Correlated Surface Roughening During Photoresist Development

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Stochastic models of lithography consider fundamental events such as the absorption of a photon or the chemical reaction of a molecule as stochastic events. As such, these events are described probabilistically, with the mean-field "rate" equation describing the probability that the event occurs. Of course, such a probabilistic description will not make deterministic predictions – instead, quantities of interest will be described by their probability distributions, which in turn are characterized by their moments, such as the mean and variance. While stochastic modeling has been successfully applied to photoresist exposure and post-exposure bake processes in recent years the stochastic behavior of resist dissolution is much less understood. Ultimately, the final result will be a roughness of the resist feature sidewalls that leads to line-edge roughness (LER) and line-width roughness (LWR) of the resist feature.

Since the final LER of a high-resolution lithographic feature will include all resist and aerial image contributions, studying LER to extract the contribution of just resist development can be difficult. A simpler approach is to remove the aerial image from the experiment and study the resist surface roughness after a uniform open-frame exposure and development. The use of surface roughness after open-frame exposure and development as a probe for understanding the stochastic nature of resist development will be examined in detail in this paper. In particular, an analysis approach known as *dynamical scaling* will be applied to photoresist development and simulated open-frame dissolution results will be analyzed in this way.

In previous work [1-3], the concepts of dynamical scaling in the study of kinetic roughness were applied to the problem of photoresist development. Uniform, open-frame exposure and development of photoresist corresponds to the problem of quenched noise and the etching of random disordered media. Using simulations of photoresist development in 1+1 and 2+1 dimensions, the resulting kinetic roughness was shown to fall in the Kadar-Parisi-Zhang (KPZ) universality class for the case of fast development. This paper will extend this previous work in several new ways.

First, simulations using correlated development rate noise (rather than the uncorrelated noise of previous work) will show whether kinetic roughness during development dominates the final lithographic roughness or whether the underlying development rate noise, coming from earlier stochastic processes such as exposure and reaction-diffusion, controls the final surface characteristics. Second, by slowing down the mean development rate while keeping the noise term high, simulations will indicate whether the KPZ class holds in this regime or a more complex depinning percolation class is needed. Finally, a thorough understanding of the uniform, open-frame development case will lead the way to the more difficult and interesting case of roughness formation during development in the presence of a steep development rate gradient, as is found at the edge of a photoresist line. Correlations in the underlying noise only partially influence final surface height correlations, depending on the mean development rate and the steepness of the development rate gradient at the final resist edge.

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2. C. A. Mack, "Stochastic Modeling in Lithography: The Use of Dynamical Scaling in Photoresist Development", *Journal of Micro/Nanolithography, MEMS, and MOEMS*, Vol. 8, No. 3 (Jul-Sep 2009) p. 033001.
3. C. A. Mack, "Stochastic modeling of photoresist development in two and three dimensions", *Journal of Micro/Nanolithography, MEMS, and MOEMS* , Vol. 9, No. 4 (Oct-Dec, 2010) p. 041202.

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50 word abstract

Dynamical scaling concepts are applied to simulation of open-frame photoresist dissolution. Correlations in the underlying noise only partially influence final surface height correlations, depending on the mean development rate and the steepness of the development rate gradient at the final resist edge.