From ArF Immersion to EUV Lithography
Lithography is enabling…

ITRS Technology Trends – MPU Gate Length

Source: 2003 ITRS - Exec. Summary
Rayleigh equation

\[ \text{resolution} = k_1 \cdot \frac{\lambda}{NA} \]

Wave length scaling

193nm

157nm
157nm Challenges

**CaF₂ lens material**

**Catadioptric lens design**

- Transmission
- Radiation hardness
- Reticle heating

**Fluorinated resist materials**

**Mask technology**

- Modified SiO₂
- Pellicle: none / soft / hard
- Purging N₂ fill
- Surface contamination
- Transmission
- Radiation hardness
- Reticle heating
Rayleigh equation

\[ \text{resolution} = k_1 \cdot \frac{\lambda}{NA} \]

NA scaling
Immersion Lithography

Improvements in resolution

Snell’s law:

\[ NA = \eta_0 \sin \theta_0 = \eta_f \sin \theta_f = \eta_r \sin \theta_r \]
Immersion Lithography
Improvements in resolution

Snell’s law:

\[ NA = \eta_0 \sin \theta_0 = \eta_f \sin \theta_f = \eta_r \sin \theta_r \]
Immersion Litho

Extremely short introduction time
March 2002: Key note presentation @ SPIE Santa Clara
Burn Lin (TSMC): First suggestion to consider immersion lithography

**Immersion demonstration in record time**

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Immersion demonstration in record time

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**October / November 2003:**
ASML and IMEC demonstrate feasibility on 0.75NA immersion prototype scanner

First immersion **scanning** image on Oct 7, 2003

> 50% DOF gain demonstration
Immersion demonstration in record time

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January 2004: Sematech Lithography Forum Los Angeles
World momentum shifts entirely from 157nm to immersion lithography
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What Technology will you employ for leading edge gate manufacturing in 2009?

Survey Results:
- 248nm with enhancements
- 193nm with enhancements
- 193nm immersion
- 157nm immersion
- EUV
- EPL
- Charged Particle Maches
- Optical Maches
- Nano-Imprint
- Other

193nm immersion
157nm
Immersion demonstration in record time

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End 2004:
multiple 2nd generation 0.85 NA immersion scanners have been shipped (TSMC, IMEC)
Immersion Lithography
A few challenges

- Process interactions
- Defectivity
- Polarization effects
- Lens dimensions
Immersion Lithography
A few challenges

- Process interactions
- Defectivity
- Polarization effects
- Lens dimensions
Process Interactions

Interaction of resist/top coat with water
Some topcoats reveal an intrafield CD fingerprint similar to the soak simulations.
Process interactions

CD soak fingerprint using new developer soluble topcoats is significantly reduced compared to TSP3A (but still visible)

New developer soluble topcoats
Immersion Lithography
A few challenges

- Process interactions
- Defectivity
- Polarization effects
- Lens dimensions
Immersion defectivity

A spherical air bubble casts a shadow
“Bubble Defects”

Simulated (2-beam imaging) aerial image of 500nm bubble defect on 100nm L/S pattern
Bubble improvement (/1250i)

Non-optimized conditions

After optimization
Immersion specific defects

Scanner contributions

Bubbles
(related to shower head design, wafer chuck design, …)

Defects
(related to water residues, related to chuck/head design, …)

Resist/process contributions

Resist leaching
(resist composition, use of top coat, …)

Hydrophobicity
(material contact angle, material response to water droplets, …)

Water quality
(particles, bacteria, TOC, …)
Immersion Lithography
A few challenges

- Process interactions
- Defectivity
- Polarization effects
- Lens dimensions
Polarization at high NA

X-polarized (TM)  
NA=0.6  
Y-polarized (TE)  

Image contrast 70%  
Angle of incidence in resist 20°  

Image contrast 92%  

Medium NA (0.6) in resist (n=1.7)
Polarization at high NA

X-polarized (TM)  NA=0.85  Y-polarized (TE)

Image contrast 49%

Angle of incidence in resist 30°

Image contrast 92%

High NA (0.85) in resist (n=1.7)
Polarization at high NA

X-polarized (TM)  \( \text{NA}=1.3 \)  Y-polarized (TE)

Angle of incidence in resist  

-1 +1

Image contrast -8%

50°

Very High NA (1.3 immersion) in resist (n=1.7)
Contrast enhancement with polarization

SRAM, half pitch 55 nm, pitch 110 nm, 6% att PSM, dipole Y

0.93 NA
dry

Un-polarized

Polarized

Design adjustments
Immersion Lithography
A few challenges

- Process interactions
- Defectivity
- Polarization effects
- Lens dimensions
Hyper NA: lens cost
Hyper NA: lens cost

G-line lens
1975

193nm lens
2003

>1000 mm

>300 mm
Cost innovations in Optics for hyper NA

- Expected according geometrical scaling dioptric
- Released or expected dioptric
- New catadioptric design

NA

Air

Water

Lens complexity

0.63 0.75 0.85 0.93

n air

0.93 i 1 1.09 i 1.1 i 1.2 i 1.3 i 1.43 i

n water

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Outline

Introduction

193nm immersion lithography
  Status, Challenges, Outlook

EUV lithography

Global collaboration

Conclusions