Lithography options for the 32nm half pitch node
Lithography options for the 32nm half pitch node

Luc Van den hove and Kurt Ronse
ITRS roadmap: 32 nm half pitch requirement

2005 ITRS Product Technology Trends -
Half-Pitch, Gate-Length

Before 1998
0.71X/3YR

After 1998
0.71X/2YR

MPU M1
0.71X/2.5YR

MPU & DRAM M1 & Flash Poly
0.71X/3YR

Flash Poly
0.71X/2YR

Gate Length
0.71X/3YR

GLpr IS = 1.6818 x GLph

Year of Production


Product Half-Pitch, Gate-Length
(nm)
### 32nm half pitch options

<table>
<thead>
<tr>
<th>NA</th>
<th>$k_1$</th>
<th>$\lambda$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ArF Immersion</td>
<td>ArF Immersion with double patterning</td>
<td>EUVL</td>
</tr>
<tr>
<td>1.65 NA (k$_1$=0.275)</td>
<td>1.35 – 1.40 NA (k$_1$=0.20)</td>
<td>0.25 NA (k$_1$=0.6)</td>
</tr>
<tr>
<td>Single exposure</td>
<td>Single exposure</td>
<td>Single exposure</td>
</tr>
</tbody>
</table>

**Technical challenges:**

- **Lens complexity**
  - New liquid ($n>1.8$)
  - New optical material ($n>1.9$)
- Overlay requirement
- Process integration
- Source power
- Optics lifetime
- Resist infrastructure
- Mask infrastructure

**Resolution formula:**

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

• Introduction

193 nm immersion lithography

• EUV Lithography

• Double patterning

• Conclusions
193nm immersion lithography

from RESEARCH IDEA… to DEVELOPMENT

in WORLD RECORD TIME
193nm immersion lithography

from DEVELOPMENT... to MANUFACTURING ???

Is immersion ready ?
Status 193nm immersion lithography

**Defectivity**

- Air bubbles
- Water marks and drying stains
- Resist / TC – water interaction
- Particles
Status 193nm immersion lithography

Defectivity

Air bubbles: no longer an issue

Early config. 24 bubbles

Latest XT:1250i config. 0 bubbles
Status 193nm immersion lithography

Defectivity

Water marks and drying stains

Receding contact angle approaching 0
- Depends on material hydrophobicity
- Depends on scan speed (500mm/s)
  ...

imec 2006
Status 193nm immersion lithography

Defectivity

Water marks and drying stains

![Graph showing the relationship between receding contact angle and number of water droplets.](image)
Status 193nm immersion lithography

Defectivity

Resist / TC – water interaction

Leaching of resist components in the water

Water uptake by resist / TC...
Defectivity

Leaching status

Method in place for dynamic leaching measurements

Amount of leaching during first 1-2 seconds is key (for a high throughput immersion scanner)
Status 193nm immersion lithography

Defectivity

Resist / TC – water interaction

Leaching status

Method in place for dynamic leaching measurements
Top coats very efficient in preventing leaching (~100 x less)

Leaching currently prime reason to use top coat
Recent immersion specific resists much lower leaching (factor 4)
(5.10^{-12}mol/cm plateau)
Status 193nm immersion lithography

Defectivity

Wafer edge film peeling
Edge bead engineering!

Particle transport
from chuck onto wafer

Particles
Status 193nm immersion lithography

**Defectivity**

**Particles**

**Wafer edge film peeling**

Edge bead engineering!

Before exposure

After exposure

Before develop

SEM after develop
Breakthroughs by strong partnership

Defect reduction trend (daily monitor)

Spectacular progress over the past 12 months
193nm immersion lithography

Polarization

“Litho friendly 6T SRAM design”

0.186 \mu m^2 \text{ cell size}

32nm node

ASML XT:1250i

0.85 NA

SRAM array after spacer etch

Fin hp : 62nm (0.273 k_1)
Poly hp : 75nm (0.330 k_1)
193nm immersion lithography

**Polarization**

"Litho friendly 6T SRAM design"

<table>
<thead>
<tr>
<th></th>
<th>BE+6.6%</th>
<th>BE+3.3%</th>
<th>BE</th>
<th>BE-3.3%</th>
<th>BE-6.6%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Un-polarized</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polarized</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>

**ASML XT:1400**

0.93 NA

Dipole Y illumination

**Fin hp 55nm (0.265 kᵣ)**

22nm node
193nm immersion lithography

Hyper NA 193i

<table>
<thead>
<tr>
<th>Feature</th>
<th>k₁</th>
<th>NA</th>
<th>σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>50nm</td>
<td>0.31</td>
<td>1.2</td>
<td>0.74/0.94, annular</td>
</tr>
<tr>
<td>400nm DoF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-210nm</td>
<td>-150nm</td>
<td>-90nm</td>
</tr>
<tr>
<td>45nm</td>
<td>0.28</td>
<td>1.2</td>
<td>0.82/0.97, C-Quad-30</td>
</tr>
<tr>
<td>500nm DoF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-300nm</td>
<td>-240nm</td>
<td>-120nm</td>
</tr>
<tr>
<td>42nm</td>
<td>0.26</td>
<td>1.2</td>
<td>0.89/0.98, Dipole X-35</td>
</tr>
<tr>
<td>950nm DoF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-500nm</td>
<td>-300nm</td>
<td>-180nm</td>
</tr>
</tbody>
</table>

ASML XT1700i - NA=1.2
193nm immersion lithography

**Hyper NA 193i**

- **41nm, approaching 0.25k₁**
  - P86 – k₁ 0.267
  - 43nm dense
- P84 – k₁ 0.261
  - 42nm dense
- P82 – k₁ 0.254
  - 41nm dense

**ASML XT:1700i**

1.2 NA

1.2NA, Y-pol, dipole X 35° s=0.98-0.89
CPL – chromeless lines
42nm barc, 120nm resist, topcoat
193nm immersion lithography

**Ultimate limits**

- $k_1$ as function of **NA** and **half pitch** ($\lambda=193\text{nm}$)

**Diagram:**

- $k_1 < 0.27$
- $k_1 < 0.4$

**32nm half pitch limit requires 1.65 NA**

**Legend:**

- Red: $k_1 < 0.27$
- Yellow: $k_1 < 0.4$
- Green: $k_1 < 0.75$

**Axes:**

- NA (0.75 to 1.65)
- Half Pitch (15 to 60 nm)
193nm immersion lithography
Liquids beyond water?

High index liquid testing on ASML Immersion Interference Printer

Excimer laser

HIL stays between prism and wafer during stage motion

Stages
193nm immersion lithography
Outlook high index liquids

- Lithographic results 2\textsuperscript{nd} generation fluids (n=1.65) : 36nm HP

\textit{Water (n=1.44)} : \textbf{14.6 \% EL}

\textit{HIL (n=1.65)} : \textbf{18 \% EL}
2nd generation HI liquids
Contact angle measurements

- Much lower surface tension: containment?
2nd generation HI liquids
Interaction HI liquid with resist (defect formation ?)

• Purpose:
  – apply droplets of the liquid on either an inert substrate or resist surface in a controlled way
  – Analyse what is left after drying (profilometry)
NA=1.65 requirements

**Application**
- High $n_f$ Resist development
  - Imaging characterization, defectivity
- High $n_f$ Fluid characterization ($n_f > 1.9$)
  - Defectivity: Leaching & drying stains

**Immersion system**
- Fluid recycling system
  - Radiation & contamination evaluation
- Fluid containment
  - Scanning tests & IH evaluation

**Lens**
- Optical system
  - HRI glass evaluation ($n_f > 1.8$)

Can we use HI fluids?
Can we make the system?
Can we make the lens?

**TIMING is most critical**
193nm immersion lithography

**Ultimate limits**

- $k_1$ as function of NA and half pitch ($\lambda = 193\text{nm}$)

![Graph showing $k_1$ as a function of NA and half pitch](image)
Outline

- Introduction
- 193 nm immersion lithography

EUV Lithography

- Double patterning
- Conclusions
• 2005 International Symposium on EUVL

Critical Technical Issues for EUV Lithography

Top 3 Critical Issues
1. Resist resolution, sensitivity and LER
2. Collector lifetime
3. Availability of defect free masks
4. Source power

2004 Rank
3
2
1

Remaining Critical Issues
• Reticle protection during storage, handling and use
• Projection and illuminator optics quality and lifetime

*** Significant concern: Timing and cost / business case for EUVL development.
Experimental : Interference Lithography
Paul Scherrer Institute (PSI), Switzerland

Mask:

$P_{\text{wafer}} = \frac{P_{\text{mask}}}{2}$
## EUV Resist progress

<table>
<thead>
<tr>
<th></th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
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<tbody>
<tr>
<td>40 nm</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
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<tr>
<td>32.5 nm</td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
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<tr>
<td>30 nm</td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
</tr>
<tr>
<td>Dose</td>
<td>20 mJ/cm²</td>
<td>7.5 mJ/cm²</td>
<td>12.4 mJ/cm²</td>
</tr>
</tbody>
</table>
AD-tool imaging results:

**40nm** scanning H-lines/spaces ‘through focus’

**40nm L/S**

-100 nm  
-50 nm  
near focus  
+50 nm  
+100 nm

>200 nm DOF

Resist: MET-2D

~18 mJ/cm²

NA=0.25, σ=0.5

no process optimization yet
AD-Tool imaging results:

**40nm** scanning H-lines/spaces ‘through slit’

Full slit coverage

**40nm L/S**

- Resist: MET-2D
- $\sim 18$ mJ/cm$^2$
- $NA=0.25, \sigma=0.5$
- no process optimization yet

(22-May-’06)
AD imaging results: 55 nm CH

Dense (aligned)  Dense (staggered)  Iso (aligned)  Iso (staggered)

All at same conditions:
- NA/Illumination/focus/dose
- Binary mask
- No OPC applied!

55 nm CH
Resist: MET-2D
no process optimization
~40 mJ/cm²
NA=0.25, σ=0.5
Double patterning

Outlook

- $k_1$ as function of NA and half pitch ($\lambda=193\text{nm}$)
Outline

- Introduction
- 193 nm immersion lithography
- EUV Lithography
- Double patterning
- Conclusions
Double patterning (2x litho + 2x etch)

Possible integration flow

Exposed 1

& development

Transfer to hardmask

Exposed 2

& development

Transfer to hardmask

1nm alignment error -> 1nm CD change

ASML XT: 1400
0.93 NA

40 nm L&S
etched in oxide
hard mask on poly-Si

$k_1$ = 0.19
Design Split exercises NAND FLASH
Double Line for Poly

TARGET
min pitch 64nm
k1 = 0.22

SPLIT + OPC
min pitch 128nm
k1 = 0.44

PROCESS CHECK
Annular 0.8/0.4
Unpolarized
1.35NA

intuitive split.
Design Split exercises NAND FLASH
Double Trench for Poly

TARGET
min pitch 64nm
k1=0.22

SPLIT + OPC
min pitch 128nm
k1=0.44

PROCESS CHECK
Annular 0.85/0.55
Unpolarized
1.35NA
Design Split exercises Logic NOR
Double Line for Poly

TARGET

SPLIT + OPC

PROCESS CHECK
Annular 0.8/0.4
Unpolarized
1.35NA

min pitch 90nm
k1=0.31
Design Split exercises Logic NOR

Double Trench for Poly

TARGET

SPLIT + OPC

PROCESS CHECK

Annular 0.8/0.4
Unpolarized
1.35NA

min pitch 90nm
k1=0.31
Double Line for Poly
DP k1=0.14

resist
48.7nm at 130nm pitch
LER(3s) 3.1nm

HM etch&strip
38nm at 130nm pitch
LER(3s) 5nm

resist+HM
48.7nm at 130nm pitch
LER(3s) 3.1nm

Poly
32nm at 65nm pitch
Double patterning

Outlook

- $k_1$ as function of NA and half pitch ($\lambda = 193$nm)
Double patterning

Outlook

• **Lowest risk route to 32nm half pitch in time**

• **But... worst in terms of CoO**
  - Requires 2 critical masks per critical layer
  - Reduces throughput (≈ factor 2)
  - Adds cost of second etch step
  - Impacts total cycle time (additional photo, etch, ...)
  - Some integration approaches very critical for alignment

• **Any development improving CoO issues is a plus for double patterning**
Outline

• Introduction
• 193 nm immersion lithography
• EUV Lithography
• Double patterning

Conclusions
Summary and conclusions

- Still 3 lithography options for 32nm half pitch critical levels
- Immersion lithography beyond water urgently needs a 3rd generation fluid (n>1.8) to be identified
- EUV lithography makes steady progress
  - First ASML EUV alpha demo tools about ready to ship to the field
  - EUV resist has become issue number one and requires a lot of focus
  - EUVL is the solution for small contact holes!
- Double patterning is the lowest-risk route towards 32nm but CoO needs to be controlled
- Towards 22nm volume production, EUVL is the only option
• $k_1$ as function of NA and half pitch ($\lambda=193\text{nm}$)
Aknowledgements

The world’s largest 193nm immersion lithography effort
Thank you!

imec