Stochastic Exposure Kinetics of EUV Photoresists: A Simulation Study

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Extended Abstract

Unlike the direct photon absorption mechanism of exposure for 248-nm and 193-nm photoresists, EUV resists are thought to be exposed via photo-ionization: a high-energy photon absorbed in the resist ionizes the polymer, generating an electron, which in turn can generate several secondary electrons.[1] These electrons then scatter through the resist losing energy and, occasionally, interacting with a photoacid generator (PAG) to generate an acid. Numerical simulation of these events leads to a prediction of acid concentration as a function of exposure dose for a given set of resist parameters. Repeated simulations can lead to a prediction of both mean acid concentration and its standard deviation. Both results are important in understanding EUV exposure kinetics and in predicting the impact of those kinetics on the line-edge and linewidth roughness of final lithographic images.

In this paper, the Stochastic Resist Model of PROLITH X4.2 is used as a physics-based stochastic simulator to predict the number of acids generated within a given resist volume as a function of EUV exposure dose and a set of resist parameters.[2] By repeated simulations, both the mean and standard deviation of the number of generated acids can be determined. This simulator can use one of two models for EUV exposure. The first model transfers energy from photoelectrons and secondary electrons to the PAG via a continuous slowing down approximation (CSDA). The second model instead allows an electron to be captured by a PAG in order to initiate a reaction. The goal of this work will be to explore the stochastic implications of these two different mechanisms. If the predictions based on these two mechanisms are sufficiently different, it may be possible to devise experiments to determine which is at work in real photoresists.

The CSDA model has already been exposure in some detail.[3] The exposure rate constant C was found to vary as

$$C = k\alpha\phi_e\left(1-\frac{IP}{110eV}\right)\phi_{PAG}\,\sigma_{E-PAG}\left(\frac{\lambda}{hc}\right) \tag{1}$$

where $\sigma_{E-PAG} = \pi(r-r_o)^2$ and $r_o = 0.008E_{excit}^2$, and where

- k = empirical constant = 4.6 nm
- α = resist absorption coefficient (nm^{-1})
- ϕ_e = Electron Generation Efficiency
- IP = Polymer Ionization Potential (eV)
- ϕ_{PAG} = PAG Quantum Efficiency
- σ_{E-PAG} = PAG electron reaction cross-section (nm^2)
- r = PAG Reaction Radius (nm)
- r_o = minimum PAG reaction radius (nm)
- E_{excit} = PAG Excitation Energy (eV)

This model was found to predict the actual value of *C* as determine from PROLITH stochastic simulations to within a few percent over a wide range of parameter values. Further, the standard deviation of the acid concentration, an important quantity that greatly influences the line-edge roughness (LER) in EUV lithography, was found to following the following expression for the CSDA model:

$$\frac{\sigma_h^2}{\langle h\rangle^2} = \frac{1}{\langle h\rangle\langle n_{0-PAG}\rangle} + \left(\frac{(1-\langle h\rangle)\ln(1-\langle h\rangle)}{\langle h\rangle}\right)^2 \frac{1}{\langle n_{photo-electrons}\rangle} \tag{2}$$

where $\langle n_{photo-electrons}\rangle = \phi_e \langle n_{photons}\rangle(1-e^{-\alpha D})$, $\langle h\rangle = 1-e^{-C\langle E\rangle}$. This model equation was found to predict the standard deviation calculated from the PROLITH stochastic resist model to within a few percent over a wide range of parameter inputs (Figure 1).

The goal of this work will be to develop similar expressions for the EUV capture model of resist exposure, and to explore their lithographic implications. Does equation (2) apply equally well for the capture model as for the CSDA model, meaning that the exact exposure mechanism does not influence such stochastic results? What is the equivalent of equation (1) for the electron capture parameters?

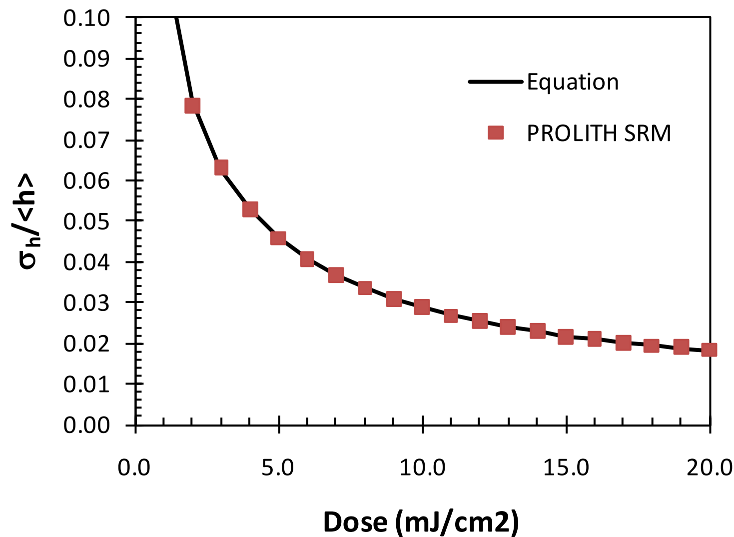

Figure 1. PROLITH simulation of the relative standard deviation of the acid concentration for an open frame exposure of a 50X50X10nm volume of resist as a function of EUV exposure. Each data point is calculated from 16,000 simulations.

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[1] T. Kozawa and S. Tagawa, "Radiation Chemistry in Chemically Amplified Resists", *Japanese Journal of Applied Physics*, Vol. 49, p 030001 (2010).

[2] J. Biafore, M. Smith, E. Setten, T. Wallow, P. Naulleau, D. Blankenship, S. Robertson, Y. Deng, "Resist pattern prediction at EUV", *Proc. of SPIE,* Vol. 7636, p. 76360R-1 (2010).

[3] C. A. Mack, James W. Thackeray, John J. Biafore, and Mark D. Smith, "Stochastic Exposure Kinetics of EUV Photoresists: A Simulation Study", *Journal of Micro/Nanolithography, MEMS, and MOEMS*, Vol. 10, No. 3 (Jul-Sep, 2011) p. 033019.