Nanometer Scale Patterning and Processing

Spring 2016

Lecture 8

Optical Lithography – Alignment

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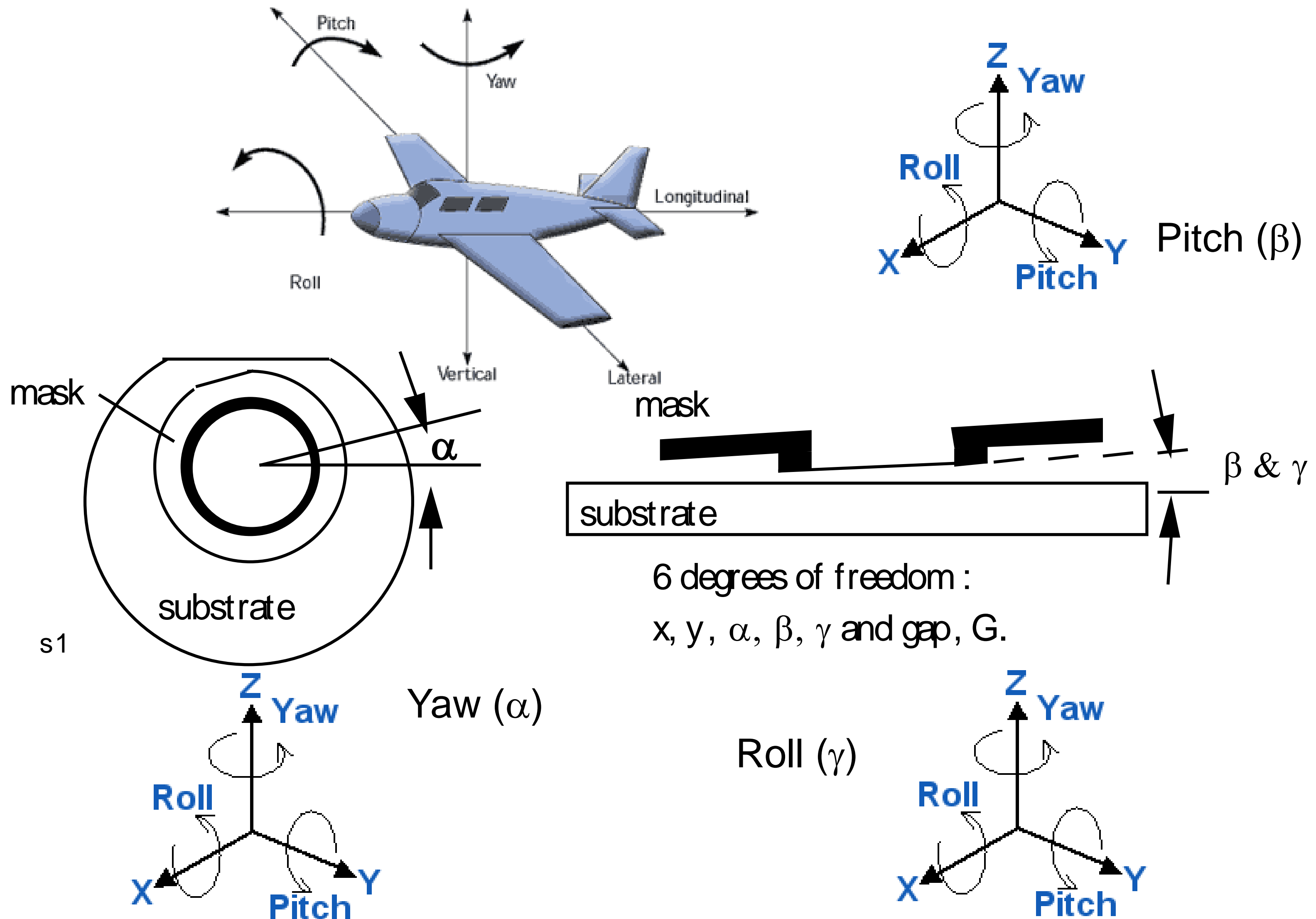
Degrees of freedom in alignment



Misalignment

- Registration: x, y, θ (yaw)
- Pitch and Roll: Mask and wafer are not perfectly placed in parallel
- Gaps are important for proximity printing using a point source (X-ray lithography)
  - Magnification error (or run-in and run-out)
- For steppers:
  - Global registration
  - Site-by-site registration
- Total misalignment $T = \left[\sum T_i^2\right]^{1/2}$

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Run-in and Run-out

Misalignment

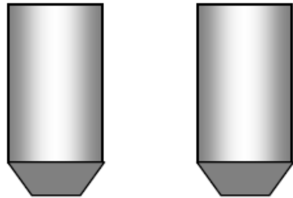
Runout

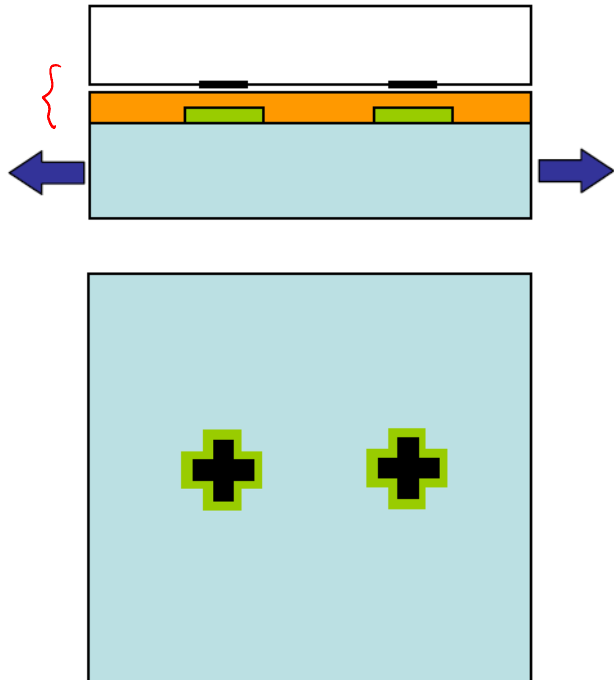
- Mask expansion
  - Fused silica thermal expansion coefficient: 5×10^{-7}°C^{-1}
  - < 20 nm over 8 inch → $\Delta T <$ 0.15 °C
  - Large amount of optical energy transmitted through masks
- Magnification Error in X-ray lithography systems

Alignment in Contact Optical Lithography

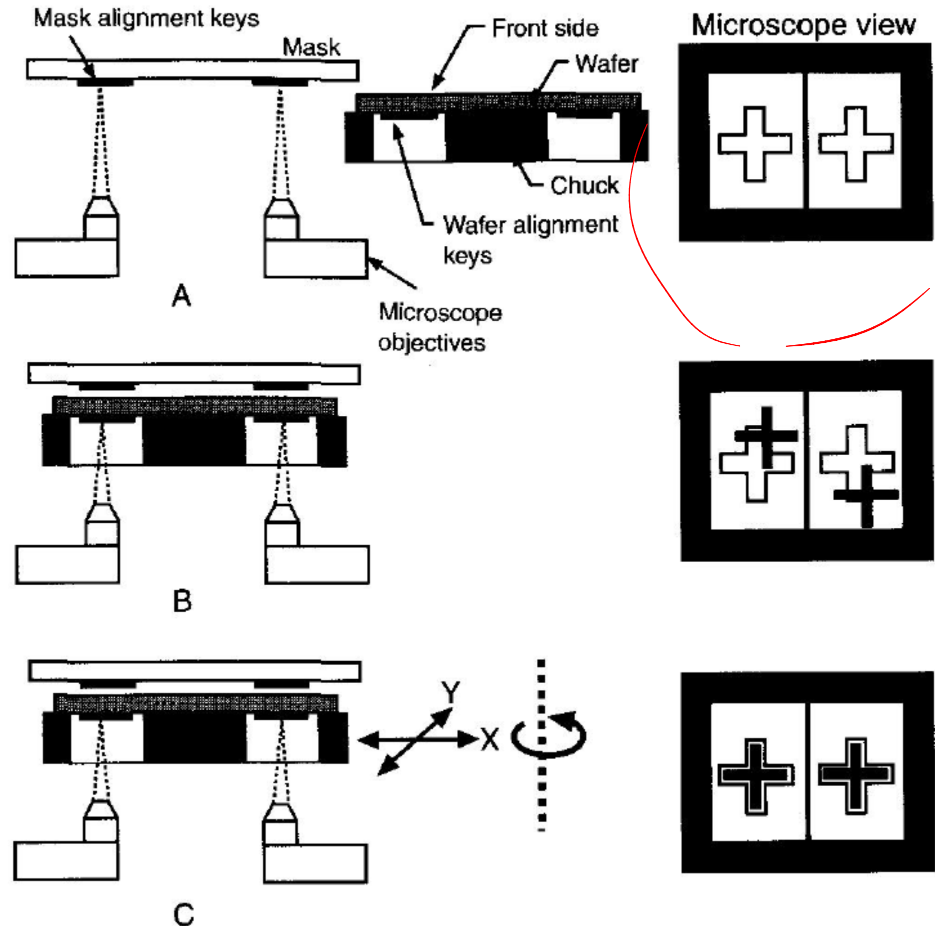
Front Side

Microscope objective lenses



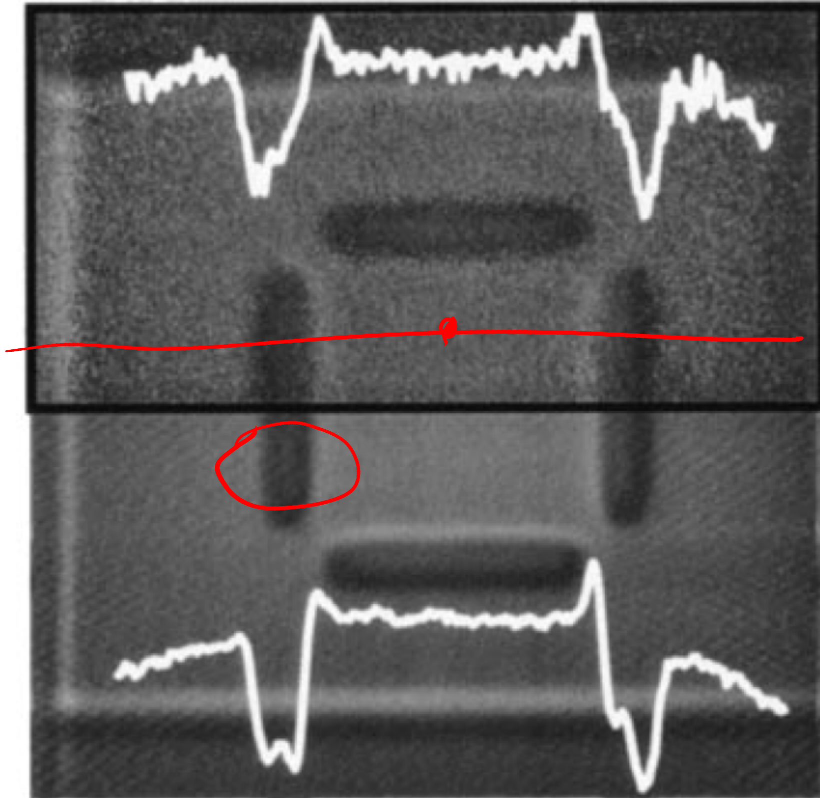


Back Side

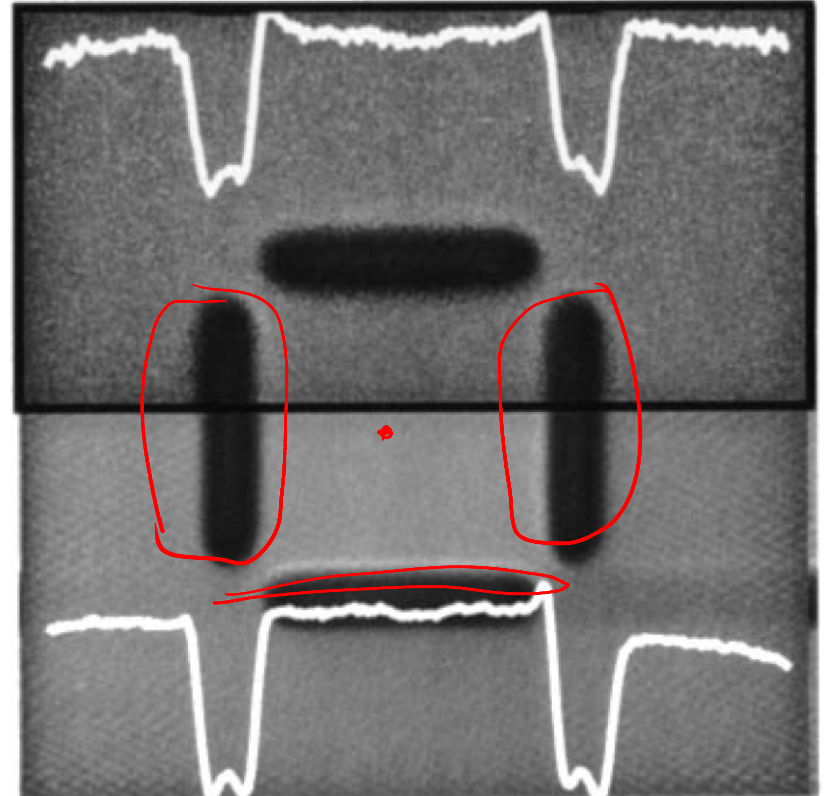


Detection of alignment marks

Low contrast



High contrast



- Algorithm looks for symmetry and calculates the center of the mark
- Alignment mark quality is the X-factor in lithography systems!

Alignment in Projection Optical Lithography

ATHENA and Reticle Blue Align

M1
M2
IMAGE FIELD
M3
M4
RETICLE
Exposure light
Reticle Alignment Mark
Fiducial
Wafer Stage

ATHENA
Wafer
Wafer Stage
TIS mark
Wafer Stage
Wafer Stage

Step 1- Align Wafer to Fiducial

Step 2 - Align Fiducial to Reticle + Focus

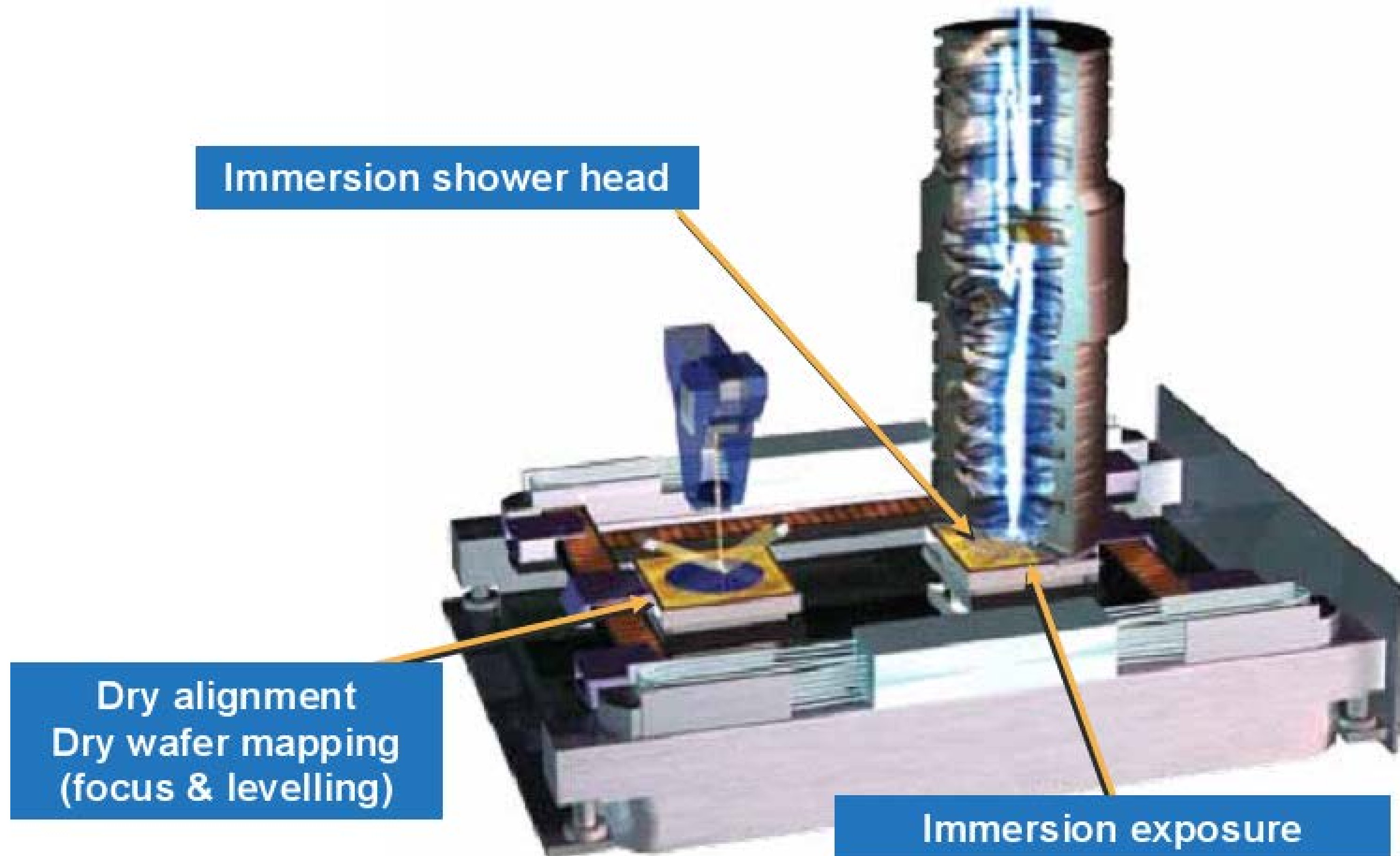
PAS5500/800 Introduction
January 2001

Lithography Throughput

$$T = \frac{1}{O + n \cdot [E + M + S + A + F]}$$

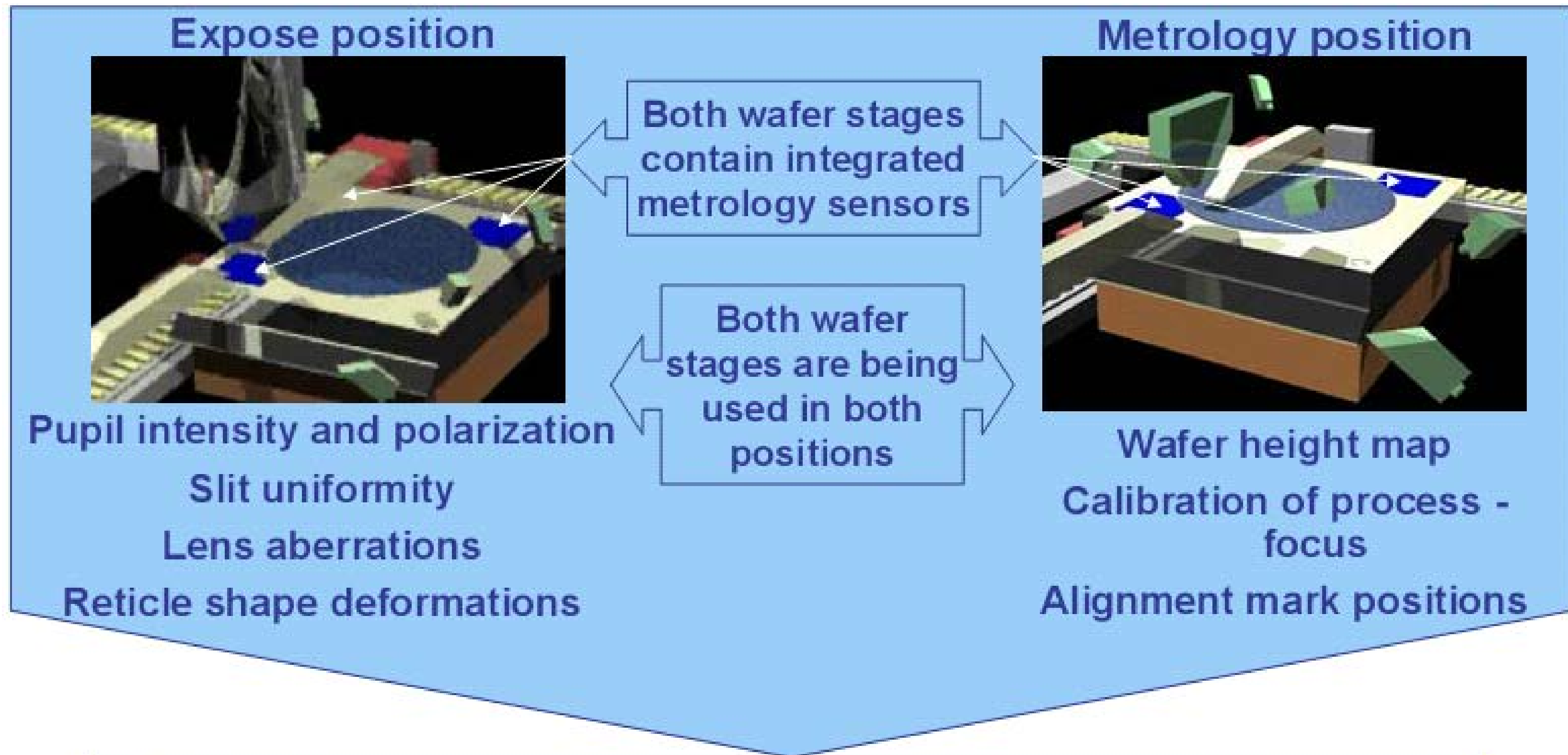
- *n*: number of die per wafer
- *E*: exposure time
- *M*: stage movement time per exposure
- *S*: stage settling time
- *A*: site-by-site alignment time (if used)
- *F*: auto-focus time (if used)
- *O*: overhead associated with loading/unloading, pre-alignment, moving the stage or wafer under the column and performing the global alignment

Dual Stages or “TwinScan”



- Eliminates *A, F, O*

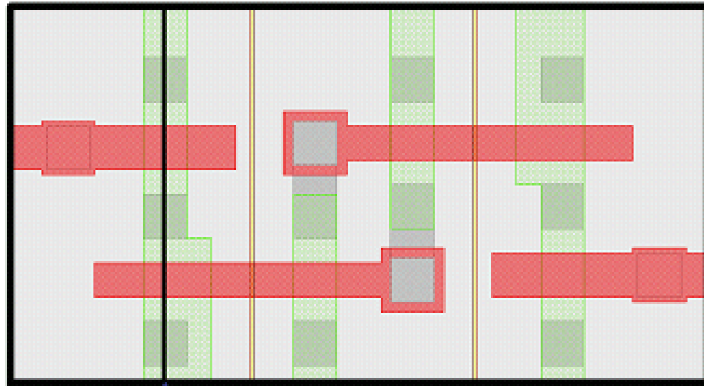
Integrated Metrology and Calibration



Increased Lithography Requirements

Resolution, CD uniformity & overlay drive shrink

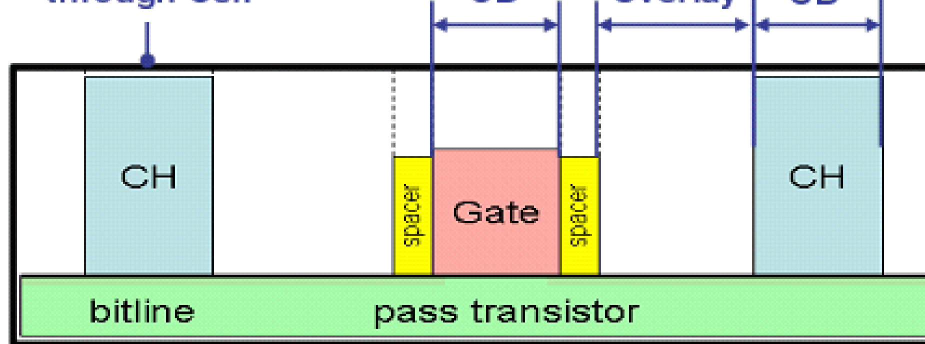
Layout 6 transistor SRAM Cell



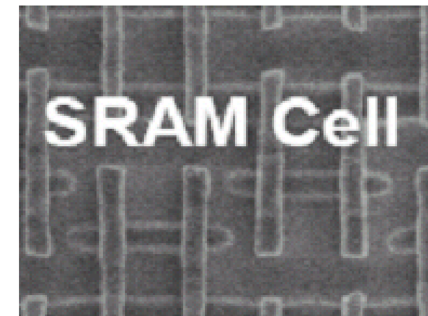
Design Rule & Cell Area [μm²]

Node	Aggressive	Typical	Relaxed
130 nm	2.00	2.50	3.00
90 nm	1.00	1.25	1.50
65 nm	0.45	0.55	0.80
45 nm	0.20	0.27	0.34
32 nm	0.10	0.13	0.19

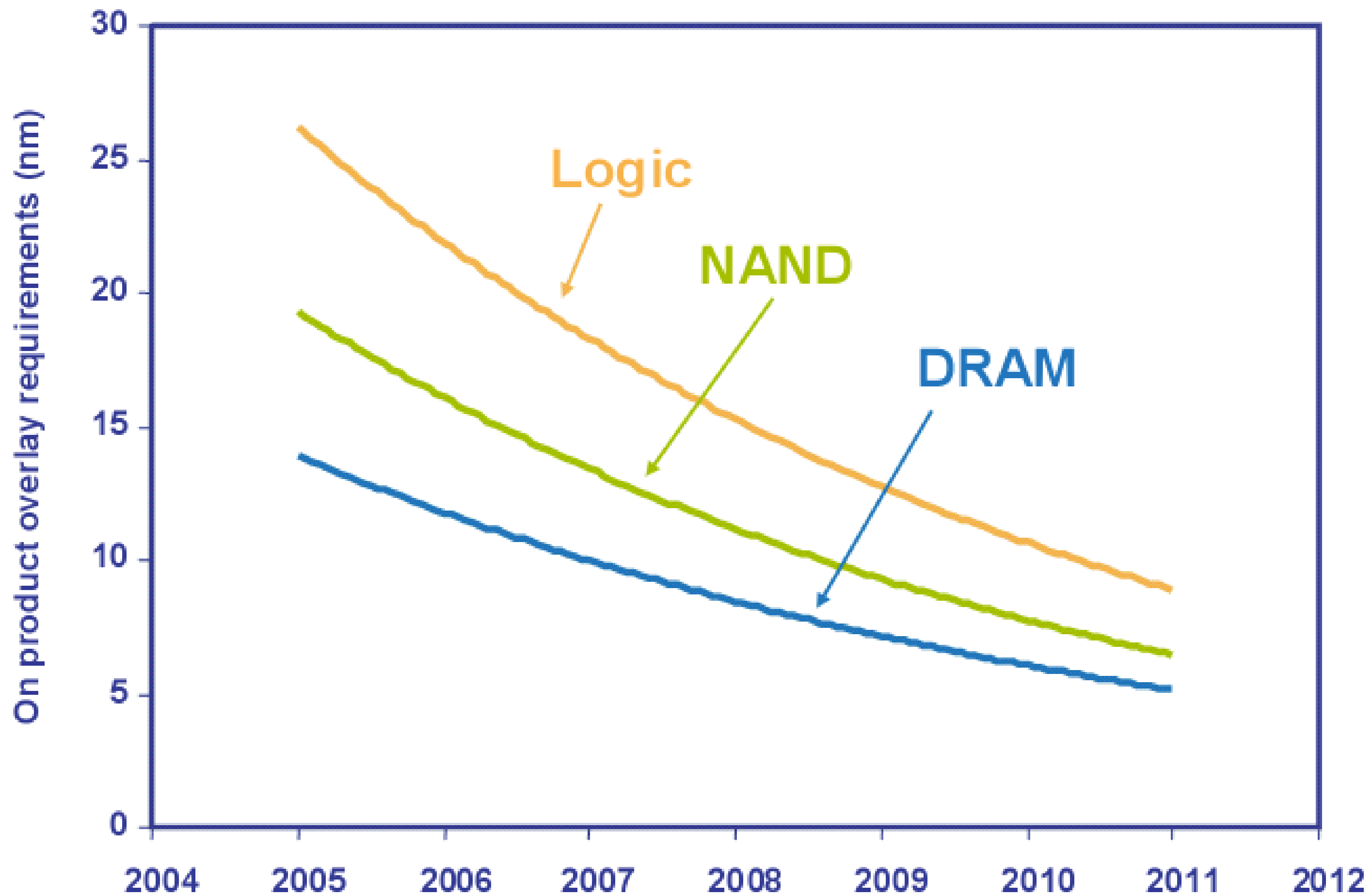
X-section through Cell



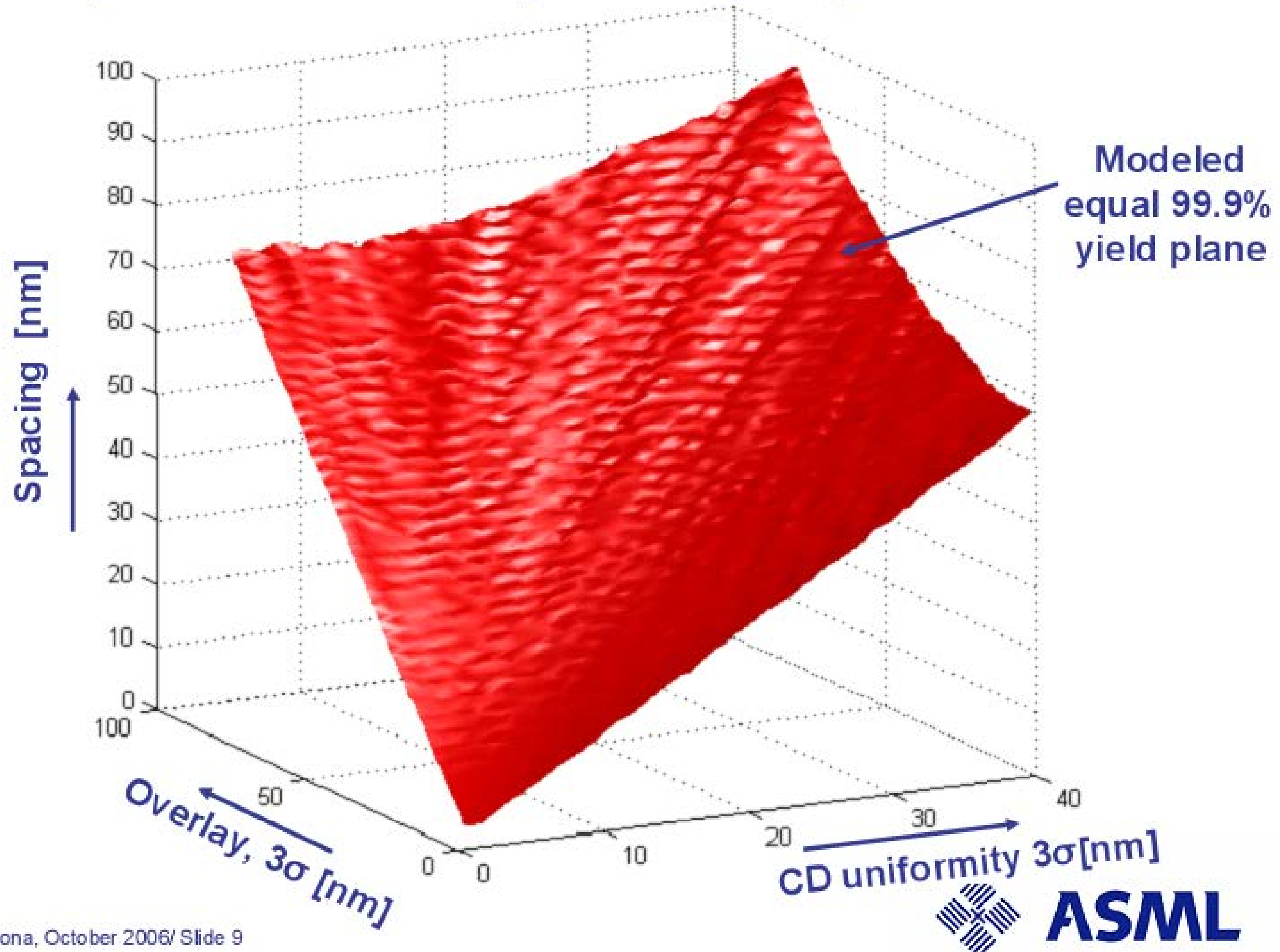
cell area 0.24 μm2
metal pitch 130nm
ArF immersion



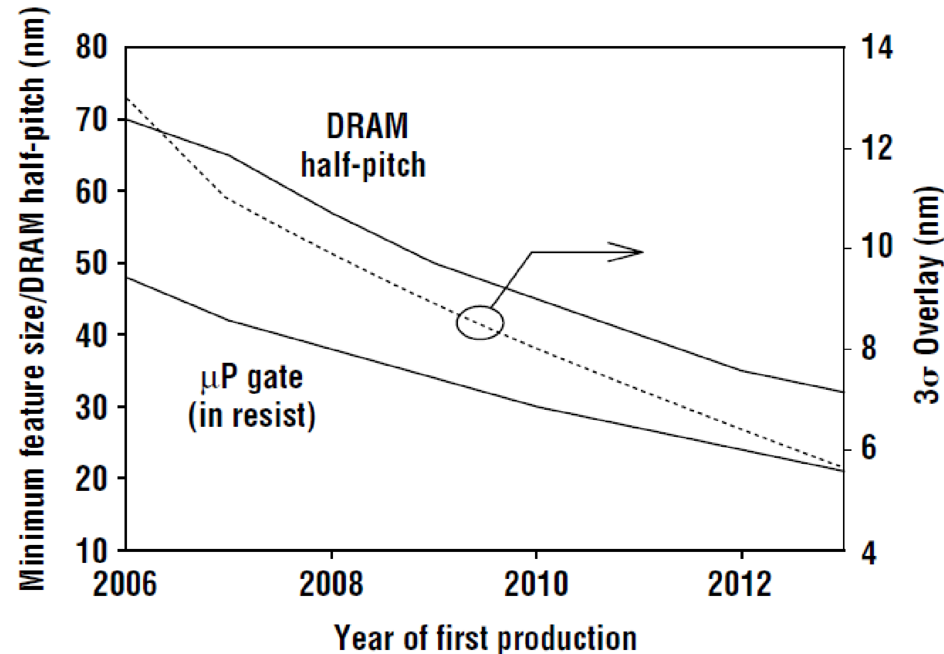
Shrink drives overlay requirements



Overlay and resolution (-control) key for device scaling



Resolution and Alignment Requirements



- Requirements are application specific
- Six-standard-deviation: 6σ
- Line width variation: $6\sigma < 10\%$ Minimum Line width (ML)
- Misalignment: $6\sigma \sim 1/3$ ML
  - Recently this requirement has been relaxed because registration at few nm is challenging