Metal Oxide EUV Photoresists for N7 Relevant Patterns

Stephen T. Meyers, Andrew Grenville
Resists Designed for EUV Lithography

Integration

Stochastic Variability

MOx Resist

RLS
Baseline MOx Resist Platform

- SnO$_x$ based resist
- $E_{\text{size}}$ @ 16nm HP: $\sim$37 mJ/cm$^2$
  - $E_{\text{Lmax}}$: 29%
  - Resist thickness $\sim$18nm

- Formulation scaled to multi-gallon batches, installed on multiple tracks/fabs enabling critical learning:
  - Track Compatibility
  - Stability
  - Filtration
  - Defectivity
  - CDSEM Metrology
  - OPC / Litho modeling

16L32P
CD = 16.3 nm
LWR = 3.8 nm
NXE:3300
dip90Y

Resist Age vs. Dg (mJ/cm$^2$)

Resist Age (Days)
MOx Resists Fab Acceptance

- Matrix Metal: Sn
  - Track / Etch Cross Contamination
  - EUV Outgassing

- Trace Metal Impurities
  - Developed ICP-MS methods to eliminate mass interferences from Sn
    - Enabling Lower Detection Limits
    - Example: isotope overlap between $^{112}$Sn and $^{112}$Cd
  - Demonstrated multiple large batches with no detectable trace metals

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**All tested trace metals < 10 ppb**

<table>
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<tr>
<th>Element</th>
<th>Batch #1</th>
<th>YP-Series</th>
<th>Batch #2</th>
<th>Batch #3</th>
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MOx Resist Integration: IMEC iN7 Metal 2 Block Layer

Conventional approach using a tri-layer system – 4 ETCH steps
- Exposure
- SOG etch
- SOC etch
- SOG removal

TiN etch
SOC Strip

Novel approach using INPRIA resist directly on SOC – 2 ETCH steps
- Exposure
- SOC etch

Simplified Etch Process

CD-X Target 21nm ± 10%
Dose to size: 49mJ/cm²
Customized illumination
$E_{\text{max}}$: 22%, DOF @ 10%EL: 118 nm
X-Wafer CDU 3σ: 1.8nm

MOx Resist Integration: IMEC iN7 Metal 2 Block Layer

INPRIA resist after development

Spin-On-Carbon opening

- High Resist-SOC etch selectivity
- Straight SOC pillar profile
- Constant litho-etch CD bias through pitch for these structures

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MOx Resist

RLS
EUV Photon Shot Noise

- Consider contacts/pillars
- Photon shot noise $\rightarrow$ dose fluctuation from contact to contact
- Billions of contacts per die: need to consider $7\sigma$ variation

Photon Density
25 mJ/cm$^2$

18 nm Contact
Absorbed Photon Shot Noise

- Variation in effective dose due to statistical distribution of absorbed photons
- When too few absorbed, contact/pillar will not form
- Exposure latitude of resist process must accommodate this variation

<table>
<thead>
<tr>
<th>Resist</th>
<th>Absorbance (1/μm)</th>
<th>Thickness (nm)</th>
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<tbody>
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<td>25</td>
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<tr>
<td>CAR</td>
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Stochastic Material Composition: CAR

18 nm contact

= 2036 PAGs, 407 Quencher

PAG = A
Quencher = Q

± 16% PAG
± 35% Quencher

At 7σ

Assume: 40 nm FT, 0.2 PAG/nm³, 0.04 Quencher/nm³
Stochastic Material Comparison

• Inpria materials have lower initial stochastic variability
  – No minor components
  – Small, uniform building blocks (~1.4 nm dia)
  – High concentration of bound photoactive centers

• Higher Homogeneity
Resist Modeling

- Initial Inpria resist model created using PROLITH™
  - Based on physical measurements and CDSEM of pillars & lines
  - Baseline resist
- 20,000 contacts simulated
  - 18P36, NA 0.33, Quad30

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<td>CAR2</td>
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MOx Resist

RLS
Resist Performance Improvements Toward N7 Targets

- Targeted design changes reduce $D_{gel}$ while preserving contrast
- Multiple formulations tested with improved Esize vs LWR relative to baseline
16nm HP below 20 mJ/cm²

- 24 mJ/cm², 3.6 nm LWR
- 18 mJ/cm², 4.2 nm LWR
- 14 mJ/cm², 5.1 nm LWR

CD = 15.9 nm
CD = 15.9 nm
CD = 16.0 nm

NXE:3300, Dipole 60x
Integrating New Formulations in IMEC M2 Process

NXE3300 – NO RETICLE BIAS, CD-X 21nm ± 10%

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Next Gen.</th>
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<tr>
<td>Dose [mJ/cm²]</td>
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<td>19</td>
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<tr>
<td>EL %</td>
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<tr>
<td>DOF @10%EL [nm]</td>
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<td>120</td>
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<tr>
<td>CDU (3σ) [nm]</td>
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Focus offset:
- 105 nm
- 85 nm
- 65 nm
- 45 nm
- 25 nm
- 5 nm
- 15 nm
Beyond N7: 13nm LS @ 26 mJ/cm² w/ Process Window

- NXE3300, Dip45x
- 13nm L/S – No Bias
- \( EL_{\text{max}} \): 17%
  \( \text{DOF}@10\%EL \): 140 nm
- Dose to size: 26 mJ/cm²

27.0 mJ/cm²
13.2 nm CD
4.6 nm LWR
Summary

Sampling baseline resist for process development and fab integration

High absorbance and small photoactive building blocks lower initial stochastic variability

Improved dose vs LWR: < 20 mJ/cm² at N7 pitches
MOx Outlook

- Low photon / material stochastic variability
- Competitive LWR-Dose

But what are the real limits?

Better MOx Modeling → parameterize descriptive understanding of MOx resists

**Effective Quantum Yield**

**Solubility Change / Radiation Event**

\[ D_g = 2.3 \text{ mJ cm}^{-2} \]
\[ \gamma = 11 \]
THANK YOU

... and all of our partners