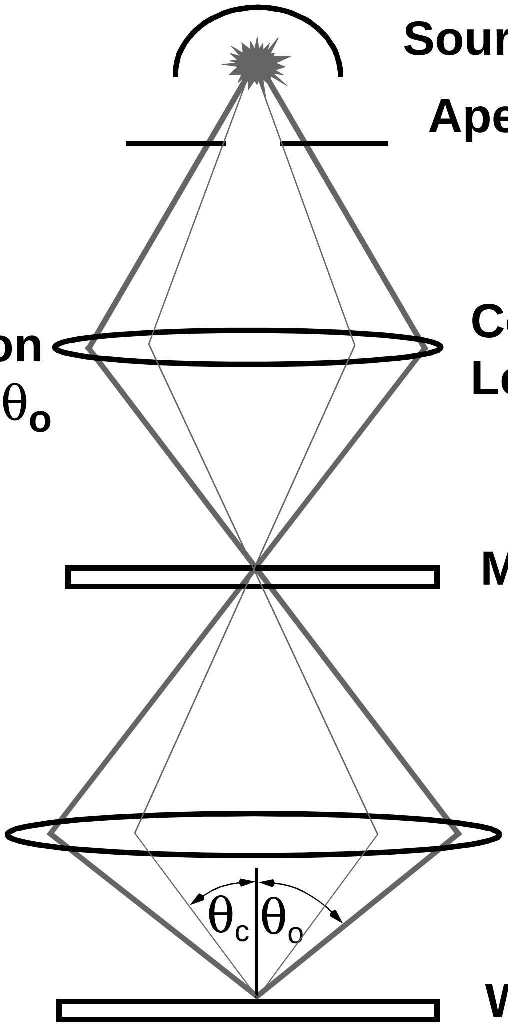
LITHOGRAPHY STEPPER OPTICS



Source

Aperture

Partial Coherence of Illumination
$\sigma = \sin\theta_c / \sin\theta_o$

Condenser Lens

Mask

Projection Lens

Numerical Aperture
$NA = \sin\theta_o$

Wafer

Lithography Handbook

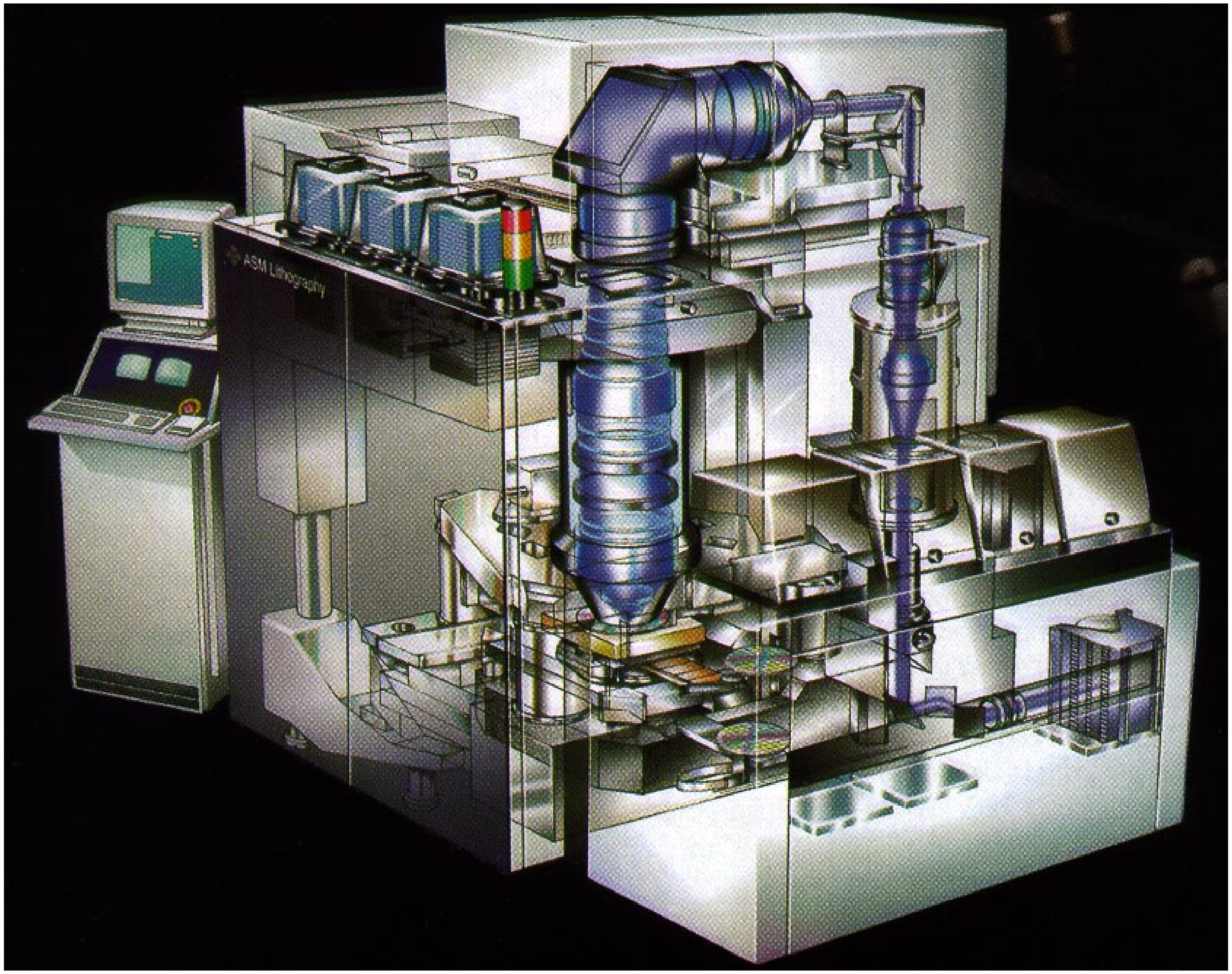
Minimum feature size (resolution)

MFS = $k_1\lambda/NA$
$k_1 \approx 0.8$
(resist/enhancements)

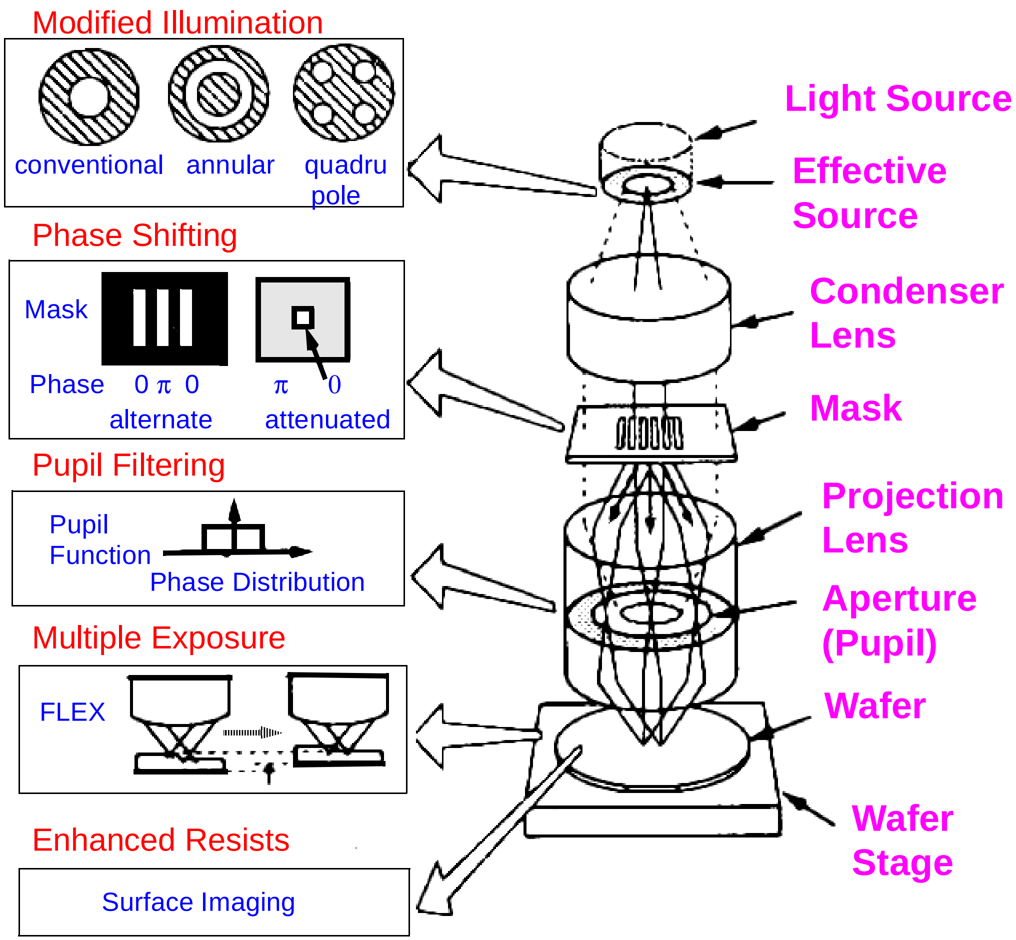
Depth of Focus

DOF = $k_2\lambda/(NA)^2$
$k_1 \approx 1$
(enhancements)

WHAT A DEEP-UV STEPPER REALLY LOOKS LIKE



“WAVEFRONT ENGINEERING” TECHNIQUES IN PHOTOLITHOGRAPHY



Modified Illumination

conventional annular quadru pole

Phase Shifting

Mask

Phase 0 π 0 π 0

alternate attenuated

Pupil Filtering

Pupil Function

Phase Distribution

Multiple Exposure

FLEX

Enhanced Resists

Surface Imaging

Light Source

Effective Source

Condenser Lens

Mask

Projection Lens

Aperture (Pupil)

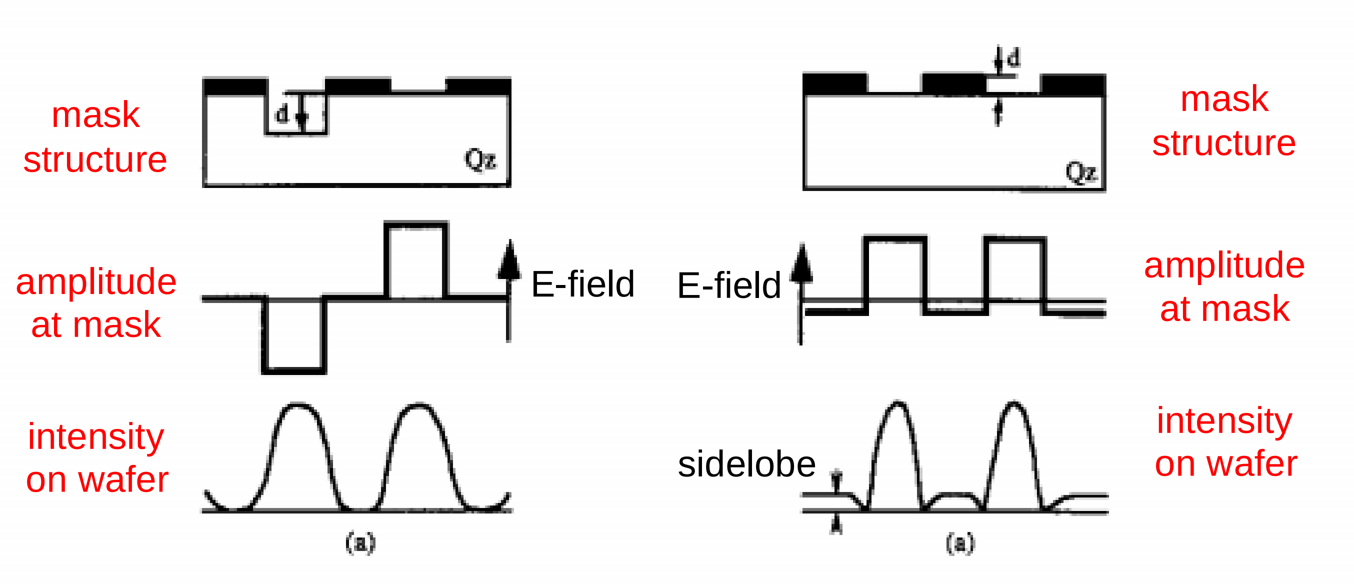
Wafer

Wafer Stage

New Image Formation Techniques

Exposure Optics

PHASE-SHIFT MASK TECHNIQUES



mask
structure

amplitude
at mask

intensity
on wafer

E-field

E-field

sidelobe

mask
structure

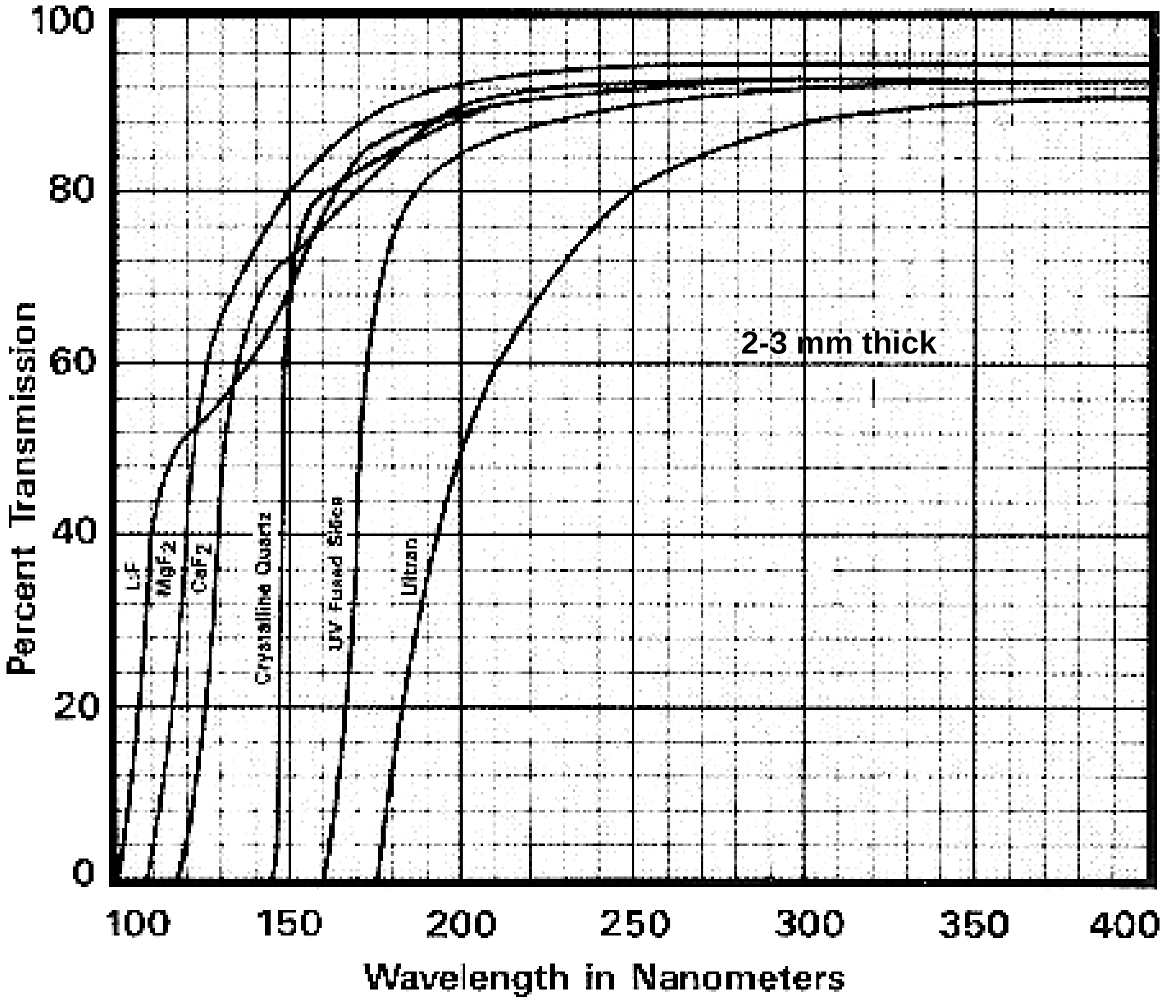
amplitude
at mask

intensity
on wafer

Alternating phase mask
(Levenson)

Attenuated phase mask

VACUUM ULTRAVIOLET TRANSMISSION CUTOFFS OF AVAILABLE OPTICAL MATERIALS



CONTINUED EXTENSION OF OPTICAL PROJECTION

- Historical approach: (MFS = $k_1\lambda/NA$)

  ⇒ Increase NA

  ⇒ Decrease λ

  ⇒ Decrease k_1

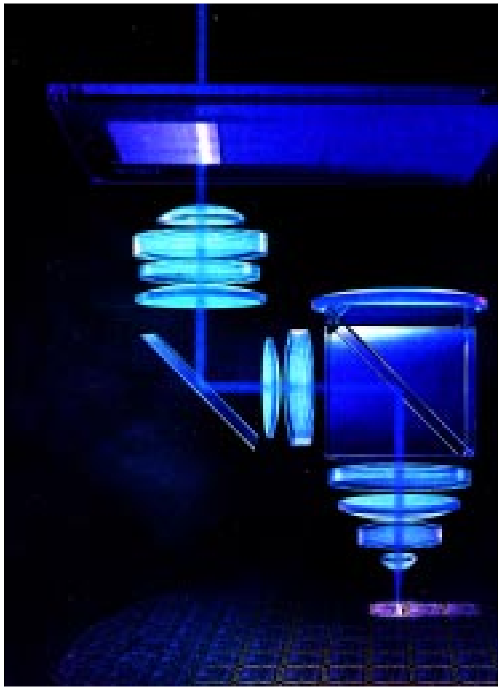
- Transmission optics reach to 193 nm

  - Expect limiting NA ≈ 0.75, $k_1 \approx 0.5$ ⇒ MFS ≈ 130 nm

- What about Vacuum UV? (λ = 100 nm - 200 nm range)

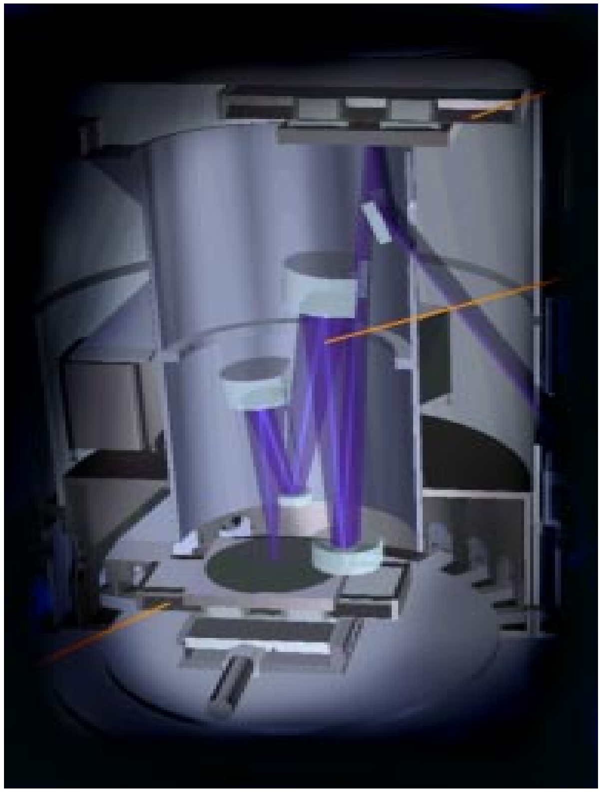
  - Diminishing returns absent further NA increase

OPTICAL LITHOGRAPHY TODAY (1997)
0.25 μm FEATURE SIZE



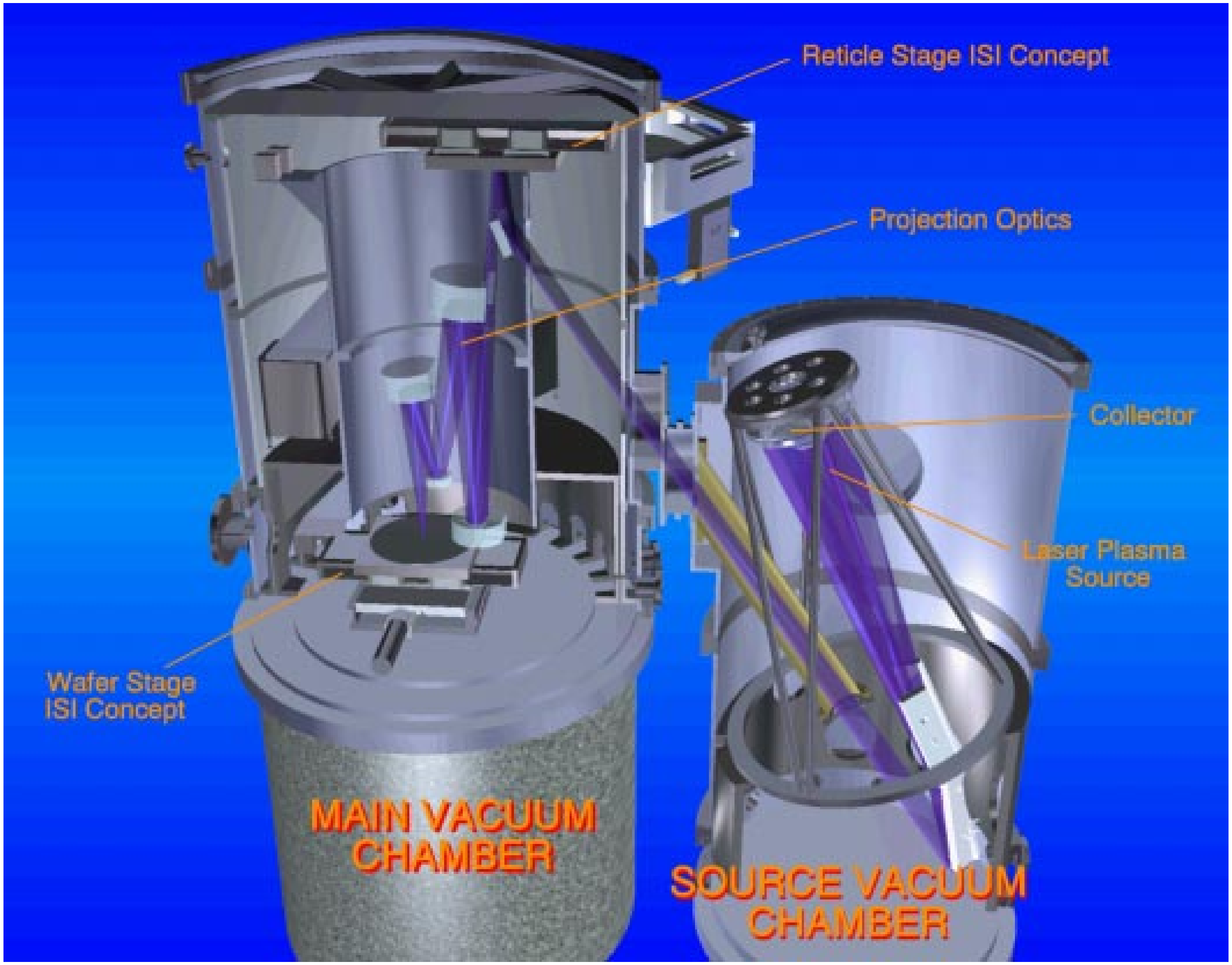
DUV (248 nm), Catadioptric optics

OPTICAL LITHOGRAPHY IN THE FUTURE
100 nm → 30 nm FEATURE SIZE

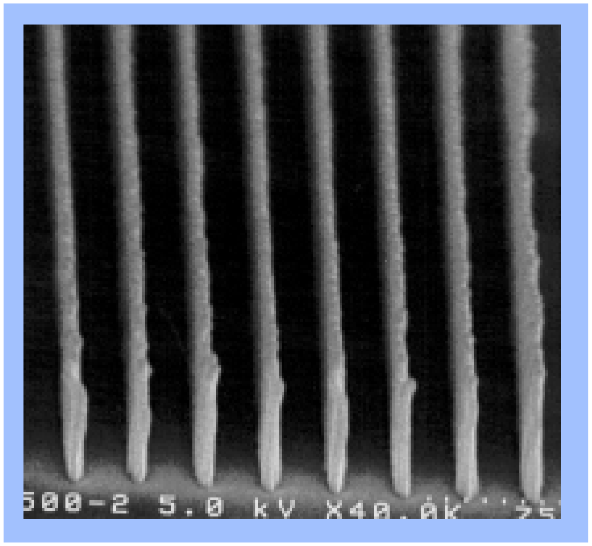


EUV (13 nm), All-reflective optics,
Reflection mask

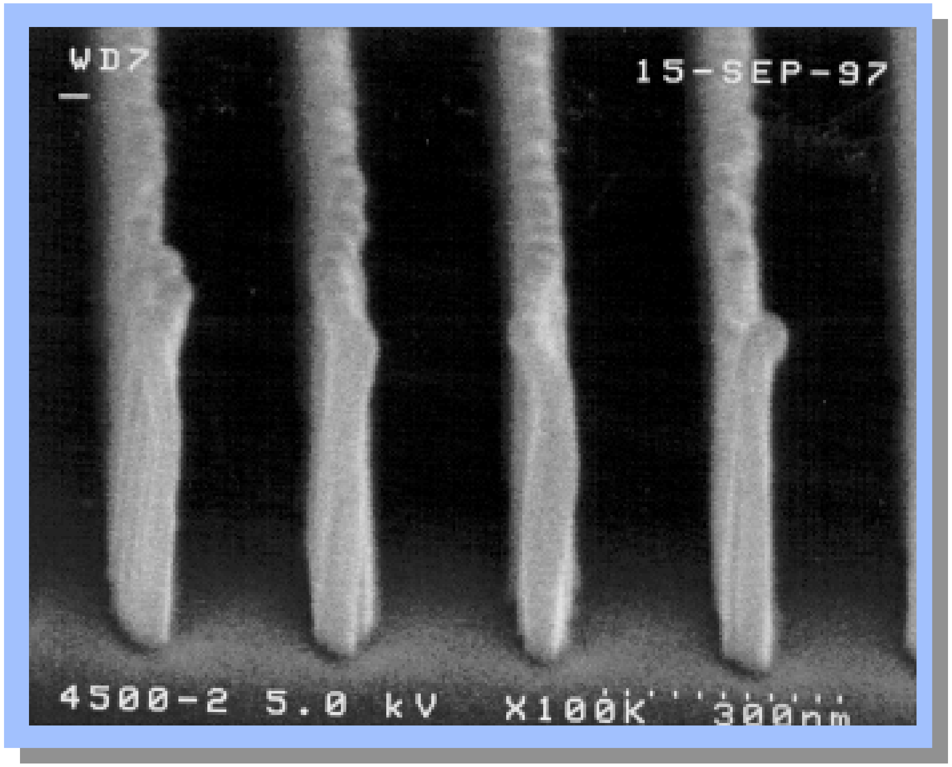
EUVL ENGINEERING TEST STAND



1997 Resist / EUVL Imaging Status



TSI process
No crosslinker
Etch selectivity 45:1



70 nm lines

70 nm lines/spaces (2:1 pitch)
Coded for 70nm
15.6 mJ/cm^2 dose
10x microstepper

EUVL Trend

Lithography "Laws"

- CD = $k_1*\lambda/NA$
- DOF = $1.2*\lambda/NA^2$

"k_1 factor"

Conventional: $k_1 = 0.7$

Strong PSM: $k_1 = 0.3$