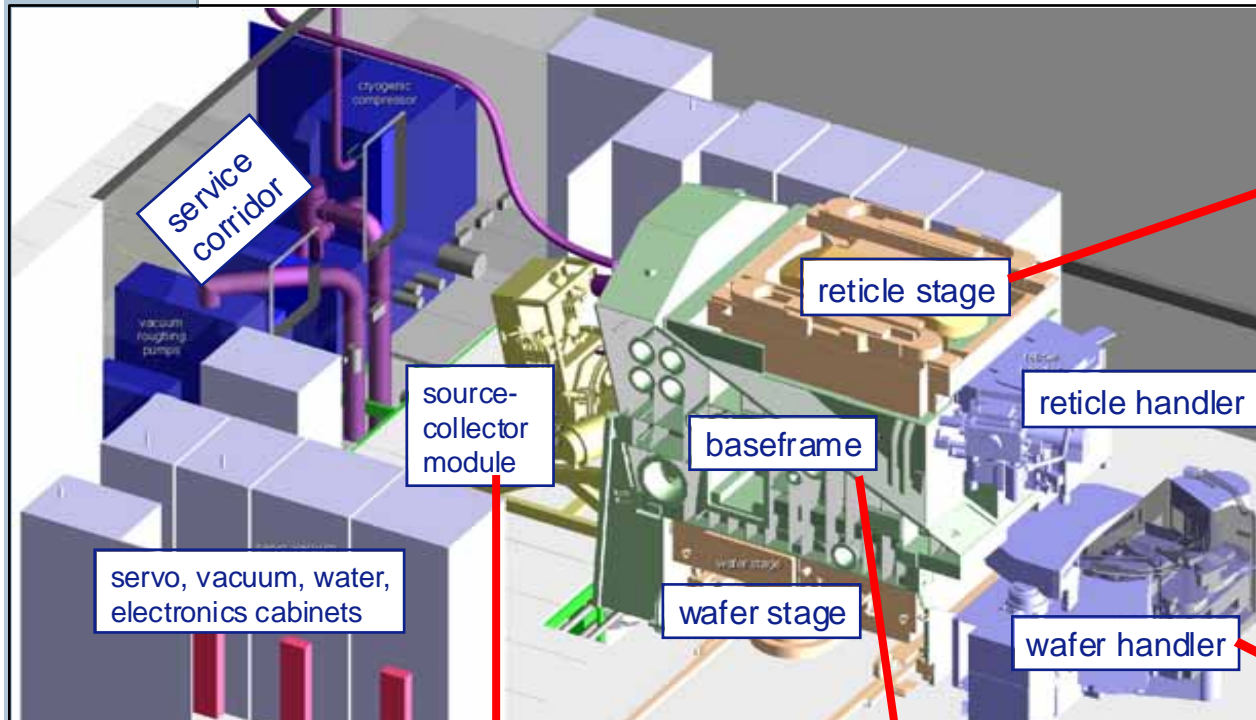
EUV lithography

Main technology challenges



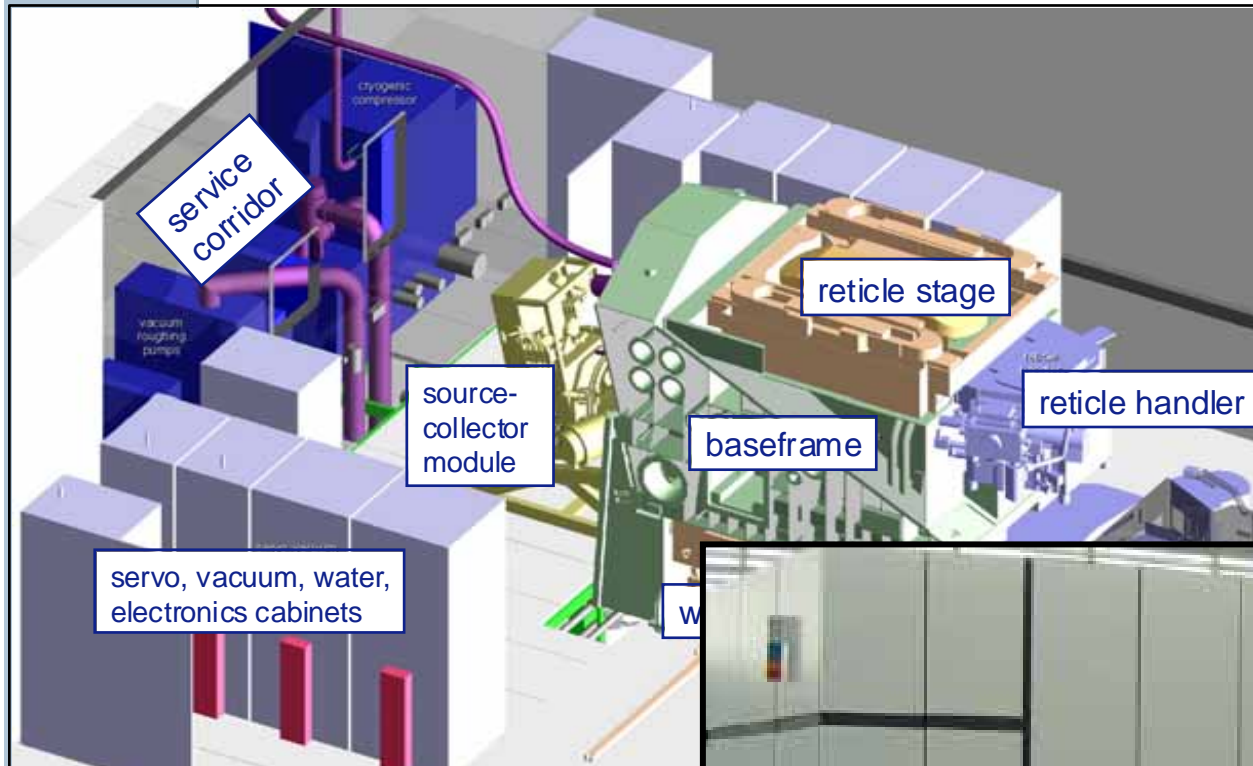


EUV tool integration progress



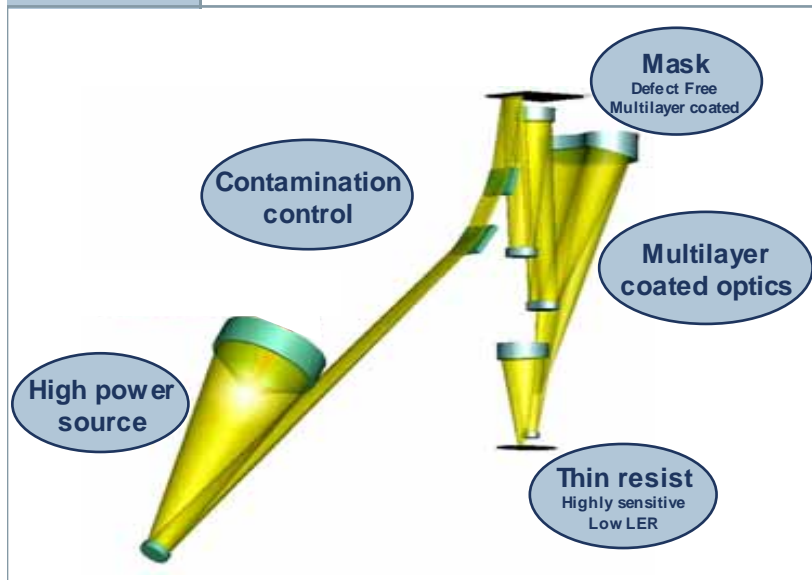
**0.25 NA
full field**

EUV tool integration progress



EUV lithography

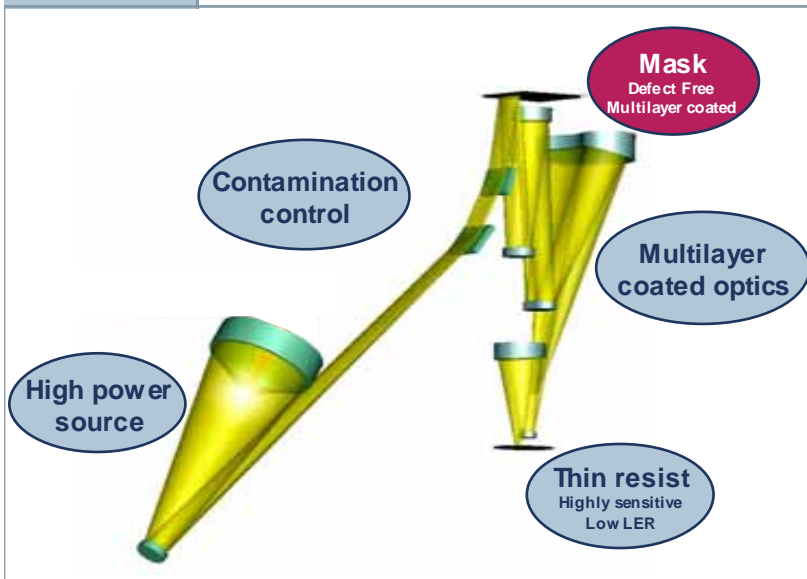
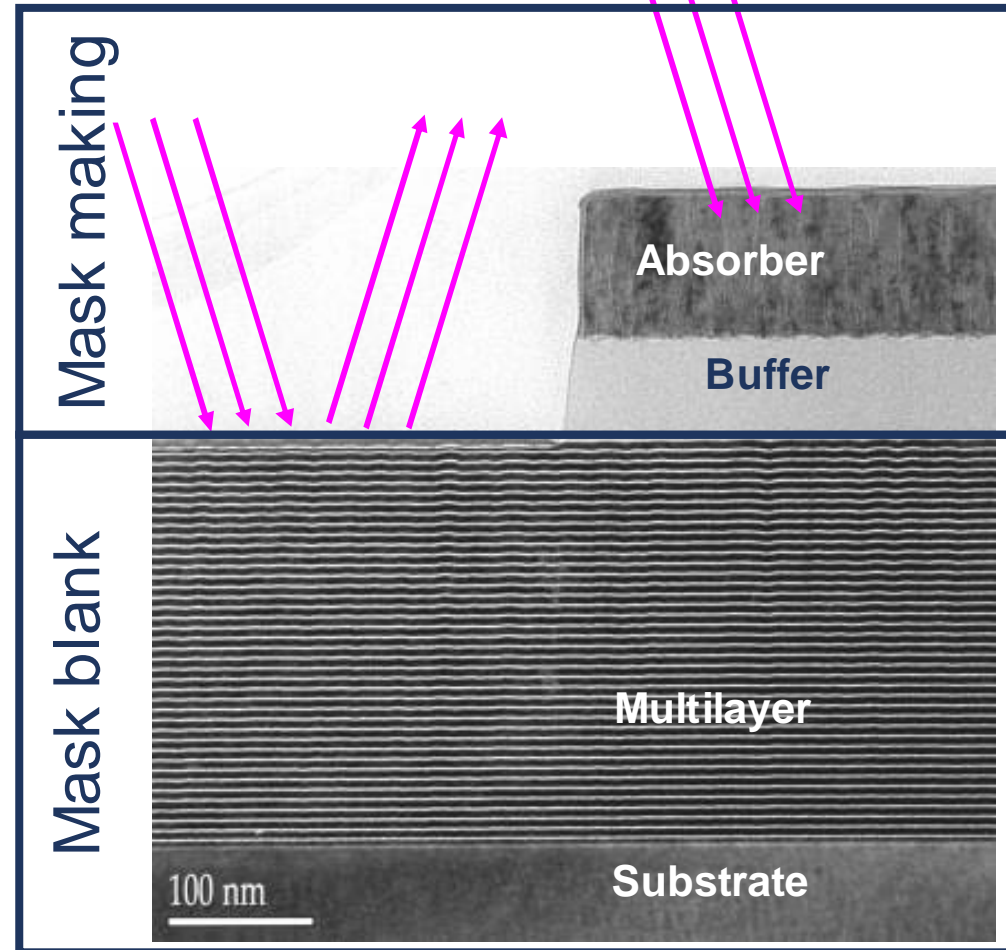
Main technology challenges



EUV lithography

Main technology challenges

no pellicle during exposure

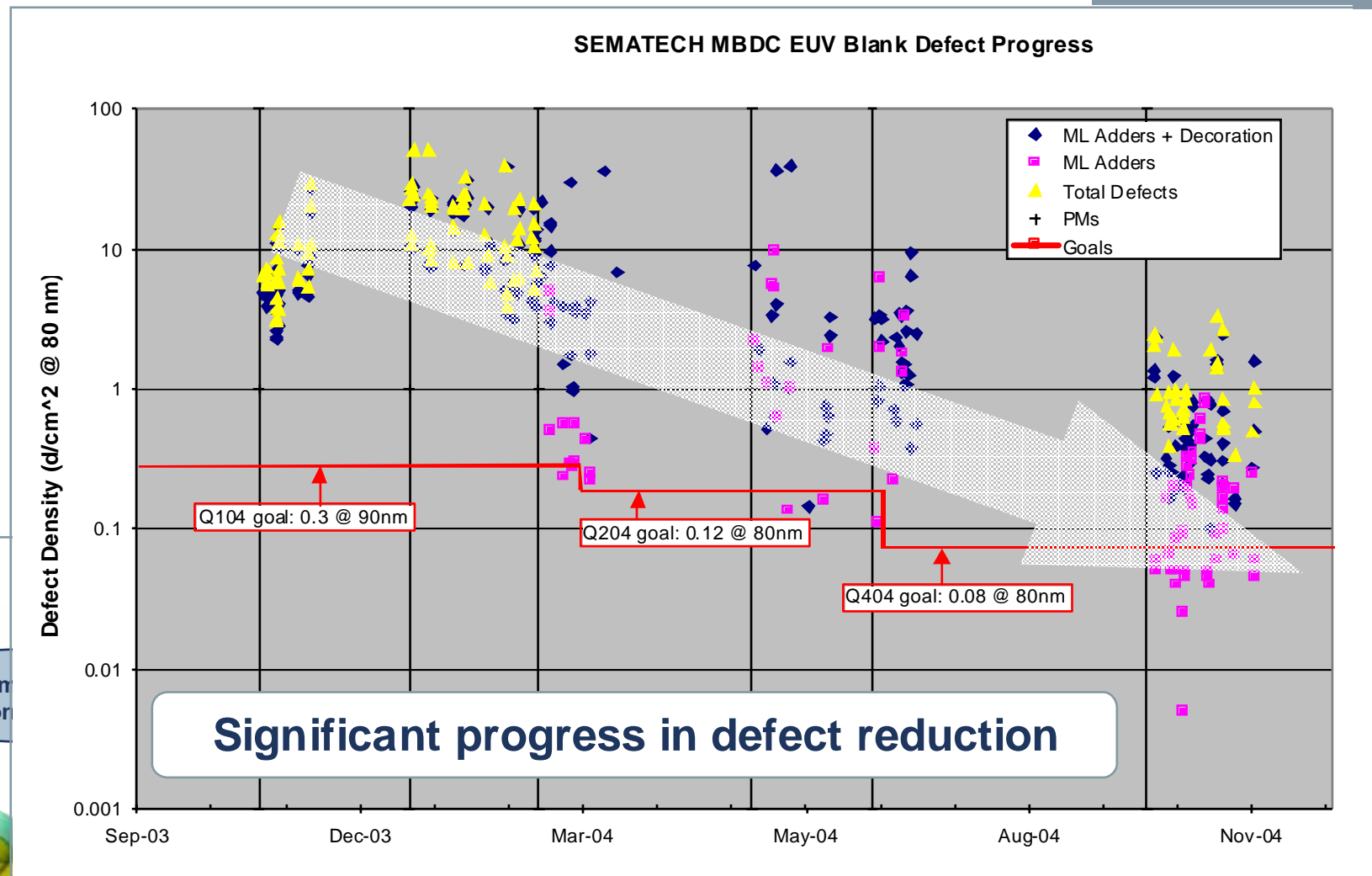


EUV mask cross section
(TEM courtesy of AMD)



EUV lithography

Main technology challenges



Contam
cor

High power
source

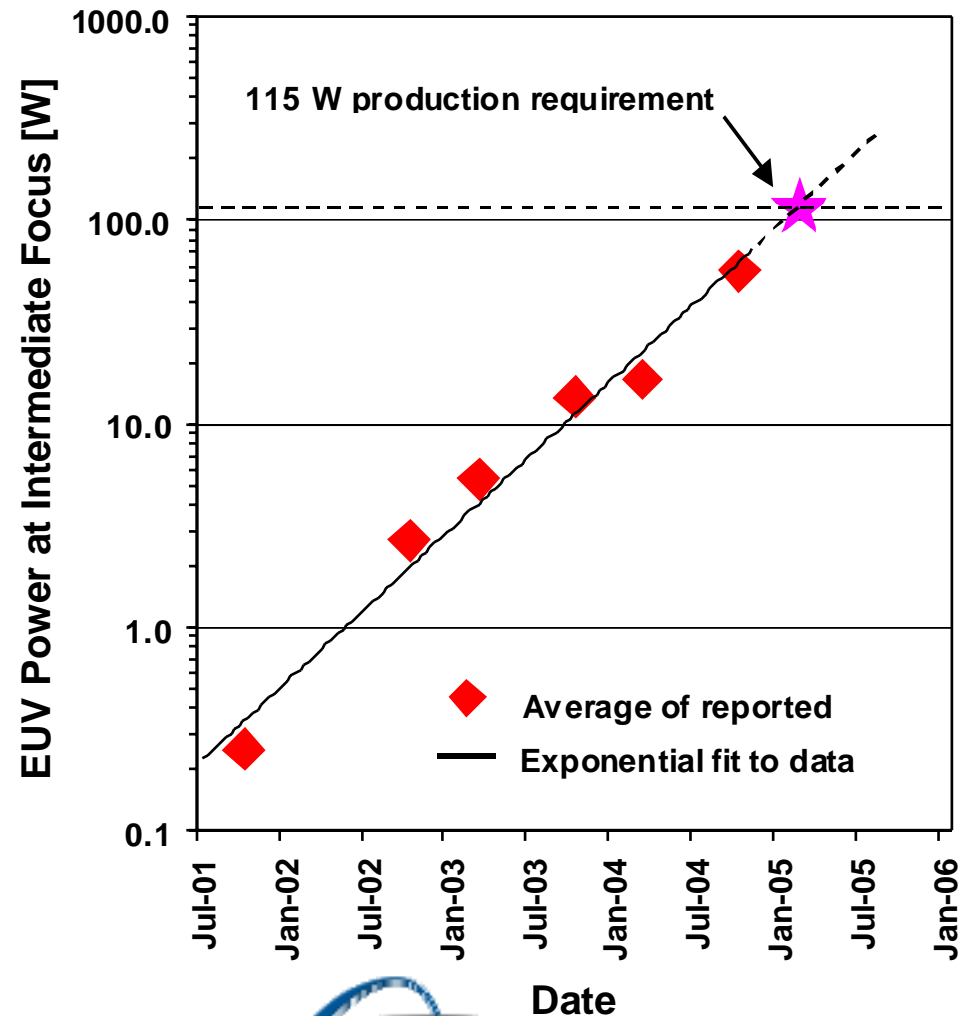
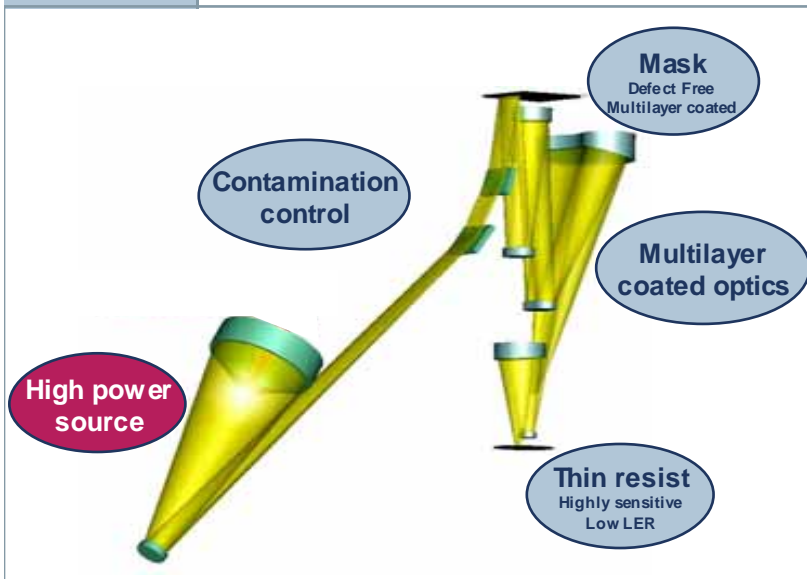
Thin resist
Highly sensitive
Low LER



EUV lithography

Main technology challenges

Fast progress on system productivity (source power)

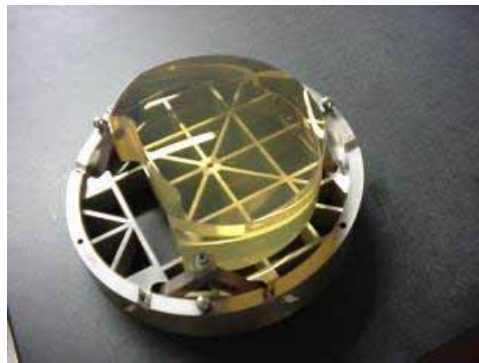


Data from REMATECH EUV Source Workshops

EUV lithography

Main technology challenges

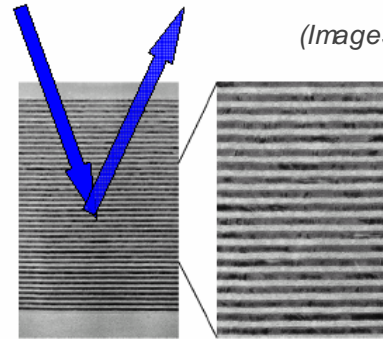
Optics substrate



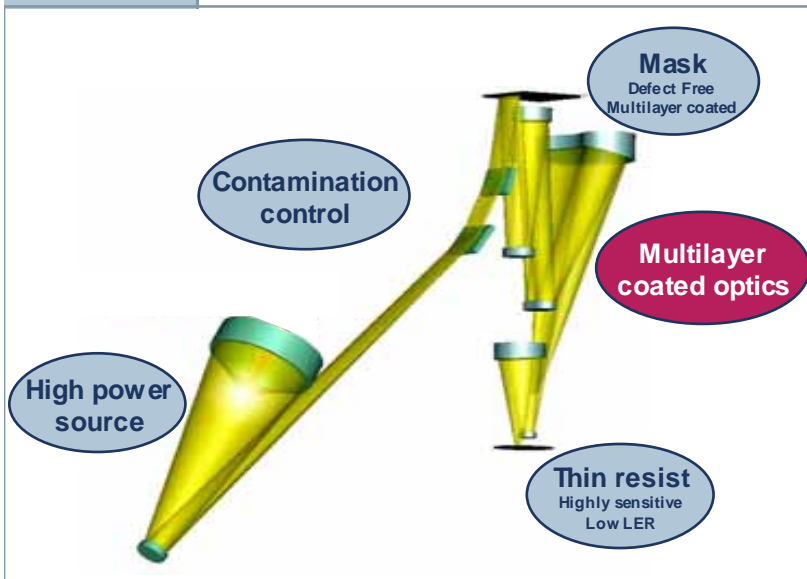
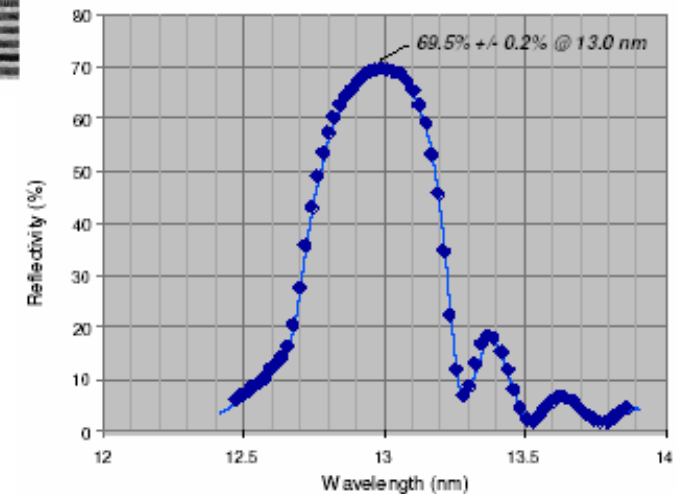
Multilayer coated optics



(Images courtesy of VNL / EUVLLC)



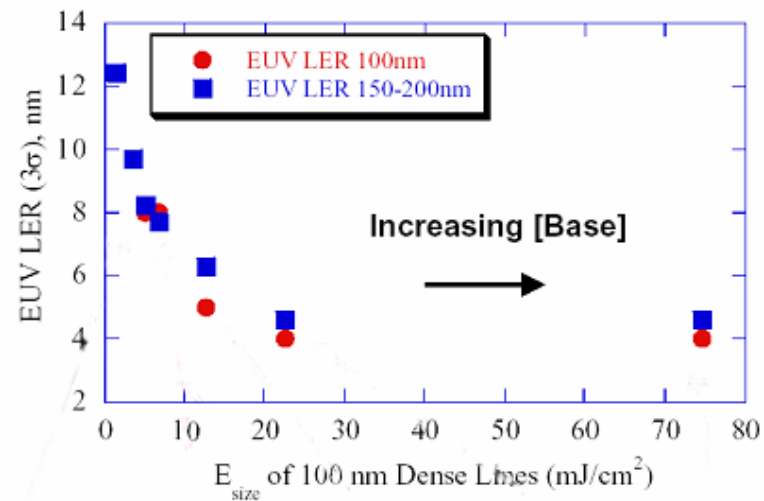
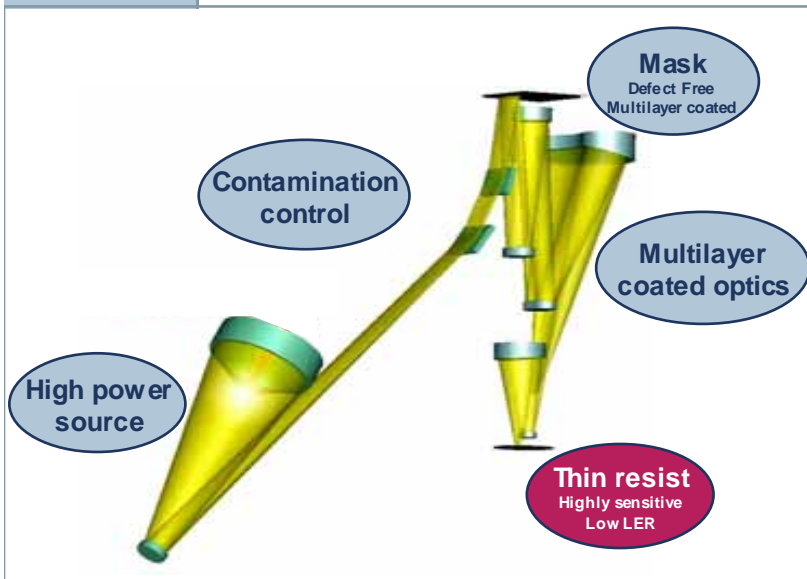
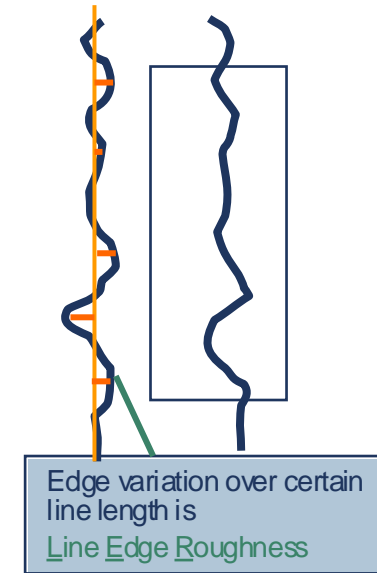
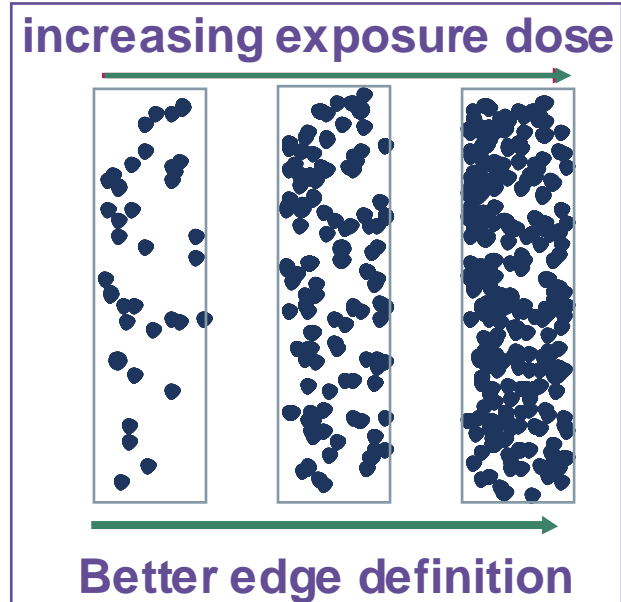
reflectivity reaches up to 70 %



EUV lithography

Main technology challenges

Resist Sensitivity vs. Line Edge Roughness (trade off)

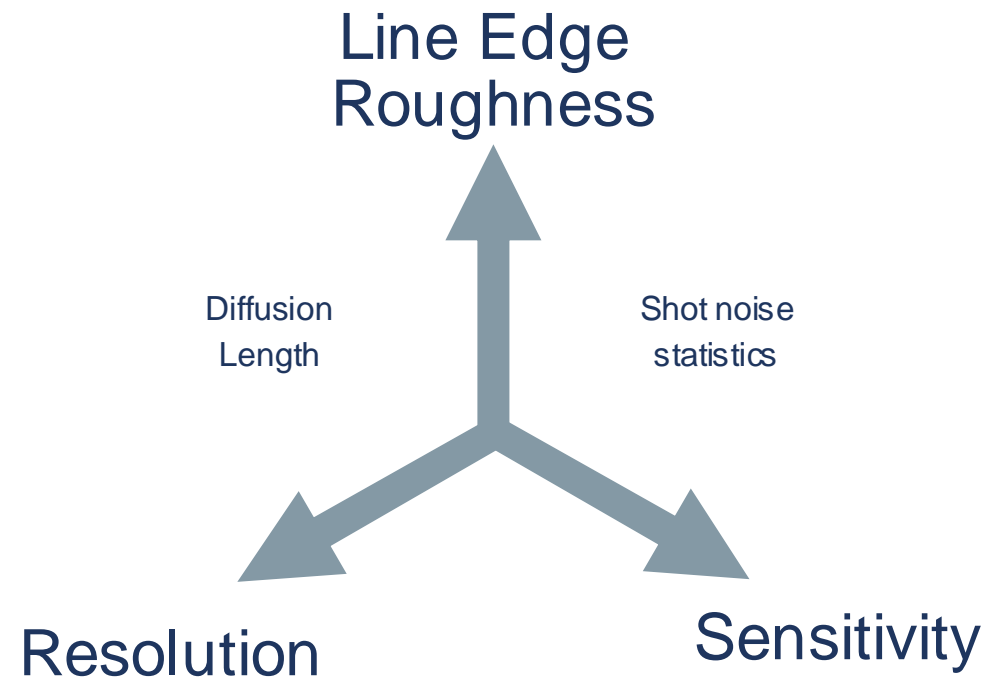
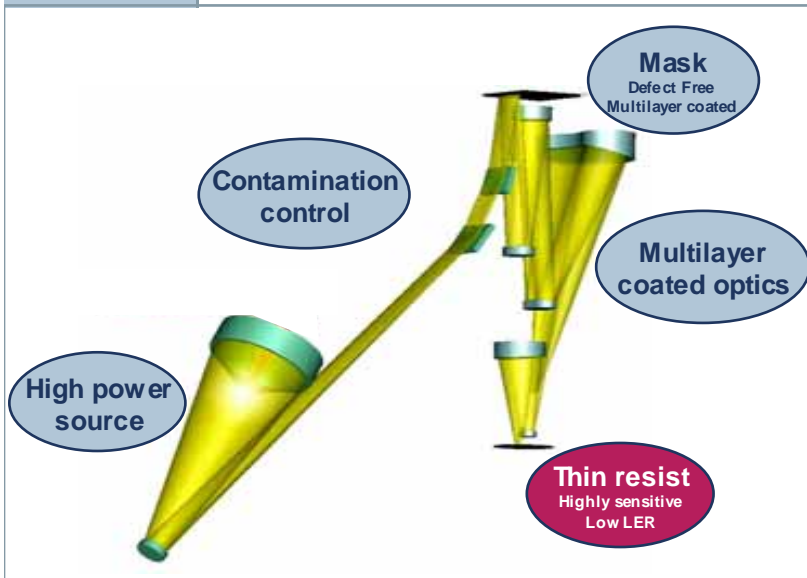




EUV lithography

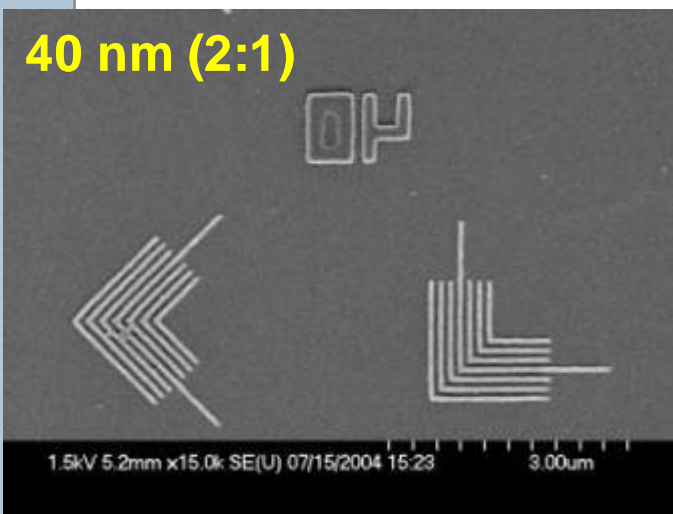
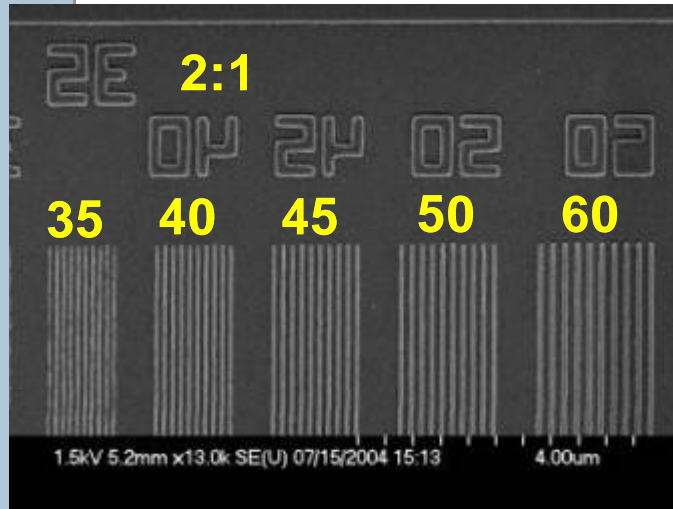
Main technology challenges

**Resist Sensitivity vs.
Line Edge Roughness
(trade off)**



New Resist Approaches

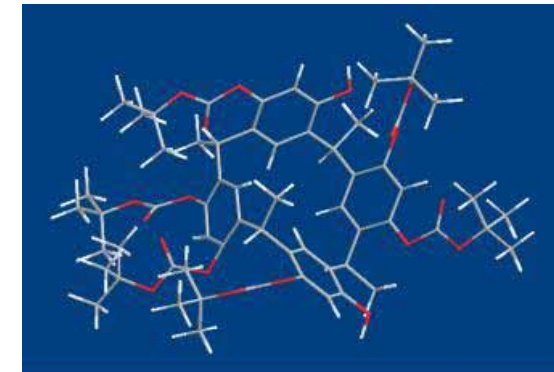
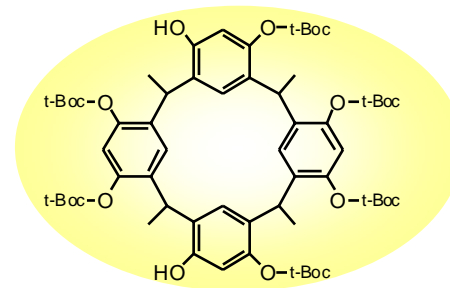
Positive-tone Molecular Glass Resist



10.0mJ/cm² Bright Field

Cornell University

- Shorter polymers may provide a possible solution



(Courtesy of Prof. Chris Ober, Cornell University)



$$resolution = k_1 \cdot \frac{\lambda}{NA}$$

hp 32nm options

NA

k_1

λ

ArF Immersion

1.8 NA
($k_1=0.3$)

Single exposure

ArF Immersion

1.35 – 1.5 NA
($k_1=0.22$)

Double exposure

EUVL

0.25 NA
($k_1=0.6$)

Single exposure

Critical challenges:

Lens size and cost

Liquid ($n_f > 1.8$)

New lens material
($n_f > 1.8$)

Cost of mask (2x)

Throughput reduction

Cost of additional process steps
(hard mask dep/etch)

Overlay requirement

Defect free mask

- Mask blank defect density
- No pellicle during exposure

CoO

- Source power
- Optics lifetime
- Resist sensitivity



Outline

Introduction

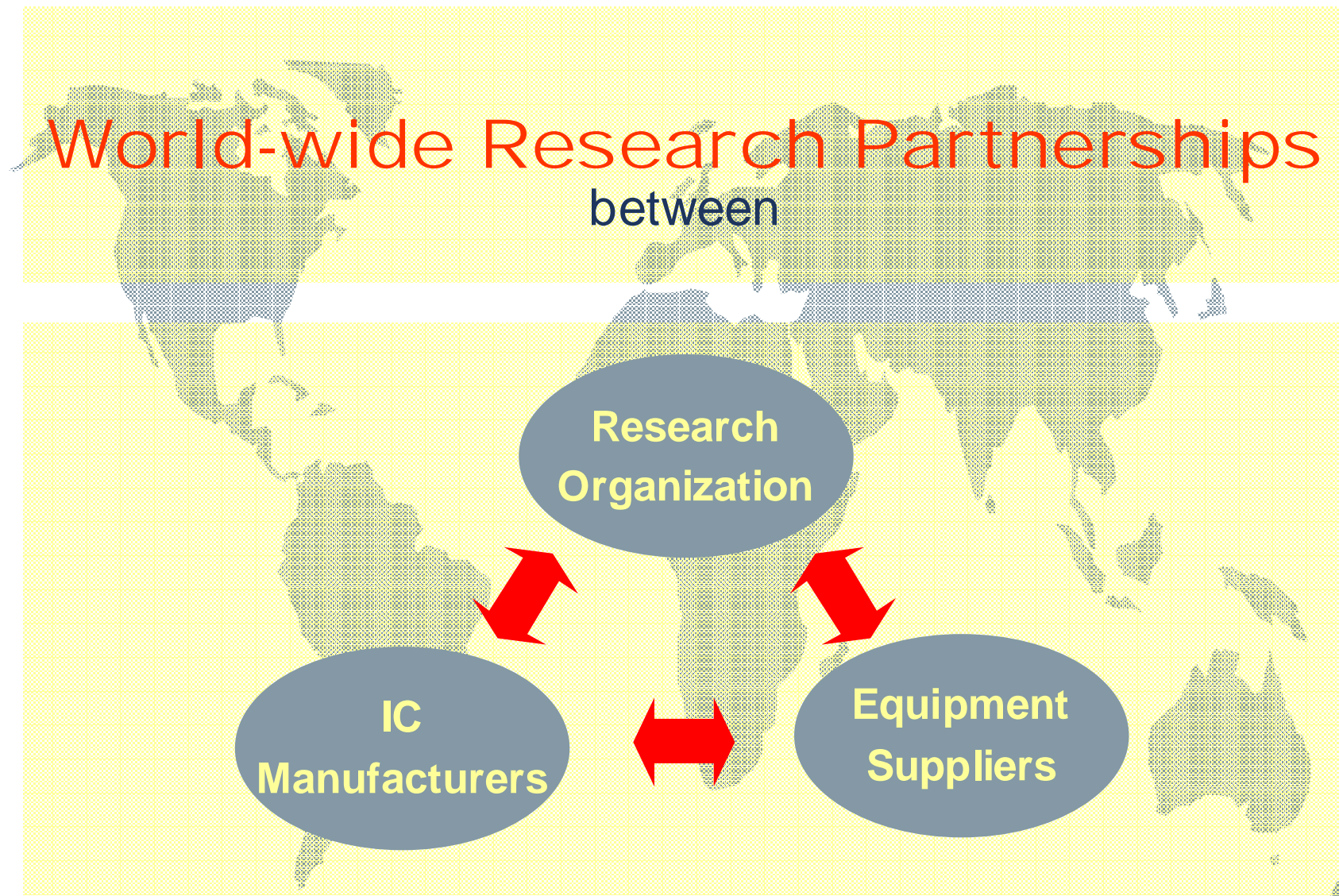
193nm immersion lithography

EUV lithography

Global collaboration

Conclusions

Research challenges require...





imec 193nm Immersion program

The world's largest 193nm immersion lithography effort

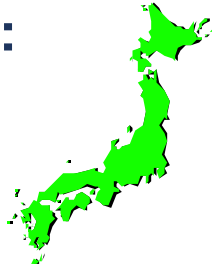


True global partnership

International EUV Initiative...

Japan:

- ASET
- EUVA
- MIRAI



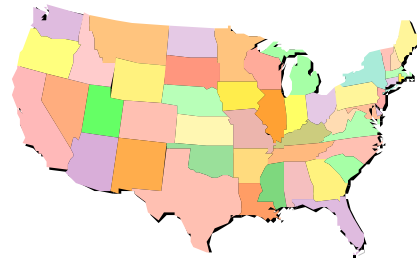
IEUVI
International
EUV
Initiative



Europe:

- MEDEA+
- LETI
- IMEC

IEUVI Chairman:
Paolo Gargini :



US:

EUV LLC
SEMATECH
VNL
SRC

IEUVI Technical Working Groups (TWG)

e.g. Mask handling solutions





Outline

Introduction

193nm immersion lithography

EUV lithography

Global collaboration

Conclusions

ArF immersion has **eliminated 157nm** lithography

Phenomenal progress has been obtained for ArF immersion lithography in less than 24 months

- End 2003: ASML/IMEC demonstrated first data on immersion feasibility prototype scanner (0.75NA AT1150i)
- End 2004: Two development scanners (0.85NA) have been installed in the field

Key **challenges** for immersion have been **identified**; solutions have been proposed/demonstrated for all issues

In order to cope with the extremely short introduction time, **world-wide partnerships** and collaboration have proven to be very effective

ArF immersion is clearly usable down to at least **hp 45nm**

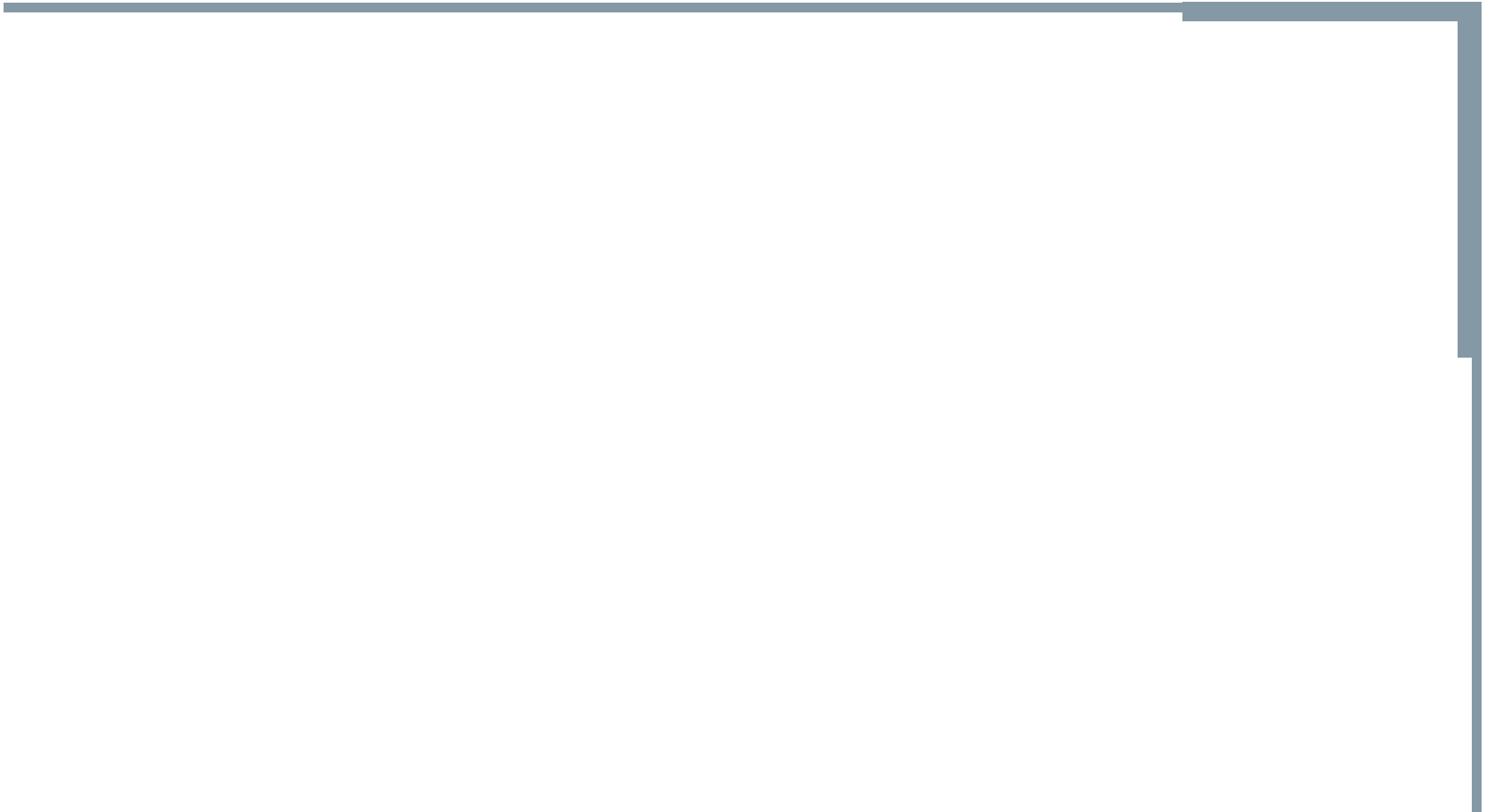
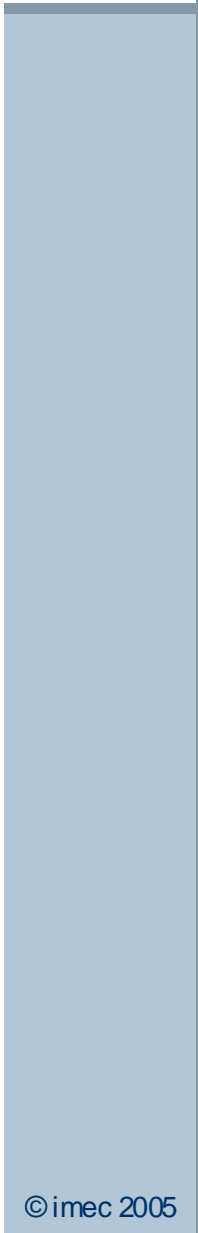
hp 32nm is unlikely to happen with immersion lithography and is believed to be the introduction node for **EUVL**

Significant progress has been made on the most important critical issues for EUVL (mask defects, source power, ...)

Acknowledgement

Many people have contributed to this presentation

- IMEC lithography team (K. Ronse, G. Vandenberghe, ...)
- ASML (M. van den Brink)
- Zeiss
- Sematech (S. Wurm)



Immersion Lithography

However, early 2004:

- Feasibility study of **IMMERSION LITHOGRAPHY** successful
- Several **advantages** (over 157nm) :

Build further on “mature” 193nm resists

Majority of optical material remains fused silica (not CaF_2)

Same reticle materials continue to be used

- No thick Qz pellicles needed
- No modified Qz blanks needed

Resolution outlook

