EUV Resist stochastics: some measurements and thoughts

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Failure rate for contacts is $\sim 10^{-4}$!

Stochastic effects in EUV Lithography: random, local CD-variability and printing failures

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JM3 2017

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Measurement of OS4 resist

From our experiments for this resist (OS4)

- Film PAG/volume is \(0.2 \text{ PAG/nm}^3\) (15 wt% TPS Nf)
- Film base/volume is \(0.033 \text{ base/nm}^3\) (1.5 wt% TBAL)
- Dose to clear is \(5.7 \text{ mJ/cm}^2\)
- Optical density is \(4.9 \mu\text{m}^{-1}\)
- Number of photos absorbed/volume at clearing \(0.017/\text{nm}^3\)
- Number of acid/volume at clearing is \(0.037/\text{nm}^3\)
  - about 20% of original PAG -> acid at clearing
  - average spacing between acid is 3 nm at clearing

OS4 formulation

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Analysis of stochastics of OS4 resist

For a 36 nm contact, in a 30 nm thick film there are 30,000 nm$^3$ containing on average:

- 6,000 PAG
- 1,000 base
- 530 photons absorbed
- 1,100 acids generated

For independent events (photons absorbed), they will follow Poisson statistics. Then, the standard deviation in the number of photons absorbed will be the square root of the expected number of photons absorbed, $\sigma = \sqrt{N}$.

The actual statistical fluctuation of reactions within each contact will be worse than simply the fluctuations in the number of photons absorbed, but the photons statistics will be the largest contributor, so we’ll simplify and only look at photon statistics.
Poisson distribution

N events on average

1+1+1+1+1+1+1+1 ... ~ N, with standard deviation \( \sigma = \sqrt{N} \) (Poisson distribution)

N=100, \( \sigma = \sqrt{100} = 10 \)

Same data on a log scale shows the outliers
Missing contact rate simply due to photon statistics

**Important assumptions**
- Only photon statistics included
- Resist has perfect threshold for clearing
- Resist has no sensitivity variations
- Not concerned with contact size, shape or position
Net failure rate is both merging and missing contacts

For this example we used 30% above threshold exposure in bright region, 30% below exposure in dark region, and 400 photons absorbed on average within contact.

Fraction of failed contacts

Exposure dose

Missing contacts

Total Failure rate

Merging contacts

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Net failure rate follows basic failure rate expected and shown in De Bisschop paper (JM3 2017).

This example for 15% above and below threshold aerial image.
What is the aerial image contrast for relevant contacts?

S-Litho simulations
1:1 contacts
No biasing
NA = 0.25
Annular $\sigma=0.4-0.6$
No aberrations
More important assumptions

• Uses aerial image from previous simulation (other parameters will give different results!)
• Absorption coefficient, $\mu = 4.9/\mu m$
• 30 nm thick resist (13.6% absorbed)
What about improving resist sensitivity/efficiency

Dose requirement compared to a 100%QE resist
(For an open field exposure)

But, what about stochastics effects?
Compound Poisson distribution

If perfect resist (one photon absorbed -> one reaction) then Poisson of photons absorbed

BUT, one absorption gives some number of electrons, some acids, some deprotection events – Compound Poisson distribution – and a larger standard deviation

N events on average
1+1+1+1+1+1+1+1+… ~ N, with standard deviation \( \sigma = \sqrt{N} \) (Poisson distribution)

N events on average, each Poisson distribution with average of 1
1+2+0+1+1+0+1+1+... ~ N, with standard deviation \( \sigma > \sqrt{N} \) (Compound Poisson distribution)
(and \( \sigma = \sqrt{2N} \) for this example)
What about improving resist sensitivity/efficiency

*Dose requirement compared to a 100% QE resist*

- **Open field sensitivity** (ignoring stochastics)
- **Better estimate** (including photon stochastics)

*Assumes statistics follow Compound Poisson*