Characterization of EUV resist related outgassing and contamination

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Outline

- Introduction
- Time dependency and post-exposure outgassing
- Identification of outgassing species and implication on outgassing quantification
- Impact of processing on outgassing
- Comparison of outgassing and witness sample testing
- Summary
Introduction

- Set-up from **EUV Technology** has been introduced in IMEC in Nov’08
  - Investigation of outgassing by Residual Gas Analysis (RGA)
  - Investigation of mirror contamination by witness plate testing

[See also poster 26 R. Perera et al. (EUV Technology)]
RGA for resist outgassing measurement
(Residual Gas Analysis)

Is outgassing measurement result affected by measurement procedure or processing?

How to identify the outgassing species?

Is outgassing correlated with witness sample contamination?

Outgassing rate 45-200amu at 10mW/cm²:
2.2e14 molec cm⁻² s⁻¹

[ASML spec 2wfr : 2.0e14]
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CNSE-NIST-IMEC outgassing comparison

See EUVI Resist TWG Feb2009:

Methods adapted to measure outgassing

NIST
- CW (synchrotron) source, 13.3+/−0.5 nm
- Expose 100 mm wafer to 2.5 x E₀ for 10 – 20 minutes.
- Sample Analysis - GCMS with Cryo-focus

IMEC
- Energetiq EUV source, 13.5 nm ± 1% bandwidth in 2π
- Expose 200 mm wafer at 2.5 x E₀ for 1 hour
- Sample Analysis - RGA

CNSE
- Energetiq EUV source, 13.5 nm ± 1% bandwidth in 2π
- Expose a strip of wafer at 2.5 x E₀ for 30 seconds
- Sample Analysis - RGA

Total outgassing amu1..200 (molec/cm²)
~2.5e14
~7.3e14
~2.5e14

Limited difference between different R&D sites!

...but can the difference in RGA sampling time be responsible for a difference in outgassing result?
Time dependency
OS1 resist

Clear impact by EUV exposure for resist related species
Difference in time dependent behavior at start of EUV exposure
Resist related species continuously increase in time

From full cycles (RGA qualification procedure)

Because of different time-frame of RGA measurements the outgassing result can change significantly
Time dependency
post-exposure outgassing (using resist F-PMMA UT1)

Measured outgassing is superposition of 'direct' EUV outgassing and post-exposure outgassing.

Based on this, the RGA test criterion for 2-wfr exposure on ADT has been increased to $5 \times 10^{14}$ molec cm$^{-2}$ s$^{-1}$.

Using high outgassing UT1 resist.
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Characterization of resist outgassing by RGA
Identification of species

Full amu spectrum required for reconstruction of the fragments

RGA contains data of fragments of different species

Resist outgassing is superposition of different species, each having a characteristic RGA spectrum
Characterization of resist outgassing by RGA
Identification of species

- **isobutene**
- **tert. butylbenzene**

**NIST**
http://webbook.nist.gov/

**carbon dioxide**

**isobutene**

**IMEC**
System specific spectrum

Determine system specific spectra by species (calibrated) leaks
(isobutene, benzene, tert. butylbenzene)
Characterization of resist outgassing by RGA
Identification of species

- **Example**: MET2D

With (basic) knowledge of resist chemistry, it is possible to identify and quantify the individual outgassing components with low unknown residual!
Calibration of outgassing rate

Partial pressures of species as measured by RGA depend e.g. on species ionization probability, so they represent not always the same number of molecules!

Therefore, once species are identified, the outgassing rate needs to be corrected according to the ratio of the species behavior to the tool calibration gas!

Determine RGA response to calibrated leak rate (isobutene, benzene, tert. butylbenzene)
Characterization of outgassing species
Outgassing rate with identified species

- **Example**: MET2D

**Unidentified OR**

\[ \text{OR(sp 1)} + \text{OR(sp 2)} + \ldots + \text{OR (sp i)} \]

tert. butylbenzene, PGMEA, isobutene, SO2

**Identified OR**

\[ \alpha_1 \text{OR(sp 1)} + \alpha_2 \text{OR(sp 2)} + \ldots + \alpha_i \text{OR (sp i)} \]

Reported values on outgassing can depend on test gas calibration and species identification.
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Impact of processing on outgassing
Use case: MET2D softbake/delay

Softbake temperature: 60, 110, 130, 150 °C
Delay bake-exposure: 2days, 20min

Outgassing rate (molec cm$^{-2}$ s$^{-1}$)

SB/delay effects can not be ignored in outgassing and contamination testing!
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Witness sample (WS) testing
Resist related contamination

WS contamination thickness\(^{\dagger}\) measured with ellipsometry (nm)


\(^{\dagger}\) In order to obtain a well defined parameter for contamination thickness which is also applicable to ADT conditions, ASML provided a 'system correlation factor' between the IMEC thickness difference and the corresponding value for ADT:

\[
\text{ADT equivalent contamination thickness} = \text{system correlation factor} \times (\text{IMEC thickness diff.})
\]

WS test procedure developed where resist related contamination thickness is compared to background (identical procedure using Si wafer).

Consistent results were found for various resists.

WS exposure during ~100cm\(^2\) wafer exposure at dose 2.5*E\(_0\)
Witness sample (WS) testing
Resist related contamination

Five resists tested according to the test procedure.
Significant difference in contamination behavior between 5 tested resists.

Resist induced contamination thickness has no direct correlation with (unidentified) outgassing rate!

Full qualification method for ADT - Pass-fail criterion:

\[ \text{ADT eq. contam. thickness} < 1.5 \text{nm} \]

[ Resist 4 is poly-sulfone based chemistry, see poster 14, K. Lawry et al. (Univ. Queensland)]

* Result extrapolated from limited resist exposed area
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• RGA outgassing measurement has been characterized; it was found that reported values can depend on
  – the time dependent RGA sampling plan with respect to resist exposure (amount of post-exposure outgassing);
  – the used test gas in RGA calibration and whether a correction is applied based on species identification;
  – the resist process conditions, e.g. softbake and coat-exposure delay variations

All items can result in changes in outgassing result with factor $\sim 1.5-3$.

• Witness sample (WS) testing
  – No direct correlation found between RGA outgassing and WS contamination, therefore information on species identification and species contamination probability is required to predict contamination from outgassing results;
  – Agreement with ASML to use WS testing for full resist outgassing qualification.

Acknowledgements:
K. Lawry (UQ), Resist suppliers and affiliates, A. Lin (Powerchip), F. Linskens (RHEM), J. Steinhoff (ASML), J. Van Dijk (ASML), N. Harned (ASML), K. Feenstra (ASML), G. Denbeaux (NCSE), G. Claeys, M. Baklanov, R. Perera (EUVT), D. Houser (EUVT).