Nowadays RLS trade-off and stochastic defects problems are important problems.

Today’ my talk is as follows:

1. Fundamental concepts of EUV CAR and PSCAR

2. Future Prospects of PSCAR
Talk today: Fundamental Concepts of CAR and PSCAR EUV lithography and Future Prospects of PSCAR

Nowadays RLS trade-off and stochastic defects problems are important problems in industries.

Today’ my talk is as follows.

1. Fundamental concepts of EUV CAR and PSCAR

2. Future Prospects of PSCAR
**Comparison of PSCAR 1.0 with PSCAR2.0**
(Nagahara et al., SPIE Advanced Lithography 2017)

In this SPIE Advanced Lithography 2020, Advances in Patterning Processes, Tuesday 10:30, Nagahara presents recent progress of PSCAR in industries.

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Step to PSCAR: Sensitivity Enhancement of CAR

• 1982 CAR: C.G. Willson, H. Ito and Fréchet

• 1984 Y. Tabata, S. Tagawa, M. Washio: EB Resist (CMS) reaction and HCl formation mechanisms were made clear by picosecond pulse radiolysis, such as geminate ion recombination, dissociative electron attachment, hole transfer.

• 1992 T. Kozawa, S. Tagawa et al: EB CAR resist reaction mechanisms were cleared by picosecond pulse radiolysis, geminate ion recombination, dissociative electron attachment, proton transfer.

• 2000 S. Tagawa, S. Nagahara et al.: Differences between reaction mechanism of EB and KrF CAR were made clearly.

• 2004 S. Tagawa, 1st European Workshop on Resist Limitations, Erlangen, 14 December, 2004 and then Co-work with Intel (2005-2008)

• 2005 Gallatin Gallatin: Importance of initial acid distribution for RLS trade-off were made clearly.

• 2008 Todd (Intel)’ report: RLS trade-off

• 2010 Kozawa and Tagawa: Review of Radiation Chemistry of CAR


• 2013 PSCAR

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When Hiroshi Ito joined IBM in 1980, high sensitivity of deep UV resists was required because of very weak intensity of deep UV exposure source. He began working on several projects under C.G. Willson. They proposed three systems: an acid-catalyzed polarity change, cationic polymerization and depolymerization. As the three systems were characterized with a gain mechanism, they decided to call these resist systems "chemical amplification resists."
Reaction mechanisms of EUV and photo resists

- **EUV resists (Main process) Ionization channel**
  - Dissociative Electron Attachment
  - Geminate ion recombination
  - Proton Transfer (Hole Transfer)

- **Photoresists (Main process) Excitation channel**
  - Homolysis
  - Heterolysis
  - in-cage Recombination
  - cage-escaped

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Interaction of EUV photon with CARs

- spatial distribution -

EUV photon (92.5 eV)

\[ \frac{\partial I}{\partial z} = -\alpha I \]

Intensity of EUV (I)
Absorption coefficient (\( \alpha \))
PHS : 3.8 \( \mu \)m\(^{-1} \)

Ionization
Thermalization
Multi spur effect

Electron > IP
Electron < IP

Inelastic mean free path
<1 nm mean free path at electron with energy > IP

Thermalization Length 4.0 nm for PHS

The number of secondary electrons is estimated experimentally. 4.2 for PHS

PHS with 10 wt% TPS-tf Acid molecules per photon: 2.6


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EUV Mechanism\(^1\) Provides RLS Gain?

- Resist Sensitivity Improved 30-50% via Addition of EUV Sensitizing Agents.
- No Loss In Resolution or Degradation in LWR

\textbf{Multiple Suppliers Achieving Similar Results in 1H’08}


\[^1\text{Kozawa, et al. JVSTB 25, 2481 (2007)}\]

\begin{itemize}
\item Resist A  
\hspace{1cm} S=27.5 mJ; L<5.5 nm
\item Resist B  
\hspace{1cm} S=14.0 mJ; L<5.0 nm
\end{itemize}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{eresist.png}
\caption{Resist sensitivity comparison with and without sensitizer.}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{eresist2.png}
\caption{High performance EUV resist image.}
\end{figure}
Subpicosecond Pulse Radiolysis System

- Femtosecond Electron Linear Accelerator
  - Femtosecond Electron Linear Accelerator
  - SHPB amplifier
  - Magnetic pulse compression system
  - E-gun
  - L-band linac
  - Linac control panel
  - Master oscillator
  - Trigger generator with synch. circuit
  - Pulse generator
  - To other devices such as oscilloscope and so on.

- Pump & Probe Spectroscopy
  - Time jitter compensation system
  - Light detection system
  - Optical delay

- Femtosecond Laser
  - Femtosecond laser system in clean room

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Femtosecond pulse radiolysis system
@ISIR, Osaka Univ.

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Attosecond pulse radiolysis (next plan)

K. Kan et al., Proc. NOCE (Nonlinear dynamics and Collective Effects in particle beam physics) 2017

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Miniaturization of ULSI and Exposure Wavelength Reduction Trends

- **Moore's Law**: $R = k_1 \frac{\lambda}{NA}$
  - $R$: resolution
  - $\lambda$: exposure wavelength
  - $k_1$: constant depending on resist materials and processes and exposure methods
  - $NA$: numerical aperture of optical system

R: resolution $\lambda$: exposure wavelength $k_1$: constant depending on resist materials and processes and exposure methods

**Very Big Change from ArF to EUV Lithography**

Only less than 2.3 times reduction from g-line to ArF (436 nm/193 nm) takes more than 20 years, but more than 14 times reduction (193 nm/13.5 nm) occurs from ArF to EUV.
PSCAR process flow to break RLS tradeoff relationship

Coating and PAB
Resist Coating

EUV pattern exposure
Acid and photosensitizer generation

UV flood exposure
Additional acid generation by photosensitization

PEB
Resist polarity change reaction (deprotection etc.)

Development
High sensitivity & high resolution pattern formation

PSCAR™
Photo-Sensitized
Chemically Amplified Resist™

PSCAR material and UV flood exposure module are new development items
Initial acid (a) and base (b) distribution exposed by EUV pattern exposure.

When photosensitizer generation is much faster than acid and base neutralization, acid (a), quencher (b) and photosensitizer (PS) distributions are shown.

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Initial acid (a) and base (b) distribution exposed by EUV pattern exposure

When photosensitizer generation is much slower than acid and base neutralization, acid (a), quencher (b) and photosensitizer (PS) distributions are shown.

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When photosensitizer generation is much faster than acid and base neutralization, acid (a), quencher (b) and photosensitizer(PS) distributions are shown.

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Acid (A) and quencher concentration (B) of resist containing PBG after UV flood exposure before PEB

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Miniaturization of ULSI and Exposure Wavelength Reduction Trends

Moore's Law

\[ R = \frac{k_1 \lambda}{NA} \]

NA = \( n \cdot \sin \theta \)

\( n \): Reflective index

R: resolution \( \lambda \): exposure wavelength

\( k_1 \): constant depending on resist materials and processes and exposure methods

NA: numerical aperture of optical system

Very Big Change from ArF to EUV Lithography

Only less than 2.3 times reduction from g-line to ArF (436 nm/193 nm) takes more than 20 years, but more than 14 times reduction (193 nm/13.5 nm) occurs from ArF to EUV.
Conclusion

- The new PSCAR processes can produce much higher concentration of photosensitizer (PS) than other PSCAR because of low quencher concentration during EUV exposure. It is good for stochastic problems.
- Higher PS can reduce flood exposure dose. The lower flood exposure dose is good for UV flood exposure side reaction problems. It is good for random noise problems.
- The new PSCAR processes can keep constant pattern resolution even for higher dose based on the control of the ratio of acid yields to quencher yields. EUV pattern exposure determine the pattern size and the new PSCAR flood exposure process getting high sensitivity without losing resolution. The new PSCAR has the possibility of overcoming or reducing the stochastics problems such as missing and kissing contact holes and micro-bridge and line braking of line/space.
Acknowledgments

We would like to acknowledge members of collaboration members of PSCAR process.
Thank you for your kind attention.