Leti Lithography Roadmap

Outline

- Introduction
  - Limits of optical lithography ?
  - Roadmaps
- Lithography a Leti
  - Advanced patterning for devices
  - Advanced studies
  - Resist Expertise Center
  - Some main achievements
- Conclusion

Limits of optical lithography

- **Raleigh criteria** :

$$R = k_1 \times \frac{\lambda}{NA} \quad with \quad NA = n \times \sin(\theta) < n$$

$$DOF = k_2 \frac{\lambda}{NA^2}$$

➔**To improve resolution we need to:**

Limits of optical lithography

- **Decrease λ**
  - DUV 193 nm
  - EUV 13.5 nm
- **Increase NA**
  - Today NA =0.93 (In air NA_{max} =1)
  - Introduction of 193 nm immersion lithography
    - NA=1.35 with water
    - NA could be increased to 1.5 if n=1.6 liquid are available
- **Decrease k_1 with:**
  - OPC and PSM masks
  - Off axis illumination or polarization
  - Double exposure/Double patterning
    - Most aggressive k1 in production today is 0.3
    - Physical limit single exposure is 0.25
    - Physical limit double exposure 0.22

CoO issues

➔ **Resolution improvements are made to the detriment of severe cost increase for masks and tools.**

➔ **To overcome these economical issues introduction in the lithography roadmap of:**

- Maskless solutions foreseen with charged particles (E-beam) or optical (193 nm or EUV wavelength)
- Nanoimprint technology

ASML technology roadmap scenarios

	half pitch	100	65	45	32	22	16	11
	year		2005	2007	2009	2011	2013	2015
λ [nm]	NA							
248	0.80	0.32						
193	0.93		0.31					
	1.20		0.40	0.28				
	1.35			0.31	0.22	0.15		
	1.55				0.26	0.18		
13.5	0.25				0.59	0.41		
	0.35					0.57	0.41	
	0.45						0.53	0.37

Pitch relaxation or Double patterning

Low k_1 challenge

Fluid/ material challenge

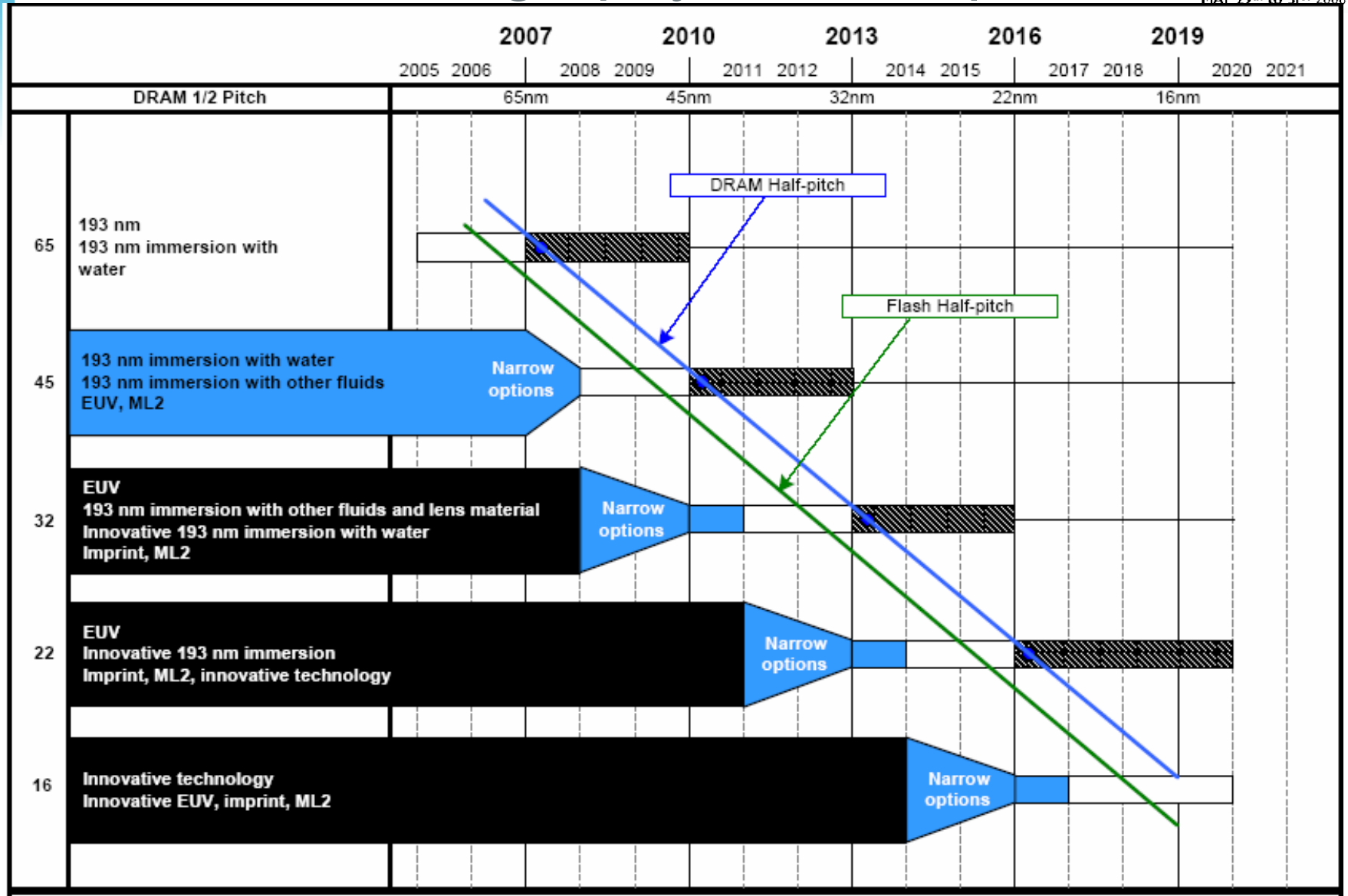
Infrastructure challenge

likely

opportunity

ASML

ITRS 2005 Lithography Roadmap



Lithography at Leti

➢Advanced Patterning for devices

- 2 X 300 mm Variable Shaped beam systems at Crolles site:
  - Devices and process modules development down to 32 nm
  - Advanced Prototyping, design validation (mask less)
  - Low volume production (mask less)

- 2 X 200mm High Resolution gaussian beam systems at Leti site
  - HR system to develop CMOS processes and devices down to 20 nm
  - UHR system nano-technology processes and devices down to 3-5 nanometers
  - Hybrid lithography : E-beam&DUV 248 nm on 200mm wafers

- 1X300 mm E-Beam system planed at Leti site
  - To provide lithography capability for our 300 mm R&D activity
  - Hybrid lithography : E-beam&DUV 193 nm on 300 mm wafer (2007-2008)

300 mm Lithography cell

To support the 300 mm R&D activity the following litho cell will be put in place at Leti site:

- 193nm Scanner (Installed Q4-2006)
- Track (Installed Q4-2006)
- E-beam (Planned Q4-2007/2008)
- CD metrology (already in place)
- Overlay metrology (Planned mid 2007)

This litho cell will be 200/300 mm compatible. Mix and match and hybrid strategies will be developed using 193 nm lithography

Lithography advanced studies

- **193 nm immersion lithography**
  - **Interferometer set up installed at leti site**
    - Process development (resist, BARC, Topcoat, leaching,..)
    - High refractive index studies
  - **Scanner 1250i installed at Crolles site**
    - Process development
    - Defectivity issues
- EUV lithography
  - **Sub-project leader of the IST More Moore project**
  - **Mask development (PSM)**
  - **Resist process development using EUV-IL**
- NanoImprint Lithography
  - **Hot embossing**
  - **Step and repeat UV-NIL for CMOS application (MEDEA+ FANTASTIC project leader)**

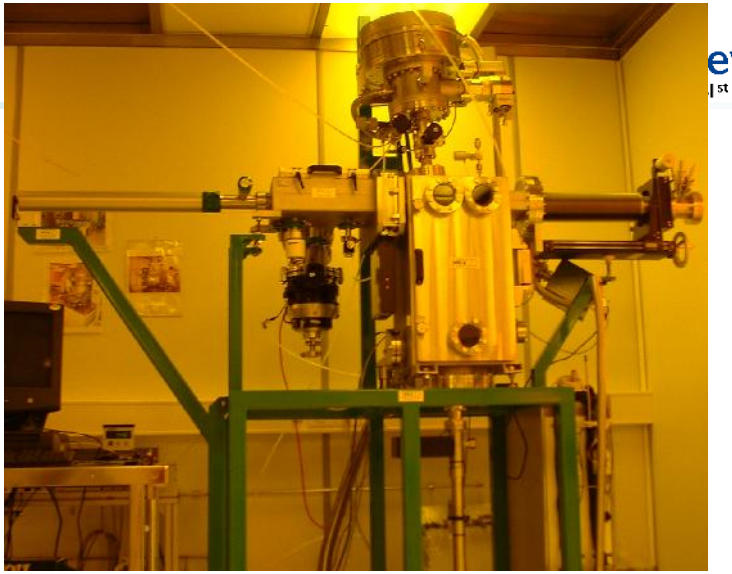
To support all these activities and accelerate the integration cycle we put in place a Resist Expertise Center

Resist Expertise Center

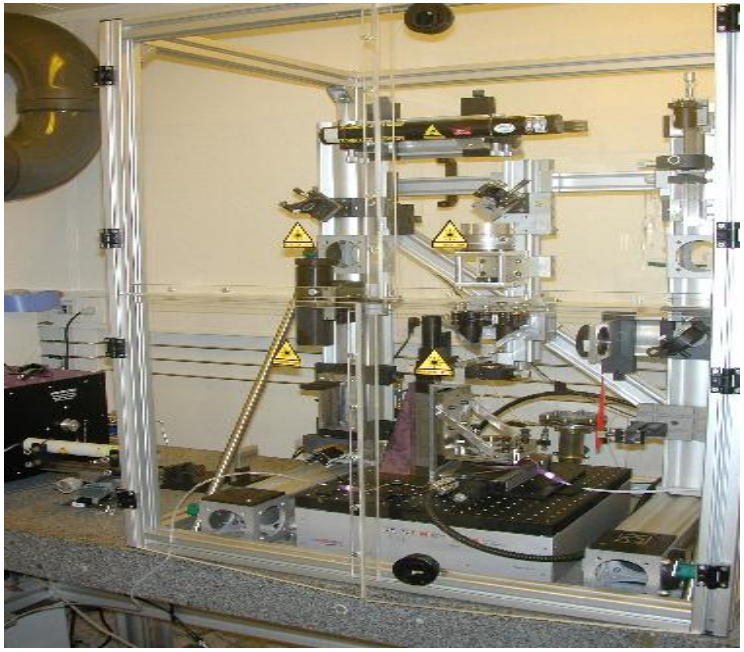
- 11 persons working on lithographic process & resist behavior understanding
- Close collaboration with Crolles (1 & Alliance) on dedicated R&D programs.
  - 193I processes, 193nm resists for implant, E-beam/193nm compatible CAR (hybrid lithography), Imager technologies.
- Fundamental studies :
  - **Negative resist (CAR) for the 45 nm node**
  - **Process integration**
    - Defectivity and resist issues
    - Polymer/plasma interactions
    - Chemical Amplified Resist limitation for the 32 nm node and alternative solutions
    - LER understanding

- Strong exchanges and collaborations with material supplier R&D teams in order to promote the synergy between our teams, the semiconductor manufacturers and the lithographic material suppliers.

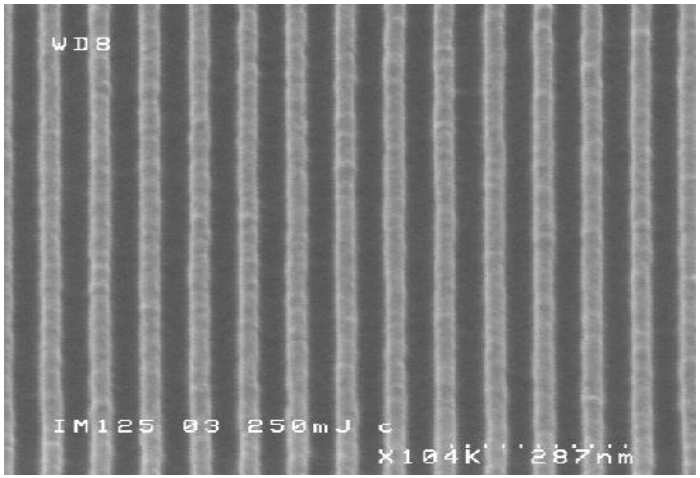
LC/MS equipment for PAG leaching studies



Outgassing system



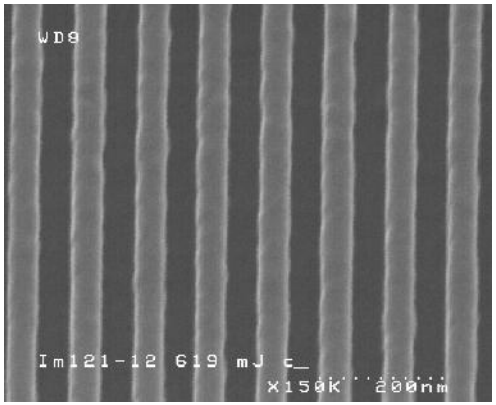
193 nm immersion interferometer

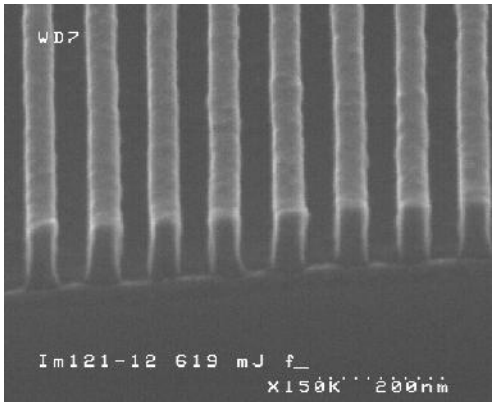


40 nm hp σ< 3 nm

Immersion lithography with water

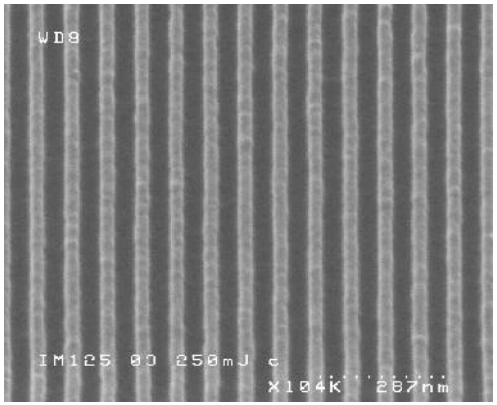
55 nm hp imaging NA=0.87

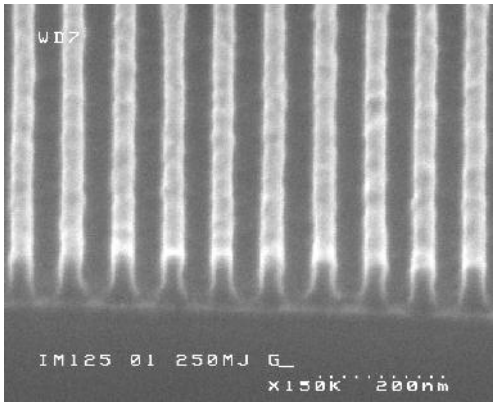




CD = 47 nm

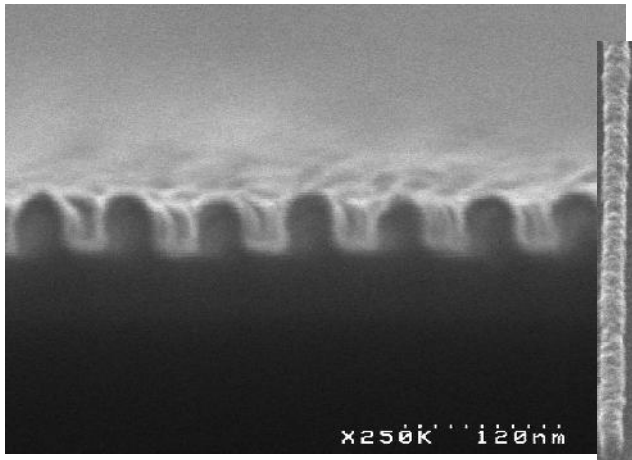
40 nm hp imaging NA=1.2

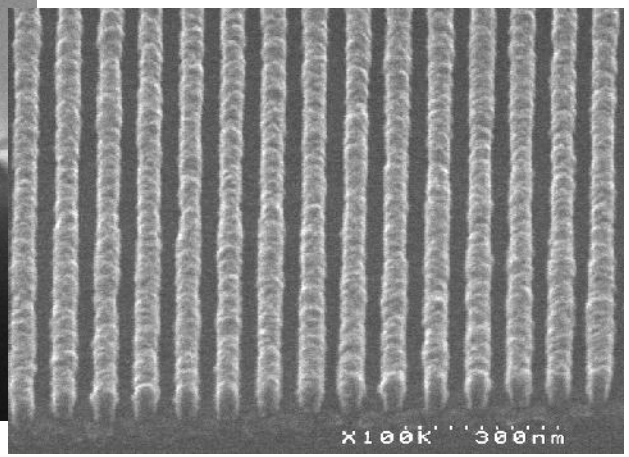




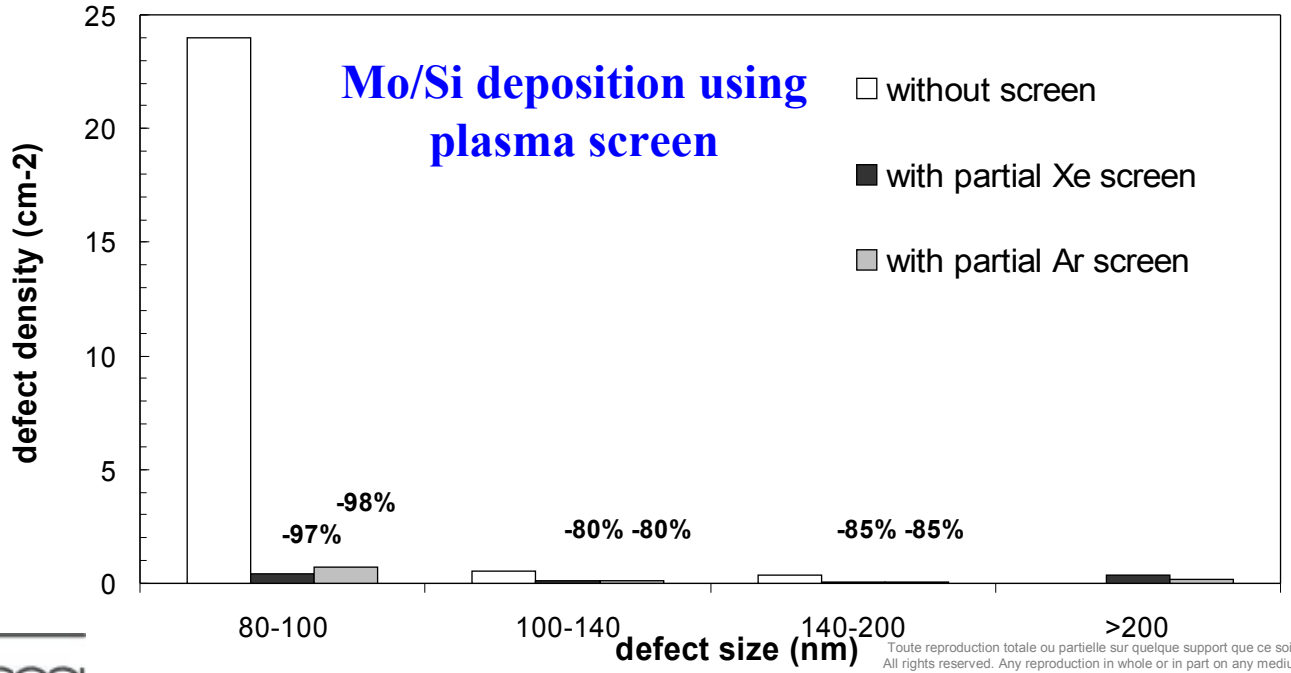
CD = 39 nm

EUV lithography main achievements





32.5 nm L/S on CAR using IL-EUV at PSI

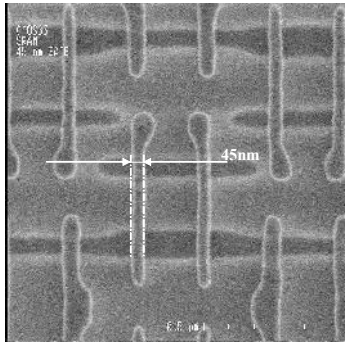


Defect density is divided by a **factor of 50** for defects size between 80 and 100 nm

Crolles 2 Alliance EBDW Litho

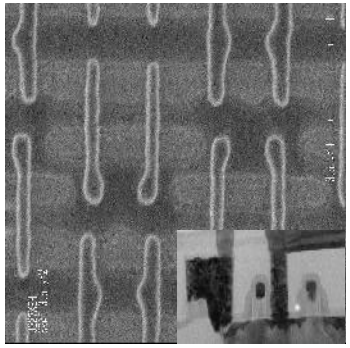
CMOS 65

Q4/2002



0.69µm² - 65nm

Q4/2003

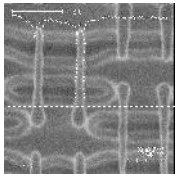


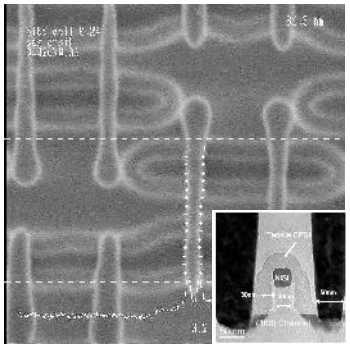
0.5µm² - 65nm

CMOS 45

Q4/2004

Scale reduction vs 0.5µm² SRAM cell



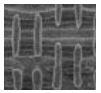


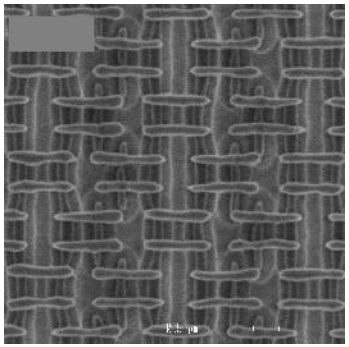
0.248µm² - 45nm

CMOS32

Q4/2005 1st studies

Scale reduction vs 0.5µm² SRAM cell





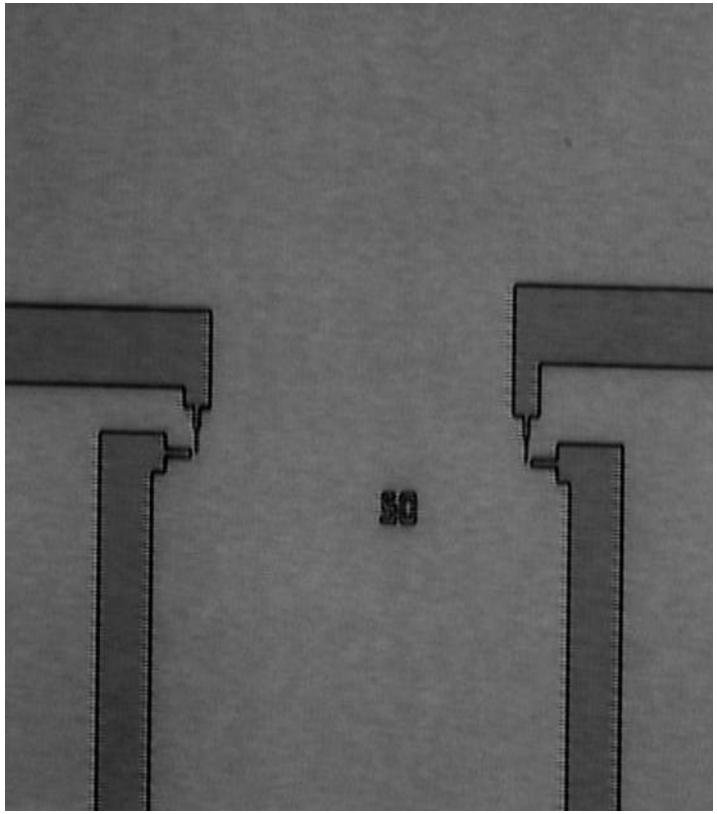
32nm

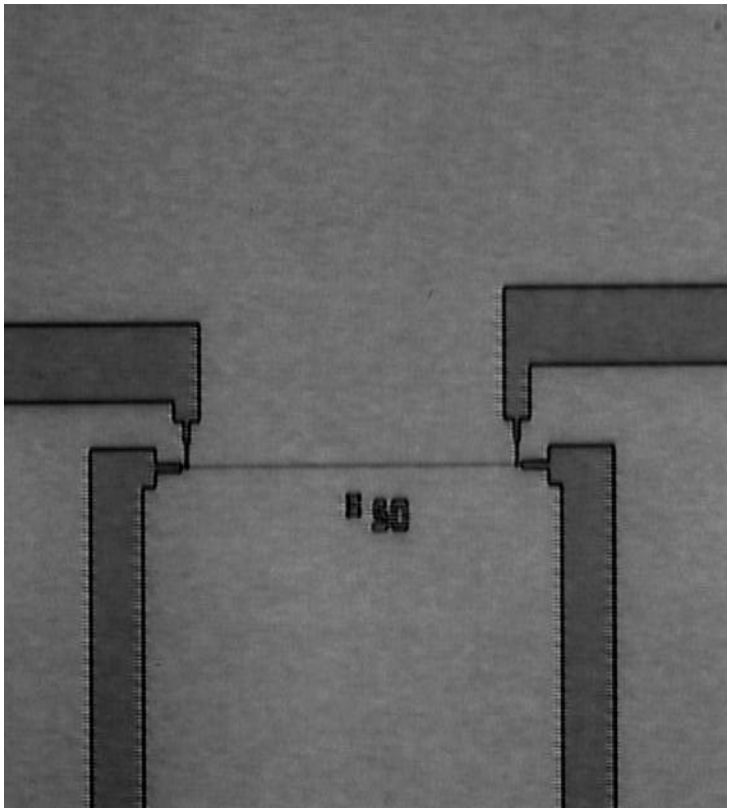
Courtesy of Laurent Pain

E-Beam litho : from HR to UHR

	LEICA VB6 HR	LEICA VB6 UHR
Accelerating voltage [kV]	50 – 100	50 - 100
Resolution [nm]	**15 - 20**	**3 - 5**
Interferometer accuracy [nm]	1.2	0.6
Overlay (mean+ 3 σ) [nm]	40	25
Stitching (mean + 3σ) [nm]	50	20

Hybrid Lithography



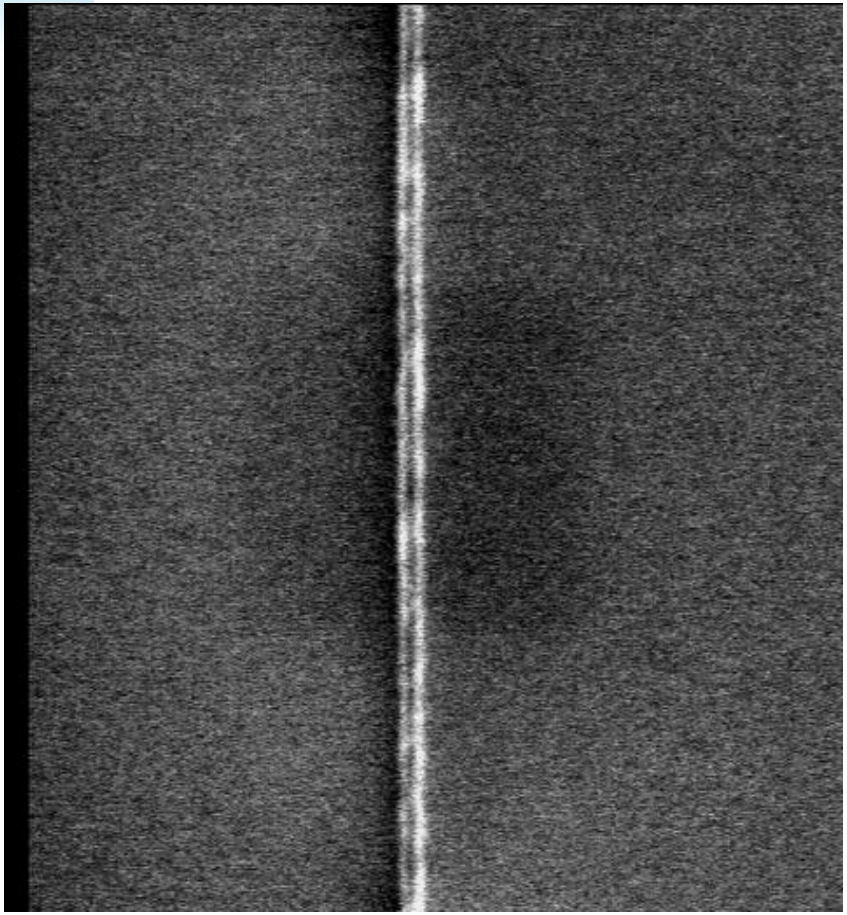


Only DUV Exposure

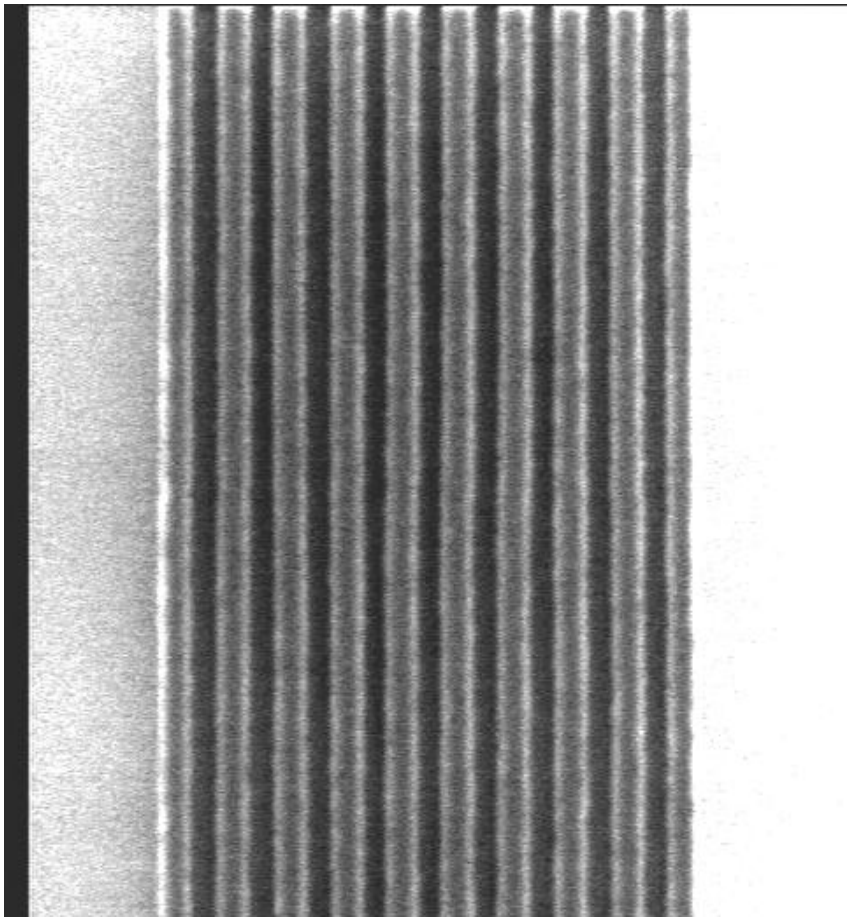
DUV and E-Beam Exposure (50 nm)

E-Beam Litho (UHR) : Nanostructures

Negative tone Chemical Amplified Resist (CAR)



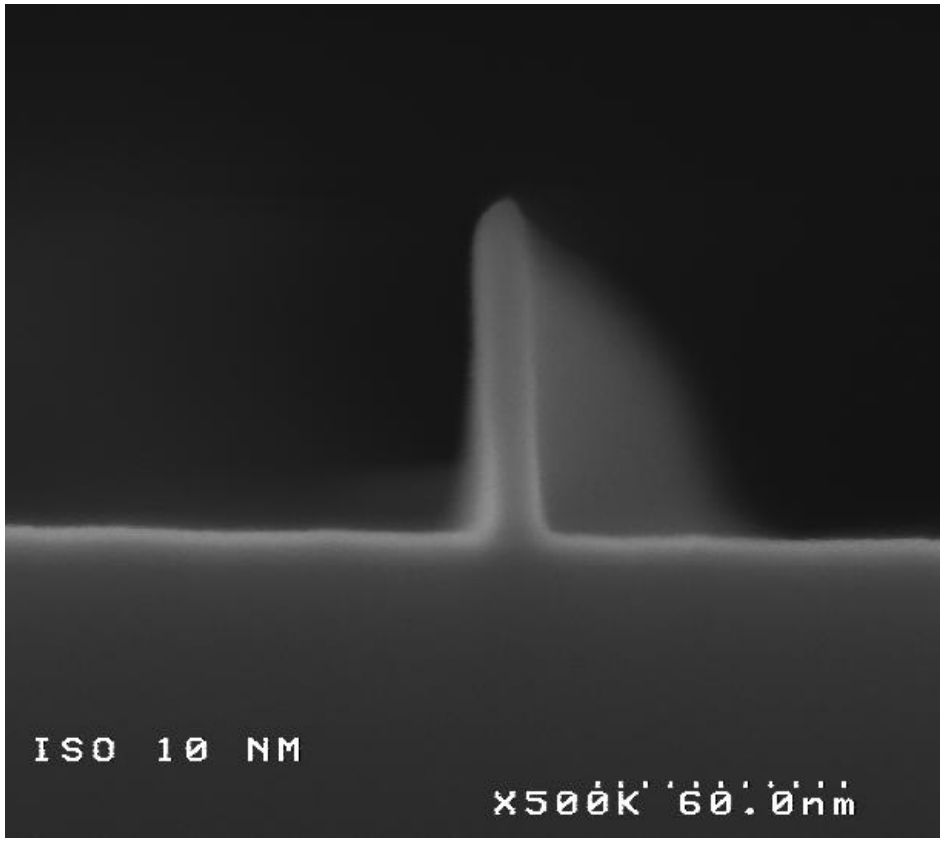
20 nm isolated line



40 nm lines and spaces

E-Beam Litho (UHR) : Nanostructures

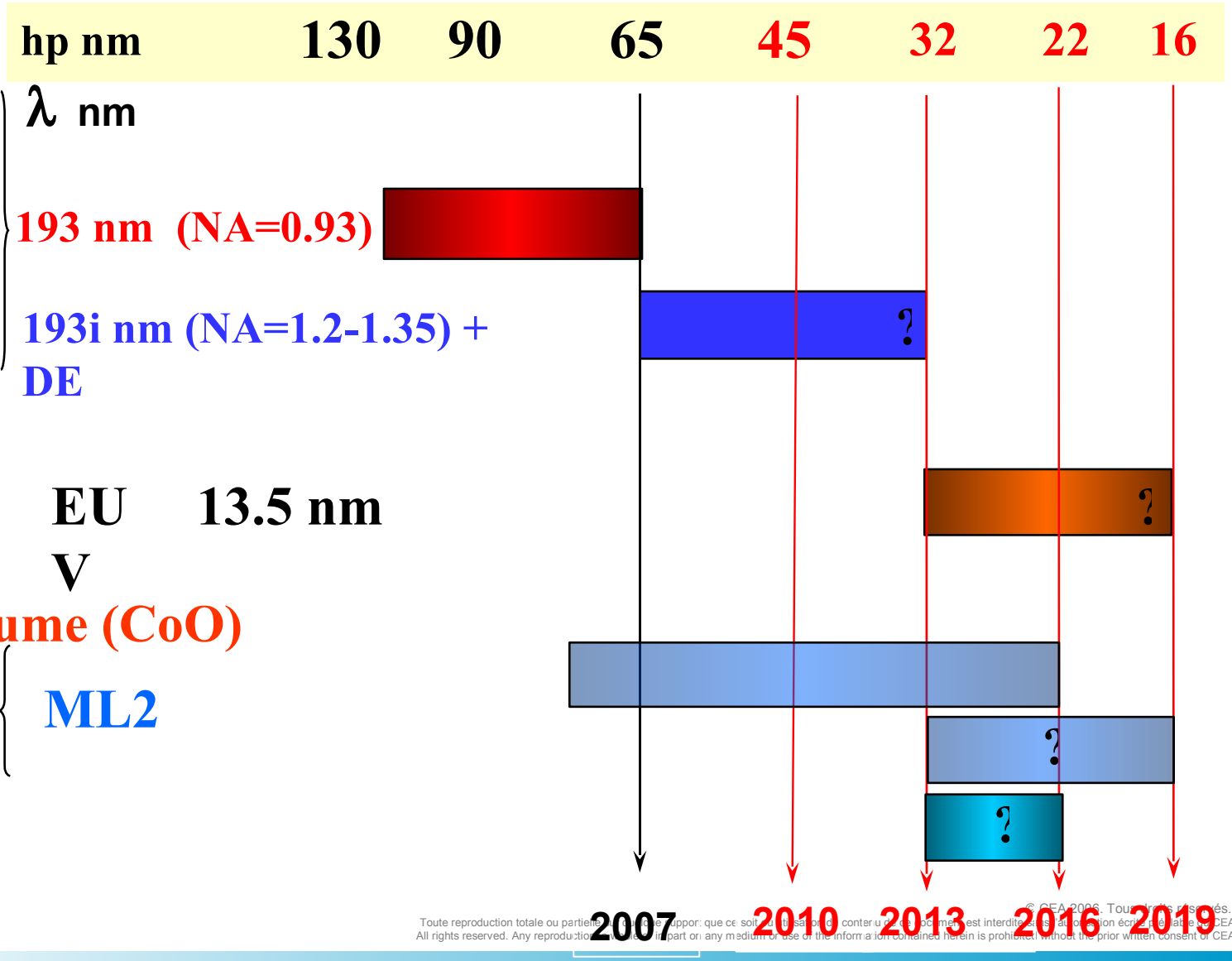
Negative tone inorganic resist HSQ (FOX)



10 nm line

6 nm line

Leti lithography roadmap (2006)



Conclusion

- 193 i with DE/DP will be pushed down to the 32 nm hp
- Today there is no alternative to EUVL for the 22 nm hp
- Actual CAR doesn't met requirements (LER, resolution and sensitivity) :
  - ➔ **new resist platforms needed for 22 nm hp?**
- For low volume production a cost effective lithography solution is urgently needed :
  - ➔ **ML2 and nanoimprint could be an alternative**
- Can optical lithography be pushed down to the 10 nm range ?
  - ➔ **surface plasmon or evanescent wave could open a multitude of new possibilities for sub-wavelength lithography.**

Thank you for your attention